Chapter 6

SCALABLE OVERLAY MULTICASTING IN MOBILE AD HOC NETWORKS

6.1 INTRODUCTION

Multicast routing in MANETs requires the source to update the routes to many group members simultaneously [58]. The dynamic topology of MANETs makes it difficult for building optimal multicast network structures and maintaining group membership in case of tree and mesh based multicast routing. Scalability in multicasting has become more critical issue in MANETs [49] because of growing popularity of wireless networks and significant growth in network capabilities i.e. more and more node counts, increased bandwidth, better routing times and decreased latencies. However, bigger multicast tables for the maintenance of network structures result in following problems:

- Inefficient consumption of bandwidth of wireless links
- Inefficient consumption of battery power of anemic mobile nodes
- Scalability problems as the network size is scaled up

We know that the traditional protocols involve both the group member nodes and non-member nodes as forwarding nodes for the maintenance of the state information [110]. Therefore, with growing group size or the number of groups, the problem of scalability render the network inefficient [19].

The above mentioned limitations can be effectively addressed by providing a scalable multicast routing protocol, based on state reduction and constraining methods. In this work, an overlay multicast protocol on application layer is being proposed which is robust and reduces control overheads. In the protocol, the network nodes construct overlay hierarchical framework to reduce the protocol's states and constrain their distribution within limited scope. In the following section the protocol is described.
6.2 SCALABLE OVERLAY MULTICASTING IN MOBILE AD HOC NETWORKS (SOM)

SOM is based on zone routing, location information of the nodes and LARDHR [43] unicast protocol at network layer. It constructs an overlay virtual multicast packet distribution tree at application layer mapped with the physical topology at network layer, thereby forming two levels of hierarchy. The hierarchies reduce the protocol state maintenance and support the vertical scalability. Protocol depends on the location information obtained using a distributed location service, which effectively reduces the overhead for route searching and updating the source based multicast tree that in turn, provides better efficiency and scalability.

In the protocol, a dynamic mesh is created which adapt to and reflects the changes taking place in physical topology. By using a dynamic mesh and hence updating the data delivery tree within mesh, the mismatching between the virtual and physical topology is decreased. Overhead generated in updating the mesh are worth considering as they compensate the redundant multiple transmission of the same packet due to mismatching in the two layer topology over the time. The number of identical packets a link carries is known as stress of a physical link [109]. The average stress value for the physical links is optimized which automatically reduces the overall bandwidth consumption and improves data delivery efficiency of overlay multicast.

6.2.1 ZONE ROUTING

A routing zone is defined for each node separately whereby the zones of neighboring nodes overlap like in BELAHR. Each node maintains a proactive unicast route to every other node within the specified limited zone. The proactive scope is reduced to a small zone around each node in the SOM protocol because in an ad-hoc network, most of the traffic is directed to nearby nodes. It also maintains a Zone Neighbor Table (ZNT) (see Table 6.1) to keep the information of all neighbor nodes in the zone. Each routing entry contains the IP of neighbor nodes, their location, next immediate hop, hop count to this particular node and a timestamp indicating when the entry was added or updated. As justified by the simulation results carried out in [14], the maximum radius of the zone can be limited to a small value, e.g. an average hop length of virtual links on the multicast tree for a group of 20 nodes.
randomly chosen from a network of 100 nodes is found out to 3.8, hence a zone of 4-hops would be sufficient for similar network. The request to find the group members also will be confined to this zone only. Therefore, membership search requests can be more efficiently performed without exploiting the flooding in the network.

Table 6.1: Zone Neighbor Table maintained by each node

<table>
<thead>
<tr>
<th>Neighbor Node IP</th>
<th>Location</th>
<th>Immediate Hop</th>
<th>Hop Count</th>
<th>Timestamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>222.24.15.06</td>
<td>420 10' E</td>
<td>560 40' S</td>
<td>222.24.15.15</td>
<td>3</td>
</tr>
<tr>
<td>222.24.15.11</td>
<td>550 10' W</td>
<td>340 33' S</td>
<td>222.24.15.31</td>
<td>2</td>
</tr>
<tr>
<td>222.24.15.20</td>
<td>230 26' E</td>
<td>150 14' N</td>
<td>222.24.15.19</td>
<td>3</td>
</tr>
<tr>
<td>222.24.15.29</td>
<td>450 30' N</td>
<td>430 20' E</td>
<td>222.24.15.43</td>
<td>1</td>
</tr>
</tbody>
</table>

6.2.2 LOCATION INFORMATION OF NODES

A node uses GPS device to obtain its geographic location information. Like in LAFHRP, the locations of other nodes are obtained through a distributed location service with the exchange of LOCN, LACK, MGREQ and MGRPL packets. A node broadcasts a LOCN (location) packet in the zone to inform other nodes about its location. Format of LOCN packet is given in Fig. 6.1. It contains IP, location (latitude and longitude) of the source node and a timestamp.

An LACK (location acknowledgement) packet, as shown in Fig. 6.2, unicasts back by a node which receives a LOCN packet from another node. This packet contains the IP and location of the source node, the IP and location of the node acknowledging receipt of a LOCN and a timestamp.
Obtaining the locations of the mobile nodes, distance $d$ between two mobile nodes is calculated using expression (4.4) given in chapter 4.

### 6.2.3 MULTICAST GROUP FORMATION AT APPLICATION LAYER

Initially a dynamic mesh is created involving all the group members. The process of searching for the existing multicast group members is initiated by the source node by broadcasting a multicast group request packet MGREQ, as shown in Fig. 6.3, within its zone. This packet contains IP and location of the source node, IP of the multicast group, a join flag and a timestamp. Each multicast group has a unique multicast group IP (address) [15]. The search process takes place as per the improved expanding ring search technique [69] which has an advantage of less overhead over conventional ring search algorithm. The group member that first constructs the tree is designated as the root node of the source based data delivery tree.

![Table: MGREQ packet format](image)

A multicast group reply packet MGRPL, as shown in Fig. 6.4, is sent in response to a MGREQ packet by a multicast group member through the forward route formed during the transmission of MGREQ. The MGRPL packet contains the IP and location of the multicast group member, the IP and location of the source node, and a timestamp. The virtual multicast tree is constructed on the basis of the distance between various group member nodes.

![Figure 6.4: Format of MGRPL packet](image)

A node while receiving multiple MGRPL, designates only those members as its children which are having a distance less than the threshold i.e. $d_{\text{thresh}}$. In case many members satisfy the distance criterion, next constraint is put up on the number of children or degree.
of a node thereby assuring the uniform load distribution among the member nodes of the multicast group. This upper limit on the degree \((\text{deg}_{\text{max}})\) of member nodes in virtual tree can be relaxed in case more members lie in the radio range of a group member. This node records the MGRPL sending nodes as its neighbors in its multicast table (MT) with downstream flags. Similarly, the node receiving the MGREQ, records the sending node as upstream node. The nodes communicating in this way become each others neighbors in the virtual mesh. Thus, the multicast table represents the map of virtual topology.

When a node reaches to a maximum of its degree then it stops the member search process. However, its children nodes then starts the search process in their zone with distance and degree bindings, as shown in Fig. 6.5. With every entry in the multicast table of children
nodes, one entry is also made in the multicast table of the source node level. Therefore, total entries at source node represent all the group member nodes. When the total entries in multicast table at source node become equal the total members of the group, no further entry is made in the multicast table. If the request node does not receive a MGRPL even after tracing the whole zone by the MGREQ packet, it assumes that the requested multicast group does not exist and has become the source for that group.

Multicast table, as shown in Table 6.2, is only maintained by the group member nodes. Each entry of Multicast Table contains the multicast group IP address, multicast group member IP address, parent node IP, degree, location of the multicast group member, next hops and timestamp. The Next Hops field is a structure having IP addresses of immediate children and link direction fields. This table has entries for all the members of a multicast group. Entries are made and updated in the multicast table with the reception of MGREQ with join flag set (MGREQ-J), MGRPL and beacon messages.

Table 6.2: Multicast Table at node 224.24.15.50

<table>
<thead>
<tr>
<th>Multicast group MG_IP</th>
<th>Multicast Group Member GM_IP</th>
<th>Parent Node PN_IP</th>
<th>Degree</th>
<th>Location of Multicast Group Member</th>
<th>Immediate Next Hops</th>
<th>Time-stamp TS</th>
</tr>
</thead>
<tbody>
<tr>
<td>224.30.15.10</td>
<td>222.24.15.50</td>
<td>Nil</td>
<td>3</td>
<td>420 10° E</td>
<td>560 40° S</td>
<td>15:39 PM</td>
</tr>
<tr>
<td>224.30.15.10</td>
<td>222.24.15.40</td>
<td>222.24.15.50</td>
<td>0</td>
<td>550 10° W</td>
<td>340 33° S</td>
<td>15:40 PM</td>
</tr>
<tr>
<td>224.30.15.10</td>
<td>222.24.15.45</td>
<td>222.24.15.50</td>
<td>2</td>
<td>230 26° E</td>
<td>150 14° N</td>
<td>15:42 PM</td>
</tr>
<tr>
<td>224.30.15.10</td>
<td>222.24.15.55</td>
<td>222.24.15.50</td>
<td>1</td>
<td>450 30° N</td>
<td>430 20° E</td>
<td>15:41 PM</td>
</tr>
<tr>
<td>224.30.15.10</td>
<td>222.24.15.60</td>
<td>222.24.15.45</td>
<td>0</td>
<td>500 10° S</td>
<td>220 14° N</td>
<td>15:43 PM</td>
</tr>
<tr>
<td>224.30.15.10</td>
<td>222.24.15.65</td>
<td>222.24.15.45</td>
<td>0</td>
<td>225 65° E</td>
<td>150 25° N</td>
<td>15:44 PM</td>
</tr>
<tr>
<td>224.30.15.10</td>
<td>222.24.15.70</td>
<td>222.24.15.55</td>
<td>0</td>
<td>215 26° N</td>
<td>160 14° E</td>
<td>15:43 PM</td>
</tr>
</tbody>
</table>

* The Next Hops field is a structure having IP addresses of immediate children and link direction fields.

6.2.4 MULTICAST TREE CREATION FOR DATA DELIVERY WITHIN MESH

In source based tree, each source has its own shortest path tree (SPT) to get its group members. Since a shared multicast tree has only one tree shared among all group members, the multicast data traffic from source travels to the shared root and then down through the shared tree to the receivers. By using source based tree, multicast traffic is transmitted
directly to the receivers without going through the shared root and hence the source based tree architecture reduces network latency and possible congestion at the shared root. For creating a shared based multicast tree the Steiner tree provides a minimum cost tree though it is not a preferred choice as its computation is very complex affecting the anemic mobile nodes with limited computational capability. Moreover it requires information about entire network and whenever a node joins or leaves a rerun procedure is always required. To avoid such problems, SOM creates bi-directional source based multicast tree for data delivery at application layer, consisting of only the members of the multicast group. An overlay-driven tree is constructed as shown in Fig. 6.6.

![Figure 6.6: Virtual and underlying physical topology](image)

Node S is the source node which becomes the root of the tree. Node S has 3 children namely A, B and C; node A has two children D and E; node B has F as its only child; and node C has no child. In the Multicast Table 6.2, the 2nd, 3rd and 4th entries give details about the children (A, B, C) of the node S and 5th and 6th entries give details of children of node A. Similarly, 7th entry gives details of the child of node B. Thus, the multicast table has the complete mapping of the virtual topology which also gets updated with the reception of special control packets or the beacon.
6.2.5 MAINTENANCE OF THE DATA DELIVERY TREE

In the ad hoc networks with dynamic topology and more occurrences of link breakages, the maintenance phase is very crucial and should be designed in such a way so as to reduce the overhead of control messages and the re-build latency [10]. The robustness of the multicast mesh at upper layer is adversely affected with the time as the physical topology at lower layer becomes too different with node mobility. Over a period of time, due to high mobility among the nodes the overall structure of the tree would be far from optimal, thereby increasing the differences between virtual topology and physical topology which in turn would increase the consumption of energy resource and bandwidth due to redundant transmission of same packets over unicast links.

As shown in Fig. 6.7 (c), because of the modified physical topology for original virtual topology shown in Fig. 6.7 (a), a total number of 17 unicasts are needed while only 11 unicasts were required for same transmission for matched topology shown in Fig. 6.7 (b). In SOM, the mesh is updated regularly and also the preventive maintenance is carried out for keeping the data delivery tree robust. Entries are added and updated in ZNT on the reception of LOCN and LACK.

When a node sends a packet to some node, all of its neighbors hear the transmission and maintains this node as their neighbor in the ZNT with the appropriate value of hop count. Old entries on the basis of time stamp are deleted from the ZNT table to ensure the removal of stale routes from the ZNT. All multicast members update their multicast table with the reception or overhearing of transmission of the MGREQ and MGRPL packets and therefore, the mesh and the data delivery tree within mesh also get updated with time. If the reception of these packets is delayed beyond a specified interval then the multicast members broadcast beacon messages within their zone in order to adapt the changes of the dynamic network topology. The beacon messages include the IP of a member node, location, the number of their multicast neighbors and IP of its children. Figure 6.7 (d) shows a changed virtual topology after updation as per the new physical topology, which ensures the reduction in the redundant multiple transmission of the same packet as shown in Fig. 6.7 (e).
6.2.5.1 Preventive Multicast Tree Maintenance

A preventive approach in case of the complete depletion of the power sources of a member node of the multicast group is also being used for tree reconstruction prior to link breakages [43]. Route is reconfigured quickly in case of a node goes off because of complete drainage of its energy sources. The power sources of the member node of multicast group is examined periodically and if the power source of a node goes below a threshold value, it is removed from the tree by grafting a link from its parent to its children. As shown in Fig. 6.8, when node A goes off, its children D and E are connected to either the parent node of A or other member node satisfying the \(d_{thresh}\) and \(deg_{max}\) criterion.
In case of nodes failure, the latency in updating the topology is reduced by reconfiguring the routes using preventive approach before the failure of the node.

6.2.5.2 Joining and Leaving the Group

Leaving and joining a group is performed in very simple and easy way. To join a multicast group a node needs to broadcast a MGREQ with join flag set (MGREQ-J) within the zone. After receiving a MGRPL from one of existing group member the node will become a member of the group whose multicast address has been sent in MGREQ packet. This member node broadcasts its MT entries within the zone along with the MGREQ packet. Only the group nodes of the zone compare this member node's MT entries with their own entries and add new entries in to their MTs if some new entry is found. The member node responding through MGRPL unicasts the packet along with those entries of the MT which are not available in the sending node's MT and these entries are then appended in the MT of the MGRPL receiving node. In case of some duplicate entries, the entry with the latest time stamp replaces the older one, thereby, exchanging the MT of the group members with one another and updation with time. The new node also captures the total virtual topology with the exchange of multicast table entries.

Like the joining process, leaving the multicast group also require a node to send an alarm message to its parent node in the virtual topology. In the protocol a non-leaf node wishing to move out of the multicast tree, will broadcast an “Alarm” message to all of its neighbors with TTL value 1 before sending the “Leave” message. Thus, new links are grafted on the tree from the upstream node to the downstream nodes of the leaving node. The children of the leaving node become the children of their grand parent as shown in Fig. 6.8. The multicast table is also updated with all entries and all the future transmissions follow the
path as per the updated links. In case of leaf node, the node simply sends the leave message to its one hop neighbor nodes. All the neighbor nodes that receive the “Alarm” packet from any node also remove the related entry from their ZNT, if there exists an entry.

6.2.6 DATA FORWARDING

Once the tree is formed within a zone, the source starts forwarding packets. At every child of this tree, excluding the leaves nodes, the multicast happens through the lower layer protocol. Every child makes duplicate copies of the packet equal to its children and pass on to the lower layer. At lower layer the packet is unicasted to the child member nodes using the proactive route maintained within the zone. When the group members lie within the radio range of a member node then packet is not passed to lower layer for multicasting and forwarding of packet is done at upper layer only by broadcasting within its radio range with TTL=1. This clearly avoids the multiple transmission of the same packet on the unicast links. This approach gives a remedy over the common problem of overlay-driven multicast protocols.

6.3 PERFORMANCE EVALUATION

**Vertical and horizontal scalability** - SOM supports both the scalability, vertical (bigger group size) as well as horizontal (more number of groups) scalability. Vertical scalability is achieved due to the fact that state maintenance is confined only to group members. SOM uses source based data delivery tree, therefore the data traffic of all the groups would be passed through the group members and the intermediate nodes fall on the path only. Since, no core or specific group of nodes is responsible for the data traffic forwarding, horizontal scalability is achieved by the protocol.

**Less network latency and delay** - By using source based tree, multicast traffic is transmitted directly to the receivers without going through the shared root; therefore, source based tree architecture reduces network latency and possible congestion at the shared root. The latency in updating the topology in case of nodes failure is also reduced by reconfiguring the routes using preventive approach before the failure of the node.

Reduction in delay is also achieved at the lower layer wherein the packet is forwarded using the location information of the child group member of the virtual tree. Moreover, the
approach further reduces the delay because the multicast happens either at upper layer in case of more group members presence in the radio range of the group node or at lower layer otherwise.

**Efficient data delivery** - Due to dynamic mesh creation and regular updation on the basis of LOCN, LACK, MGREQ and MGRPL packets, the mismatch between virtual and physical topology is minimized and this way the multicast tree is optimized which results in less consumption of energy power of nodes and bandwidth of the links. Efficient data delivery is achieved as an end result.

**Moderate control overhead** - Although additional structure overlay is maintained to provide multicast, extra overhead incurred is kept controlled as many of the tasks related to multicasting are managed by upper layer protocol.

**Uniform load distribution** - By putting a constraint on the degree or the number of children of a member node, a uniform load distribution is assured. This is because no node is overburdened by passing the information to many nodes.

### 6.4 CONCLUDING OBSERVATIONS

In the presenting work a new approach to overlay multicast with dynamic mesh and updated source based data delivery tree within the mesh has been proposed. The methodology adopted for the protocol eliminates the drawback of more delay and less data delivery efficiency by using a dynamic mesh. The tree updation with the mesh that avoids the mismatch between virtual and physical topology is the basis of such efficiency of the protocol. The unicast protocol at the lower layer on which SOM depends, uses the location information of the nodes with incorporation of GPS and distributed location service in the nodes. It also ensures no extra burden in terms of overhead due to the incorporation of distributed location service for obtaining the physical location of the nodes and for other information sharing. In order to provide multicast, extra overhead in maintaining the additional overlay structure is worth considering in trade-off the obtained benefits.