

**ROUTING OPTIMIZATION BY APPENDING ACO WITH
AODV IN MANETs**

*Thesis submitted towards the partial fulfillment of requirement
for the award of degree of*

Master of Engineering

In

Wireless Communication

Submitted by:

Ronak Khurana

Roll No: 801463022

Under the guidance of:

Dr. Ankush Kansal

Assistant Professor, ECED



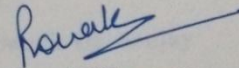
**ELECTRONICS AND COMMUNICATION ENGINEERING DEPARTMENT
THAPAR UNIVERSITY**

**(Established under the section 3 of UGC Act, 1956)PATIALA – 147004
(PUNJAB)**

DECLARATION

I **Ronak Khurana**, hereby, declare that the work presented in the thesis entitled "**Routing Optimization by Appending ACO with AODV in MANETs**" by me in partial fulfillment of the requirements for the award of degree of Master of Engineering in Wireless Communication from Thapar University, Patiala, is an authentic record of my own work under the supervision of **Dr. Ankush Kansal**, Assistant Professor, Electronics and Communication Engineering Department. The matter presented in this thesis has not been submitted in any other University/Institute for the award of any other degree.

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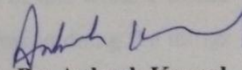


Ronak Khurana

Roll no: 801463022

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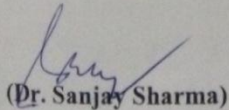
Dr. Ankush Kansal

Assistant Professor

ECED

Thapar University, Patiala

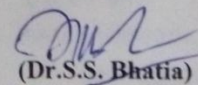
Countersigned by:



(Dr. Sanjay Sharma)

Professor and Head, ECED

Thapar University, Patiala



(Dr. S.S. Bhatia)

Dean of Academic Affairs

Thapar University, Patiala

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801463022

ABSTRACT

MANET is one of the most popular networks these days due to their feature of being temporarily installed and removed when the desired goal has been achieved. They provide a cost effective solution as they don't require any predefined infrastructure i.e. all the nodes are autonomous in nature with no centralized control. Hence each node itself performs the function of host and router. Apart from this their self-configuring and self-healing nature allows them to implement in almost all fields (defence applications, home applications, education fields etc.). The main issue related to these networks is they require a routing algorithm which makes the network efficient by increasing the throughput rate and reducing average.

One of the most efficient reactive routing algorithm named as AODV is being used to find the optimal path between source and destination node. The main advantage of using such algorithms is that nodes only need to track the network information when a request for transmission is being initiated. Unlike pro-active routing algorithms which includes updating nodes with each and every network information regardless of whether transmission is being taken place or not. A random network of nodes is deployed and the shortest path between the desired nodes is obtained using AODV routing protocol.

Link failure occurs very frequently in networks such as MANETs due to mobility of nodes, dynamic network topology etc. Hence the routing protocol must be capable of handling such issues in an efficient manner. AODV has a drawback that local link repair is not possible; it shifts to an alternate route in such cases. This may lead performance degradation of the network. To avoid this it is necessary to find alternate route in case of link failure from the point of occurrence of failure. Hence an ACO (Ant Colony Optimization) appended approach has been proposed in to achieve this goal. ACO is a type of Swarm Intelligence technique inspired from the collective behavior of the biological ants in search for their food. ACO provides an efficient solution in finding routes with minimization of routing overheads in the network.

In the proposed work the evaluation of ACO appended AODV algorithm is carried out on the basis of certain network parameters such as throughput, end-to-end delay, packet loss ration and route failures. The comparison of proposed approach with the traditional AODV approach revealed that the new algorithm outperformed the existing AODV approach in terms of network performance.

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LIST OF ACRONYMS

MANET	Mobile Ad Hoc Network
VANET	Vehicular Ad Hoc Network
DOS	Denial of Service
PAN	Personal Area Network
MAC	Media Access Control
CSMA	Carrier Sense Multiple Access
QoS	Quality of Service
GRP	Gateway Routing Protocol
TCP	Transmission Control Protocol
EXOR	Extremely Opportunistic Routing
LS	Link State
GA	Genetic Algorithm
OSLR	Optimized Link State Routing
DSDV	Destination Sequenced Distance Vector Routing
WRP	Wireless Routing Protocol
STAR	Source Tree Adaptive Routing
FSR	Fisheye State Routing
CGSR	Cluster Head Gateway Switch Routing
DSR	Dynamic Source Routing
TORA	Temporarily Ordered Routing Algorithm
LAR	Location-Aided Routing
CBRP	Cluster Based Routing Protocol
DYMO	Dynamic MANET On-demand Routing
AODV	Ad Hoc On-demand Distance Vector Routing
RREQ	Route Request Message
RREP	Route Reply Message
RRER	Route Error Message
ARA	Ant Colony Based Routing Algorithm
ZRP	Zone Routing Protocol

ZHLS	Zone Based Hierarchal Link State Routing
CEDAR	Core Extraction Distributed Ad hoc Routing
DDR	Distributed Dynamic Routing
DST	Distributed Spanning Tree
GUI	Graphical User Interface
MATLAB	Matrix Laboratory

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Chapter 1

Introduction

This chapter includes the description of wireless networks and its applications in various fields. A detailed description of Ad hoc networks (MANET specifically) has been provided. This includes the advantages, disadvantages and challenges faced in the deployment of an ad hoc network.

1.1 Background

One of the most emerging technologies of present era is wireless networking which allows the end user to access the services without concerning about the geographical location. Due to recent advancements in wireless technologies the wireless networks are becoming ever so popular. Features such as cost effective and higher data rates led to the increasing interest in mobile computing for widespread applications. Wireless network are capable of communicating with the rest of world even if they are mobile. Wireless communication is applicable in two ways for interaction between various mobile hosts present in the environment. The use of fixed infrastructure network is the first way. In this we have a number of access points which cover a particular region. All the devices interact using this access point. *Cellular network* is the best existing example for this approach. Whenever a mobile hosts wants to communicate with other it communicates through the access point of that region (Base station of the cell in case of cellular networks). As the mobile host's remains in the communication range of the access point it uses that point for interaction. If the mobile node leaves the transmission range of a particular access point it needs to interact with some other access point in order to carry forward its communication with the desired node. In cellular technology this process is known as *hand off strategy*. This means whenever the device leaves its cell's boundary handoff strategy must handle the situation by efficiently transferring the host from one access point to the other with no noticeable delay and packet loss. Another issue related with this approach is that devices can communicate only when they are in the range of fixed network infrastructure which limits the mobility of the mobile host.

The second approach is to use ad hoc networks in which the nodes which want to communicate sets up a temporary network among themselves. The nodes in such networks play a dual role as route and host. This means they take part both in route establishment and maintenance [1]. One

of the drawbacks of such networks is that they have a very limited range of operation. The unique features of such networks are that these can be deployed in any area without any requirement of fixed infrastructure [2]. The assumption made while using such networks is that any node which is a part of the network can be used to forward the data between arbitrary source and destination point. Presently, various routing protocols have been defined to carry out route establishment in ad hoc networks. These protocols are responsible for interaction of various nodes present in the network. Highly mobile nodes and topological variations are some issues which restrict the performance of ad hoc networks. Although routing protocols are designed in such a way that these limitations are minimized while implementing such networks in practical scenario.

1.2 Wireless Ad Hoc Networks

These networks are becoming more and more popular in the present era due to their flexibility and adaptability in changing geographical conditions. It is a collection of devices which needs to communicate among them. These devices may be mobile, laptops etc. and are generally termed as nodes of the network. These networks are temporary networks and are initialized only for a desired application and can be uninstalled when the desired goal has been achieved. Ad hoc network is a type of wireless network which does not rely on a pre existing infrastructure for carrying out communication between the various nodes of the network [3]. Hence the need of centralized authority for controlling the operation is eliminated which makes this network cost effective. Consider the following figure:

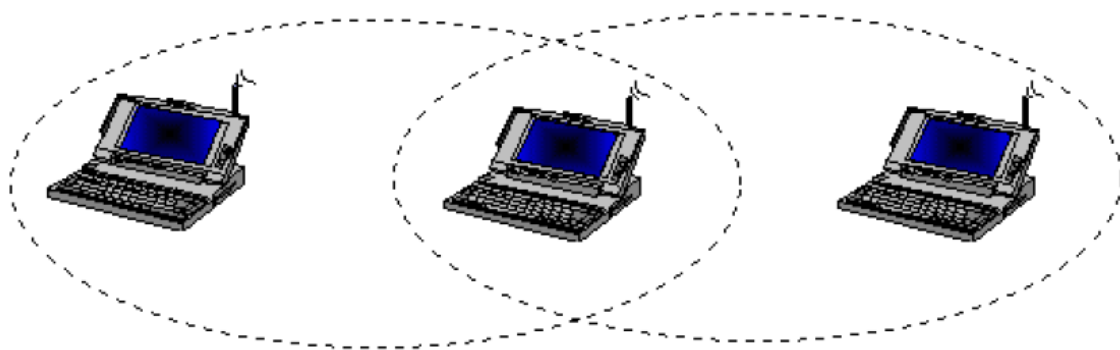


Fig 1.1: Simple Ad Hoc Network [2]

The outermost nodes do not share a direct link for transmission of data and are not in the transmission range of each other. Hence the only way in which they can communicate is through the intermediate node present in the network. This results in sharing of information among all the

three nodes and an ad hoc network is established. As there is no centralized authority these networks eliminate the risk of failure of whole network if the root node fails. As these networks have limited transmission range multiple hops are required to reach desired destinations in the network. As the mobile nodes are free to leave and enter the network whenever required, the functioning of the network does not depend on the behavior of a particular node. The communications between various nodes are independent of each other. Two of the widely implemented Ad Hoc networks are as follows:

- MANETs
- VANETs (Vehicular Ad Hoc Networks)

As the nodes are mobile in nature the topology changes depends on the behavior of the node. These changes occur at the time of joining of a new node in the network or leaving of an existing node. Hence it is necessary that routing protocols must maintain the route information on various nodes of the network. The frequency of transmission used in ad hoc networks is similar to that of the radio transmissions. Limited power, storage capacity and bandwidth constrain the transmission range of these networks [4].

1.3 Mobile Ad Hoc Networks

It is a type of network which has the capability of attaining variable locations as it can configure itself on the fly. It has a wide range of applications and can be modeled as a Wi-fi connection or a stand cellular or a satellite transmission system [5]. It consists of wireless mobile nodes communicating with each other without having any centralized authority. The most important feature of this network is that it does not require any pre-defined infrastructure for its operation. These mobile nodes interact with each using radio waves. MANETs are temporary networks formed using multi hop technique and are established spontaneously [6]. Mobile nodes are free to move randomly with each node acting as both host and router. In MANETs as there are no designated routers mobile nodes themselves act as end points and intermediate relay points. Mobile nodes exchange information as per the requirement of the application by using wireless transmissions. Since the nodes are mobile in nature MANETs involves dynamic network topology. This means network topology changes unpredictably and hence mobile nodes can enter and leave the network at their will [7]. As the mobile nodes are communicating using various intermediate nodes the communication in MANETs is end-to-end. The mobile nodes

have limited power which should be efficiently utilized in order to transfer the desired data to the destination node.

As the topological changes are very frequent each node must be updated with this information at periodic intervals. Hence synchronization among various nodes is a necessity for these networks.

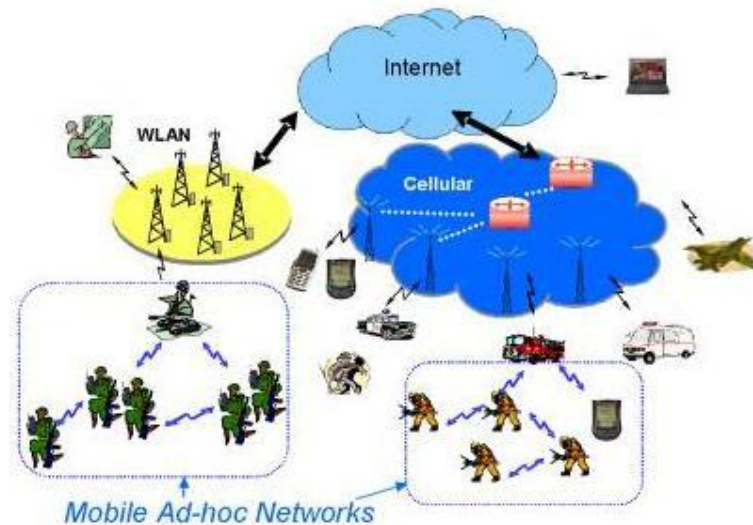


Fig 1.2: MANET Structure [5]

A self-configuring network having distributed nature of security, routing and host configuration are some of the features of MANETs. Each node in the network has a routing function which involves packet forwarding via intermediate nodes. If the nodes are in transmission range then the packet is forwarded to that respective node. If not so, then the packet is passed to the next node in a direction towards the destination node. However the nodes are not bound to any centralized authority, the network management responsibility is totally on the nodes of the network. The concept on which MANET works is generally known as *Infrastructure less networking* [8]. The mobile nodes are capable of forming links dynamically on the fly. One of the main issues related with MANETs is their security. These networks are prone to attacks such as eavesdropping, malicious nodes, DOS etc. As there is no centralized administration deployment of techniques such as cryptography and certification authorities is a difficult task. The malicious nodes may break the cooperative anomaly of the nodes by modifying the traffic in the network. Static security solutions are not efficient for these networks due to frequent topology changes. Along with this, all nodes in the network carry limited battery life. This can

help the attacker to create a DOS attack by asking the node to resend its packets again and again which will lead to wastage of power [9].

One of the most challenging issues while dealing with MANETs is the selection of routing algorithm to transfer data from one node to the other. The constraints involved in MANETs [10] such as limited bandwidth, physical security, decentralized infrastructure, limited power devices etc. must be taken into consideration while selecting a routing protocol for the network. Another feature that a routing protocol must possess is efficient and timely delivery of the data. As the nodes in the network communicate on their own the routing algorithm must be capable of defining an optimized route between the desired pair of nodes. Since MANETs involve multi hop transmission, as the nodes communicate through the environment the routing protocol must be capable of forming stable links. As the nodes in these networks possess high mobility with rapidly varying network topology link failures occur on a large scale. The routing protocol should have the ability to take care of these link failures with minimized delay in the transmission process. The features and process of route establishment of various protocols have been described in detail in chapter 3.

1.4 Advantages of Mobile Ad Hoc Networks:

As we have described above the flexibility and ease of deployment of MANETs, these networks have following advantages which makes them applicable in various fields:

- *Infrastructure less networks:* These networks do not require a pre established infrastructure for communication among various devices of the network. This makes them a cost effective solution for small applications.
- *Dynamic topologies:* The rapid fluctuations in the topology of ad hoc networks in one way can provide security. As the routing information of the network is changing in a frequent manner it is difficult for an intruder to track the nodes of the network.
- *Self- configuring:* Due to the absence of any centralized controlling authority, nodes of the network themselves start building the network whenever required. Nodes play a dual role of router and host. Therefore establishing a path, maintenance and data transmission functions are taken care of by the nodes.
- *Fast installation:* As the requirement of any predefined infrastructure is eliminated the installation of these networks requires very less time. Only some changes in the network

settings are made to establish an ad hoc network. Therefore these networks can be brought up and torn down in a fraction of time.

- *Self-healing:* Frequent topological changes results in link failure in MANETs. Since the nodes themselves control the functioning of the network these failures are also handled internally by the nodes of the network. Also the routing protocols are designed so as to minimize these failures in the network. As all the links formed between various nodes of the network are independent failure, of one does not affect the rest of the network.
- *Speed:* It requires only some changes in the setting to develop an ad hoc. No changes in the hardware or software are required. Hence if a set of devices wants to communicate then ad hoc network is the ideal solution.

1.5 Disadvantages of Mobile Ad hoc networks:

Following are some of the drawbacks of MANETs which degrades their performance:

- *Bandwidth Constraint:* Wireless links possess limited bandwidth as compared to that of the wired links. Effects such as fading, multipath distortion, interference etc. limits the capacity of the network over time. Also the nodes used radio links to transmit information. Hence sometimes the throughput of the network is less as compared to that achieved in radio transmissions systems.
- *Power Limitation:* As the nodes in the network have limited battery lifetime. Hence they carry less power which must be utilized efficiently. This can help the intruders to attack the nodes by asking them to transmit unnecessary data. This makes these networks vulnerable to attacks such as DOS etc.
- *High Latency:* There are some nodes in the network which behaves as idle to conserve energy. These nodes are not aware about the routing information as they were not the part of the route for quite long time. Whenever the data is passed through such nodes the delay in transmission increases resulting in high latency.
- *Security:* Security requirement is more in wireless network as they are prone to the attacks such as spoofing, malicious nodes, eavesdropping etc. As the nodes are not controlled by a centralized system it is difficult to implement cryptography technique in such networks.
- *Location:* IP addressing is another issue faced by network layer while dealing with these networks. As these networks have limited routing facilities as compared to the fixed

networks. Also the addressing in MANETs has nothing to do with the position of the node.

1.6 Applications of Mobile Ad Hoc Network:

As described in the above section that flexibility and ease of installation of MANETs make them applicable in almost all fields. Some of the applications are as follows:

- *Emergency services:* such as disaster recovery and rescue operations.
- *Tactical networks:* automated battle fields and military operations.
- *Education:* deployment of virtual classrooms and university campus activities.
- *Commercial and civilian environments:* can be deployed in business activities, E-commerce operations, vehicular services etc.
- *Home and enterprise networking:* can be used in conferences, meetings, PAN etc.
- *Sensor networks:* data tracking of various environmental conditions, weather forecasting operations, animal tracking etc.
- *Coverage extension:* extending cellular networks and linking them with internet, intranet etc.

1.7 Challenges in Mobile Ad Hoc Networks:

Security issues, bandwidth constrains etc. pose many challenges while deployment of MANETs.

These challenges are as follows:

- *Limited bandwidth:* Overheads in the networks results in bandwidth wastage. Hence the routing algorithm must minimize these traffic overheads in order to utilize the bandwidth in an efficient manner.
- *Dynamic topology:* This leads to frequent link failures in the network. The protocol used must be capable of handling these failures in such a manner so that the time delay involved is minimized.
- *Routing overheads:* To make all the devices in the network or only those which are present in active paths aware about the topological changes, routing information is shared periodically. This will synchronize the nodes of the network but at the same time increase the routing overheads in the network. This can result into increased congestion in the network which should be handled efficiently by the routing protocol.

- *Hidden terminal problem:* There can be a possibility of multiple packet reception on various nodes. Also multiple nodes can transmit at the same time. This will lead to packet collision and bandwidth misuse.
- *Packet loss due to transmission errors:* Presence of hidden terminal nodes, frequent link breaks, stale paths, interference etc. can lead to large packet loss in the network. Hence their effect should be considered while designing routing protocols for these networks.
- *Security threats:* As described earlier security is an important issue while dealing with wireless networks. These networks are vulnerable to various attacks initiated by intruder to gather confidential information and shutting down the network. Attack of malicious nodes, spoofing etc. leads to power and bandwidth wastage of the network.

1.8 Dissertation Structure:

Chapter1 (Introduction): This chapter includes the description of wireless networks and its applications in various fields. A detailed description of Ad hoc networks (MANET specifically) has been provided. This includes the advantages, disadvantages and challenges faced in the deployment of an ad hoc network.

Chapter2 (Literature Survey): In this chapter a survey of the work done in the previous years on MANETs has been described. This in brief describes the attempts to provide best solution for challenges related with MANET. Based on the requirements of this network different approaches have been proposed to fulfill those necessities. These methods are being described in brief in this chapter.

Chapter3 (Routing Protocols): A large number of routing protocols have been proposed by various personalities trying to cover requirements of the wireless ad hoc networks. This chapter includes the description of those routing protocols. These protocols are broadly classified into three categories: proactive, reactive and hybrid routing protocols.

Chapter4 (Methodology and Analysis): This chapter defines the system model of the work presented. An ACO appended AODV approach has been proposed in the work to establish a local link repair mechanism for mobile ad hoc networks. Also the route formation can be viewed with the help of GUI representation. GUI is a MATLAB tool for graphically representing operations of the routing algorithm. Mathematical analysis has also been described in this chapter

Chapter5 (Results and Discussion): This chapter describes the evaluation of the ACO appended AODV on the basis of various network parameters. These are compared with the performance of the traditional AODV approach. The results depicts that the proposed algorithm provides an enhanced network performance as compared to the existing algorithm.

Chapter6 (Conclusion and Future Scope): In this chapter the conclusion of the work done is described which includes the comment on performance of the proposed algorithm. Finally the advancements that can be done in this field are also discussed.

Chapter 2

Literature Survey

In this chapter a survey of the work done in the previous years on MANETs has been described. This in brief describes the attempts to provide best solution for challenges related with MANET. Based on the requirements of this network different approaches have been proposed to fulfill those necessities. These methods are being described in brief in this chapter.

Yi-Sheng Su *et al.* [1] proposed a joint approach for enhancing the QoS of ad hoc network with topology transparent scheduling (TTS) routing protocol. TTS had been as the MAC protocol as it provides single-hop QoS support. Firstly the QoS of the network had been enhanced by bandwidth estimation and proper allocation without considering the slot status information. After that the non assigned bandwidth has been calculated and assigned for the best flow. Therefore a solution to utilize the limited bandwidth of ad hoc networks has been described. The results are obtained by considering a standard radio model with an assumption that radio interference has been ignored. The comparison of the proposed approach was done with DSR/CSMA has revealed that the new approach provides a noticeable reduction in QoS violation. Also the throughput using this approach was increased by 31%-104%.

The major challenges in ad hoc networks are efficient energy consumption as the devices carry limited battery. To provide this a MAC protocol was proposed for ad hoc networks which were fully connected by **Kamal Rahimi Malekshan** *et al.* [4]. Radio interfaces were used periodically to reduce energy consumption during sleep states. This scheme also addressed the energy saving in real time traffic by reducing the transmission collisions. This involved very low packet transmission delay and results in high throughput value. The simulation results revealed that the proposed approach minimizes power consumption and delay as compared to the existing MAC scheme.

MANETs involve devices with limited battery life which limits their operation for a limited time period. Traditional DSR approach ignores the energy consumption of nodes of MANETs. Whereas the modified DSR approach proposed minimizes the power consumption while route discovery with maximum network lifetime elucidated **Golla Varaprasad** *et al.*[7]. Along with this the new approach possessed features such as selecting only energy efficient paths, minimizes

maximum node cost etc. This approach was also capable of finding selfish nodes which drop packets in order to save energy and hence was named as Efficient DSR approach. The results depicted that the overall packet delivery ratio was enhanced with 45%-60% increase in the average node lifetime.

In MANETs local link information for route establishment and maintenance is necessary. To achieve this, an Adaptive HELLO messaging algorithm was described, which is an improved version of the existing HELLO messaging scheme, proposed **Seon Yeong Han** *et al.* [2]. Hello messages are sent at regular interval to detect the failure of route if present. To achieve this average latency (time gap between sending and receiving) on a node was calculated. A constant risk level was used instead of a constant HELLO interval. This HELLO interval increases with increase in event interval without increasing risk and hence reduces HELLO messaging with almost 54% reduction in energy consumption.

Ting Lu *et al.* [3] considered that efficient energy consumption may resolve the problem of network exhausting batteries in wireless networks. This was achieved by partitioning the entire network. An energy-efficient GA to resolve QoS multicast routing problem is considered into effect. The proposed GA relies on bounded delay and energy cost of the multicast tree. This algorithm along with energy consumption takes into account average delay in route selection. The results describe that the projected algorithm was effective and efficient. This algorithm only focuses on source-based routing trees.

Scott Linfoot *et al.* [6] observed that the efficiency of a wireless cellular network follows an inverse relationship with the number of overheads present in the network, especially in the environments having large traffic. A carrier sensing threshold was defined by using virtual and physical carrier sensing which was used to find a suitable transmission route with minimized overheads in the network. The results proved that by using an efficient carrier sensing scheme which provides an optimized threshold value the performance of the ad hoc networks was enhanced in high density and noisy conditions.

Throughput is an important parameter while dealing with the efficiency of wireless networks. It defines the number of packets which successfully reached the destination node. A routing algorithm was presented which has the ability to detect the MANET mobility and routing metrics accordingly. Based on the mobility indicator, the dynamicity of network was obtained by the nodes. After this they switch the routing metric to either to ETX or to MF respectively. MF is

generally used in the highly mobile networks on the other hand static environment utilizes ETX better than MF. But in modern user mobility pattern the environment may change from static to dynamic and vice-versa very frequently. Hence a combination of both the metrics has been introduced, which is based on the current state of the network at each node. It was observed that the packet delivery rate increases by 10% while reducing the drop rate to half of its value elucidated **Hoa Le Minh** *et al.* [11].

MANET performance depends on the selection of routing algorithm to define route between the desired destination/source pair. The evaluation of the routing algorithm depends on the stability links between various nodes present in the network proposed **Naveen Bilandi** *et al.* [12]. The comparison of protocols such as AODV, OSLR and GRP was done on the basis of their performance in MANETs. The metrics involved in the evaluation were network overheads, throughput and average delay. The results depicted that reactive protocol AODV outperformed the other algorithms and provided the best network performance among the three.

Protocols which initiate route discovery on-demand only are most suitable for the communication in ad hoc network. An approach for local link repairing for traditional AODV was introduced, by **Jyoti Jain** *et al.* [13] to improve its performance. Alternate route discovery for next-to-next node in case of link rupture is a better option of route management. These protocols are beacon-less for efficient bandwidth utilization. Control overheads were reduced by using 802.11b protocol to keep connectivity of moving nodes. Significant improvement was observed in the QoS parameters like throughput, average delay and packet delivery ratio and link rupture through simulations. In case of link rupture an alternate path was selected using proactive or reactive algorithms.

No routing protocol had been proposed till now which can alone handle all the challenges present in the ad hoc networks. As the conditions in which these networks perform changes rapidly, hence each routing protocol has certain advantages and disadvantages. A routing algorithm is efficient if it uses the limited resources of the network in an optimized manner. But which algorithm would perform better in which network scenario is still a challenging task said **Anuj K. Gupta** *et al.* [14]. The paper presented an overview of many of the existing routing algorithms. It described the mechanism of route discovery in various routing protocols in brief. Along with these network scenarios for some protocols was also described with their merits and demerits.

L.J.G. Villalba *et al.* [15] proposed that the ad hoc networks require self organization due to the absence of any predefined infrastructure and hence there is no centralized authority. The nodes in the network use multi hop routing technique to communicate with each other. This allows existence of multiple routes in the network as it is not necessary that the desired nodes find a direct link between them. The proposed work introduced a bio-inspired approach which was based on AntHocNet for these networks. The algorithm took into account the limited resources and highly dynamic environment through the sharing of only relevant routing information in the network. The main aim of the proposed approach was to handle dis-joint link and nodes in the network. The approach was capable of distinguishing between regular and virtual pheromone in diffusion process. The results showed that using the proposed approach the overheads involved were minimized with higher packet delivery ratio.

MANETs are networks comprising of mobile nodes which forms various network topology. This is due to high mobility environment in which they generally exist. The proposed work compared the performance evaluation of proactive protocol (DSDV) and reactive protocols (AODV and DSR). These were evaluated using the network metrics such as network overheads, delay in route discovery, routing information broadcast mechanism etc. The simulation was carried out using TCP as system model and results depicted that AODV outperformed the other two algorithms due to its ability to maintain relevant network information which is a necessity in TCP environments said **Basu Dev Shivahare** *et al.* [16]

A buffer management system was described in which the packet queues were handled efficiently for fixed network size elucidated **Muhammad Aamir** *et al.* [17]. The dynamic space allocation was done on the basis of number of packets received from the neighboring nodes. Hence a central communicating MANET node can handle its packets efficiently with a decrease in the lost packets. Although the proposed approach provided an efficient way of packet queuing but the delay involved in the transmission was enhanced.

The work carried out presented characteristic features of routing protocols such as AODV (reactive protocol), OSLR (Proactive protocol) and ZRP (Hybrid protocol). The study revealed that AODV provides a loop free solution and latest path available in the network with the use of unique destination sequence number. In OSRL the route information was already present in the routing table hence predefined routes were available. Also the delay involved in route discovery for OSLR and ZRP was negligible as compared to AODV speculated **Harjeet Kaur** *et al.* [18]

Security in MANETs must provide following features adaptability, integrity, confidentiality etc. elucidated **Loay Abusalah** *et al.* [19]. In the proposed work the protocols were mainly evaluated on the basis of security. Reactive protocols (AODV, DSR and TORA) and proactive protocols (OSLR) were discussed. All these protocols differ on the basis of method of routing and routing decision information. The above requirements for security were kept in mind while analyzing these protocols.

Since the nodes in the network have limited transmission range and does not have a backbone infrastructure, multi hop routing is one of the necessities for ad hoc networks. Therefore the routing protocols play an important role in establishing an optimized path between various nodes in the network. The proposed work evaluated the performance of on-demand protocol (AODV) and table driven protocol (DSDV) and their performance was compared using various network parameters. The analysis made it clear that AODV provided better network performance as compared to DSDV only relevant routing information was shared among the required nodes proposed **B.N. Jagdale** *et al.* [20]

The main focus while designing a routing protocol for MANETs is the capability to handle rapid topological changes with minimized routing overhead and optimized use of limited network bandwidth speculated **Richa Vats** *et al.* [21]. Many routing protocols had been described in the past with different routing mechanisms and varying performance in different network scenarios. In this work the analysis of protocols such as DYMO, ZRP and STAR on the basis of network parameters such as packet loss, transmission time, throughput etc. was performed using NS-2 simulator. The results obtained collectively showed that DYMO was the most suitable protocol among the three.

S. Velmurugan *et al.* [22] proposed a FSR (Fisheye State Routing) protocol for opportunistic data forwarding in MANETs. This data forwarding technique had drawn attention in recent years especially for stationary wireless networks. To implement this along with FSR a high capability source routing had been used. The requirement of getting efficient data was fulfilled by using EXOR and LS protocols. The comparison of FSR was carried out with proactive source routing on the basis of network parameters such as jitter and packet delivery ratio. The results revealed that the proposed algorithm provided an excellent network performance in case of smaller networks. But the proposed algorithm does not provide scalability for large bandwidths.

Anita Yadav et al. [23] proposed a link prediction way for getting the information about link failure prior to the occurrence of that failure. The link prediction was done on the basis of power of the packet received. The technique used for link prediction was Newton divided difference interpolation. The link breakage time was estimated by setting a threshold power level for various packets. This information is passed to the neighbouring nodes which in advance starts the search for an alternate path. The results revealed that QoS for link predicted AODV approach was much better than that of traditional AODV approach.

MANETs are vulnerable to effects like node failure, interference etc. due to dynamically varying network topology. Several routing protocols have been proposed in past for providing an optimized path between the desired nodes. Some of the most efficient algorithms among them are AODV, DSR and TORA confirmed **M. Lalli et al.** [24]. The work proposed compares these protocols features and described their performance in various network scenarios. The study also provided a theoretical aspect of how the demerits of these protocols can be improved.

In the proposed work the performance comparison of two most prominent reactive protocols DSR and AODV had been analyzed. As MANETs possess features such as frequent topological changes and multi hop wireless connectivity, a need of highly dynamic routing protocol arises. Interlayer interactions in MAC simulation model were considered as the performance basis. Even though on-demand behavior of DSR and AODV is same, the different route mechanisms leads to difference in performance of the two proclaimed **Charles E. Perkins et al.** [25]. Load in the network, size of network and mobility were the parameters used for the performance evaluation.

An ACO based framework for QoS has been proposed in order to improve the network performance in dynamic traffic variations and dynamic topologies. The framework was termed as AntQoS by **Young-Ming Kim et al.** [26]. This provided two capabilities, one a self configured adaptive network which reconfigures itself in sudden situations of high traffic and second a self organized network control to avoid multiple network failures. AntQoS employs artificial ants which gather the information regarding the status of the network. On the basis of this information virtual sub colonies named as QoS colonies are formed. These colonies are capable of predicting a path which fulfills the demand of flow. The result depicted that AntQoS was applicable in diverse delay environments with an increase in throughput efficiency. It was also capable of resisting unwanted or sudden failures.

Pasquale Arpaia *et al.* [27] modified the ACO in order to diagnose multiple faults in industrial applications. A likelihood based trail intensity function was described for high dimension multiple faults diagnosis applications. The algorithm proposed was named as Ant Search Diagnostic Strategy (ASDS). An industrial research project was taken into consideration to compare the performance of existing benchmark genetic algorithm with that of ASDS. The simulation results depicted that ASDS outperformed GA.

MANETs are temporary in nature and can be used in emergency communications. Routing protocols can be classified into two folders: tree-based and mesh-based. But these protocols have poor robustness due the presence of a single link between two nodes. To overcome this MAODV (Multicast AODV) protocol was introduced. As the load of network increases, QoS is degraded. It was analyzed that the impact of network load on MAODV protocol, and an optimized protocol MAODV-BB (MAODV with Backup Branches) was proposed, which improves robustness of the MAODV protocol. MAODV-BB enhances the network performance in heavy load ad hoc networks as compared to conventional MAODV was proved by **Liu Tian Jiao** *et al.* [28]

A modified version of ACO was proposed in which the position of the node was tracked to find route between the desired pair of nodes. A mobile software agent was integrated with GPS to establish the desired path. The proposed approach is abbreviated as OANTGPS (Optimized Antnet GPS) by **Deepak C. Karia** *et al.* [29]. The major drawback of antnet system is the looping problem which was removed using this approach. The simulation results depicted that the proposed approach outperformed traditional AODV, DSR and ACO routing protocols.

Gaps in Study:

Following gaps were in the above described literature survey:

1. The routing algorithms used involved large computations. Although they provided an optimal path but they were not efficient [13].
2. A buffer management system for MANET was explained for a limited number of nodes. This can be extended for environment with higher mobility and more variations in flow arrival rate [17].
3. The work proposed a theoretical aspect of performance of various protocols in link failure scenarios [24].
4. An ACO based framework capable of resisting link failures was proposed. The framework lacked in dealing with link failures efficiently [26].

Thesis Objective:

1. To study various Routing Algorithms for evaluating network routing performance under link failure.
2. To repair the link dynamically as well as locally by appending ACO with AODV from the point of link failure.
3. To make a Graphic user Interface (GUI) of the proposed ACO appended AODV network with dynamic link repair for user defined number of nodes in MATLAB. Also to achieve minimum delay along with enhanced throughput.

Chapter 3

Routing Protocols

A large number of routing protocols have been proposed by various personalities trying to cover requirements of the wireless ad hoc networks. This chapter includes the description of those routing protocols. These protocols are broadly classified into three categories: proactive, reactive and hybrid routing protocols.

Routing is basically defined as the process of finding the best suitable path between two nodes which want to share some information. The approach used for finding the path should be able to adapt conditions in which the wireless network is present. This means the protocol must be able to utilize all the resources available and find the best suitable path. Ad Hoc network is class of wireless networks in which nodes communicate using request and reply messages [11]. These networks neither require any centralized authority nor fixed infrastructure, hence are autonomous in nature. The nodes are mobile in nature with rapidly varying network topology these links become unpredictable over time. Hence a challenge of finding the most flexible routing approach arises. This becomes more difficult with limited physical security and energy constraint issue related with MANETs. As the nodes are mobile in nature the topology involved in such networks is dynamic which can lead to frequent link failures [12]. Hence the routing protocol should be capable of responding to such frequent changes occurring in the network. Other issues related while designing a routing algorithm is control over routing overheads, interference etc. The other important issue related with such networks is link failure due to rapid topological changes present in the network. These link failures may lead to packet loss and hence may degrade the network performance. Hence it is an important task to handle these with an efficient manner. So the routing algorithm must be capable of resolving such issues while maintaining the network issues. In ad hoc networks multi hop routing is a necessity as these networks have constraint bandwidth and have to communicate via intermediate nodes [13]. Following are the challenges which arise while designing a routing protocol for wireless networks:

- Frequent topological changes due to mobility of nodes present in the network.
- No centralized authority to control the network functionality.
- As transmission range is limited, two nodes are not able to communicate directly.

- As each node acts as host and router therefore maintaining the routing table in an efficient way is necessary.
- Mobility leads to congestion in network which increases with the increase in network size.

Routing in ad hoc networks can be classified as follows:

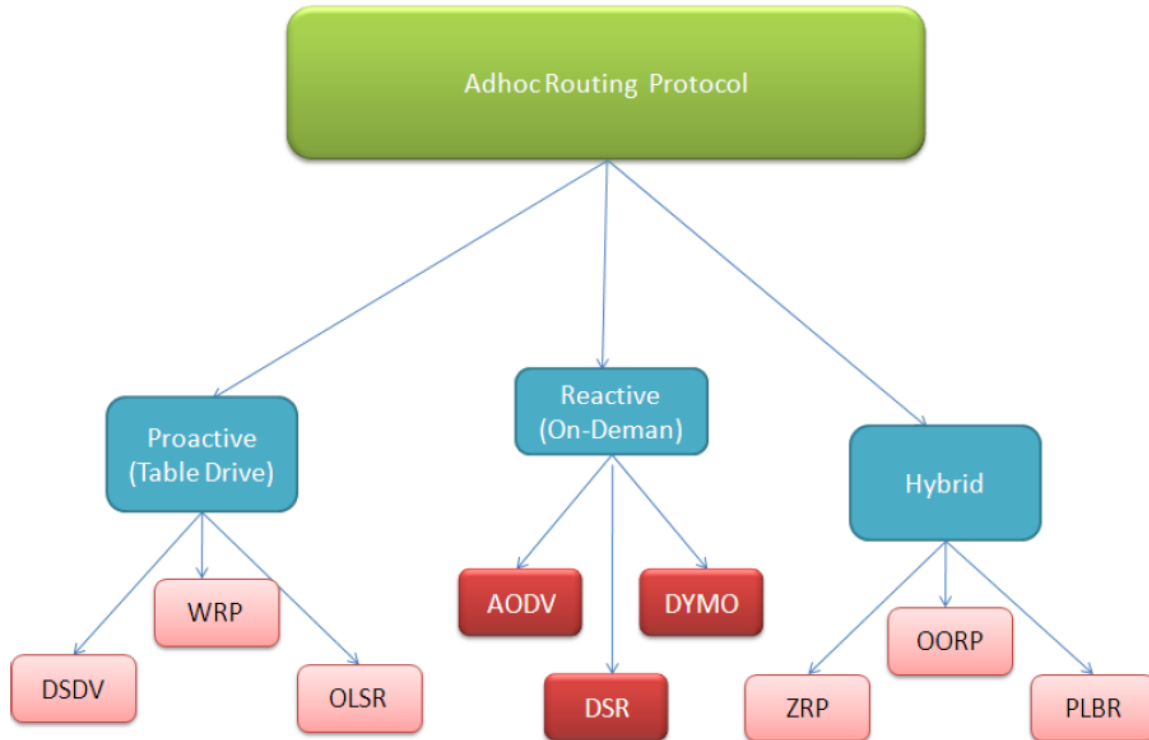


Fig 3.1: Classification of routing protocols [13]

A large number of algorithms have been proposed to carry out communication between various network devices and parallelly controlling the traffic and computational load on power constraint devices. Many link state and distance based solutions for wired networks have been proposed in this field to carry out efficient transfer of information. These were later transformed into a class of routing protocols known as *pro-active or table driven routing protocols*. Updating the routing tables of nodes present in the network with the latest route information is an important aspect of routing algorithms. In pro-active protocols all the nodes in the network are updated with all the information in the network at all times [14]. Hence the control information is updated periodically. Now sometimes it is not necessary to share all the information every time. Hence in this case information regarding active paths is only shared with the concerned nodes [2]. This can reduce the number of control overheads in the network. Such protocols are grouped into a

class named as *reactive routing protocols*. These protocols only update the information to the nodes they communicate. The routes developed using such protocols are kept only till the time they are in active mode. Once the purpose of these routes is being fulfilled they become inactive. A combination of these two routing protocols gave rise to another class named as *hybrid routing protocols*. In these protocols the nearby route (Max. two hops) is discovered proactively i.e. updating all the information on regular intervals. On the other hand to set up long routes reactive routing approach is used [15].

3.1 Pro-active Routing Protocols:

In these protocols continuous updating of routing tables of all the nodes in the network takes place. Every time the network topology changes the information is passed into routing tables of all the nodes present in the network [16]. Hence whenever route information is required between two nodes it can be immediately obtained using the routing tables of network nodes. The information present includes presented destinations, hop counts needed to reach the desired node. A sequence number is used to define such information for the forwarding of packets towards destination. The node which wants to initiate communication broadcast a request message time to time. A new sequence number is generated for each node broadcasting the route message with following information [17]:

- Hops required to reach the destination
- Destination address
- Destination marked new sequence number

Since the routing takes place on the basis of information present in the routing tables of the nodes, a Table-Driven routing protocol is another name given to them. To synchronize these tables it is mandatory to update these with latest information of the network. This leads to increased number of overheads in the network and hence degrades network performance. The main advantage of doing this is that no delay is involved in discovering the route [12]. Following are some types of proactive routing protocols:

- OSLR
- DSDV
- WRP
- STAR
- FSR

- CGSR

3.1.1 Optimized Link State Routing (OSLR):

A point-to-point protocol based on link state packet forwarding mechanism was proposed by Clausen and Jacquet. This was named as Optimized Link State Routing protocol. To find an optimized routing either size of control packet can be reduced or the links required to reach the destination can be decreased. All the nodes in the network use HELLO and Topology Control messages to update its routing table with latest link state information in the network [18]. Based on this information each node identifies the next hop in the forward direction towards the destination. This is done while maintaining the fact that the next hop chosen leads to the shortest path available in the network. Since it is a type of proactive protocol all the required routes to the destination are already known before using it. The implementation of this algorithm includes three steps: neighbour sensing, flooding and discovery of an optimal path [19]. Neighbour sensing updates the changes taking place in the neighbourhood nodes. Based on this topology information the network nodes define an optimal route to the entire known destination. The information regarding this route is stored in the routing table.

As mentioned above there are two types of control messages used in this approach. To get information on link status and one hop neighbours HELLO messages are used. Based on these messages the MRP (Multipoint Relay) Selector set is constructed. On the other hand to advertise information on personal neighbours which are present in the MPR list TC messages are used. Hence TC messages are broadcasted in the network whereas HELLO messages are sent to single hops only.

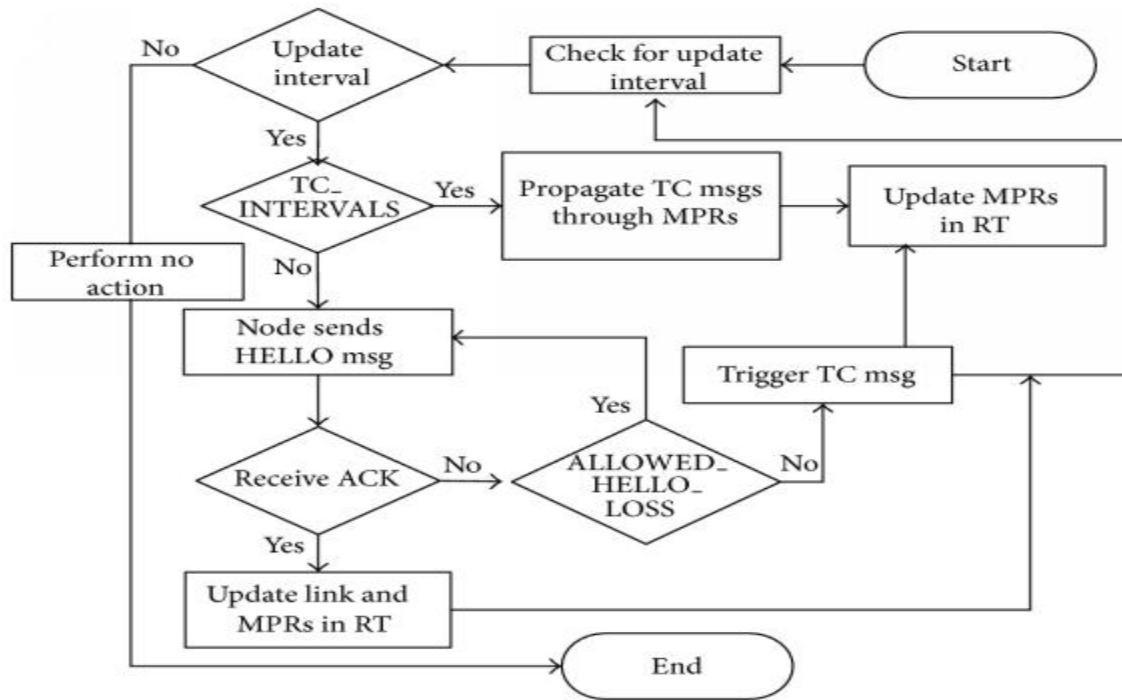


Fig 3.2: OLSR Flow Chart [18]

3.1.2 Destination Sequenced Distance Vector Routing (DSDV):

Making the classical Bellman-Ford Routing algorithm loop-free Perkins and Bhagwat proposed a new approach named as *DSD* routing protocol. Based on the information in the routing tables of the network node, destination node originates a unique *sequence number (SN)* for each route entry [16]. To maintain synchronization between various nodes the topological changes in the network are periodically updated by each node in the network. Multicasting of packets is done in order to advertise this information in the network. Routing table contains information such as SN, hop count, next hop, destination IP address and install time. Install time basically defines the time at which the information is updated in the network. Stale routes are determined using this time and their deletion also depends on the value of this parameter [20]. Any change in the distance value occurs if the node receiving a request message has a link to the destination. It compares the cost value with that present in the routing table.

Each node in the network has to advertise itself to its neighbour node in a continuous manner so that the information of the latest and most optimized route in the network can be obtained. As the data packets reach the destination node, it compares the SN of the packet with the available entry in the routing table. The table information is updated with the new SN if it is greater than the

existing one. If the two sequence numbers are same then hop count is checked and if the numbers of hops are found to be less than the existing entry, new value of hop count is set and updated to all the nodes. While updating this information the metric is increased by a value 1 and the SN is increased by a value 2. The main advantage of this algorithm is that the count to infinity problem existing in distance vector routing protocols was removed. The drawback of this algorithm is bandwidth wastage due to continuous updating of information in the network [20].

3.1.3 Wireless Routing Protocol (WRP):

It is another table based algorithm designed by Murthy and Garcia-Luna-Aceves to remove the issues related with count to infinity problem in ad hoc networks. Wireless Routing Protocols also inherits the features of Bellman- Ford Algorithm to find paths between desired nodes. The main feature of this protocol is to reduce route loops and maintaining information to define the shortest path to every destination [13]. To overcome the problem of count to infinity and enable faster computation, the information of every destination and the penultimate node in that direction is maintained at all the nodes in the network. For this each node maintains four tables:

- Distance Table (DT): contains the information of all the neighbours with respect to a particular node. For this a matrix is formed where the distance and penultimate node w.r.t. a particular destination is stored.
- Link-Cost Table (LCT): defines the hop count (or cost) required to reach a particular destination through all the links available. If we have a broken link then its cost is set to infinity. This also contains the information of update periods to detect link breaks in the network.
- Routing Table (RT): this contains the updated information of the network w.r.t to all known destinations. This includes shortest distance, penultimate node, next node and a flag to indicate the status of the path.
- Message Retransmission List (MRL): defines the update messages that are to be retransmitted. This is done by using a counter which is decremented for every retransmission of an updated message.

In case of link failure or change in the link nodes use update messages to communicate among them. Suppose a node is not updating the information, to ensure its connectivity it must send a HELLO message. After receiving a HELLO message from a new node the receiving node adds that information into its routing table.

3.1.4 Source Tree Adaptive Routing Protocol (STAR):

Source Tree Adaptive Routing protocol was proposed by Garcia-Luna-Aceves and Spohn in a source tree is maintained at each node to define preferred links to all possible destinations. This is also a type of link state algorithm. The source is a combination of all the links available in the network to reach all known destination and are updated periodically by each node [21]. This protocol is a combination of two algorithms LORA (Least overhead routing approach) and ORA (Optimum routing approach). To reduce the overheads in the network LORA is used for updating each with the information related to the topological changes occurring in the network. The shortest path to the desired destination is obtained by implementing ORA approach with minimized packet overhead due to LORA. The source trees are responsible for finding the optimized path to the destination, hence information exchange takes through these source trees to update the entries in the routing table. The routing table contains the information regarding routes available to the destination and the next node to be accessed in order to move forward in the direction of destination node. The changes in the information present in the source tree of each node are done according to the link state update messages. Requirement of periodic messages is eliminated as these exclude the time constraint problem [15].

3.1.5 Fisheye State Routing (FSR):

Klein rock and Stevens designed a technique for graphic information compression named as “Fisheye”. Inspired from this technique Pei et al. proposed FSR Protocol for routing in Ad Hoc networks [22]. While implementing this approach in case on routing tables, this means the node must maintain the information of the quality of all paths in its vicinity along with the accurate distance on those paths. But the distance from the node decreases with the amount of details retained in the table of that node. Areas termed as *fish-eye scopes* are considered by each node where it can access with 1,2,... hops. In this approach the information updating for the nodes lying in the fisheye scope is done at a higher frequency as compared to the nodes lying outside this region. This reduces the size of the updating messages. This feature of FSR increases its scalability in large networks.

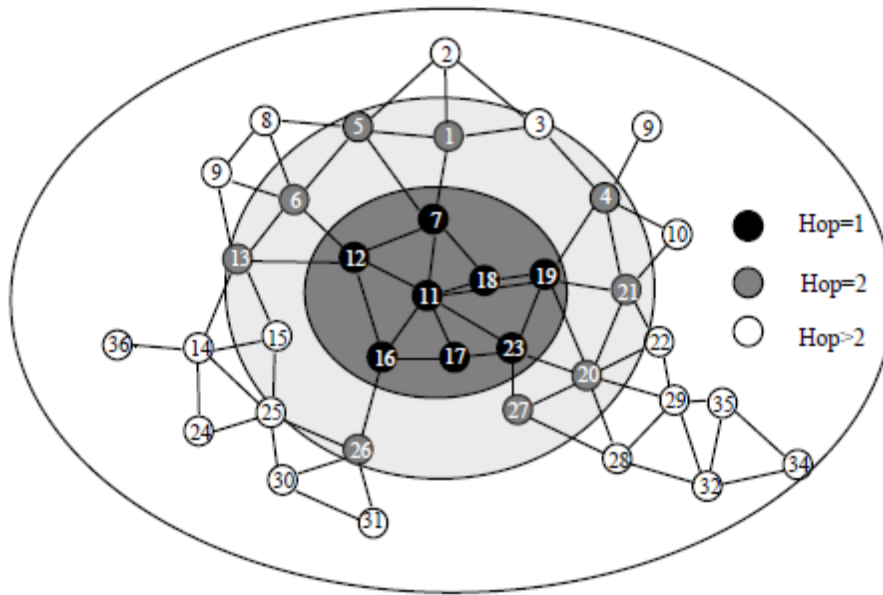


Fig 3.3: Scope of Fisheye [22]

3.1.6 Cluster Head Gateway Switch Routing (CGSR):

Chiang [23] described a Cluster Head Gateway Switch Routing protocol for routing in ad hoc networks which had a unique feature of using hierarchical topology. In this the whole network is organized into various clusters with one of the node in the cluster named as cluster head [23]. Hence it is a clustered network instead of a flat network as present in other algorithms. Using LCC the cluster head is chosen dynamically. The approach used to route the traffic is cluster head to gateway. Each cluster is destined with a cluster node and a node which lies in the range of two or three cluster heads is destined as gateway node. Hence whenever a node in a cluster tends to send some data, the data is first routed towards the cluster head. The cluster head node forwards this data to the gateway node and the process continues till the data reaches its desired cluster head. Then finally the cluster head delivers the data to the desired destination. Each node has to maintain a cluster member table which stores the information regarding the destination cluster head. This information is shared periodically using DSDV approach. In this algorithm DSDV is extended and modified with the use of clusters. This improves the performance of the network and reduces the packet overheads.

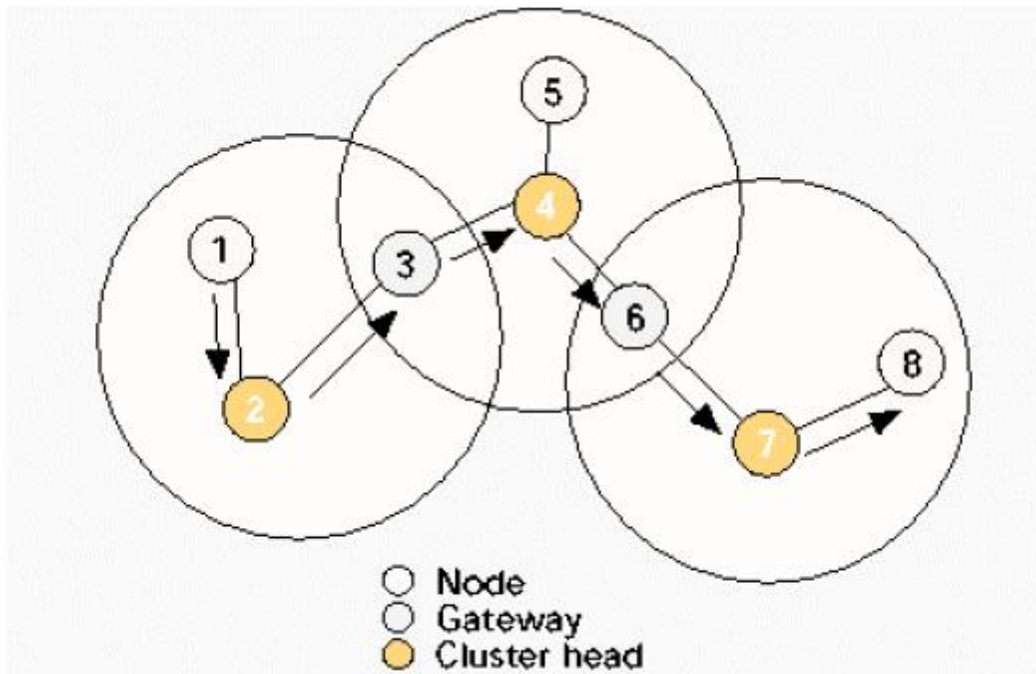


Fig 3.4: Routing for CGSR [23]

Table 3.1: Comparison of Proactive Protocols

Parameters	DSDV	WRP	OSLR
Loop free	Yes	Yes	Yes
Caching Overheads	Medium	High	High
Routing Overheads	High	High	Low
Throughput	Low	Low	Medium
Route Updates	Periodic	Periodic	Periodic
Routing Tables	2	4	4

3.1.7 Advantages of Proactive routing protocols:

- The routing overheads present in the networks remains constant with the number of routes involved.
- The delay involved in configuring a path is almost negligible as all the nodes are periodically updated with the latest route information in the network.
- Protocols such as WRP have a faster convergence period which enhances the network performance in terms of end-to-end delay.

3.1.8 Disadvantages of proactive routing protocols:

- Large number of overheads involved due to updating of routing tables with every topological change occurring in the network.
- Slow reaction on failure of nodes and reconstruction of network.
- Bandwidth wastage due to unnecessary sharing of information with all the nodes present in the network.
- The complexity involved in maintaining all the network information requires large memory and more processing power, which is a constraint in wireless networks.

3.2 Reactive Routing Protocols:

Many times it is not necessary to update all routing information to all the nodes present in the network. As this leads to wastage of bandwidth and increases the overheads in the network. Hence it results in congestion and degrades the performance of the network. Also the nodes involved in ad hoc networks have a power constraint issue and maintaining the routing tables requires more processing power. To overcome all the drawbacks of proactive routing protocols another class of routing protocols named as *reactive protocols or on-demand routing protocols* was introduced. As the name indicates the routes using such protocols are established only when a request for communication is initiated by a node in the network. These protocols use *Query-Reply* mechanism for discovering the desired route in the network [24]. Hence it is not necessary to continuously update routing tables of all the nodes present in the network. The aim behind reactive protocols is to reduce the traffic overheads involved in the process and can enhance the performance of the network. In this routing all the nodes maintain the information of only active paths to the destination node instead of maintaining complete routing information. A route search is needed for every new destination therefore the communication overhead is reduced at the expense of delay to search the route. Rapidly changing wireless network topology may break active route and cause subsequent route search. A procedure which involves flooding request-reply messages is invoked by reactive protocols whenever a need to find a particular destination is initiated [19]. The mechanism used for discovering routes is common for all reactive protocols. Whenever a node wants to transfer some data to a particular destination, it broadcasts a request message. This message is forwarded by each node until it reaches the desired destination. To update the source node with the desired route information all the intermediate nodes add their respective information in the message. Finally using these intermediate nodes

the destination sets a backward path to the source using reply messages. Once the source node receives the information regarding the path established it starts transmitting data through that path. Now there can be a possibility of occurrence of more than one path at the source node due to multiple reply messages. Hence the best path is chosen for sharing the required information. Following are some types of reactive routing protocols:

- DSR
- TORA
- LAR
- CBRP
- DYMO
- AODV
- ARA

3.2.1 Dynamic Source Routing (DSR):

Drawback of proactive protocol is the bandwidth wastage while periodic update messages were advertised in the network. To put a restriction on consumption of bandwidth by control packets D.B. Johnson, Maltz and Broch proposed an on-demand routing approach named as *Dynamic Source Routing Protocol*. The feature which distinguishes DSR from other protocols is the use of *source routing* [25]. As no periodic routing messages are advertised in this protocol, a route cache containing the source route of which a particular node is aware of is maintained. In source routing the transmitter node is aware of all the nodes through which the packet has to pass to reach its destination. Hence the source node lists the route information in the header of the packet. Using this information (Address of next hop) the packet can easily indentify its next hop until the destination is reached. The mechanism of DSR protocol is divided into two parts:

- Discovery of route
- Maintenance of route

Whenever a node wants to initiate a request for route establishment, it first checks the route cache to know whether a route to the desired destination is already available or not. If yes, the validation of the existing route is carried out. If the existing route is found to be unexpired the source node uses that route to transmit its data. Otherwise the source node broadcasts a route request message with following information [26]:

- Source address

- Destination address
- Unique identification number

Any intermediate node which receives this packet checks whether it has a route to the desired destination. If it has a defined route it sends a reply message in the backward direction. If not so it appends its address in the packet routing table and rebroadcasts the message to its neighbour. The process continues until the desired destination receives this request packet. The intermediate node discards the packet if its address is already present in the packet header. As soon the packet reaches an intermediate node having a path to its destination or the destination, the route reply mechanism starts. The route reply message contains the information of all the hops it visited between the source node and the node which has generated this message.

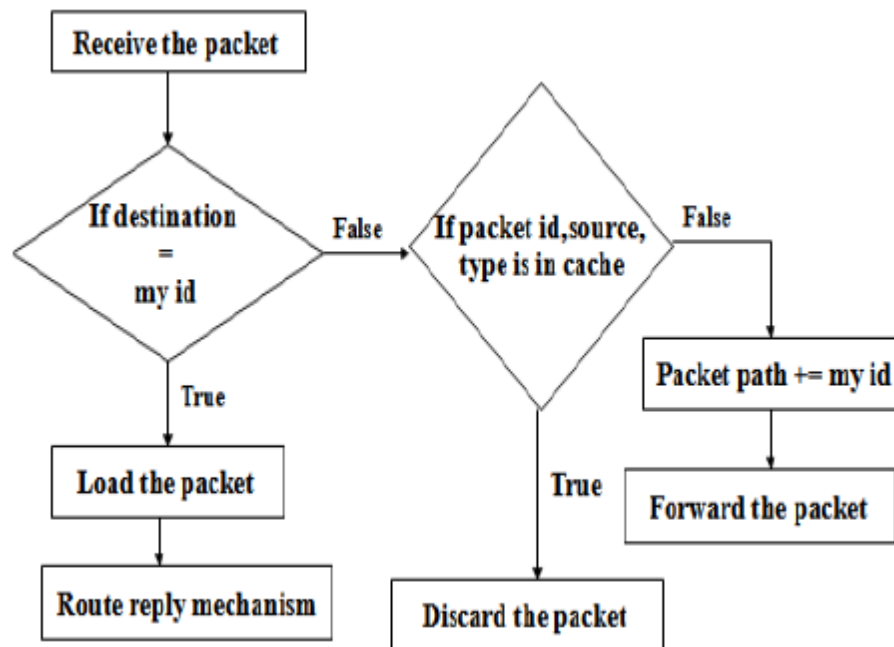


Fig 3.5: Route discovery mechanism [26]

Once the route is established the next important aspect is to maintain that route till all the packets reach their destination in a perfect form. To govern this mechanism Route Error Packets and Acknowledgement packets are used. As soon as an intermediate node finds a link failure in the path during transmission of the information, it generates a Route Error message. After receiving this message all the intermediate nodes remove the information of link failure from the route

cache. On the other hand acknowledgement packets are used to verify that the packet is following the destined route.

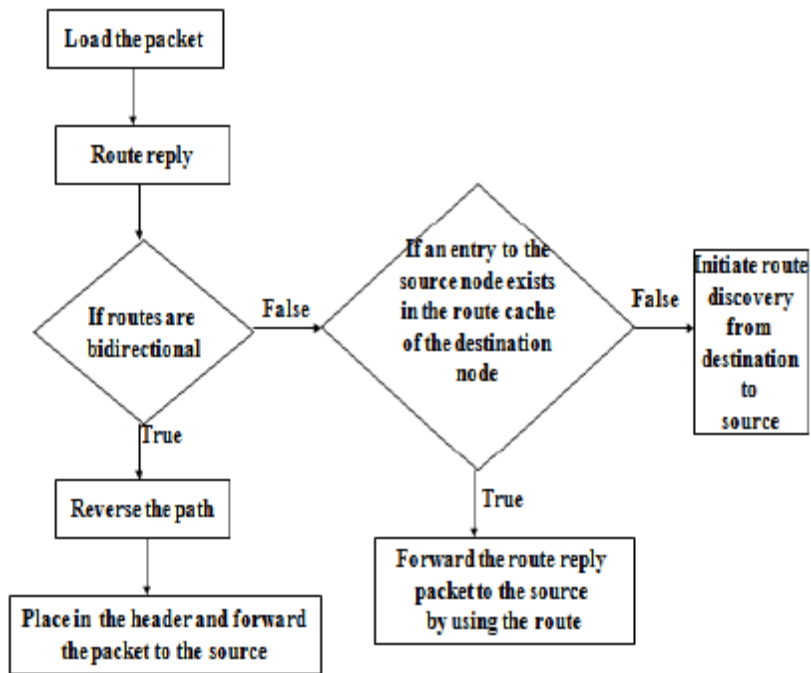


Fig 3.6: Route Reply Mechanism [26]

3.2.2 Temporarily Ordered Routing Algorithm (TORA):

Park and Corson introduced an approach which uses the concept of link reversal and is highly adaptive in nature. The feature that makes this algorithm unique is that whenever a link failure occurs control messages are only shared with neighbours of point of failure, instead of re-initiating route discovery process as in other reactive protocols. TORA is a highly scalable routing protocol for large networks whereas in case of smaller networks the traffic load is higher. Since the control messages are limited to a particular set of nodes the reaction of topological changes is minimized [11]. The process of this algorithm involves the following steps:

- Creating routes
- Maintaining routes
- Erasing Routes

It uses the technique of Directed Acyclic Graphs (DAG) for creating routes between various network elements and hence provides multiple routes between a source-destination pair. Each node is defined with a particular height and the message flow takes place in the downward direction from a node with higher height towards a lower height node. For route establishment

Query and Update messages are used. Whenever a source node needs to find a route to the destination, it broadcasts the Query message. A node having a path to the destination will broadcast an Update message with node height. Each node on receiving this Update message will set their height greater than the value specified in the Update message and then rebroadcasts the Update message. This process continues till the destination is reached [16]. The route maintenance refers to reacting to the topological changes so as to re-establish the route between the source and destination within a finite period of time. After these dynamic changes all the routes which became undirected are erased using Clear messages.

3.2.3 Location-Aided Routing (LAR):

With an aim to reduce the routing overheads Vaidya proposed a location information algorithm. Based on DSR features LAR uses the position information of a particular node and restricts the flooding of routing packets to a specified area. Along with the use of Route Request and Route Reply messages LAR makes the use of GPS (Global Positioning System) to determine the physical location of a node in the network. This basically defines two regions namely *Expected Zone & Request Zone*, and the flooding is limited to these two regions only. With respect to the source the request zone is fixed and nodes lying in the request zone will only forward the request packet to their neighbours. On the other hand, expected zone defines the region where the probability of finding the destination node is high. The request message is forwarded only to the nodes which are closer to the desired destination based on the information gathered by defining the expected zone [27].

3.2.4 Cluster Based Routing Protocol (CBRP):

The whole network is divided into small parts with limited number of nodes known as cluster forming a hierarchal structure. One of the nodes in each cluster is selected as cluster head. Generally the node having maximum number of neighbours in the cluster is considered as the cluster head node [28]. This node is responsible for transmission of data within the cluster as well as with other clusters. CBRP has an advantage that the routing information is only exchanged between the cluster heads. Hence the number of overheads involved in the network is much less as compared to the traditional flooding methods. The drawback of this routing approach is that due to long propagation delay inconsistent information regarding the route can be found in the routing tables of the nodes [16]. This can lead to stale routes and can degrade the network performance.

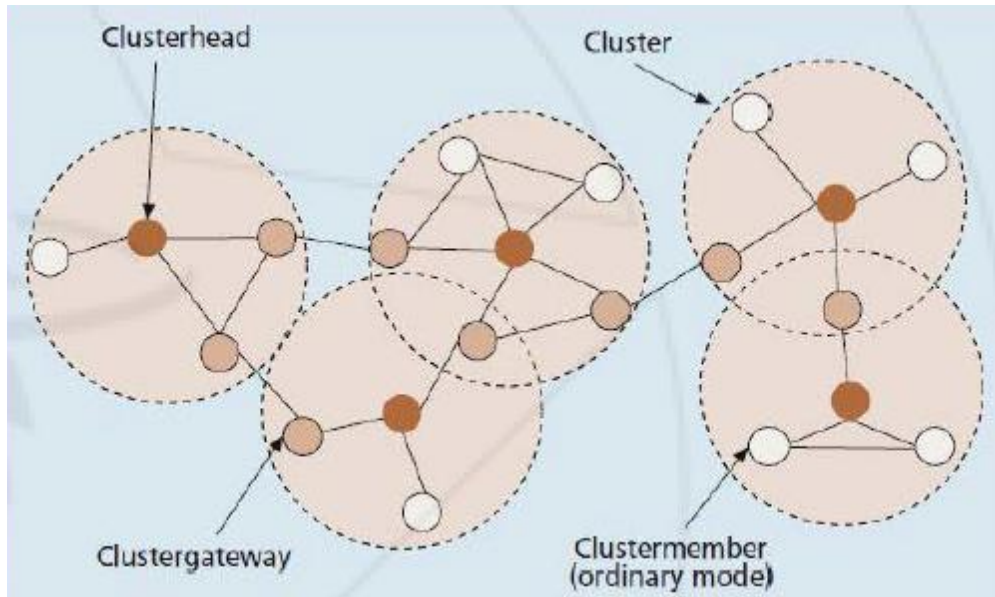


Fig 3.7: Network with various clusters [28]

3.2.5 Dynamic MANET On-demand Routing (DYMO):

Wireless multi hop networks having mobile nodes generally require flexible routing protocols due to frequent topological changes. Keeping this in mind DYMO was designed for communication among various mobile nodes in a network. It is basically a descendant of AODV and DSR [16]. Route discovery and route maintenance are the two operations involved in the implementation of DYMO. Similar to other reactive routing protocols the node which wants to communicate with other node initiates with a Route Request message. This message is broadcasted to the neighbour nodes and the process goes on until the destination is found. On receiving this request message the destination node unicast a Route Reply message establishing a backward path towards the source node. After receiving the information regarding the route established the source node starts transmitting the data. Information of link failure or disruption in the path is sent to the source node using Route Error message. After receiving this error message the route discovery process is again initiated by the source node if it still wants to transmit some data [29]. The route formation is done with the help of sequence numbers given to different packets. Due to this reason DYMO ensures loop freedom. One of the unique features of DYMO is that it can be used both in IPv4 and IPv6 internet protocols. DYMO and AODV share many common features except that DYMO only supports unicast routing whereas AODV supports unicast, multicast and broadcast mechanism. Hence it establishes a unicast route

between target and source node whenever required. It is a highly scalable routing protocol with an ease of implementation.

3.2.6 Ad Hoc On-demand Distance Vector Routing (AODV):

C.E. Perkins and E.M. Royer designed a routing algorithm which incorporates the feature of DSDV and DSR and has ability to minimize the routing overheads by creating routes on-demand. The algorithm was given a name *Ad Hoc On-demand Distance Vector Routing Protocol*. DSDV approach is useful for creating a small network but as the network size increases this becomes a brute force approach. This is because each node in the network has to maintain separate routing table for all destinations present in the network. This can reduce the latency in route acquisition for the first packet to be sent. But overall delay of the network increases due to overheads involved in the network [30]. Hence an on-demand approach can play a useful hand in such networks. The only parameter that has to be controlled while using on-demand protocols is the time required to establish the required path. Therefore to minimize number of broadcasts and transmission latency AODV routing protocol was introduced which enhanced the network performance. It is a pure on-demand routing approach in which nodes neither maintains the routing information nor deal with the periodic table exchanges. There is no requirement of maintaining a route with neighbours until communication is required between them. Only when required each node can create a local connectivity with its neighbours by using HELLO messages. AODV was designed keeping in mind the following objectives [31]:

- Route discovery packets are only broadcasted whenever necessary.
- Capability to distinguish between topological maintenance and neighbourhood detection.
- Information regarding any change in the topology is shared with only those neighbours who require that information.

As DSR implements route discovery process same is the case with AODV approach. The only difference is DSR involves source routing whereas in AODV intermediate nodes dynamically update the route table entries. This removes the drawback of carrying large source route information at the intermediate nodes. The other unique feature of AODV approach is the use of destination sequence number as used in DSDV. Every node maintains a monotonically increasing destination sequence number to eliminate the stale routes. Hence this approach utilizes the bandwidth in an efficient manner and provides loop free routing. Similar to other reactive protocols AODV also uses the following two operations to establish a path:

1. Path discovery
2. Path maintenance

1. Path Discovery:

As AODV is an on-demand protocol the path discovery process is initiated whenever a node in the network needs to communicate with other node. Two counters one for sequence number and other for broadcast ID is maintained by each node. The procedure to discover a route is invoked by broadcasting a Route Request message to the neighbour nodes. Figure 3.8 shows the information contained in this message:

Source Address	Source Sequence Number	Broadcast Id	Destination Address	Destination Sequence Number	Hop Count
----------------	------------------------	--------------	---------------------	-----------------------------	-----------

Fig 3.8: RREQ Message [32]

RREQ is uniquely defined by source address and the broadcast id. Whenever the source node issues a new RREQ message broadcast id is incremented by one. As the node receives this message either it sends a reply message to the source node or it rebroadcasts this message with an increased hop count. On receiving multiple RREQ messages with same source address and broadcast id the intermediate nodes discards the message. Now if an intermediate node has a path to the desired destination it replies back with a Route Reply message towards the source node. Figure 3.9 shows the information contained in the reply message:

Destination IP address	Source IP address	Destination Sequence Number	Hop count	Lifetime
------------------------	-------------------	-----------------------------	-----------	----------

Fig 3.9: RREP Message [32]

1.1 Reverse path setup:

RREQ contains two sequence numbers namely source sequence number and the last destination sequence number updated at the source node. The freshness of the reverse route to the source is maintained using source sequence number. Whereas destination sequence number defines the freshness of the route available at the source to reach the destination. As the RREQ traverses in the network a reverse path is automatically established towards the source node. The intermediate nodes maintain the address of the neighbour node from which the RREQ was received. The RREP message has a life span greater than the time required by the RREQ message to reach its destination [31].

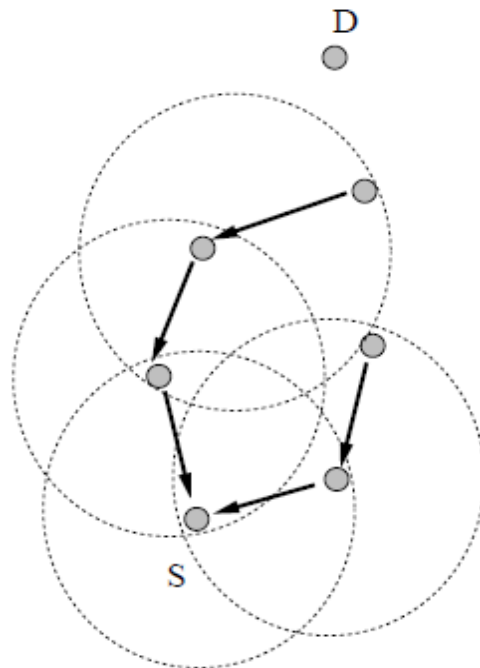


Fig 3.10: Reverse path setup [33]

1.2 Forward Path Setup:

As the RREQ message travels in the network it will eventually reach an intermediate node having a current path to the desired destination. The next step is to validate that the route available is the latest in the network. This is done by comparing the destination sequence number present in the nodes routing table with that present in the RREQ message. If the node finds that the sequence number in the routing table is less than the RREQ's sequence number then that node will not respond to that message and will rebroadcast the RREQ message [32]. Otherwise, it unicasts an RREP message to its neighbour from which the RREQ message was received. As

the RREQ message arrives at an intermediate node having a direct link with the destination a reverse path has been established. Each node in the path sets up a forward pointer in the direction of node from which the RREP message is received. Along with this each node updates the time out for the route established and enters the latest destination sequence number in the routing table. All the intermediate nodes which are not a part of the final route will exit after a fraction of time termed as *Active Route Timeout* (Around 3000ms).

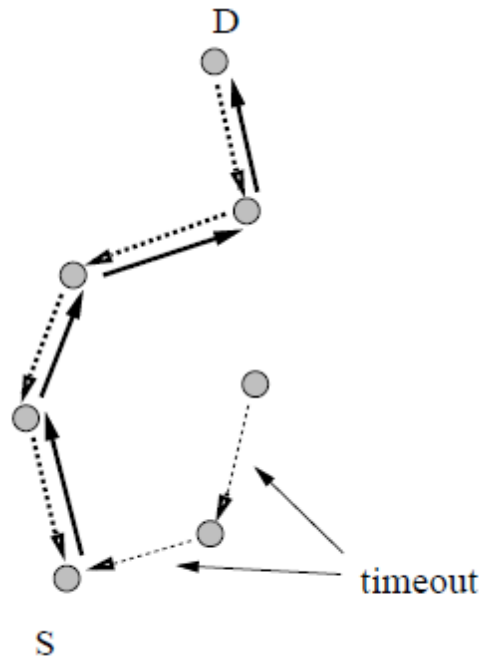


Fig 3.11: Forward path setup [33]

After receiving the RREP each node forwards that message towards the node for which it is destined i.e. the source node. While doing this the node updates its routing table with the information carried by RREP. Now if the node again receives an RREP message destined for the same source it compares the destination sequence number with the entry made using the information of the previous RREP message. The node will only propagate this RREP if its destination sequence number is greater or same with lower hop count as compared to the entry in the routing table [30]. Otherwise it will discard all such multiple reply messages and hence reduce the congestion in the network.

The data present in the routing table of the various nodes is the network keeps on changing during the routing discovery process. Along with the sequence number there are several other parameters required to minimize the overheads present in the network. During the process of

route establishment many on the network nodes exists which receives the information but are not the part of the final route. These nodes keep the information for a limited period of time known as *Active Route Timeout*. Another important time factor is the *route cache timeout* for the route request. After this time the route is considered as invalid. Following are the entries which are maintained at the routing tables of the intermediate nodes:

- Destination
- Destination sequence number
- Next hop
- Active neighbours for the route
- Hop count
- Expiration time of route entry

2. Path Maintenance:

Since the ad hoc networks exhibits high mobility, this can affect the performance of the network. Hence the routing algorithm should be such that it can take care of such mobility issues. Suppose the intermediate nodes of the established path leave their actual position. This can lead to broken link in the route established. The nodes inform the entire affected source node with help of RREP message. Along with this periodic HELLO message are sent to ensure the validity of link and detect link failures. Whenever an intermediate node finds that the next node is out of range, the upstream node issues an RREP message with a new sequence number (incrementing the last sequence number by one) [33]. All the active upstream nodes are updated with hop count infinity. The process continues till the source node receives the information about the broken link. The path terminates as AODV is a loop free technique. Upon receiving the information of the disruption made source node decides whether it wants to re-establish an alternate path or not. If the source node again wants to invoke a route discovery process, it initiates with an RREQ message having destination sequence number one greater than the last updated value. This ensures that the new route built is valid and latest.

Example of AODV routing approach:

1. Consider the following network with node S wants to establish a route towards node D.

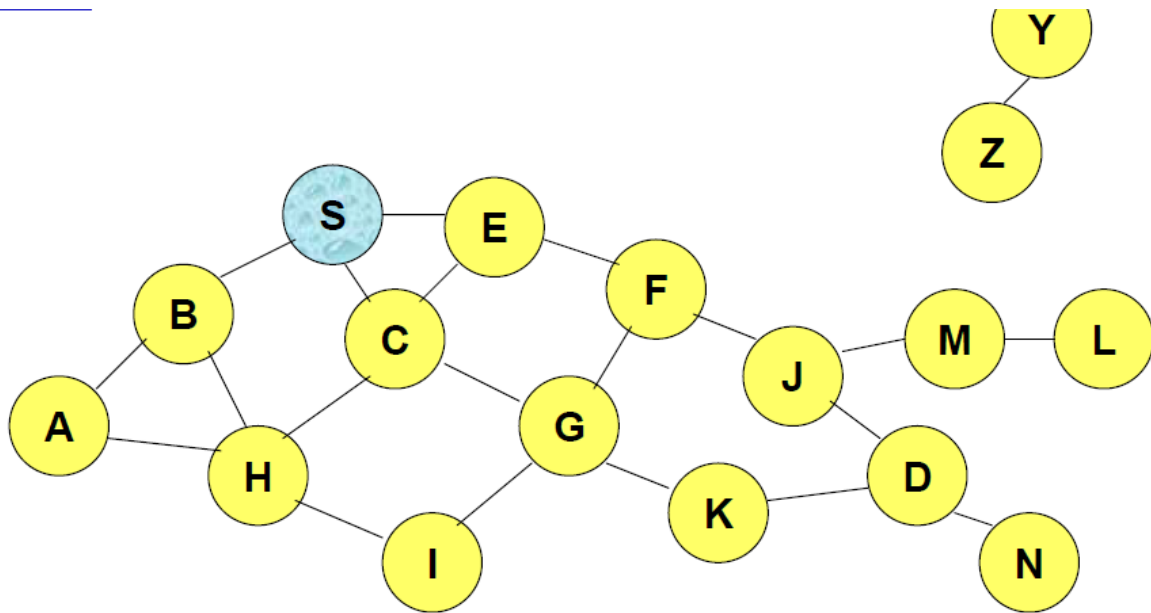


Fig 3.12: Random ad hoc network [31]

2. Transmission of RREQ

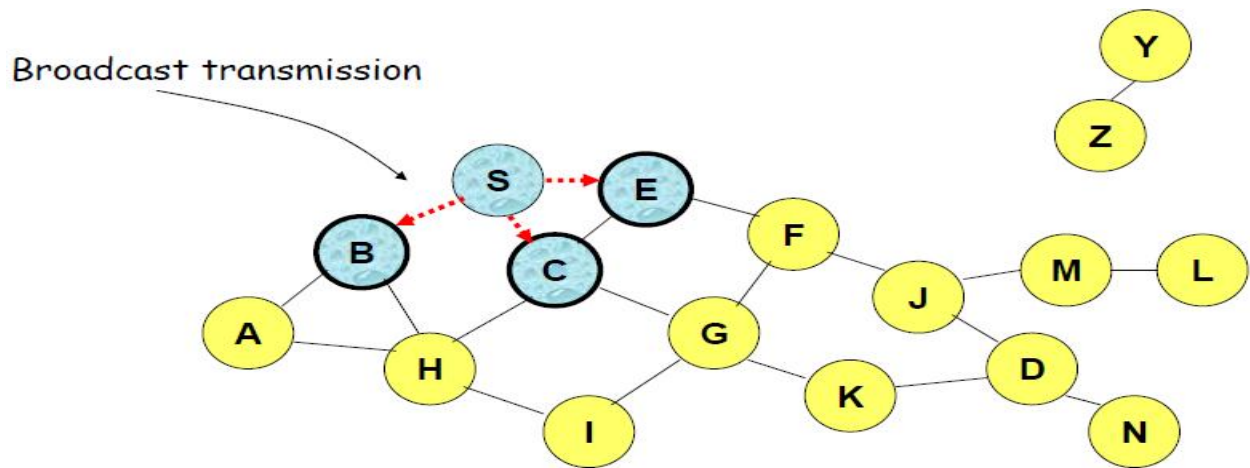


Fig 3.13: Node S broadcast RREQ [31]

3. Transmission of RREP

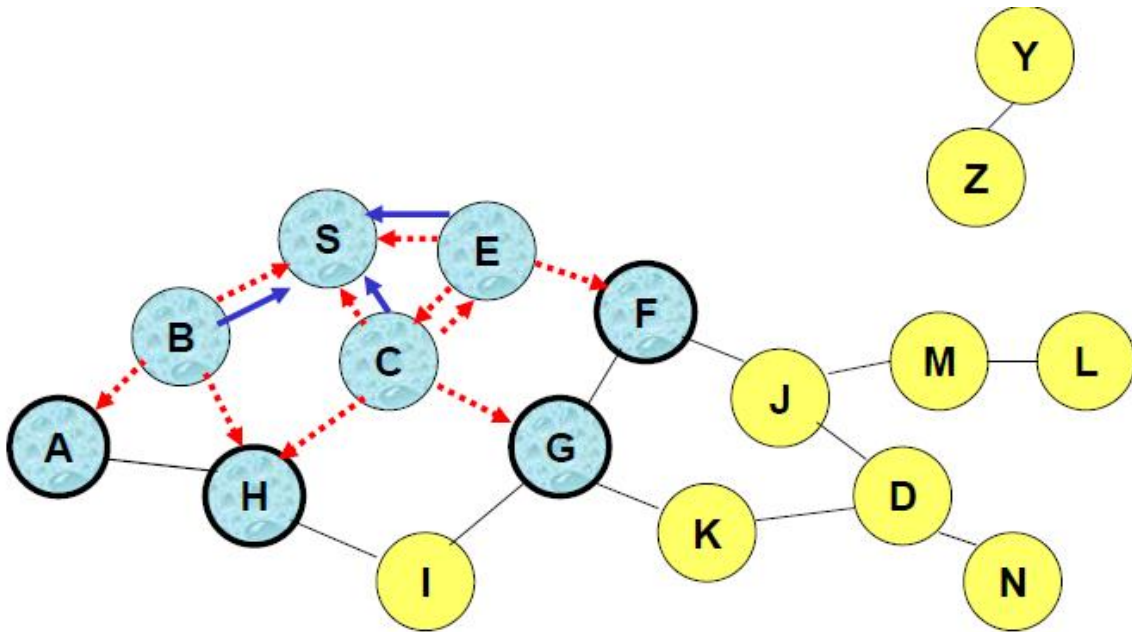


Fig 3.14: Link on reverse path [31]

4. Node C receives RREP from G and H, but it does not rebroadcast that message.

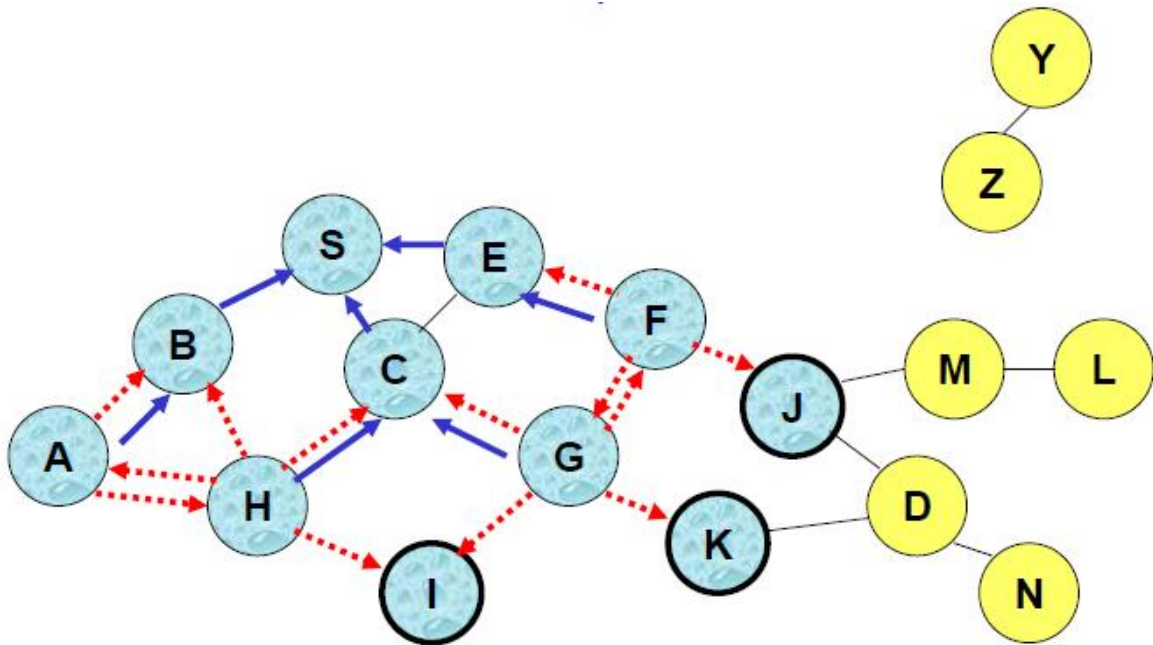


Fig 3.15: Discarding Multiple RREP [31]

5. The desired destination is found i.e. RREQ reaches node D

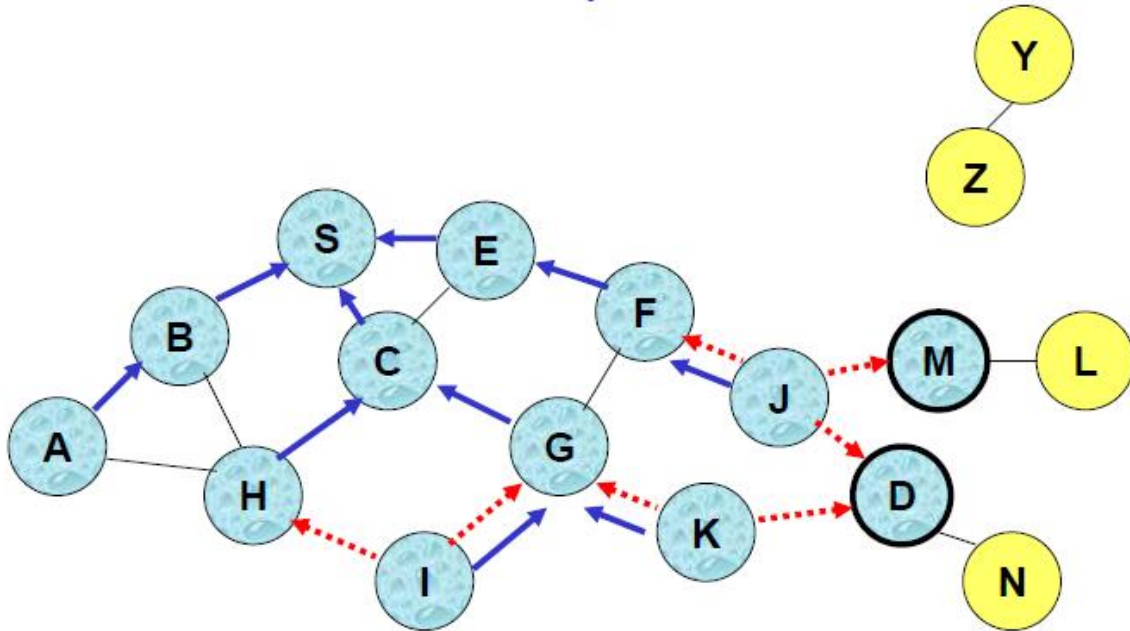


Fig 3.16: RREQ arrives at node D [31]

6. Forward and reverse path established between source and destination

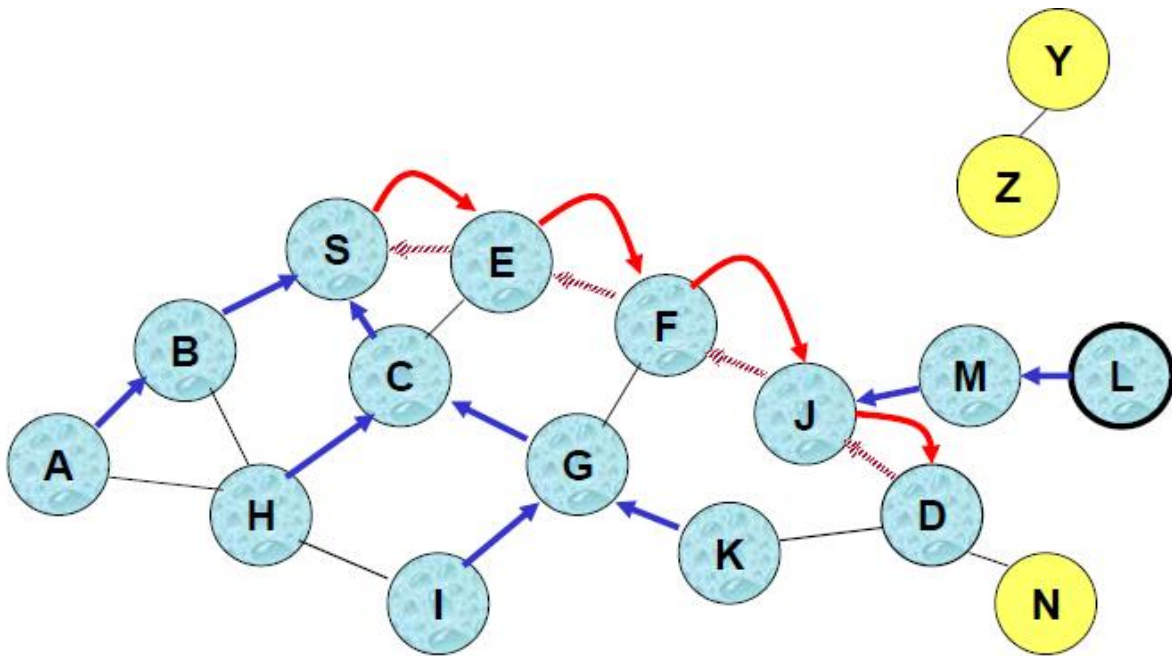


Fig 3.17: Forward and reverse link [31]

3.2.7 Ant Colony Based Routing Algorithm (ARA):

To address routing issues in MANETs a group of algorithms named as *Swarm Intelligence* was introduced. A swarm can be defined as a homogeneous group of members interacting among themselves and the environment. The best part is they do not require any centralized authority to control their operation. They themselves work as a group and emerge with an interesting behavior. Inspired from the collective behavior of various animal societies (such as colonies of ants) SI provided a fast and robust solution to a large number of complex problems [34]. Using the concept of SI distributed optimization problems in networks having no centralized authority can be efficiently handled. The agents communicate in the social environment either directly or indirectly. The indirect way of interaction is done using the environment in which the agents are present and is termed as *Stigmergy* [35]. One of such SI algorithm is **Ant Colony Optimization Technique**. This approach was introduced by Marco Dorigo in 1992 which describes a probabilistic approach of route optimization in a complex network [36]. This algorithm is inspired from the social organization of ants which is genetically evolved commitment of each individual to the survival of the colony. Ants follow a pheromone (a volatile chemical substance) trail. This pheromone trail is used by ant species for marking paths on the ground i.e. path from food source to nest. By sensing this pheromone trail ants can follow the path for food discovered by other ants. This collective trail-laying and trail following behavior where an ant is influenced by a chemical trail left by other ants is the inspiration source of ACO. Ants chose the probabilistic path by smelling the pheromone and moves on the path with highest pheromone concentration [37].

Consider figure 3.18 (a), it shows a set of ants moving from point A (nest) to point B (food source). Let us suppose on their way an obstacle is present in such that the path through C is longer than the path through D as can be seen in figure 3.18 (b). The first ant which reaches the point where obstacle is placed will choose a random path either through D or C placing pheromone on the way. But the ants following path D will reach the destination earlier than those following path C depositing more pheromone. On the basis of the intensity of pheromone present on both the paths rest of ants will choose their path to the destination. Therefore the intensity of pheromone will influence the following ants to choose the path ADB instead of ACB. The same path is chosen by all the ants to propagate back towards their nest. As pheromone is volatile each ant will deposit the pheromone after reaching the destination. $H_{t,i,j}$

represents the amount of pheromone deposited by each ant. An ant changes the amount of pheromone on the path (i, j) when moving from node i to node j as follows [36]:

$$\tau_{i,j} = \sigma \cdot \tau_{i,j} + H \cdot \tau_{i,j} \quad (3.1)$$

where σ is the pheromone evaporation factor. It must be lower than 1 to avoid pheromone accumulation and premature convergence. At one point i , an ant chooses the point j (i.e. to follow the path (i, j)) according to the following probability [36]:

$$P_{i,j} = \frac{(\tau_{i,j})^a (\eta_{i,j})^b}{\sum_{i,k \in C} (\tau_{i,k})^a (\eta_{i,k})^b} \quad (3.2)$$

where,

- $\tau_{i,j}$: is the pheromone intensity on path (i, j) .
- $\eta_{i,j}$: is the ant's visibility field on path (i, j) (an ant assumes that there is food at the end of this path).
- a and b : are the parameters which control the relative importance of the pheromone intensity compared to ant's visibility field.
- C : represents the set of possible paths starting from point i ((i,k) is a path of C)

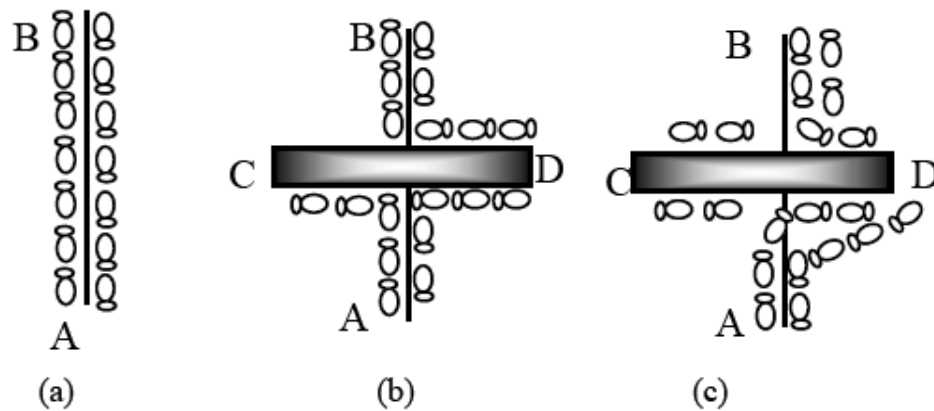


Fig 3.18: ANT Colony Description [36]

Table 3.2: Comparison of Reactive protocols

Parameters	AODV	DSR	TORA
Periodic Updation	No	No	No
Routing Overhead	High	High	High
Multipath	No	Yes	Yes
Route Updation	Non-Periodic	Non-Periodic	High Routing Overhead
Caching Overhead	Low	High	Medium
Throughput	High	Low	Low
Route Creation	By Source	By Source	Locally

3.2.8 Advantages of reactive routing protocols:

Following are some of the advantages of reactive routing protocols:

- Periodic updating the routing table is not required which minimizes the routing overheads involved in the network.
- As the traffic overheads are reduced unnecessary information is not advertised in the network. Hence bandwidth can be efficiently utilized.
- As nodes only carry the information of active routes in the network memory utilization is effective. This also help to reduce the processing power required which is a constraint while dealing with wireless networks.
- The information regarding the active routes is only shared by the nodes involved in the path. This increases the throughput of the network as unnecessary information is discarded.
- Reacts quickly in case of network restructure and link failure

3.2.9 Disadvantages of reactive routing protocols:

- High latency in route discovery as route is established only when a request is initiated.
- The probability of clogging is high as network is flooded with the query-request messages.
- Intermediate nodes may lead to inconsistent and stale routes if the sequence number becomes too old.

3.3 Hybrid Routing Protocols:

This is a class of routing protocols which incorporates the features of both proactive and reactive routing protocols. In these protocols the route establishment starts proactively i.e. the links between nearby nodes are setup using proactive features. Whereas the demand of additionally activate nodes is fulfilled using reactive routing [38]. Another feature of this type of routing is more routing information is maintained by the nodes having higher topological information as compared to the other nodes. This leads to complexity in organizing the network in accordance with network parameters. Following are some types of the hybrid routing protocols:

- ZRP
- CEDAR
- ZHLS
- DDR
- DST

3.3.1 Zone Routing Protocol (ZRP):

Haas and Pearlman designed a hybrid routing protocol which divides the whole network into smaller sub-networks known as *Zones*. The zones are defined on the basis of distance between various nodes of the network. For a given hop distance l and node M , all the nodes at a distance l from the node M will lie in the zone of M . Whereas rest of the nodes will lie in others i.e. nodes having equal hop distance between each other are kept in one zone. Since it is a type of hybrid routing protocol the nodes within a zone communicates proactively whereas nodes in different zones use reactive protocols to communicate among themselves [39]. Therefore whenever inter-zone interaction occurs it implements on-demand protocols. The routing overheads are reduced as nodes lying in a single zone needs to periodically update the network information. In addition to this local route optimization techniques are used at each node. These perform functions such as link failure detection, redundant routes removal and shortening of routes [40].

3.3.2 Zone Based Hierarchal Link State Routing (ZHLS):

Joa and Lu designed a routing protocol which is based on a hierarchal network in which only non-overlapping zones are present [41]. In this protocol each node carries two IDs, one is node ID and the other is zone ID. This pair of IDs is unique for each node present in the network. Hence this involves a two level structure of topology namely node level and zone level. For each zone we have a link state update packet (LSP) i.e. the node level LSP and zone level LSP

respectively. The node IDs of the nearby nodes or the nodes present in the zone are stored in the node level LSP whereas zone IDs of the other zones are stored in zone level LSP. Hence the node level LSP can propagate only in the limited zone area whereas zone level LSP can propagate among various zones of the network [42]. In case a node in a particular zone wants to transmit some data, it first observes the intra-zone routing table. If it finds the routing information in this table it utilizes that route and starts transmitting. If not so then the source node transmits a location request to all other zones of the network with the help of gateway nodes. After finding the desired destination the gateway nodes reply back with the zone ID of the destination. ZHLS involves less routing overheads as compared to reactive protocols and is adaptable to various topological changes as only zone ID and node ID are required for communication. Therefore till the destination lies in the zone itself the need of search for a routing path is eliminated.

3.3.3 Core Extraction Distributed Ad hoc Routing (CEDAR):

QoS support and partitioning is provided by CEDAR as described by Sivakumar and Bharghavan [43]. The network is divided into different partitions each having a core node termed as *dominator node*. Along with this a graph is defined with a set of nodes known as *dominator set*. The DS is defined in such a way that every node is a member of it or in the neighbour of one of the nodes present in DS. For establishing a route between the source/destination pair, the core nodes use reactive routing protocols. CEDAR mechanism is parted into three phases:

- Route computation with the help of proper establishment of a self-organizing core infrastructure.
- Routing information propagation in the core network which includes the high bandwidth link state information and stable links information.
- Determining the QoS of the network using an efficient QoS algorithm executed at the core nodes using local states only.

For achieving QoS in CEDAR stable links bandwidth availability information is propagated in the core sub-graph. Fast moving decrease waves and slow moving increase waves are used to indicate the decrease and increase in bandwidth respectively.

3.3.4 Distributed Dynamic Routing (DDR) Algorithm:

This protocol is a tree based approach proposed by Nikaein which does not require any root node for routing. This strategy involves continuous beaconing of messages which are only shared by

neighbouring nodes [44]. These trees collectively form a forest type structure with gateway nodes acting as links between different trees. The normal nodes of the tree which are in transmission range of each other are considered as gateway nodes. Each tree is provided with a unique zone Id using a zone naming algorithm. The DDR algorithm is comprised of following operations:

- Preferred neighbour selection
- Clustering within the tree (intra-tree)
- Clustering among various trees (inter-tree)
- Construction of forest
- Assigning different zone names
- Partitioning of different zones

HARP (Hybrid routing protocol) is used to establish routes in the network. Stable path is established by HARP using the routing information present in the zone routing tables (intra or inter) created by DDR. The main advantage of DDR is that no static zone location related information is required as in the case of ZHLS. It also eliminates the need of cluster heads or root node to control the data transmission between different nodes.

3.3.5 Distributed Spanning Tree (DST) Protocol:

The network is divided into a number of trees having limited number of nodes. There are two types of node present in each tree: root node which only one and internal nodes [45]. Root node takes the decision whether the tree can be merged with the other trees present in the network or not i.e. the root node maintains the control mechanism of a tree. Other nodes in the network can have three stages: it can act as router, merger or configure depending on the task performed by the node. To determine a route there are following two strategies:

- *HTF*: In this all the adjoining bridges and the neighbours of the source node receives the control messages shared by the source node. All the nodes receiving these packets keep them static during hold time.
- *DST Shuttling*: the control packets are only shared with the tree edges until they reach a leaf node. From the leaf node the packets are forwarded to a shuttling level.

The major drawback of DST algorithm is the point of single failure present in the architecture i.e. the root node. If a failure occurs in the root node, this can lead to the failure of whole routing process. Also the holding required to keep the control packets increase the delay in the network.

Table 3.3: Comparison of hybrid routing protocols

Parameter	ZRP	ZHLS	DST	DDR
Multiple routes	No	Yes	Yes	Yes
Beacons	Yes	No	No	Yes
Route metric	Shortest Path	Shortest Path	Forwarding using tree neighbours	Stable routing
Routing structure	Flat	Hierarchal	Hierarchal	Hierarchal
Advantage	Reduced transmission	Low control overheads	Reduced transmission	No zone coordinator or zone map
Disadvantage	Overlapping zones	Static zone map required	Root node failure problem	Neighbours may become bottleneck
Route information stored in	Intra zone and inter zone tables	Intra zone and inter zone tables	Route tables	Intra zone and inter zone tables

3.3.6 Advantages of hybrid routing protocols:

- Remove the problem of overheads (proactive protocols) by periodic flooding of information packets.
- Reduce the latency (reactive protocols) involved in finding the optimized route in the network.
- No practical limitation on the size of the network as the nodes has enough memory to store information about all the other nodes in the network.

3.3.7 Disadvantages of hybrid routing protocols:

- Overlapping zones may lead to inconsistent routes in the network
- Failure or root nodes may lead to failure of entire routing process.

- More topological information carrying nodes consumes more power and requires more memory.

Table 3.4: Comparison of routing protocols

Parameters	Proactive Routing	Reactive Routing	Hybrid Routing
Route Availability	Always available	Only when required	Depends on destination location
Delay	Low	High	Low for local destination and high for inter zone
Control traffic	High	Low	Lower than other two types
Routing information	Stored in tables	Does not store	Depends on requirement
Storage requirements	Higher	Depends on routes maintained	Depends on size of zones or clusters
Periodic route updates	Always required	Not required	Used inside zones only
Scalability	100 nodes	>100	>1000
Routing Philosophy	Mostly flat	Flat	Hierarchal

Chapter 4

Methodology and Analysis

This chapter defines the system model of the work presented. An ACO appended AODV approach has been proposed in the work to establish a local link repair mechanism for mobile ad hoc networks. Also the route formation can viewed with the help of GUI representation. GUI is a MATLAB tool for graphically representing operations of the routing algorithm. Mathematical analysis has also been described in this chapter.

4.1 System Model:

Selection of routing protocol is one of the most important task while deployment of MANETs. As all the challenges described in chapter1 must be covered while designing the routing protocol for ad hoc networks. Routing overheads are one of the key factors which evaluate the performance of a network. These should be minimized in order to enhance the performance of network and utilize the available bandwidth in an efficient manner. As discussed in chapter3 proactive routing algorithms involve a large amount of routing overheads as periodic updating of routing information is done [14]. Many a times it is not necessary to update all the nodes in the network with all routing information in the network. This led to the designing of reactive protocols which specifically shares the required information only with the concerned nodes and hence minimizes the routing overheads involved in the network [31]. Chapter3 describes the mechanism of various reactive protocols. One of such reactive protocol is *AODV routing algorithm* [33]. The unique feature of this algorithm is the use of *destination sequence number* for establishing a route between source/destination pair. As we know that MANETs involve a frequent topological variation which leads to a link failures in the networks. AODV fails to repair these links locally. As soon as the route failure information is obtained by the source node, the route formation is takes place from the beginning. This leads to an increased over all delay in the network. Also the packet loss factor increases which degrades the network performance. To overcome this *ACO appended AODV approach* has been described in this work. Firstly using AODV an optimized route is obtained between the source and destination. Then occurrence of link failure is handled by implementing ACO algorithm from the point of link failure.

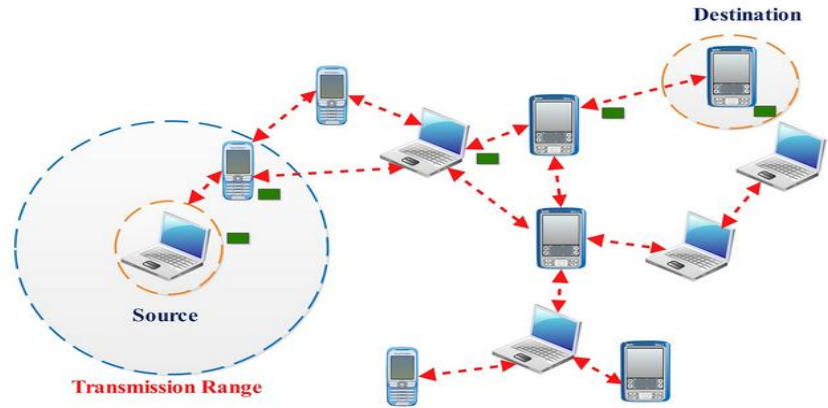


Fig 4.1: Mobile Ad Hoc Network [46]

The above figure represents a random MANET structure with one source and one destination. It can be observed from the figure that the source node has limited transmission range. Hence there is a requirement of an optimized route through which data can be transferred to the destination with minimized scope of error and delay. This can be achieved using the other nodes of the network by an efficient routing algorithm.

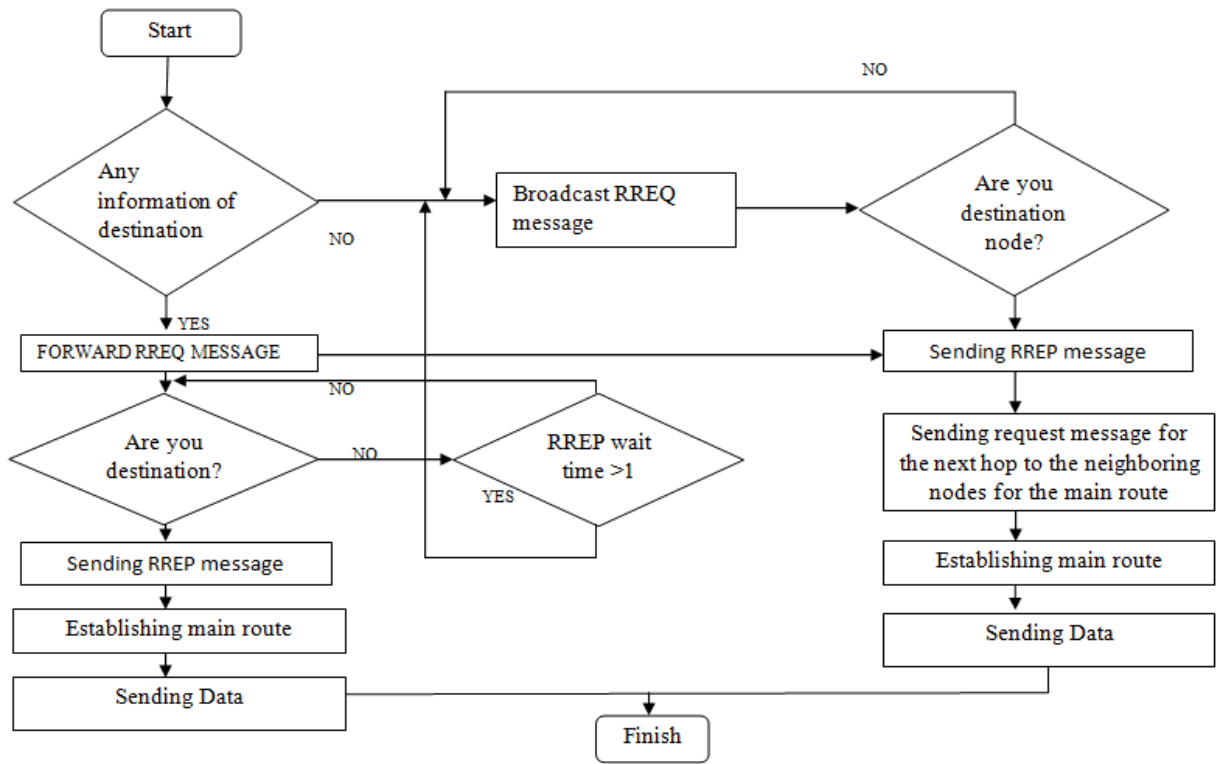


Fig 4.2: AODV Process [33]

For finding the route in for the source node in the MANET shown before, we have applied AODV routing approach. AODV can provide an optimized solution to this problem as it uses the *destination sequence number technique* [47] to find the latest route available in the network. The flow chart in figure 4.2 describes the mechanism of AODV routing protocol for route establishment. The process includes the broadcasting of RREQ (route request) messages and unicasting of RREP (route reply) [48] messages of finding information regarding destination. After the route has been established between the desired node pair, the source node starts transmitting the data through that node. As MANETs involve dynamic topology due to mobility of the nodes in the network, link failures are very common in these networks. Suppose the path found using AODV suffers from link failure [49]. The information regarding the link failure is forwarded to the source node with the help of RRER (route error) message. After receiving this information the source node will again initiate the process of route discovery if required. Now this process of alternate route discovery starts from the beginning which will introduce a large delay [50] in the network and hence degrade its performance. To avoid this we can apply some other routing approach from the point of link failure. Here we have used ACO approach which is a type of Swarm Optimization technique to build all the alternate paths from the point of link failure to the destination. This will help us to reduce delay and transmission errors in the network. Among all the alternate routes that have been obtained using ACO we again apply AODV to find the latest route available. To understand the end-to-end processes refer to the following block diagram.

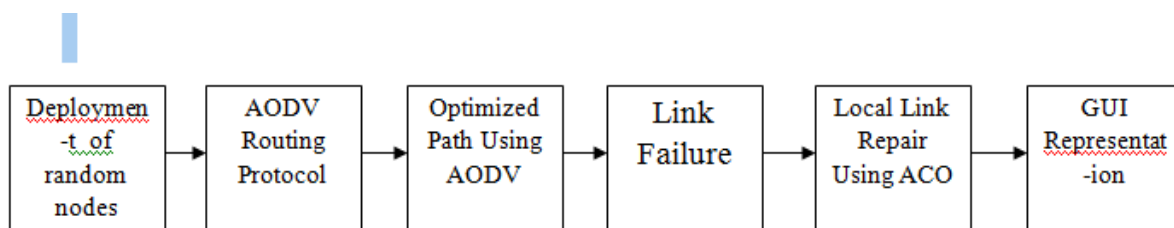


Fig 4.3: Block Diagram

The output of each block is represented using GUI tool in MATLAB. This shows the route search procedure of the routing protocols involved in the network.

a) Deployment of random nodes

An area of 100km by 100km has been considered in which some nodes are deployed randomly. The network parameters are calculated by varying network size. The window in figure 4.4 represents a network with 25 nodes. Node2 is the source searching for a destination named as node17.

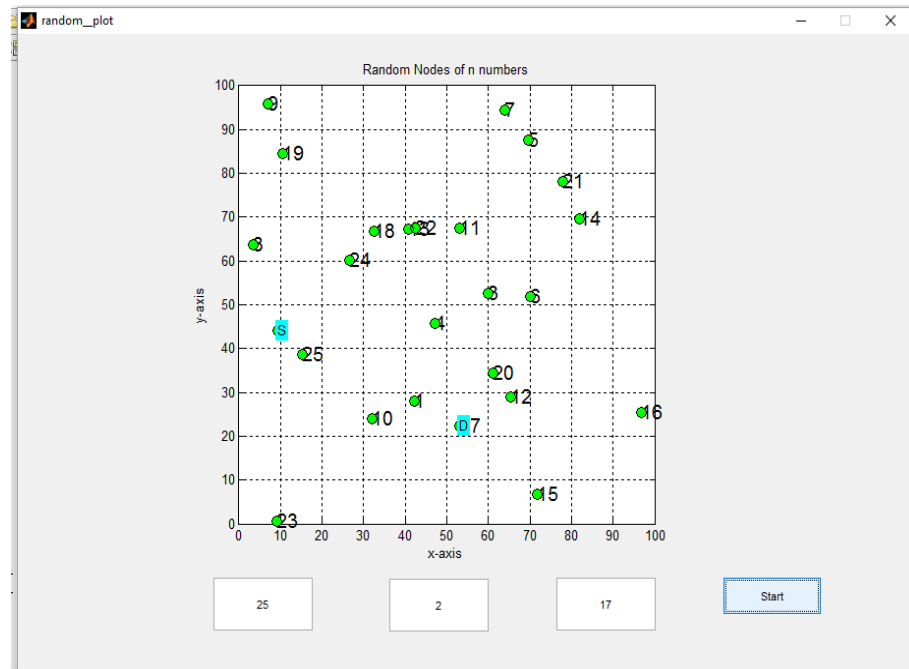


Fig 4.4: Random nodes

b) Optimized path using AODV

The use of destination sequence number in AODV helps the routing algorithm to select the latest route in the network. This also helps to discard the multiple receptions of same route request messages and hence reduce the network overheads. The window below represents the transmission of RREQ and RREP messages between node 2 and node 17. Forward and reverse paths are being represented in the following graphical representation.

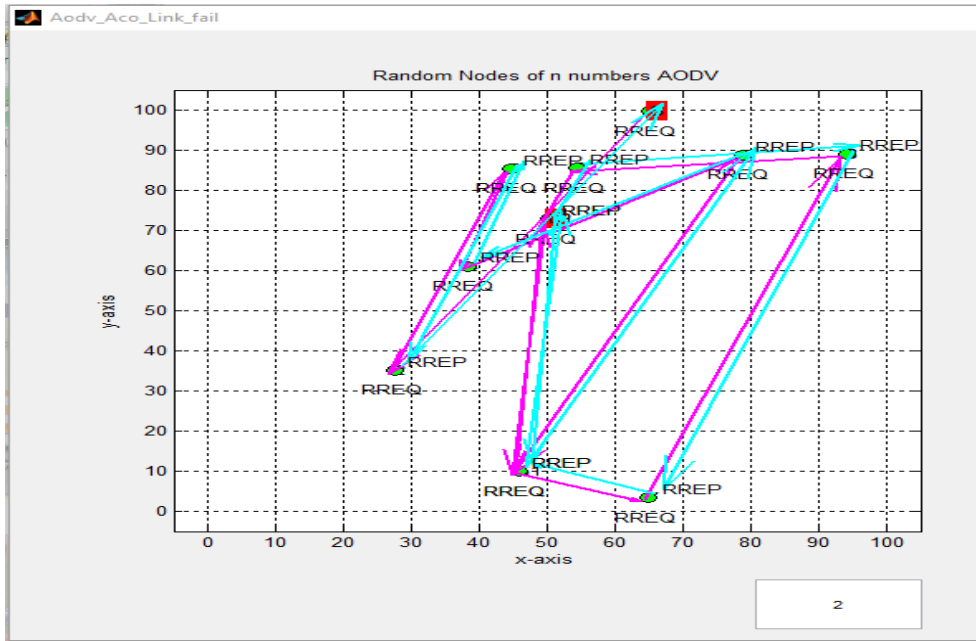


Fig 4.5: Path using AODV

c) Link Failure

Link failure is one of the main drawbacks of ad hoc networks due to rapidly varying topologies of the network. High mobility and congestion may also lead to such failures. Hence a local link repair is a necessity for such networks.

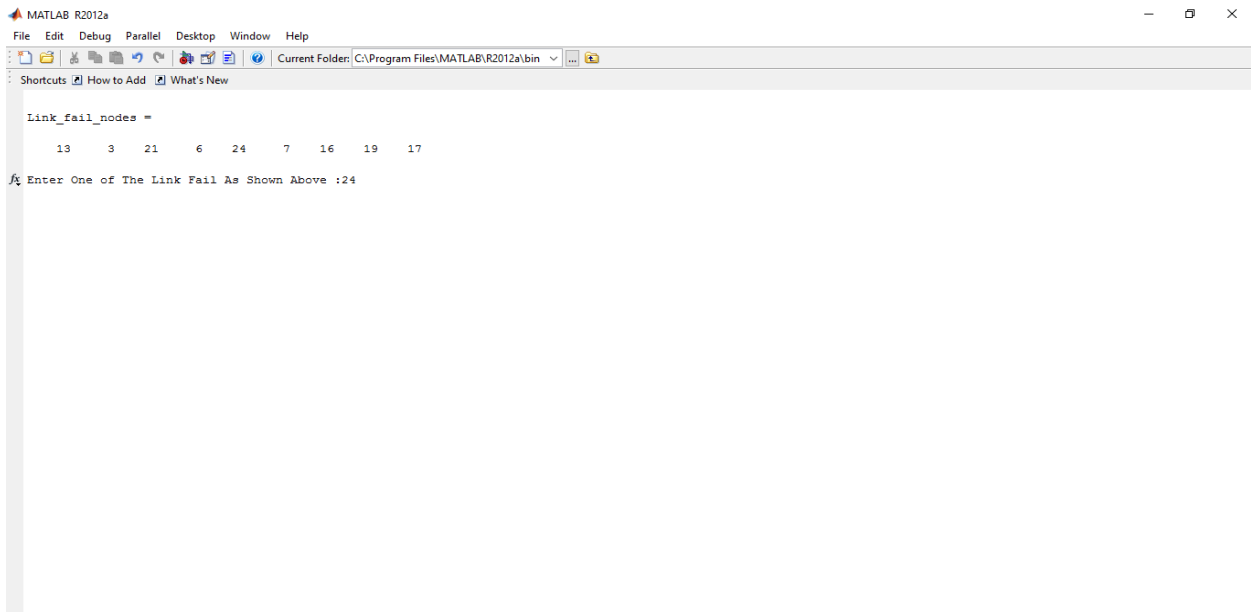


Fig 4.6: Link failure input window

The window shown above describes the various nodes which forms the final route between node 2 and node 17. It also includes an option of entering a node failure. Node 24 has been set as the link failure in this case.

d) Local link repair using ACO

ACO approach has been applied from the point of link failure to repair the link locally.

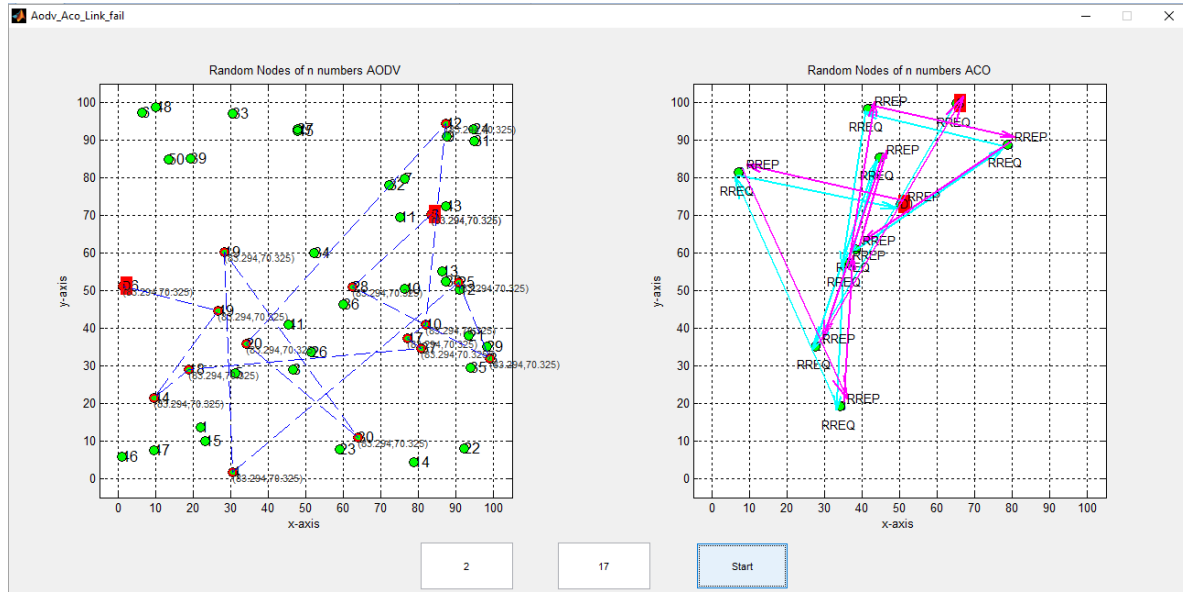


Fig 4.7: ACO appended path

As node 24 is input as the link failure the alternate route search starts from the node before node. Using ACO all the alternate routes are obtained and the best is chosen by again applying AODV. The evaluation of the routing protocols is done on the basis of certain network parameters. The value of network parameter defines the performance of the network and hence defines the routing approach efficiency. Some of the network parameters are described as follows:

1) Throughput:

In a communication channel the measure of average rate of successful transmission of data packets is defined as the throughput of the network. In mathematical terms it is defined as the ratio of packets received at the destination to the total number of packets sent by the source. The rate of transmission is also found using this parameter i.e. the number of packets or bytes sent per unit time. This is an important parameter defining the efficiency of network. The mathematical formula for throughput can be written as [31]:

$$Throughput = \frac{Received\ packets}{Packets\ generated\ at\ the\ source} \times 100 \tag{4.1}$$

2) End-to-end Delay:

The time consumed by a data packet to traverse through the path defined between the source/destination pair is defined as end-to-end delay. This includes delays involved in route discovery, propagation and transmission delays and delay in staying in the queue. Let H bps denotes the capacity of a single link between nodeX (source) and nodeY (destination). Let v m/s denotes the propagation speed across the link and l m is the distance between the two nodes. The propagation delay can be mathematically written as [31]:

$$\tau_p = \frac{l}{v} \text{ secs} \quad (4.2)$$

Each packet has a size of n bits. The mathematical expression for transmission delay can be written as [31]:

$$\tau_t = \frac{n}{H} \text{ secs} \quad (4.3)$$

The sum of the above mentioned delays represents the *end-to-end delay*, which can be expressed as [31]:

$$t = \tau_p + \tau_t \quad (4.4)$$

$$t = \left(\frac{l}{v} + \frac{n}{H} \right) \text{ secs} \quad (4.5)$$

3) Packet loss:

Due to link failures in the network and varying network topology many packets are not able to reach the destination node. The measure of packets which were lost during the transmission process is defined as the packet loss in the network. The efficiency of the routing algorithm mainly depends on this parameter.

$$\text{Packet loss} = \text{Generated packets} - \text{Received packets} \quad (4.6)$$

4) Route Failure:

This is one of the main parameter defining the performance evaluation of a routing algorithm. The routing algorithm should be capable of dealing with these route failures in an efficient manner as the packet loss may increase. Along with this the delay involved in repairing or re

establishment of the route increases which degrades the network performance. Here we have defined a route as fail which was not able to carry the data successfully to the destined location. For finding such routes a *minimum distance value* has been defined. Whenever the distance between nodes of the final path exceeds this value the route is considered as broken. As the nodes are highly mobile in nature, hence as the distance between two nodes exceeds the threshold value the route is discarded and the search for new route starts.

Chapter 5

Results and Discussion

This chapter describes the evaluation of the ACO appended AODV on the basis of various network parameters. These are compared with the performance of the traditional AODV approach. The results depict that the proposed algorithm provides an enhanced network performance as compared to the existing algorithm.

The simulation is being carried out using following parameters in MATLAB:

Table 5.1: Simulation Parameters

Parameters	Values
Area	100km by 100km
No. of nodes	25, 50, 75, 100 and 125
Traffic Pattern	Constant bit rate and UDP
Data packet size	128 bytes
Propagation Speed	2×10^8 m/s
Evaporation rate	0.5
Pause time	.001sec

5.1 Results for AODV Routing Protocol:

- *Throughput* on the network decreases with increasing network size for AODV routing protocol. As the network size increases the congestion in the network increases which can increase the number of link failures in the network. Throughput lies in the range of 90% - 99% as can be seen in the figure 5.1.

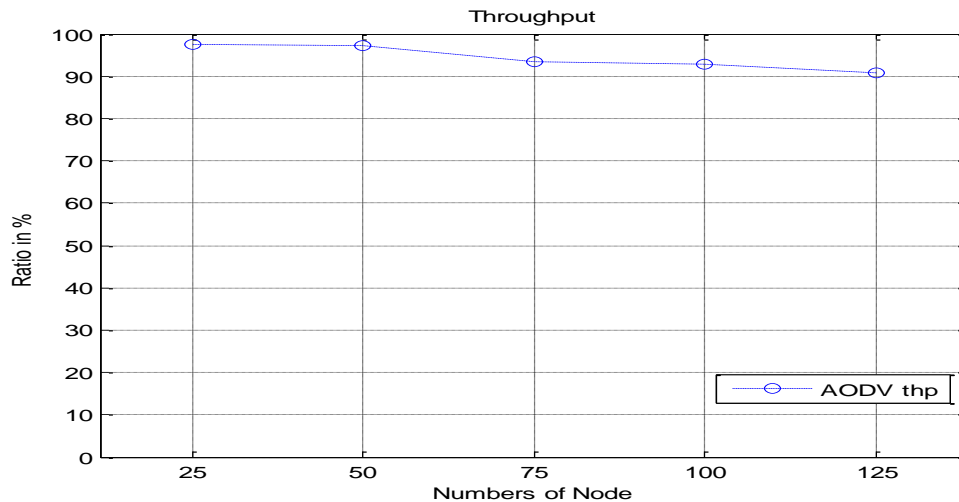


Fig 5.1: AODV Throughput

- For AODV routing protocol *packet loss* during transmission decreases with increase in network size. It lies in the range of 4% - 20% as shown in the figure 5.2.

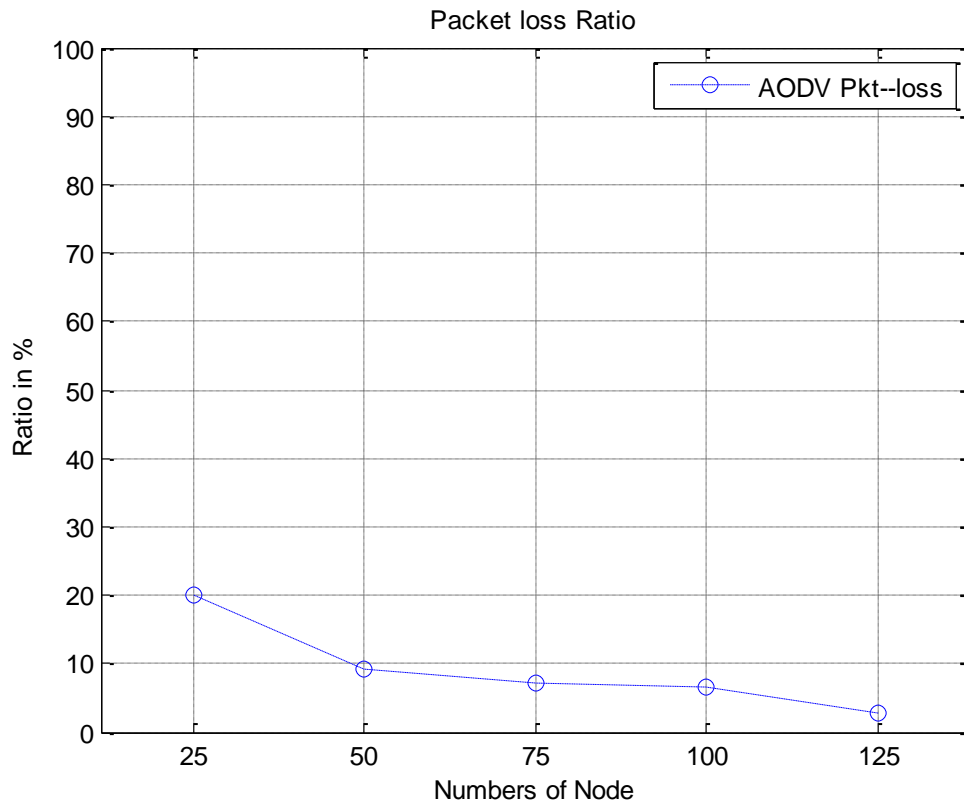


Fig 5.2: AODV Packet Loss

- As we increase the network size the overall delay for AODV approach increases. As the congestion in the network increases the *end-to-end* delay involved in route establishment and transmission of all required data is enhanced. The range of delay is 0.03s – 0.25s as can be viewed in figure 5.3.

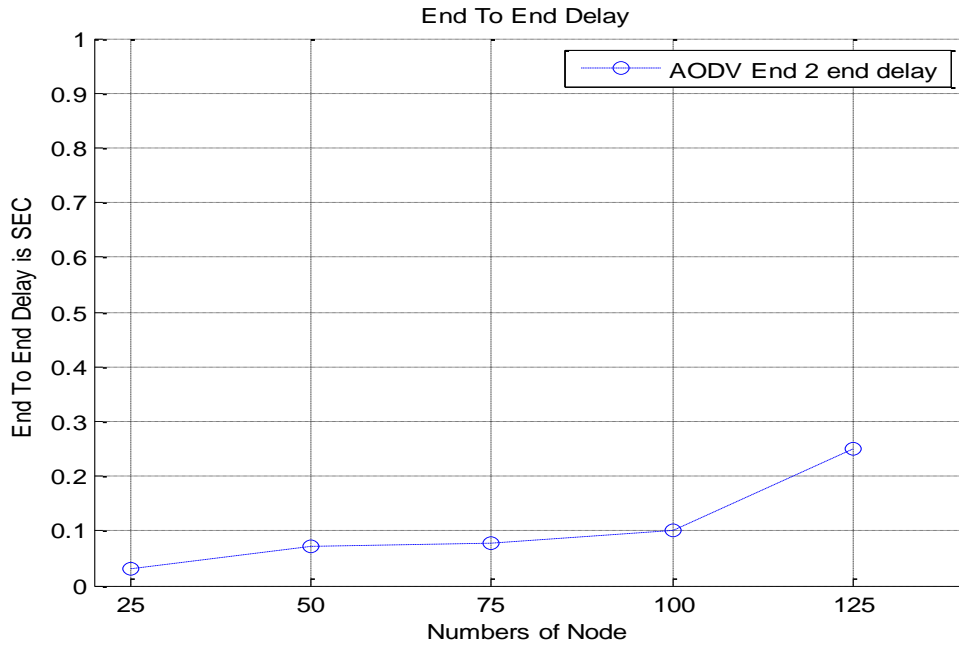


Fig 5.3: AODV End-to-End Delay

- The number of routes which were not able to carry the required data to the destination defines the route failure in the network. As the network size increases route failure for AODV follows a growing curve. The number of route failure lies in the range 690- 790 as can be observed in figure 5.4.

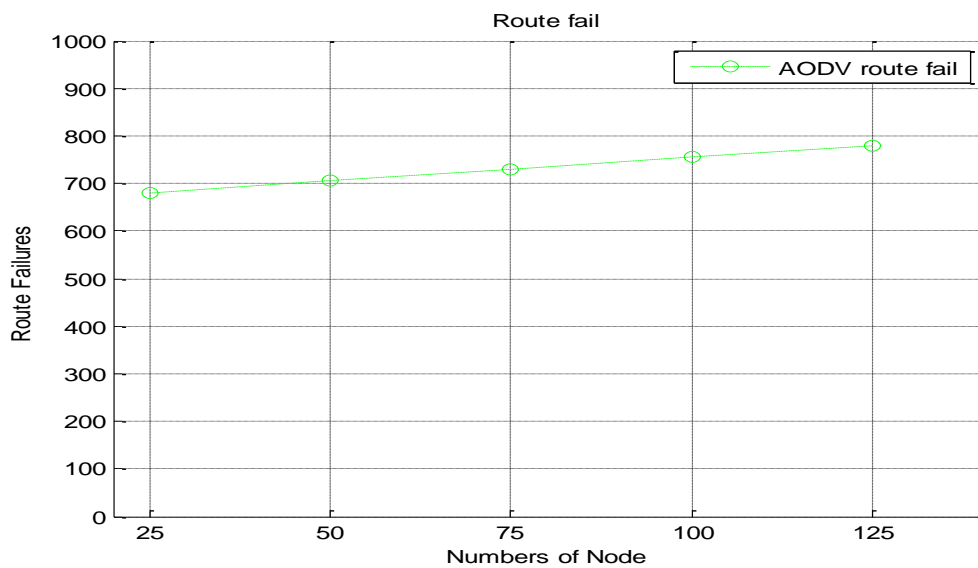


Fig 5.4: Route Failure for AODV

5.2 Results for ACO Appended AODV Routing Protocol:

- *Throughput* for the proposed approach also decreases with increasing network size due to link failure and congestion problem. Its value lie between 95% - 98% as can be seen in figure 5.5.

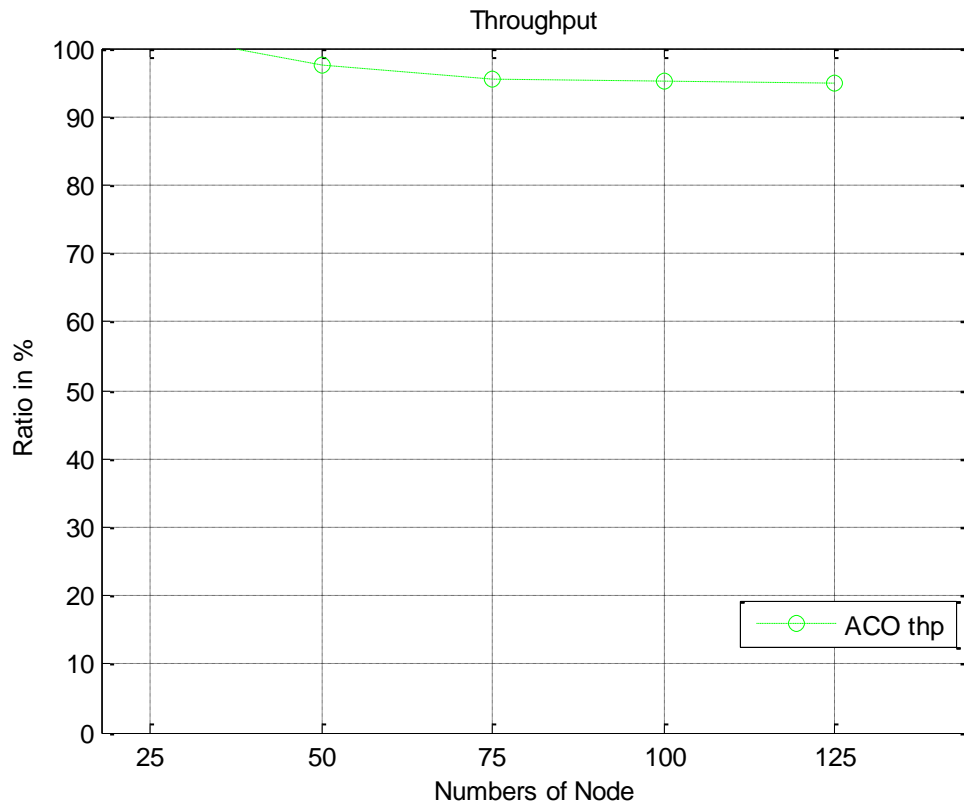


Fig 5.5: Throughput for ACO appended AODV

- *Packet loss ratio* for the proposed algorithm decreases with increasing network size. Its value lies between 2% - 10% as shown in the figure 5.6.

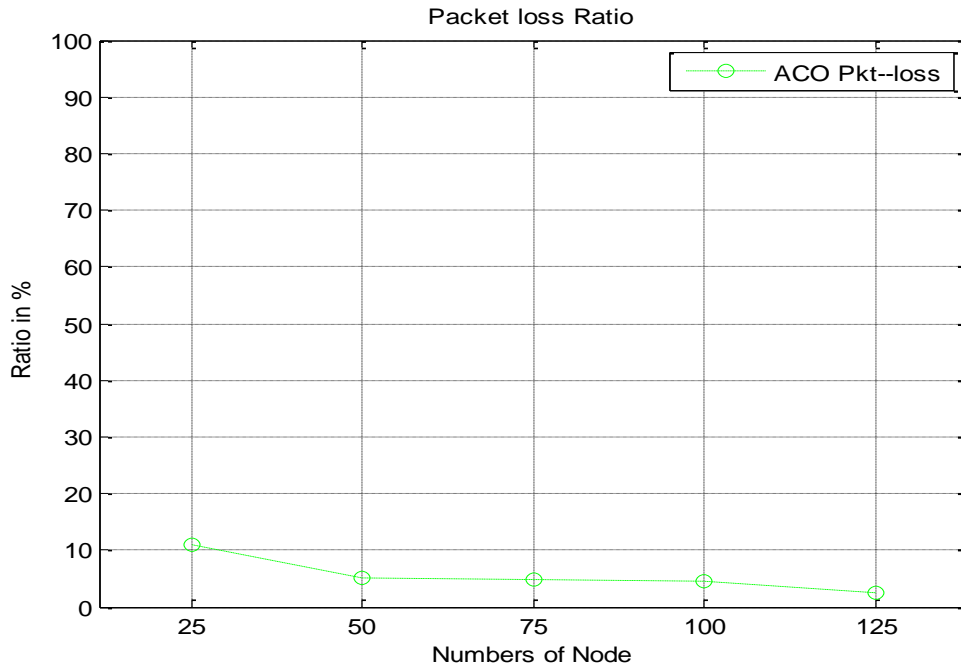


Fig 5.6: Packet loss for ACO appended AODV

- *End-to-end* delay for the proposed approach increases with increase in network size. Its value lie between 0.02s – 0.13s as can be viewed in figure 5.7.

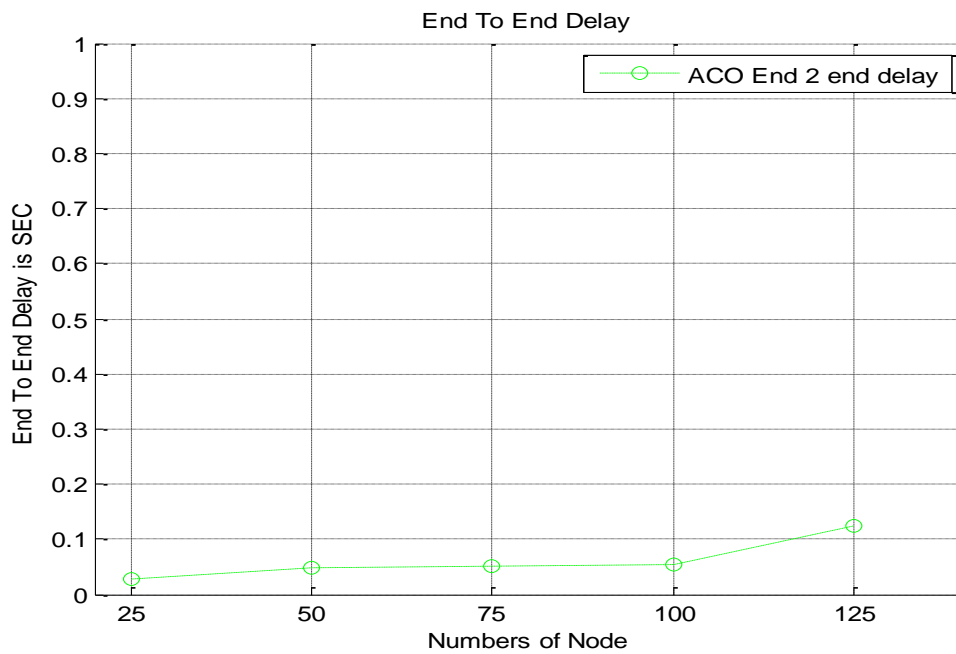


Fig 5.7: Delay for ACO appended AODV

- Route failure for the proposed algorithm increases linearly with the increasing network size. Its value lie in the range 600 – 700 as can be observed in the figure 5.8.

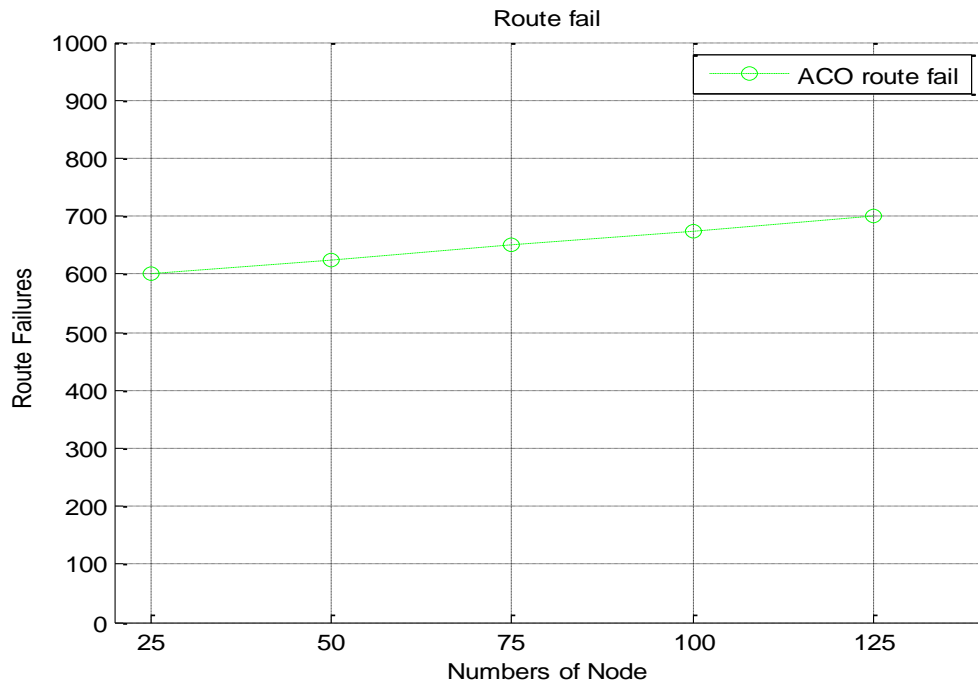


Fig 5.8: Route Failure for ACO appended AODV

5.3 Comparison of ACO appended AODV approach with the traditional AODV algorithm:

- *Throughput* obtained using the proposed approach is better as compared to the traditional AODV approach. Figure 5.9 shows that although the throughput decreases for both the approach but its value are more in ACO appended approach. The decrease is due to the increase in network size which increases congestion in the network. A 5% increase in the throughput was obtained using the proposed approach for a network size of 125 nodes.

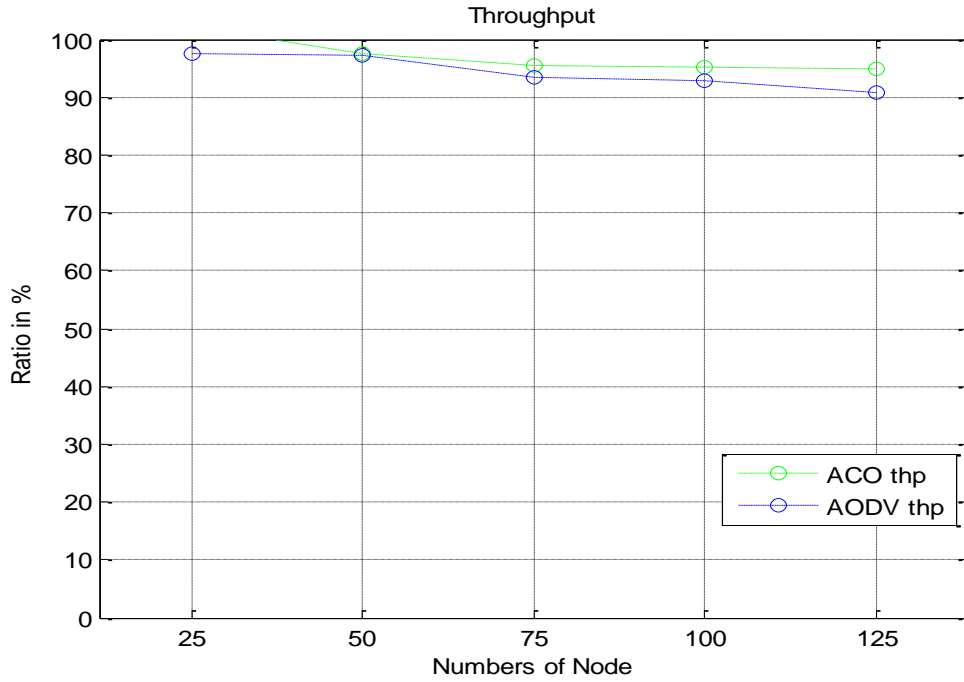


Fig 5.9: Throughput Comparison

- It can be observed from figure 5.10 that *packet loss ratio* is less in case of ACO appended approach. This parameter follows a decreasing curve for both the algorithms but is better in case of proposed approach and hence the network performance is enhanced.

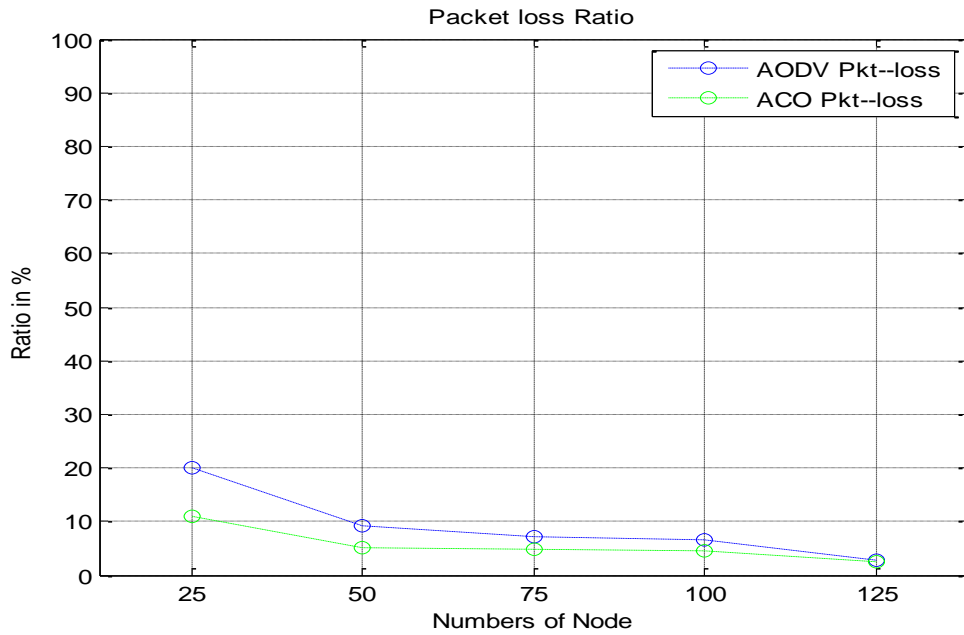


Fig 5.10: Packet loss ratio Comparison

- *End-to-end* is one of the most important parameter for evaluating the routing approach performance. It can be observed from figure 5.11 that ACO appended AODV approach involves much less delay as compared to the traditional AODV approach. Although the delay for both increases with increase in network size due to congestion in the network. For a network size of 125 nodes 53.84% decrease in delay was achieved by implementing the proposed approach.

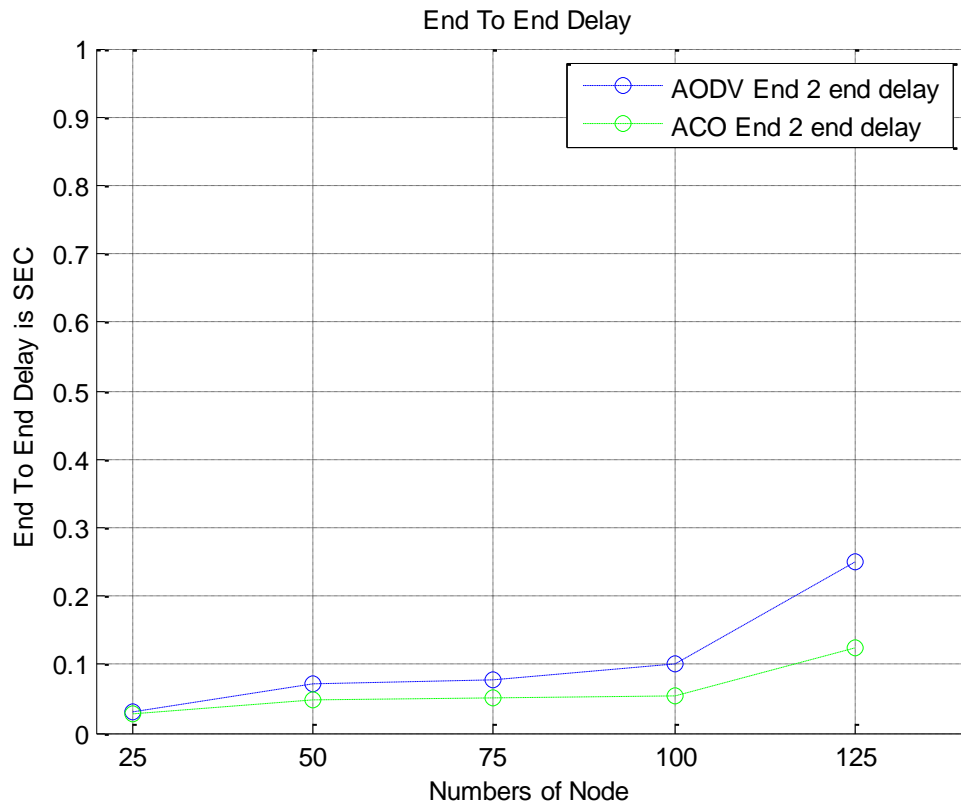


Fig 5.11: Delay Comparison

- As the network size increases due to dynamically varying network topology route failure probability increases. The routing approach proposed in the work helps to reduce number of route failures in the network as can be depicted from figure 5.12. Although with increase in network size the route failure follows a linearly increasing curve but they are less in case of ACO appended AODV algorithm. The number of route failures reduced by almost 100 for a network with 125 nodes using the proposed approach.

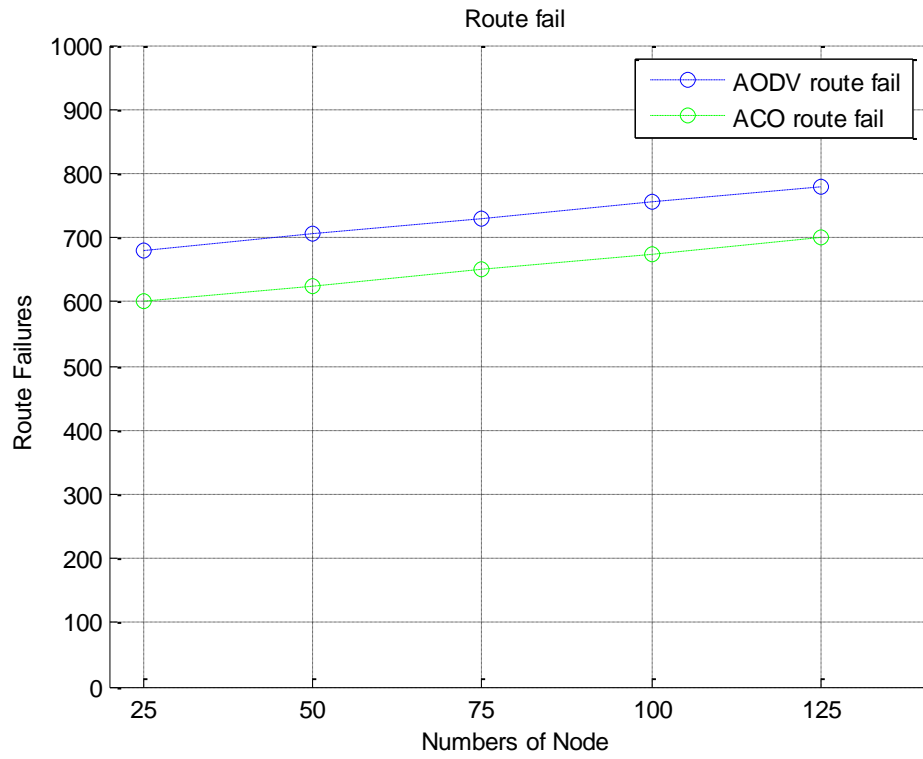


Fig 5.12: Route Failure Comparison

Chapter 6

Conclusion and Future scope

In this chapter the conclusion of the work done is described which includes the comment on performance of the proposed algorithm. Along with this the advancements that can be done in this field are also discussed.

6.1 Conclusion:

MANETs has become one of the most popular areas on research in wireless networks due to their application in various fields such as military operations etc. Frequently changing topology, routing, limited bandwidth, overheads etc. pose challenges in the QoS of such networks. A large number of routing algorithms have been proposed in past to find an optimized solution for these networks. Among them reactive protocol such as AODV is one of the most prominent as it involved unique feature of destination sequence number. In this thesis work ACO appended AODV protocol has been proposed. This is a modification in the traditional AODV approach to remove its drawback of local link repair. The traditional AODV approach was not able to repair the link locally which degrades the network performance in large networks. To overcome this ACO was applied from the point of link failure to select an alternate route dynamically. Also, the whole process was represented graphically in which one can observe the route formation mechanism of both the algorithms using Graphical User Interface (GUI) based on MATLAB. The performance of both the algorithms traditional AODV and proposed ACO appended AODV was compared using same network metrics. The simulation results revealed that ACO appended approach outperformed the existing ADOV approach in terms of metrics such as throughput, delay, loss in transmission and failed routes. Considering the delay metric a reduction of approximately 53.84% and 5% improvement in throughput was obtained with the implementation of proposed approach. Also the number of route failures was reduced by approximately 17%.

6.2 Future Scope:

The proposed work can be extended with the implementation of ANN (Artificial Neural Network). Neural Routing Algorithm is a technique inspired from the self organizing capabilities of brain. This technique possesses a unique characteristic of updating the current

changes in the neighborhood of a node uniformly. For monitoring the local route information a two hop mechanism is implemented. Apart from this the neural technique is also capable of dealing with the security issues such as malicious attacks, black hole attacks etc. in ad hoc networks. Henceforth, ANN implementation in proposed ACO appended AODV algorithm may further help in reducing the delay and improvement of throughput of the system.

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