CHAPTER 4

SCALABLE ROUTING PROTOCOL FOR CLUSTERED 802.11S BASED WIRELESS MESH NETWORKS.

INTRODUCTION

One of the desirable features of WMNs is Scalability. The careful design of scalable wireless mesh networks may increase the network performances such as throughput and delivery rate, and reduce the average end to end delay and packet loss rate, with negligible protocol overhead. These parameters can be maintained, as the network coverage and users in the network increase. The challenge in the design of WMNs is the development of a scalable routing protocol. The HWMP is not a scalable protocol, and is very sensitive to the network size and traffic. Since HWMP suffers in network performance under heavy traffic, and while operating in large networks, there is a need to develop a new scalable protocol for WMNs (Nassereddine and Maach 2009).

In this chapter, a new cluster based routing technique to enhance scalability and load balancing is proposed. The performance of the proposed algorithm is analyzed, using the SLRP routing algorithm, which provides satisfactory results in a dense network compared to the HWMP. In this routing algorithm, nodes (mesh points) under the same cluster will follow reactive routing. The data or code packets forwarded to the MPP for inter cluster or external communication, will be forwarded only through the cluster head (CH). In addition, the control packets are limited within each cluster,
and are not flooded to the whole mesh network. So the proposed protocol maintains a good PDR and throughput performance, even in highly dense networks under heavy traffic. The simulation results show that the protocol is scalable, load balanced and provides high level of delivery ratio, while routing the packet inside the cluster as well as outside the cluster. The SLRP protocol reduces the average end-to-end delay and drop rate.

4.1 CHALLENGES IN CLUSTERING OF WMNS

The proposed protocol SLRP helps to address the scalability issue of the HWMP. There are many factors to be considered while clustering the mesh network (Ameer Ahmed and Mohamed Younis 2007).

4.1.1 Scalable Network

When adding new mesh clients or increasing the backbone nodes, in order to cover more area or to increase the life time of the current network, the clustering scheme should be able to adapt to changes in the topology of the network. There should not be much throughput degradation of the network, while adding new nodes to the existing network.

4.1.2 Network Deployment

Mesh nodes such as MAP, MP and MPP may be fixed or randomly deployed in the network area. So, the careful management of the network is necessary in order to ensure that the entire area is covered.

4.1.3 Integration of Heterogeneous Network

The WMN is compatible with the existing network and various heterogeneous networks such as Wi-Fi, Wi-Max and sensor networks can be easily integrated into the mesh network. While clustering the mesh network
with the heterogeneous network, care should be taken in selecting the cluster head. If the cluster head is selected from the client network, it will suffer from energy issues. Hence, the cluster head should be either MAPs or MPs.

4.1.4 Load Balanced Clustering

In WMNs, the maximum traffic will be towards the MPP. In a clustered environment, all the nodes will forward their packets to the MPP through the CH. All the CHs should forward their traffic to the MPP on a time division basis. The default value of the number of a member under a cluster will be periodically compared. If it is lower than the default value, the cluster will be merged with the nearest one. If it is above the default, then the clusters will be divided.

4.2 NETWORK LAYOUT AND WORKING

There are two phases in the SLRP. The first is the clustering phase and the second is the routing phase. The former is a stage for the configuration of a topology formation, cluster head selection and cluster member registration, and the latter is a stage for routing the packet inside and outside the cluster.

4.2.1 Clustering Phase

4.2.1.1 Topology formation

Node deployment in WMNs is either fixed or random, depending upon the applications. In a fixed deployment, the network is deployed in predefined locations whereas in a random deployment, the resulting distribution can be uniform or non uniform (Nauman Israr and Irfan Awan 2007). For clustering, the network is divided into a number of clusters comprising of ‘n’ number of nodes. In WMNs, the stable nodes form the
backbone of the network. The topology of the network will not change significantly while a packet is being transmitted, since mesh nodes have very less or zero mobility.

The SLRP follows the fixed position based clustering of network nodes and energy constraint is not an issue to select the Cluster Head (CH). Figure 4.1 shows the cluster formation in WMNs.

![Figure 4.1 Network Layout of Clustered 802.11s Mesh Topology](image)

### 4.2.1.2 Cluster Head Selection

The node which is nearest to the MPP and having maximum number of neighboring nodes will be selected as the cluster head. A cluster head is responsible for routing the packet to the other cluster heads or to the Internet through the MPP. Information regarding the nodes under the same cluster will
be exchanged between the cluster heads. In the SLRP, the cluster membership is maintained by using the hard state approach i.e., any node can join or leave the cluster by exchanging the join or leave information.

The MPP should compare the number of cluster members under one cluster with the predefined threshold value. If it is below the lower threshold value ($T_L$), then the cluster should be merged with the nearest one. If it is above the upper threshold ($T_U$), then the clusters should be divided. The SLRP will fix the lower and upper thresholds by considering the total number of nodes under one cluster.

4.2.1.2.1 Cluster head table formation

Each cluster head stores the membership information about the cluster nodes of the same cluster and the mesh portal point, and other cluster head information for inter cluster and external communications.

The cluster table contains the following fields.

- Number of Clusters
- Cluster Address
- Join_Flag
- Cluster Members
- Cluster size

<table>
<thead>
<tr>
<th>Number of Clusters</th>
<th>Cluster Address</th>
<th>Join_Flag</th>
<th>Cluster Members</th>
<th>Cluster Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1200200</td>
<td>1</td>
<td>3,8,9,2,7,6,1</td>
<td>7</td>
</tr>
</tbody>
</table>
4.2.1.3 Cluster Member Registration

Every node has the knowledge of its position in the network. Two hops away nodes from the cluster head will register their identity under one cluster.

4.2.1.3.1 Cluster membership maintenance

For cluster maintenance each node broadcasts its information by the cluster member_Info Packet, which includes its ID, cluster address, and status to others within the same cluster, so that each node obtains the topology information of its cluster. Whenever a mesh point decides to join or leave a cluster, it conveys the corresponding Join_Info or Leave_Info message packet respectively to the cluster head. The CH that receives these messages updates its cluster member table correspondingly.

4.2.2 Routing Phase

Route discovery in a clustered network is purely on-demand. Each mesh point maintains a neighbor table for routing the packets. The SLRP protocol can work both in intra cluster and inter cluster packet forwarding.

4.2.2.1 Intra cluster routing

In intra cluster routing, the source node will forward the packet to another node which is under the same cluster using the reactive routing method. The route will be established between the source and the destination on demand. The source will broadcast the RREQ to its neighbor nodes of the same cluster. Since the flooding of RREQ is only within the cluster nodes, the number of RREQ messages forwarded to all the nodes will be reduced, which in turn, reduces the overall traffic of the network. When an intermediate node receives the RREQ packet, it creates or updates the path to the source MP, if
it has the latest sequence number. If the intermediate MP has no path to the destination, it resends the packet to all its neighbors after updating the link metric, hop count and the TTL field. If the intermediate MP node has a valid path to the destination, it will perform according to the DO and RF flags of the RREQ packet. The destination will select the route through the shortest path. Since the SLRP configures two hop away nodes in one cluster, the route establishment time taken by intra cluster routing is very short, with less overhead.

The format of the RREQ packet, which flooded only inside the cluster, is shown in Figure 4.2.

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**Figure 4.2 Frame Format of RREQ Packet**
4.2.2.2 Inter cluster routing

Inter cluster routing plays a vital role in a clustered environment. In the SLRP, the nodes which need to forward their packets to the MPP or to the nodes of other clusters, will send them to the CH. The CH will check the destination address of the packet. In inter cluster routing, the packet will be forwarded to the MPP if the destination address is beyond the cluster address. The MPP will check the packet, and if it is destined to the external network it will forward the packet to the wired network. If the destination address of the packet is within the mesh network, then the MPP will forward the packet to the corresponding CH, and the CH will forward the packet to its cluster member.

The format of the RREP packet, which is a unicast message in a reverse path to the source, is shown in Figure 4.3.

![Figure 4.3 Frame Format of RREP Packet](image-url)
The node which is nearest to MPP & having maximum number of neighbouring MP is selected as CH

CH broadcast hello message

Clusters are formed depending on distance of nodes from CHs

Two hop away nodes from CH will register with the nearest CH.

Nodes broadcast ID, cluster ID (CID), and status (cluster head/member/MPP)

Nodes build a table of their neighbours depending on the hello message they receive from neighbours.

Figure 4.4 Procedure to handle the clustering phase
Figure 4.5 Procedure to Handle an Intra Cluster Packet
Figure 4.6 Procedure to Handle an External Cluster Packet
4.3 PACKET SPECIFICATIONS

- **Cluster Member _Info Packet**

<table>
<thead>
<tr>
<th>Member Address</th>
<th>Cluster Head Address</th>
<th>Status(cluster head/member/MPP)</th>
</tr>
</thead>
</table>

**Member Address**

This address is the cluster member.

**Cluster Head Address**

Member node will store its corresponding cluster head address in this field.

**Status (cluster head/member/MPP)**

This field will indicate whether the initiating node is mesh portal point, cluster head or cluster member.

- **Join _Info Packet**

<table>
<thead>
<tr>
<th>Member Address</th>
<th>Cluster Head Address</th>
</tr>
</thead>
</table>

**Member Address**

This address is the cluster member from which the Join_Info packet is send.
Cluster Head Address

The member node will store its corresponding cluster head address in this field.

- Leave_Info Packet

<table>
<thead>
<tr>
<th>Member Address</th>
<th>Cluster Head Address</th>
</tr>
</thead>
</table>

Member Address

It gives the address of the member node, which initiates the Leave_Info packet that is sent.

Cluster Head Address

It indicates the address of the cluster head of the originating member node.

- Beacon Packet

<table>
<thead>
<tr>
<th>Member Address</th>
<th>Flood</th>
<th>Cluster ID</th>
</tr>
</thead>
</table>

Member Address

It gives the address of the member node, which initiates the beacon packet.
Flood

This contains number of times the beacon was initiated.

Cluster ID

This field gives the address of the cluster head of the originator node.

4.4 SIMULATION

The simulation was done to analyze and evaluate the performance of the SLRP. Cluster networks of different sizes placed in a 1000*1000 square meter area were simulated. The radio propagation range of 250 meters was chosen for each node.

Table 4.2 lists the simulation parameters and environments which are used as default values unless otherwise specified.

<table>
<thead>
<tr>
<th>Table 4.2 Simulation Parameters</th>
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</thead>
<tbody>
<tr>
<td><strong>Terrain Range</strong></td>
</tr>
<tr>
<td>Transmission Range</td>
</tr>
<tr>
<td>Mobility Model</td>
</tr>
<tr>
<td>Propagation Model</td>
</tr>
<tr>
<td>Station Association Type</td>
</tr>
<tr>
<td>MAC type</td>
</tr>
<tr>
<td>Traffic type</td>
</tr>
<tr>
<td>Number of Mesh Points</td>
</tr>
<tr>
<td>Data payload</td>
</tr>
<tr>
<td>Routing protocol</td>
</tr>
</tbody>
</table>
The following metrics were used in computing the protocol performance.

**Packet Delivery Ratio:** It is measured as the number of data packets actually received by the destination, to the number of data packets sent by the source.

**Average End-End Delay:** This is measured in ms as the time between the reception of the last and first packet/total number of packets reaching the application layer. This delay includes processing and queuing delays in each intermediate node. If no neighbor is available, the time spent on building a neighbor table is included.

**Throughput:** It is measured as the ratio of the number of data packets delivered to the destination and the number of data packets sent by the sender per second.

**Routing Overhead:** It is measured as the number of control packets transmitted during the simulation period to the number of data packets transmitted.

### 4.5 PERFORMANCE ANALYSIS

Many scenarios are configured using the NS2, in order to investigate the performance of the proposed protocol by varying the cluster size. The performance of the algorithm is studied and presented in this section.

The proposed protocol SLRP for IEEE 802.11s based mesh network is evaluated. In the simulation environment, the number of nodes in each cluster is increased step by step, and the packet delivery ratio, throughput, average end-to-end delay and the control overhead performances were
analyzed with respect to varying CBR connections and number of nodes and compared with the existing AODV and HWMP protocols.

![Figure 4.7 Effect of the Number of Nodes on the Average Packet Delivery Ratio](image)

**Figure 4.7 Effect of the Number of Nodes on the Average Packet Delivery Ratio**

Figure 4.7 shows the effect of the number of nodes on the packet delivery rate performance. The proposed protocol SLRP is compared with the HWMP.

The results indicate that the SLRP has a lower packet loss rate than the HWMP under increasing traffic loads. This is essentially due to the less number of hops taken by the packets to reach the destination through the CH and MPP. Being stationary, the portal points and CHs produce a very low loss rate. The PDR performance of the SLRP scheme is found improved by 22% compared to the HWMP. It is also observed that the SLRP is able to maintain a good PDR performance.
The average throughput performance of the SLRP with increasing number of nodes is shown in Figure 4.8. The SLRP is compared with the HWMP and on-demand routing protocol AODV.

As the number of nodes increases, the number of RREQ packets broadcast will also get increased, which will create traffic in the network. But, in the SLRP, the RREQ will not be forwarded to all the nodes, but limited only to the nodes in clusters. This will increase the throughput of the network and reduce the protocol overhead.

The packet delivery ratio and throughput of the SLRP are analyzed for with load balancing and without load balancing conditions. SLRP without load balancing is compared with the SLRP with load balancing, AODV and HWMP protocols.
Figure 4.9  Effect of the Number of Nodes on the Average Throughput

Figure 4.9 shows the effect of the number of nodes on the average throughput. The throughput performance of the SLRP with and without load balancing is compared. The SLRP with load balancing, maintains the network traffic inside the cluster. As the number nodes increases, the SLRP maintains the number of nodes in a cluster by considering the threshold value.

For the cluster of size 20, threshold will be set to 20, and the lower threshold will be 15 and the upper threshold will be 25. When the number of nodes became below the lower threshold, the cluster was merged. Number of nodes in a cluster exceeds the upper threshold, the cluster was divided.
Average throughput as a function of the number of nodes is shown in Figure 4.10. The average throughput performance of the SLRP with load balancing is compared with the SLRP without load balancing, AODV and HWMP protocols.

As shown in the above figure, the SLRP with load balancing achieves maximum throughput than that of the other three protocols. This is essentially due to, the SLRP maintains number of nodes in a single cluster and the traffic inside the cluster. So it increases the overall network throughput.
Figure 4.11 Effect of the Number of Nodes on the Average End–End Delay

Figure 4.11 shows the average end-end delay performance of the SLRP. The delay performance of the SLRP is compared with the AODV and HWMP.

Since all the packets are routed to the MPP through the CH, the time taken by the packet to reach the destination is very short compared to the HWMP. The SLRP based routing produces 3ms less latency than the AODV. The initial latency of the HWMP was very high. So the SLRP performs better compared to the HWMP.
Figure 4.12 Effect of the Number of Nodes on the Average Control Overhead

Figure 4.12 illustrate the effect of the number of nodes on the performance of the average control overhead. The control overhead of the SLRP is compared with that of the existing AODV and HWMP protocols.

The overhead of performing clustering increases the control overhead of the SLRP than the AODV and HWMP. Up to 30 nodes, both the SLRP and the HWMP perform more or less identically. As the number of nodes increases, the control overhead also increases.
The average End-End Delay as a function of the number of CBR connections is shown in figure 4.13. The average delay performance of the SLRP is compared with that of the AODV and HWMP protocols. As shown in the above figure, under light and medium traffic loads and lesser CBR connections, the delay is less.

As the traffic increases, the time taken by the data packet to reach the destination also increases. More hops results in more processing time to compute the path in the HWMP and AODV. Since the SLRP uses clustering for route discovery and packet forwarding, the average time taken by the SLRP is comparatively lower than that of the HWMP and SLRP.

Figure 4.13 Effect of the Number of CBR Connections on the Average End-End Delay
Figure 4.14  Effect of the Number of CBR Connections on the Average Packet Delivery Ratio

Figure 4.14 shows the performance of average packet delivery rate of the SLRP protocol. The PDR performance of the SLRP is compared with the HWMP and AODV, with respect to the number of CBR connections.

In the HWMP and AODV, heavy traffic loads result in more frequent link failure and serious congestion in the network. So the packet loss is more in the HWMP and AODV. But the scalable routing of the SLRP reduces the loss due to congestion and more number of hops. So, the SLRP shows an improved PDR performance than the HWMP and AODV.
4.6 SUMMARY

This chapter addresses key challenges, such as scalability and load balancing of IEEE 802.11s based wireless mesh networks from a network architecture perspective. A new scalable and load balanced routing algorithm is proposed. The performance of the proposed protocol, is studied using the simulation, and the results show an improved packet delivery ratio and throughput at the expense of an increased control overhead.

The main advantage of the SLRP is that the RREQ packet is broadcast only within the cluster nodes. So it reduces the overall traffic of the mesh network; hence, the packet drop due to traffic. Another advantage is that packets to the external network or to the inter cluster nodes will be sent through the cluster head. Hence, the number of hops to reach the destination gets reduced, which in turn, increases the throughput, packet delivery rate and reduces the average end to end delay. The common drawback of the SLRP protocol is that the protocol overhead and the system complexity are high due to the clustering of the network.

Since the HWMP is a basic protocol, security during routing and packet forwarding was not specified in the protocol. Therefore, in the following chapter, a secure routing protocol for the clustered wireless mesh network is proposed.