CHAPTER 3

SYSTEM ARCHITECTURE

3.1 INTRODUCTION

Multicast routing is an efficient mechanism when compared with other modes of transmission in supporting group-oriented applications. A number of multicast routing protocols have been proposed to enable group communication in MANETs, since it is an important aspect of future network developments. Hence, it is mandatory to explore its design factors, design issues, tradeoffs, challenges and other issues emerging while implementing a multicast routing protocol in MANETs. Moreover, it is a dire need to discover and compare solutions for the protocol design issues. The key factors in designing such protocols are identified as, node mobility, MANET topology, multicast group size, number of nodes in the network, type of connectivity, quality of service issues such as delay, bandwidth, jitter, throughput, the complexity involved in MANET routing algorithm, complexity with existing protocols, multicast tree construction method and system cost.

In MANETs, as the nodes keep changing their location, a topology change is encountered, which is a basic characteristic of this type of networks. In designing optimized multicast protocols for MANETs, the main consideration is, what topology is in use? Therefore, multicast restructuring methods are the basics for an optimum protocol in MANETs. The design gets simpler and completely depends on the network topology discovery, when the node mobility is low. Moreover, the group members are involved in data
transmission when they are in the communication range. The reliability may be increased, and delay and control message overhead may be reduced when the number of links in the group increases. However, the links are not reliable and link failures are unpredictable.

The conventional multicast routing protocols may not be useful in MANETs because those protocols are designed for static hosts; so, when a multicast forwarding tree is constructed permanent locations are expected. Although many protocols have been implemented, mobility and other related issues are still not addressed completely. In order to improve the efficiency of the multicast routing protocol, the thesis proposes optimized reactive multicast routing protocols for MANETs under multiple scenarios.

3.2 REACTIVE MULTICAST ROUTING PROTOCOLS

In MANETs, multicast tree structures are not stable and need to be reconstructed continuously as the connectivity changes. Maintaining a routing tree for the purpose of transmitting multicast packets under dynamic topology is a tedious task and can incur substantial control traffic. The frequent exchange of routing information and link state tables, triggered by continuous topology changes, yields excessive control and processing overheads. Depending on topology, reactive multicast routing protocols are classified into two types, namely, tree based and mesh based. In tree based multicast routing protocols, there exists only a single path between a source-receiver pair, whereas in mesh based multicast routing protocols, there may be more than one path between a source-receiver pair.

The main characteristic of a tree based infrastructure is that the number of transmissions tends to be optimized and the frequent link break causes considerable changes in tree based structures and packet loss is
inevitable during the recovery process, since each destination is connected to the tree by a single path. Tree based protocols provide high data forwarding efficiency with less robustness, and their disadvantage is that until the tree is reconstructed after the movement of a node, packets may possibly have to be dropped (Luo Junhai et al 2008).

Mesh based schemes provide redundant paths for forwarding multicast packets in order to deal with packet loss caused by mobility. Packet loss is reduced at the cost of increased data overhead in highly mobile scenarios, where the most reliable and feasible solution may be a simple broadcast scheme. Packets are distributed along mesh structures that are a set of interconnected nodes. Route discovery and mesh building are accomplished in two different ways by using broadcasting to discover routes or by using central points for mesh building. They perform better in high mobility situations as they provide redundant paths from source to destinations while forwarding data packets (Luo Junhai et al, 2008). The drawback in mesh based protocols is the excessive consumption of network resources due to a large amount of duplicate data packets.

In this work, the multicast routing protocols considered are; On Demand Multicast Routing Protocol (ODMRP), Multicast Ad hoc On demand Distance Vector Protocol (MAODV) and Adaptive Demand-driven Multicast Routing (ADMR). The ODMRP is a mesh based on demand multicast protocol, ADMR is a source-based multicast routing protocol which uses an on-demand mechanism that creates a tree only if there is at least one source and one receiver active for the group, and the MAODV is a tree based multicast routing protocol, which is a multicast extension of the Ad hoc On-demand Distance Vector (AODV) protocol. A performance comparison and study of reactive multicast routing protocols which provide an insight into their functionality and performance, is reported by (Xiaoyan Hong et al 2004).
3.2.1 ADMR

The ADMR is a source specific multicast protocol that allows receivers to join source specific groups; any node can send data to any multicast group without explicitly announcing its intention to send or to stop sending data and any node can join or leave a multicast group at any time. When source based forwarding trees are used for multicast data delivery, each multicast packet is forwarded from the data source along the shortest path through the tree to the members of the multicast group. Sources periodically send a network-wide flood, at a very low rate which recovers the network partitions. Each node in the network that receives the packets forwards it, unless it has already forwarded a copy of it and the node records in its Node Table the MAC address of the node from which it received the packet and the sequence number stored in the packet’s header. This information is useful for duplicate detection and forwarding Receiver Join packets back to the source. The multicast state is setup when a new source starts sending packets to a group or when a receiver joins a group. The protocol tunes its behavior in response to the changing mobility in the MANETs without requiring any external positioning information. Figure 3.1 shows the ADMR process for forwarded packet and receiver join packet.

The forwarding nodes in the multicast tree may monitor the packet forwarding rate to determine when the link has broken or the source has become silent. The forwarding node monitors the traffic pattern of the multicast source application and detects link breaks in the tree, as well as sources that have become inactive and will not be sending any more data. For monitoring, a limited number of keep alive messages with increasing inter packet times are forwarded. Likewise, the receiver monitors the packet reception rate and can re-join the multicast tree if intermediate nodes have been unable to reconnect the tree (Jetcheva and Johnson 2001).
The receivers adapt dynamically to the sending pattern of the senders and the mobility in the network in order to efficiently balance the overhead and maintenance of the multicast routing state as nodes in the network move or as wireless transmission conditions in the network change. Without the need for control signaling or application level notification at the source, the state for groups whose senders have become inactive or whose receivers have left the group is expired automatically.

The ADMR has a mechanism of multicast source and receiver discovery to create a membership table at each node. The table contains one entry for each group. Once the multicast state has been set up, the source will start sending packets. Once a node detecting a disconnection reconnects to the multicast tree, the node uses the FAT loss recovery mechanism to request retransmissions.
3.2.2 ODMRP

Multicast trees usually require a global routing substructure such as the link state, and the frequent exchange of routing link state tables, triggered by continuous topology changes, yields excessive channel and processing overhead (Sung Ju Lee et al 1999). To overcome these limitations, the On-Demand Multicast Routing Protocol has been developed (Sung Ju Lee et al 2002).

In general, the ODMRP is implemented by means of the flooding mechanism, in which the data packets are flooded by the forwarding group members. This causes redundant broadcasts, which can considerably increase the data forwarding overhead. To overcome this, a variation in flooding, called scoped flooding is used by the forwarding group members. In scoped flooding implementation, each node transmits hello messages at regular intervals, which also contain the nodes neighbour list. These hello messages are used to update their own neighbour list and add received lists to their neighbour list table. When a node receives a data packet, it compares the neighbour list of the transmitting node to its own neighbour list. If the transmitting nodes’ neighbours list contains the receiving nodes neighbour list, then it does not flood the data packet. In the ODMRP, group membership and multicast routes are established and updated by the source on demand. When a multicast source has packets to send, it floods a member advertising packets, control packets with data payload piggybacked. The mesh creation process is shown in Figure 3.2.
Figure 3.2  ODMRP Mesh Creation using Join Query and Join Reply Process

Nodes that are members of the multicast group respond to the flood and join the tree. When a node has information to send but no route to the destination, a Join Query message is broadcasted. The next node that receives the Join Query, updates its routing table with the appropriate node ID from which the message is received in the reverse path back to the sender. Then the node checks the value of the time to live and if this assessment is greater than zero it rebroadcasts the Join Query.

When a multicast group member node receives a Join Query, it broadcasts a Join Reply message. A neighbor node that receives a Join Reply consults the join reply table to perceive if its node ID is the same as any next hop node ID. If it is the same then the node understands that it is on the path to the source and sets the forwarding group flag.
The ODMRP uses a soft state approach to maintain the mesh; that is, to refresh the routes between the source and the receiver, the source periodically floods the Join Req control packet, and this robustness is at the expense of the high control overhead.

### 3.2.3 MAODV

The Multicast Ad hoc On demand Distance Vector Protocol (MAODV) is considered to be an integral part of the Ad hoc On demand Distance Vector Protocol (AODV) which can perform unicasting, broadcasting and multicasting (Royer et al 1999). When a node desires to send a message, it discovers a route through which it can send the message. If the node desires to join a multicast group or to send a message which has no prior route to that group, then the node sends a Route Request (RREQ) message.

Likewise, if a member node wishes to terminate its group membership, that node has to request the group for termination. Then its membership will be terminated. Each multicast group has a unique address and a group sequence number. The group member that first constructs the tree is the group leader, which is responsible for maintaining the group tree by periodically broadcasting the Group Hello (GRPH) message.

Each node has three tables, namely, the Unicast Route Table, Multicast Route Table and Group Leader Table. The Unicast Route Table has the address of the next hop to which the message is to be forwarded. The Multicast route table has the address of the next hops in the tree structure of each multicast group. The group leader table records the current multicast group addresses with its group leader address and the next hop address towards the group leader, which receives a periodic GRPH message. The
MAODV multicast route discovery and forward path setup process is shown in Figure 3.3.

Nodes in a tree structure are described as downstream or upstream nodes. When a node leaves the multicast group, the tree structure needs pruning. When a link breaks, the downstream node is responsible for repairing the breakage. Also, the downstream node is responsible for sending GPH-U to every downstream node. The GRPH indicates a new leader and updates the group information into the Multicast Route Table.

![Figure 3.3 MAODV Multicast Route Discovery and Forward Path Setup Process](image)

Tree maintenance is accomplished by means of an expanding ring search using the RREQ, RREP, and MACT cycle. The downstream node is responsible for issuing a fresh RREQ to the group. The RREQ contains the hop count of the requesting node from the group leader and the last known sequence member for that group. Once the multicast group is set up and the route is selected, the MACT message activates the multicast route.
3.3 OBSERVATIONS AND MOTIVATION

In this work, the performance of three multicast routing protocols, the ADMR, MAODV and ODMRP are compared on a common simulation platform under a wide range of mobility and communication models. A detailed simulation model to demonstrate the different performance characteristics of the three reactive protocols has been used for the experiment.

3.3.1 Qualitative Comparison of Reactive Protocols

A qualitative comparison of the existing multicast protocols, the ODMRP, MAODV and ADMR is given in Table 3.1. The MAODV reacts to link failure by discovering a new route to the multicast tree. Data may be lost during the discovery period. The ODMRP uses the concept of a forwarding group when the link fails, resulting in data redundancy.

The significant benefits of the ODMRP over the ADMR as well as the MAODV have been clearly demonstrated that, even though the performance of all multicast protocols degrade, in terms of packet delivery as node mobility increases, the ODMRP performs considerably better than the MAODV and the ADMR. The MAODV does not perform as the other protocols in terms of packet delivery ratio, but has the lowest routing overhead among other protocols, whereas the ADMR has a moderate performance compared with the other two.

In the ODMRP, the same data packet propagates through more than one path to a destination node, resulting in an increased number of data packet transmissions, thereby reducing the multicast efficiency. The increased mobility in the MAODV protocol causes frequent link breakages and data
packet drops; link outages also generate repair messages and increasing control overhead.

**Table 3.1 Comparison of existing multicast routing protocols**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>ADMRP</th>
<th>MAODV</th>
<th>ODMRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Need unicast protocol</td>
<td>No</td>
<td>Yes, AODV</td>
<td>No</td>
</tr>
<tr>
<td>Periodic flooding through network</td>
<td>Yes, source</td>
<td>Yes, group leader</td>
<td>Yes, each sender</td>
</tr>
<tr>
<td>Group member receive redundant data</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Primary Structure</td>
<td>Forwarding structure</td>
<td>Source trees</td>
<td>Mesh of shortest path</td>
</tr>
<tr>
<td>Route setup overhead</td>
<td>Moderate</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>Route maintenance overhead</td>
<td>Moderate</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>Data forwarding overhead</td>
<td>Moderate</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Reliability</td>
<td>Moderate</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Traffic concentration</td>
<td>Moderate</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Scalability</td>
<td>Moderate</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>

It is concluded that, given the diversity of MANETs, it is impossible for any one multicast routing protocol to be optimal under all the concerned scenarios and network operating conditions. As a conclusion of this experiment, it is noted that the ODMRP exhibits a good packet delivery ratio but it suffers from high control overhead. The MAODV performs considerably poor in terms of packet delivery ratio, but it requires only a low control message overhead. The ADMR has an average performance in both
the cases. Hence, it serves as a motivation to optimize the ODMRP as a representative of mesh based protocols against the MAODV representing tree based multicast routing protocols.

3.3.2 Motivation

From the study, it is learnt that a MANET faces issues like limited bandwidth, error prone wireless links, frequent hand-off of the mobile host, and limited battery power. The movement and node mobility cause considerations that affect the network performance. Minimizing network resource consumption and overhead while maximizing reliability are important in an optimized protocol design. The key factors to be considered for the optimal protocol design are as follows (Abdussalam Nuri Baryun and Khalid Al Begain 2008).

3.3.2.1 Routing Mechanism

Multicast forwarding tree, core placement, proactive or reactive, tree or mesh and network inactivity.

3.3.2.2 Receiver Behavior

Join latency, packet loss fraction, packet duplication, out of order delivery and leave latency.

3.3.2.3 Deployment Consideration

Packet delivery rate, scalability, interoperability, cost, security and QoS parameters throughput, delay and jitter.
In most cases, the solution proposed may add overhead to the network, encounter delay or compromise on reliability. In addition, the following problems are still not solved completely, even though large numbers of multicast protocols have been proposed for MANETs.

1. Non-optimal delivery path
2. Datagram duplication
3. Overhead resulting from frequent reconstruction of a multicast tree

This work has made an attempt to address, among various problems, the issues of getting optimal delivery path and minimizing control message overhead by applying intelligent techniques. To achieve this, a method of getting optimal multicast routes satisfying the QoS requirements like throughput in the form of packet delivery ratio, as well as optimizing network resources such as latency, and also to improve the performance of the network in terms of control message overhead in computationally feasible time, using population based heuristic techniques like the GA and PSO, is proposed. The proposed algorithm is integrated along with the protocols the MAODV and ODMRP to get an optimal multicast tree to deliver the data.

3.4 SYSTEM DESIGN

The principal idea to design optimized multicast routing protocols is to offer group members a path with minimum cost but greater reliability. Node mobility is a very influencing issue in designing the protocol because it creates link failures and may form loops (Abdussalam Nuri Baryun and Khalid Al Begain 2008). Considering these facts, it is proposed to have the following system design to implement optimized reactive protocols.
3.4.1 Problem Definition

MANETs can be represented as an undirected graph $G(V,E)$ where, $V$ is the set of vertices and $E$ is the set of edges. The problem is formulated in such a way as to find an optimal multicast data forwarding path with minimum cost, from the sources to all the multicast destinations.

The multicast data forwarding path is defined by the union of all those trees involved in the transmission of data with minimal cost. The problem of finding the optimal multicast path can be formulated as follows:

Let $C_m: T \rightarrow Z^+$ be a function so that, given a tree $T$, $C_m(T)$ is the tree with minimum data forwarding cost. Given an undirected graph $G = (V, E)$ a source node $s \in V$, a set of receivers $R \subseteq V$, and given $V'$ defined as $V' = R \cup \{s\}$ so that $V' \subseteq V$, find a tree $M_T \subseteq G$ such that the following conditions are satisfied.

$$M_T \supseteq V'$$
$$C_m(M_T) \text{ is minimum}$$

From the condition of $M_T$ being a tree, it is clear that it is connected, which satisfies the constraints

1) $M_T$ is a multicast tree.
2) $M_T$ is the minimum cost tree.

3.4.2 Design Goals

In this work, optimized multicast routing protocols based on heuristic techniques have been developed. The design approach achieves the following goals.
3.4.2.1 Scalability

Scalability is achieved by significantly reducing the control message overhead of constructing a multicast tree. The protocol design aims to design optimized routing protocols which minimize the number of forwarding nodes involved, so that the control message overhead is reduced considerably.

3.4.2.2 QoS Awareness

Minimizing the overhead and maximizing the chance of efficiency in terms of packet delivery ratio are contradictory goals. These two goals are balanced by making the multicast routing process QoS aware. In general, throughout the design phase, only a limited overhead is spent wisely on a careful route selection strategy by using heuristic approaches.

3.4.2.3 Efficiency

The protocol may detect optimized feasible multicast tree connecting the members on to the tree within a stipulated time.

3.4.2.4 Robustness

The protocol does not rely on any extra control mechanism. The entire route selection strategy is decentralized.

3.4.2.5 Loop Free

The protocol always constructs loop free multicast trees.
3.5 OVERALL DESIGN ARCHITECTURE

In a dynamic network topology like MANETs, it is noted that the routing information is updated, especially when packets are sent. Based on this, designing an optimized multicast routing protocol for MANETs, is started by defining service and their requirements and constraints.

The main environment and requirement characteristics for a MANET multicast protocol design are node mobility and user mobility. It is learnt that, the compatibility of the protocols with other systems is crucial for flexibility. There are many applications in MANETs modeled as one-to-many Group Communication Applications (GCA). Examples are scheduled audio/video distribution, file distribution, tele-education etc. Other types of applications in MANETs are modeled as many-to-many GCA, like multimedia conferencing, concurrent processing, chat groups, and multiplayer games. These different kinds of applications in MANETs make it difficult to have one protocol for all services. In MANETs, heterogeneous devices are in use, so the task of designing becomes more difficult. The system needs to have a dynamic mechanism to construct optimal multicast routes and maintain group membership. It is also observed that, the protocol must avoid global flooding and advertising. To satisfy these requirements, scoped flooding is introduced, which, in turn, greatly reduces the amount of flooding done by the source and forwarding group members.

Due to the high mobility of nodes, it is essential that, the optimized multicast protocol should be designed by considering scalability and reliability as important issues. The network size and group size are factors related to scalability issues. The QoS factors like packet delivery ratio, latency and jitter give priority to multicast restructure methods. When the system cost is taken into consideration, multicast services are significantly
more expensive than unicast services in terms of deployment and installation. So it is desirable that, multicast services are chosen only where bandwidth savings are higher than the cost of deployment and management. In the proposed system, the multicast tree with optimal cost is selected among the population of multicast routes. By applying heuristics like the GA and PSO, the issues in multicast routing protocols can be minimized. The design of the proposed system is shown in Figure 3.4.

Figure 3.4 Design of Proposed Optimized Multicast Routing Protocols in MANET

3.6 EXPERIMENTAL SETUP

The goal of our simulation is to analyze the behavior of reactive multicast routing protocols, the ADMR, MAODV and ODMRP. The aim is also to study the performance analysis of optimized reactive multicast routing
protocols such as the GA-MAODV, GA-ODMRP, PSO-MAODV and PSO-ODMRP, and hence, various simulations are conducted under different network scenarios. The simulation environment is created in NS-2, a network simulator that provides support for simulating multihop wireless networks. NS-2 is written using C++ language and it uses the Object Oriented Tool Command Language (OTCL). It is an extension of the Tool Command Language (TCL) (Kevin Fall and Kannan Varadhan 2000).

3.6.1 Simulation Scenario

The simulations are carried out using a MANET environment consisting of 60 wireless mobile nodes roaming over a simulation area of 1000 meters x 1000 meters flat space operating for 900 seconds of simulation time. The radio and IEEE 802.11 MAC layer models are used. Nodes in this simulation move according to the Random Way Point Mobility model, which is in random direction with speed ranges that vary from 0 m/s to 20 m/s. A free space propagation channel is assumed. Group scenario files determine the receiver and source nodes, and also when to join or leave a group. A multicast member node joins the multicast group at the beginning of the simulation and remains as a member throughout the whole simulation.

Multicast sources start and stop sending packets; each packet has a constant size of 512 bytes, with a transmission range of 250m and uses the CBR traffic model with a data packet size of 64 octets. Each data point represents an average of at least five runs with identical traffic models, but different randomly generated mobility scenarios. For fairness, identical mobility and traffic scenarios are used across the compared protocols. Only one multicast group is used for all the experiments.
Each mobile node starts its journey from a random location to a random destination at a randomly chosen speed. Once the destination is reached, another random destination is targeted after a pause by the mobile node. Once the node reaches the boundary of the area, it chooses a period of time to remain stationary.

At the end of this pause time, the node chooses a new direction, this time between 0 and 180 degrees, adjusted relative to the wall of the area on which the node is located. This process repeats throughout the simulation, causing continuous changes in the topology of the underlying network.

### 3.6.2 Metrics

In these simulations, different MANET scenarios are used, with a large scale of mobility and variation in multicast group characteristics (number of senders and receivers). Metrics such as packet delivery ratio, latency and control overhead are used in comparing the protocol performances. The metrics are derived from the ones suggested by the IETF MANET working group for routing and multicast protocol evaluation.

#### 3.6.2.1 Packet Delivery Ratio

Packet delivery ratio is defined as the number of multicast data packets delivered to all multicast receivers and the number of multicast data packets supposed to be delivered to multicast receivers. This ratio represents the routing effectiveness and throughput of the multicast protocol in delivering data to the intended receivers within the network. To evaluate the effects of mobility, the speed is varied from 0 m/s to 20 m/s.
3.6.2.2 Latency

Network latency is a measure of how fast a network is running. It refers to the time between the transmissions of data packets from a multicast source and the time of its reception by a multicast receiver. Latency is the delay between the initiation of a network transmission by a sender and the receipt of that transmission by a receiver. In a two way communication, it may be measured as the time from the transmission of a request for a message, to the time when the message is successfully received.

3.6.2.3 Control Overhead

Control packet overhead is the ratio of the number of control packets originated or forwarded, related to the route creation process that are received by a node per multicast data delivery. This metric indicates the percentage of the total control messages transmitted for data forwarding.