An Improved Hierarchical Cluster Based Routing Approach for Wireless Mesh Network

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***Abstract*—Applications of Wireless Mesh Network(WMN) are now visible everywhere in the world ranging from battle field to community networking and satellite constellation to university networking . Routing on WMN is one of the most sought research topic these days. Many routing protocols have been proposed by the researchers and works are being done in different dimensions. For better scalability Hierarchical Cluster based routing methods have been studied. These protocols group the nodes into clusters which consist of a cluster head(CH) and cluster members. Gateway nodes connect one cluster to another cluster. Nodes are assigned different functionalities in hierarchical order. The performance will not be impacted if the network is large. In the existing hierarchical cluster based routing protocols the CH is heavily loaded, so it increases end to end delay. In this paper, we propose an improved hierarchical cluster based approach in WMN which reduces the load on CH by using Assistant CH and a node clustering algorithm is proposed which works with varying cluster heads. The results are compared with two other important routing protocols for WMNs.**

Keywords—Wireless Mesh Network; Scalability; Hierarchical Cluster based routing ; Cluster Head ; Assistant Cluster Head; Node Clustering Algorithm

I. INTRODUCTION

Wireless mesh networks are dynamically self-organized and self-configured, with the nodes in the network automatically establishing an ad hoc network and maintaining the mesh connectivity [1]. It is said to be a promising wireless technology that can overcome the limitations of WLAN[2].WMNs have received widespread use and attention over the last years. The number of installations of WMN is growing rapidly. Mesh networks can be used for providing "last mile" IP connectivity to a number of users without the need of any infrastructure. The wireless nodes can be added as and when required. The mesh network acts as a common backhaul network which provides a link between different types of networks and eventually access to the Internet.

WMNs architecture has been classified into three categories namely, Infrastructure WMNs, client/Infrastructure-less WMNs and Hybrid WMNs. In infrastructure WMNs, mesh routers create an infrastructure for mesh clients, whereas in client WMNs nodes make peer-to-peer network among them and perform mesh functions, such as routing and self-configuration. Hybrid WMNs are a combination of the previous two methods where the Mesh clients can connect to the network through mesh routers and can also directly mesh with other mesh clients [3].

Scalability is an important issue for Wireless Mesh Network. Cluster base and Hierarchical routing protocols are quite helpful in this case. End to end delay, bandwidth consumption, energy consumption, throughput, and scalability all these performance metrics may be improved with efficient clustering techniques [4]. In this paper we are proposing one clustering algorithm and introduce an Assistant Cluster Head(ACH) to reduce the load on the CH among some other modifications to hierarchical cluster based routing. Ultimately, we analyze the scalability performance of our proposed method and compare the results with BATMAN and HWMP protocols by simulations in ns-3 considering packet delivery ratio (PDR), throughput and delay.

The remaining sections of the paper are structured as follows: In section II, Cluster based routing protocols are discussed. Section III discusses the proposed method. In section IV, Simulation results are presented and analysed. Finally, a conclusion is drawn in section V.

II. CLUSTER BASED ROUTING PROTOCOLS

There are a number of cluster based routing protocols proposed in the literature. The Cluster-head Gateway Switch Routing(CGSR) [5], The Hierarchical State Routing (HSR) [6], Hierarchical Cluster-Based Link State Routing(L-HCLSR)Protocol [7] etc. Some are used for MANETs and some may be implemented in WMNs also. But, we mainly focus here on the following two routing protocols as these are particularly focused on WMN.

A. Cluster Based Routing Protocol (CBRP)[8][9]

CBRP is based on cluster formation of mesh points and the communication between Mesh Portal Points(MPPs) and Cluster heads(CHs).MPP assigns one node as a CH of each cluster group and stores the CH and CH's neighbors information in its own table. The cluster formation algorithm is initialized by the new node which sends a CH query to its one hop neighbor. At the same time, the new node also initializes its topology data table and inserts a table entry at level 0 which indicates that it is a member of a cluster which

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does not have any CH until now. If no reply comes within a specified time interval, the node promotes itself as cluster leader. Many criteria may be used to select a CH or refuse the inclusion of a member in a cluster. Polling is performed from the CH periodically, to inform the members that the CH is active and also to know that all the members are active or not. When a CH is promoted, it initializes a list of all cluster members' addresses. In CBRP , the path establishment process is completed in 4 steps: setup of the cluster head, path creation, path reply, and path setup. CHs maintain two tables, one for neighboring CHs and another for MPs under it. Every cluster member stores the information on its CH. The Path creation process is started when a normal cluster member wants to communicate with a destination node. The source MP sends a path request (PREQ) message to its CH which checks its own member list first. If the information is available with CH, it sends a path reply, otherwise it forwards the PREQ to the MPP. The MPP multicasts a PREQ message to all of the cluster heads and the CH under which the destination node belongs, will respond with a path reply (PREP)which is forwarded to the source CH and ultimately to the source node. In this way, the path between the source and destination nodes is established. So, in CBRP two kinds of routing, viz, Intra-cluster routing and inter-cluster routing are performed. In CBRP, when the CH fails, then broadcasting is required.

The drawbacks of CBRP are that the load on MPP is quite high here and also, even when destination MP is in the same cluster, the Mesh Points (MPs) must communicate with the CH for communicating with the other MP.

B. Hierarchical Cluster Based Routing For Wireless Mesh Networks Using Group Head[10]

This approach is an extension of the cluster based routing scheme for wireless mesh networks . Here, WMNs are divided into different domains of Mesh Points(MPs) which are further subdivided into different clusters. One MP is regarded as a Group Head (GH) in each domain and one MP as a Cluster Head (CH) in each cluster. Almost all mesh points are distributed into clusters. MPP maintains the information about all the GHs. As shown in figure 1, MPP, GHs and CHs are all staying in fixed positions and only MPs may be mobile. An MP cannot be CH and GH at the same time. Here, MP9 and MP10 are group heads and maintain two clusters each. Big circle is denoting one cluster and every cluster is having one cluster head(CH) .Here MP1, MP3, MP5 and MP7 are cluster heads. The functioning of MP,CH, GH and MPP are shown in the flowcharts.

The Hierarchical cluster based routing approach works following the hierarchy i.e., MP-> CH -> GH -> MPP with mesh points on the bottom of the hierarchy and mesh point portal on the top. So, if an MP needs to communicate with an MP which is its neighbor in the same cluster, the RREQ need not be forwarded to the CH. The MP itself will find the entry for the neighbors in its routing table. But, if the destination MP is not a neighbor the RREQ will be forwarded to CH and CH finds out the route if its entry is there in its routing table. The REEP will be forwarded to source MP. If the destination MP's entry is not there in the CH's table, the CH forwards the RREQ to its GH which in turn forwards the RREQ to all CHs(except the source CH) under it.

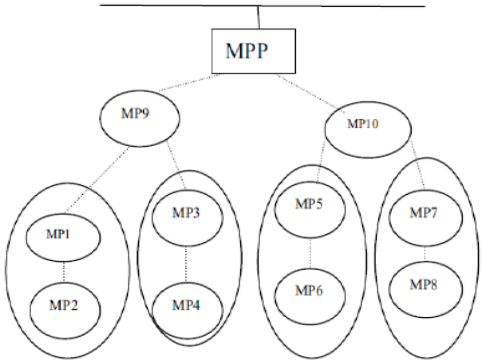

Fig 1:Wireless Mesh Network divided in Domains

If any CH is having that entry in its routing table, it will respond, otherwise will do nothing .If any RREP is received from any CH, it will be forwarded to the CH and ultimately to the source MP. If the GH is unable to find the route, it will forward the RREQ to the MPP, which forwards the RREQ to all its GHs(except the source GH) under it. Accordingly, the GHs will forward the RREQ to all their CHs and if the route is found by any GH, the RREP response will come to the MPP. The MPP forwards the RREP to the source GH which forwards it to source CH and lastly from GH to source MP. If the MPP is not able to find the route within a timeout interval, it will send a RERR message back to the source. Thus, CH, GH and MPP are sharing the loads hierarchically.

III. PROPOSED ROUTING PROTOCOL

In the hierarchical cluster based routing for wireless mesh networks using group head we have noted following drawbacks:

i) If the destination is two-hops neighbor node but is in another cluster, there can't be a direct communication between these two neighbor nodes. The routing path has to pass through their two CHs if the CHs are in the same group or else path should pass through their GHs. So it increases path length.

ii) Addition of GH reduces the load on MPP but there is still load on cluster head. Due to this reason end to end delay is increased.

To improve the performance of the previous protocol discussed we add some new features and propose a cluster based approach which may be used to reduce load on the CH.

In the previous algorithm the CH, GH and MPP are fixed. In our algorithm we take changing CH so that if CH fails the algorithm can work with new CH. For these reasons we have made the following changes in the proposed method -

1) An Assistant Cluster head (ACH) is introduced which share the load of CH.

2) A Cluster formation algorithm is proposed.
3) Each node in the network contains neighbor table which contains information about neighboring nodes and cluster adjacency table contains information about CH and ACH.
4) CH and ACH node contain cluster adjacency table.It contains information about cluster member nodes and gateway nodes.
5) GH stores information about CH/ACH of all clusters under it.
6) MPP stores information about all GHs under it.
7) GH, MPP are fixed but CH and ACH shall not be fixed.

A. Proposed cluster formation algorithm

Step 1: Initially each node is in undecided (Un) state.
node → Un
Step 2: Each node broadcasts hello message to 1 hop away nodes which contains
hello={ id, state, Sn, no. of neighbors}
//id=node id state=node's state Sn=Signal strength
Step 3: The receiving node send reply_hello message if sender(Sn)>receiver(Sn)
Step 4: The node will elect itself as CH if connectivity is highest and in case of tie of highest connectivity the node will elect itself as a CH(Cluster head) if Sn is higher than other node.
Step 5: CH will elect a node as ACH if connectivity of CH > connectivity of that node but higher than others or in case of tie elect the one with Sn or in case of tie of Sn elect the one with lower id .
Step 6: CH broadcast announcement message to the neighbor nodes along with ACH which contains
Announcement ={CH id, ACH id ,cluster id}
Step 7: The receiver node -> CM
if it received one announcement message
else receiver node ->GW
//CM=Cluster member GW=gateway
Step 8: The CM and GW reply with register message which contains
Register = {id, state, list_of_neighbors}
Step 9: CH forward register message to ACH.
Step 10: CH/ACH include CM and GW in its cluster adjacency table and form the cluster.
Step 11: End

Initially each node is in undecided state. For cluster formation each node sends hello message which contains node id, node's signal strength (Sn), state (Un/CH/CM/GW) and no. of neighbors. The receiving node checks its Signal strength with sender's Signal strength, if it is less than sender's Signal strength then send reply for hello message it received otherwise do nothing. The node with highest connectivity will elect itself as a CH. CH selects the node with next highest connectivity as an assistant cluster head (ACH) or in case of tie select the one with more signal strength or in case of tie of signal strength select the one with lower id as an ACH and broadcast announcement message which contains CH id, ACH id and cluster id to the neighbor nodes along with ACH. The receiving node sends one announcement message to set its state as cluster member (CM) and the node with more announcement message will set itself as gateway node (GW).The CM and GW nodes reply with register message which contains its id, state and its neighbor nodes. CH forwards the register message to ACH. CH and ACH then include these nodes in its cluster adjacency table and form the cluster. There is a need of re-election of CH/ACH if connectivity of CH is beyond the maximum threshold value or is below the minimum threshold value.

B. Routing in proposed approach

1. Source node (S) checks destination (D) in neighbor table (N) .
2. If (D in N)
Begin
S sends packet to D;
End
3. S unicasts RREQ to CH.
4. If (CH is not overloaded)
Begin
5. CH check D in cluster adjacency table (C)
6. If (D in C)
Begin
CH unicast the RREQ to D
D Send RREP to S through the path where RREQ was sent
End
7. Else if (D not in C)
Begin
8. CH multicasts RREQ to gateway nodes
End
End if
9. Else
Begin
CH forward RREQ to ACH
End
End if
10. ACH check D in C table
If (D in C)
Begin
ACH unicasts RREQ to D
D sends RREP to S using the path where RREQ was sent
End
11. Else
Begin
ACH multicasts RREQ to gateway nodes.
End
End if
End if
12. The receiving gateway nodes forward RREQ to CH.
13. Repeat step 4.

14. Repeat step 5.
15. Repeat step 6.
16. Repeat step 7.
17. If after certain timeout source CH doesn't get any reply forward RREQ to GH.
18. GH multicasts RREQ to all CH of clusters under it.
19. For all clusters
Begin
Repeat step 5;
Repeat step 6;
Repeat step 7;
CH discards RREQ;
Repeat step 9;
Repeat 10;
ACH discard RREQ
End
20. If after certain timeout GH doesn't get any reply
Begin
Forward RREQ to MPP
End
End if
21. MPP multicasts RREQ to all GH under it
22. For all receiving GH
Begin
Repeat step 18;
Repeat step 19;
End
23. End

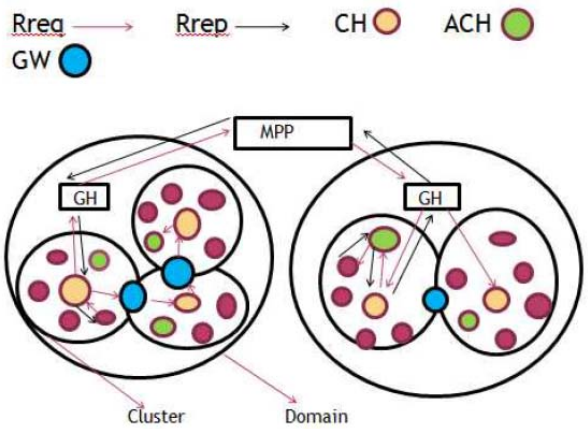

Fig 2: Routing in Proposed method

If a node needs to send packet to other node then the sender node checks if the destination node is in its neighbor table, if it is there, source MP sends the packet directly to that node. If it is not in the neighbor table then it sends Rreq message to CH.CH will check if the destination node is in its cluster adjacency table, if it is there, the CH forwards the Rreq to that node otherwise multicast it to 48 gateway nodes. If the CH is overloaded i.e. number of Rreq received exceeds the threshold value (THload) then it forwards the Rreq to ACH.ACH does the same thing as CH did. Gateway (GW) node will forward the Rreq message to CH of the clusters to which it is associated except the sending CH. Same procedure will be repeated by these CHs like source CH .If the destination node gets the Rreq message, it sends Rrep using the reverse direction of the same path it got Rreq message. If after certain time period if CH/ACH does not get any reply then it forwards the packet to GH.GH will forward Rreq to MPP.MPP will multicast to all the GHs under it.GH will multicast Rreq message to all the CHs of the clusters under it. If CH is not overloaded, it will check its cluster adjacency table, if it contains the address, it forwards the Rreq message to the destination, otherwise forwards Rreq message to ACH.ACH does the same thing as CH did. When the destination node gets the Rreq message , it replies with Rrep message using same path in reverse direction through which Rreq came. Thus a bidirectional path will be established between source and destination. Using that path both the MPs can communicate with each other.

IV. SIMULATION RESULTS AND DISCUSSION

This section presents the results obtained from different simulation scenarios described in previous section. In Figure 3, 4 & 5 , we compare the performance of our proposed modified Hierarchical Cluster Based Routing Protocol with BATMAN((Better Approach to Mobile Ad-hoc Networking)[11] and HWMP(Hybrid Wireless Mesh Protocol) [12] routing protocol. The comparison between these two protocols from the scalability point of view is already discussed in our previous work[13].Here, we performed the simulation in ns-3[14].

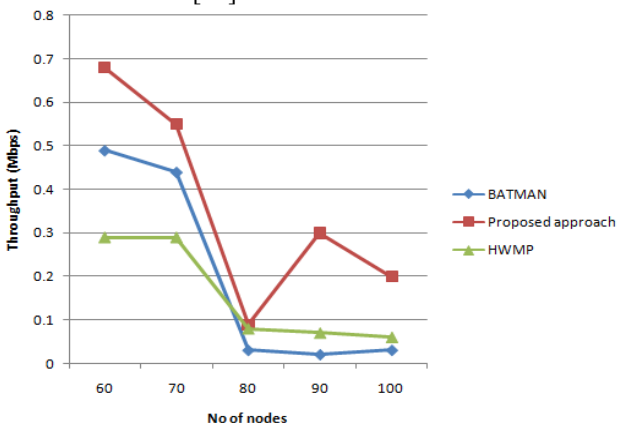

Figure 3: Variations of Throughput and Number of Nodes

Figure 3 shows that the performance of proposed modified hierarchical cluster based routing protocol in terms of throughput is better than HWMP and BATMAN. Up to 30 nodes, throughput (in kbps) of the proposed approach decreases but when the number of nodes is higher than 30 throughput increases .After 40 nodes throughput of the proposed approach again decreases, but the overall performance is better than HWMP and BATMAN. Throughput of HWMP is higher than that of BATMAN if number of node is small, i.e., less than 40. However, if the number of node is large, i.e., more than 40, throughput of the

BATMAN is increased but that of HWMP remains nearly constant. When number of nodes is large, the least number of control packets (e.g., RREQ, RREP or ORG) are successfully received from the clients to choose the routes in HWMP, so its throughput degrades in larger network.

Figure 4 shows end-to-end delay (in seconds) of proposed approach is lower than BATMAN up to 50 nodes. After 50 nodes end to end delay of proposed approach increases and becomes higher than BATMAN. End-to-End Delay of proposed approach is higher than HWMP.A distance-vector tree rooted at a single root mesh point is proactively selected by HWMP, so as to quickly select a routing path. On the other hand, BATMAN divides the information about the best possible end-to-end paths between nodes in the mesh to all

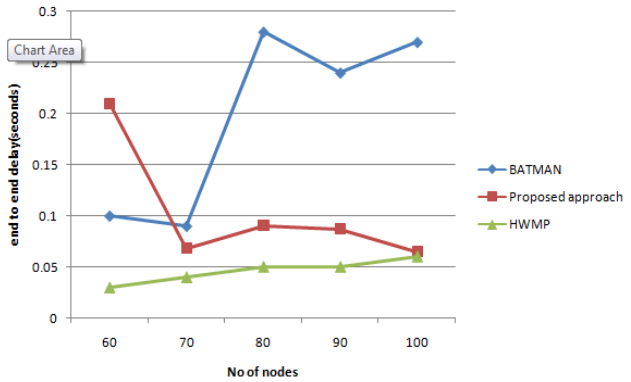

Figure 4 : Variations of End to end delay and Number of Nodes

participating nodes. Therefore, more time is required to select the routing path. In the proposed approach, path selection takes some time if destination is in other cluster or domain but congestion of packets is decreased using this clustering technique.

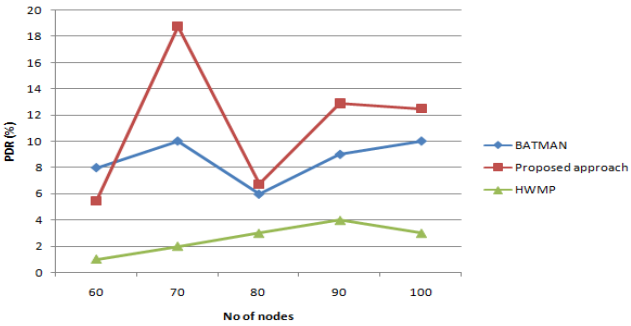

Figure 5 : Variations of Packet Delivery Ratio and Number of Nodes

Figure 5 shows packet delivery ratio (%) of proposed approach is lower than HWMP if number of nodes is small, i.e., less than 20 but higher than BATMAN when the number of nodes is less than 60. Increase in number of nodes cause much collision in the proposed hierarchical cluster based routing protocol, BATMAN and HWMP, which is caused by the following two reasons. Firstly, there is more number of nodes contending for the channel to send their data packets. Secondly, to choose routes, the clients have to send control packets, such as the RREQ, RREP or ORG message. Although these packets are very small in size, the nodes have to contend for the channel again and again to send these control packets. This leads to more packet loss.

Thus, Packet error rate(PER) in our proposed approach may be more than the other two protocols. This may be reduced by introducing better clustering approach which may also explore other alternative paths when there is more PER in the current route

V. CONCLUSION

In this paper, we presented a modified hierarchical cluster based routing approach for wireless mesh networks to reduce the drawbacks of previous approach. Although this approach creates an extra load on the mesh point portal and group heads, but reduces loads on cluster heads by introducing assistant cluster head. In this approach, hierarchical clustering is used and if source mesh points and destination mesh points are in same domain, the MPP does not participate in the route discovery which reduces the burden of the mesh point portal by group head. In the proposed approach cluster formation algorithm is proposed so that even if cluster head fails, the algorithm still works with new cluster head. In a large network the proposed Hierarchical Cluster Based Routing Protocol gives higher throughput than the other two protocols. Packet delivery ratio of proposed approach is lower than HWMP if number of nodes is small but when the number of nodes is large it provides lower PDR than BATMAN. When more numbers of node are added, there is a significant decrease in packet delivery ratio (PDR) in all the protocols. The proposed Hierarchical Cluster Based Routing Protocol gives higher delay than HWMP but gives lower delay than BATMAN when the number of nodes is small. Further improvements with introducing even better clustering algorithm may give better results in terms of scalability.

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