Bandwidth Management Framework for Multicasting in Wireless Mesh Networks

Manaswi Saha and P. Venkata Krishna

***Abstract*—Wireless mesh networks (WMNs) provide a reliable and a scalable solution for multicasting. This paper proposes a framework called Multicast Framework for Bandwidth management in WMN (MFBW) which combines the advantages of Shortest Path Tree (SPT) and Minimum Cost Tree (MCT) algorithm for efficient multicasting with optimal use of the bandwidth.**

***Index Terms*—Bandwidth management, multicasting, wireless mesh networks etc.**

I. Introduction

Wireless Mesh Network (WMN) [1] [2] consists of a wireless backbone and mesh clients. The backbone consists of mesh routers and gateway nodes which form the back-haul links for providing Internet connectivity. The mesh clients may be stationary or mobile. The backbone can serve several types of networks such as mobile ad-hoc networks (MANETs), ad-hoc networks, WLANs, cellular networks, wireless sensor networks etc. WMN is considered good for providing last mile access to various services. The mesh routers can also be mobile but in this paper, we are taking into consideration the infrastructure/backbone mesh network which is the most widely used network structure e.g. in community networks [1].

Multicasting is the method of group communication where a source node transmits a message to a group of destination nodes. It doesn't transmit it individually for each of the destination nodes. The message is sent only once and it is forwarded and replicated to the other users by the intermediate nodes leading to the destination nodes.

Wireless bandwidth [3] is a scarce resource. It is shared by many wireless nodes which are located close to each other. Some nodes may dominate the channel and some may not get enough bandwidth for their service requirement. Thus, proper mechanisms should be in place to manage the bandwidth. Bandwidth management [3] involves efficient utilization of bandwidth by proper channel allocation, reducing unwanted traffic, estimating available bandwidth, monitoring the wireless channel, adapting the flow and rate, providing QoS guarantees etc.

When taking multicasting over WMN into consideration, bandwidth management is very essential. With the advent of new applications and services which require group communication, multicasting is the natural choice for implementing them. And as these services start becoming popular, the number of users is bound to increase. Thus, proper bandwidth management mechanisms should be implemented so that problems like congestion, unsatisfactory service and slow performance is not encountered.

In this paper, we propose a framework called Multicast Framework for Bandwidth Management in WMN (MFBW) for providing multicasting over WMNs which takes bandwidth management as the central issue. Our framework incorporates the advantages of both Shortest Path Tree (SPT) and Minimum Cost Tree (MCT) algorithms.

The rest of the paper is organized as follows: Section II contains the related work done in this area. Section III explains our proposed framework. Section IV illustrates the proposed framework with the help of a working example. Section V compares our approach with some existing approaches. Section VI concludes the paper and enlists the future work which we plan to do. The last section lists the references cited in this paper.

II. Related Work

A lot of work has been presented for the ad-hoc networks, cellular networks etc. WMN is becoming the most popular choice for catering to the needs of the future applications and services. Significant amount of research still has to be done to meet the challenging demands of this area. Many previous works have taken into consideration various aspects in WMNs such as routing, resource allocation, multicasting, congestion control etc. But since multicasting over WMNs is an upcoming field of research, not many works can be found. Some of the related works on multicasting over WMNs have been discussed here.

Varshney [4] discusses the various issues in multicasting over wireless networks. Kumar and Hegde [5] specifically take multicasting into consideration for the WMNs. The authors of [5] tell about the various challenges in developing multicast protocols for WMNs as they must consider several factors such as availability of static mesh router infrastructure backbone, availability of multiple channels among nodes, load balancing among channels and nodes, selection of multicast routing metric, Quality of Service (QoS) guarantees, cross layer heuristic etc.

Many QoS based routing for multicasting have also been presented. Zhen [6] proposes an effective heuristic algorithm for calculating bandwidth of a multicast tree and a novel DSR-based multicasting routing algorithm to build a multicast tree among all the multicast members. Zhao et al [7] present a new load balancing aware multicast algorithm with the aim of enhancing the QoS in the multicast communication over WMNs. More works related to QoS are reported in [8,

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The authors are with Vellore Institute of Technology (VIT) University, Vellore, Tamil Nadu - 632014, India (e-mail: manaswi_7@rediffmail.com, pvenkatakrishna@vit.ac.in).

9].

Other than these, mobile node clustering [10] and group-based hierarchical structures [11] can be used to support scalable multicasting techniques and mobility management functions in ad-hoc networks.

Yang and Chen propose a bandwidth-efficient multicast mechanism for heterogeneous wireless networks. Their mechanism uses fewer cells to save bandwidth by clustering more mobile nodes together [12]. Wei et al [13] propose a light weight bandwidth management scheme called SRAM framework. Nguyen in [14] tells that bandwidth in WMN is saved when number of forwarding nodes used for transmission is less in number for performing multicasting.

Few works on multicast architectures also exist. In [15], the authors have presented a multicast architecture for wireless mesh networks where the backbone is a wired one which uses a wired multicast routing protocol and the networks which are connected to this backbone, with the help of the edge routers, run a wireless multicast routing protocol. Their architecture provides seamless access to the global Internet multicast groups.

Shittu et al [16] propose a hybrid QoS Multicast routing framework for wireless mesh network, which uses a proactive/mesh multicast routing protocol on the backbone mesh routers and a reactive/tree multicast routing protocol between the Mesh Access Point (MAP) and client end stations for each multicast group.

In this paper, we present a framework for performing multicasting. It is suitable for infrastructure based WMN and it addresses the issue of bandwidth management for multicasting in WMN. To the best of our knowledge, not much work has been done in the area of bandwidth management for multicasting in WMNs.

III. Proposed Framework - MFBW

Our proposed framework Multicast Framework for Bandwidth management in WMN (MFBW) builds on some of the ideas presented in the papers [4], [14] and [17]. We consider the infrastructure based WMN (Fig.1) whose backbone's topology doesn't change i.e. remains static (but only subject to node failures). This mesh backbone is local and can be spread throughout a city or a metro. It has backhaul links to the Internet through the gateway nodes. Many such backbones may be connected to the Internet cloud thus connecting many regions.

To save bandwidth, a proper multicast tree should be constructed such that data reaches the destination in the shortest time and without much delay. Also, the multicast traffic should have less impact on the existing unicast traffic in the network without creating congestion and delay in the currently carried connections.

Nguyen [14] recommends SPT algorithm for small to medium size groups, or large groups with low transmission rates, because SPTs perform better than MCTs such as Minimum Steiner Trees (MSTs) and Minimum Number of Transmissions (MNTs). Additionally, Nguyen also suggests that for a dynamic topology for example, ad hoc networks, SPTs give a better support for dynamic joins than MCTs. The paper also shows that MCTs are better than SPTs when the multicast group is large. Thus, additional overhead is not generated in case of MCTs compared to SPTs.

Taking into consideration all the points emphasized in the paper [14], we propose the framework MFBW in which the backbone mesh routers, or just mesh routers, incorporates both tree features i.e. SPT and MCT and adapts the tree construction according to the network it is connected to. That is, the mesh backbone router uses MCT algorithm (preferably MST in this paper) to find the network sub graph for the backbone mesh routers and SPT algorithm for the dynamic ad hoc networks where there is high mobility and possibility of network topology changes such as ad hoc WLANs, MANETs, and WSNs etc.

This framework is designed in order to perform multicasting in such a way that it saves bandwidth by combining the advantages of MCT and SPT. As Nguyen suggested in [14], by decreasing the number of forwarding nodes in the multicast tree using MCT algorithm, the bandwidth is saved as less number of nodes are using the bandwidth. The backbone mesh routers use the MCT algorithm for forming the multicast tree for the mesh backbone. Also in [14], the author recommends SPT algorithm for networks with dynamic topology because SPT supports dynamic joins better than MCTs. Thus, the mobile nodes of the ad hoc networks or the highly mobile networks that are being serviced by the backbone construct the multicast tree using SPT algorithm. Finally, the mobility of the mesh clients is managed with the help of Hash Table Node Identification (HTNI) method [17].

A. *Route Discovery Phase*

We use a receiver initiated routing protocol [18] to find the various routes/paths to the source. Though, a source initiated routing protocol can also be used. The receiver, who wants to join a multicast group, floods JOINREQ packets to its neighboring nodes. The intermediate nodes keep forwarding these packets until it reaches some multicast group member or the source. The forwarding nodes add their node IDs to the route-node-list. The group member or source (whichever comes first) acknowledges the request by sending a JOINREP packet in the reverse path to the receiver. The paths are calculated to form a tree according to the algorithm used by the node i.e. either SPT or MCT (described in the next section). The node which sent the JOINREP packet to the receiver can then serve as the node to forward the data packets to it.

B. *Multicast Routing Tree Construction Scheme*

After the route discovery phase, various paths will be available to different destinations from various sources. In this phase, the multicast tree of a multicast group is formed. The tree construction takes place in two different parts of the network i.e. mesh backbone and the mesh mobile nodes' network also called the External Network (EN) in this paper. ENs are the external networks that are being serviced by the mesh backbone such as WLANs, MANETs, WSNs etc. The mobile nodes belong to any of these ENs.

1) *Part 1 - Mesh backbone*

The multicast tree for the mesh backbone is created as soon as the paths between the mesh routers are available. A MCT (here a Minimum Steiner Tree) for the mesh backbone is created after all the possible paths between the source and the destination nodes are determined during the route discovery phase. The nodes in the tree generated are mesh routers. We call the mesh routers, that are connected to the ENs directly, Boundary Routers (BRs). They may be connected to other routers of an EN or the mobile nodes itself. We call the routers belonging to an EN that are connected to the mesh backbone, Mesh Representative Routers (MRRs). That is, MRRs are connected to the mesh backbone through the BRs.

2) Part 2 - Mesh mobile nodes/mobile clients

A multicast tree is constructed for an EN, which has a BR or MRR as the root. It is created only on demand when the group communication is requested. The SPT algorithm will be used to construct the multicast tree of EN. The BR constructs the multicast tree for the EN only when no MRRs are present in that EN else the MRR is responsible for the construction of the tree. Nodes in the tree are mobile nodes which are a part of the dynamic ENs. The mobile nodes only need to know the details of the BR it is connected to or its' MRR. All the multicast transmission requests are forwarded to the BRs or MRRs depending upon the absence of a MRR for the EN. In case the EN is an ad hoc network where mobile nodes also participate in the forwarding of packets then they use SPT algorithms for tree construction.

The mobile nodes specify the list of the destination node IDs in the data packet for initiating a group communication. It is the job of the corresponding BR to find the route to the nodes in the destination list. Thus, for any multicast communication, the MRR (or BR) becomes the intermediate destination node or receiver for the mobile nodes which want to initiate the group communication or to join a multicast group.

The main job of a MRR of an EN is to forward the multicast packets to the BR received from the mobile nodes and vice versa and to construct the multicast tree for the concerned EN it is a part of. It is not responsible for finding the route to the final destination (or group) nodes. In the ENs where MRR is not present, the BR does the same job. But additionally, it also has to create the multicast tree for the mesh backbone which is not a MRR's job. The multicast packets are routed using MCT paths through the backbone from the BRs and they reach the destination mesh routers (BRs) which then forward the packets to the corresponding mobile receivers or the MRRs of the EN it is connected to.

The computation of both types of trees is specifically for the mesh backbone routers since it is connected to both types of networks. The energy constrained mobile nodes are only required to compute the multicast tree for the ad hoc network it is present in.

C. Node Identification Process

The node identification process is taken from [17] i.e. HTNI (Hash Table Node Identification) method with few modifications. As in [17], the network is divided into cells but here, each cell is managed by a BR. We assume that the mesh routers are placed in such a way that they are connected to its neighboring mesh routers but the cells, which are individually managed by them, are non-overlapping. Thus, a mobile node can belong to only one cell. The mobile nodes of an EN under a cell are managed by its BRs. These BRs are required to keep track of the mobility of the mobile nodes belonging to its cell.

Each of the mesh routers is given a unique ID to identify each other. The mobile nodes are also given an ID which is calculated based on its BR's ID using HTNI method [17]. The source mesh router extracts the router ID of the BR to which the destination mobile nodes belong from the destination mobile nodes' IDs by HTNI [17] calculation and then routes the packets to that BR using the MCT created during the tree construction phase. After reaching the respective BRs, the packets are forwarded to the destination mobile nodes by their corresponding BRs by the help of SPT created for the EN to which the mobile node belongs.

The BRs keep track of its' mobile nodes' current location as well as it also keeps a check of the mobile nodes which are foreign to its cell. Whenever a BR gets a multicast data packet to forward to its' mobile nodes and if that node moves to some other location, the BR sends a node search request (NSREQ) packet to its neighboring mesh routers to obtain its current location. This packet will contain that BR's ID, the destination mobile nodes' ID, sequence ID of the packet. Once the destination mobile node is located by some mesh router i.e. it is in the cell of the mesh router, that router sends its own router ID in the node search reply (NSREP) packet to the BR which initiated this search process. Then the BR forwards the packet to that identified mesh router through the backbone network using the MCT. That destination mesh router forwards the received multicast data packet to the concerned mobile node. The BR stores the last discovered location of all its mobile nodes belonging to the same multicast group, thus keeping track of the members of the multicast group.

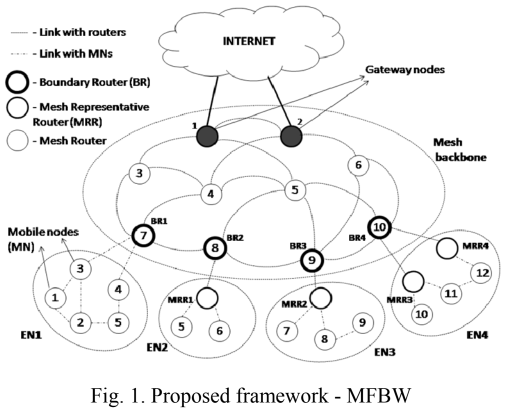

Fig. 1. Proposed framework - MFBW

IV. Illustration

Consider Fig. 1. It demonstrates our proposed framework. Here, the mesh backbone has mesh routers. The routers connected to the ENs are the Boundary Routers (BRs). The routers of the ENs which are directly connected to the BRs are the Mesh Representative Routers (MRRs). There are two gateway nodes connected to the Internet through wired links. These are access points to the other networks. Our architecture considers a local city wide network. Also, the numbers written inside the mesh routers are the Router IDs.

Based on these IDs, the mobile nodes managed by them are located.

Suppose there is a mesh router which has some data to send to a multicast group. Let that be the router with Router ID 6. The members of that multicast group are mesh routers 3, 5 and mobile nodes 3, 2, 5, 9, 11, 12.

A. Multicast data communication process

The mesh router 6 becomes the source and sends JOINREQ to its neighboring routers 2, 9 and 10. These routers in turn forward them to their neighboring routers and this process is repeated till it reaches the destination nodes. The mobile nodes send the JOINREP packets back to the source. During this process, the intermediate nodes store the router IDs of the mesh routers and the IDs of the other nodes. Using these, the multicast tree is formed.

The mesh routers construct a MCT for the mesh backbone. The MCT multicast tree doesn't consider the nodes of the ENs. Thus, the source 6 forwards the packets to the destination BRs with IDs 7, 9 and 10 which manage the destination mobile nodes with IDs (2, 3, 5), (9), (11, 12) respectively.

The BRs now construct the multicast tree for their respective ENs using SPT algorithm. The EN's mobile nodes also create the SPT tree for its own network. Thus, the mobile nodes are not required to know the network structure of the mesh backbone. They only forward the packets to the MRRs/BRs whenever transmission of packets to other ENs is required. Thus, the nodes (2, 3, 5) receive all their packets from BR1; node 9 receives from MRR2 and nodes (11, 12) from either MRR3 or MRR4 depending on the path calculated. In this way, the mobile nodes aren't required to compute the multicast tree of the entire WMN but only their EN. Similarly, the mesh routers need not compute the tree for the ENs. Only the BRs are required to compute the tree for the EN it manages.

Now, during the data transmission period, the node 2 moves to the cell managed by BR2, then the link for node 2 no longer exists in the EN1. In this case, the BR1 sends NSREQ to the neighboring routers 2 and 8. If they know that the node is in their cell then this information is sent to the node requesting for the search. Thus, node 8 sends NSREP to the node 7. The node 8 finds out the cell node 2 belongs to by the help of the node identification process described previously.

V. ANALYSIS

We give a comparative analysis of our approach with the networks using only SPT and MCT algorithms for multicast tree construction.

The networks which use SPT algorithm for multicast tree construction, find the shortest path for all the source – destination pairs of a multicast group. When a new node wants to join the multicast group, the node has to calculate the shortest path till that source node of that group. The source may be a mobile node or a mesh router. In this approach, all the nodes in the entire network have to be considered while constructing a multicast tree. Thus, more time is consumed in finding the path and tree construction. This affects the performance when number of nodes increases in the network. Also, when the sending rate is high and the multicast receivers are more, the performance degrades [14].

In case of networks which use Minimum Cost Trees (MCTs) for tree construction, the same problem of considering the whole network arises again. Additionally, the computation of MCTs (e.g. MST) is complex in nature [14]. Thus, there is a huge load on the energy constrained mobile nodes. Also, when a new multicast receiver joins in the network, the whole tree has to be recomputed.

Our approach MFBW divides the job of tree construction in two parts. One part has the mesh routers of the backbone constructing a MCT tree. And the other part constructs a multicast tree using SPT algorithm for the ENs. Thus, in this approach, the whole network is not considered each time the tree is constructed. Also, new multicast receivers can be easily added to the tree based on the EN it enters. Re-computation of the entire tree is not required. Only the cell, in which the new node enters, is required to add the node in the multicast tree. The range of the WMN can easily be extended by the addition of mesh routers to the backbone which would not affect the operation of the existing network.

MFBW makes use of the wireless broadcast advantage to save the bandwidth consumption. As the transmission of a multicast data packet to its neighbors can be done in a single transmission [14], the bandwidth can be saved by limiting the number of transmissions. The boundary routers can transmit the multicast data packet to the cell in a single transmission. Thus, this reduces the bandwidth consumption. Also, the increase of nodes doesn't affect the performance of the network as the framework operates as separate modules instead of a whole network.

VI. CONCLUSION AND FUTURE WORK

In this paper, we present a basic framework for performing multicasting in which the backbone nodes of the WMN uses MCT for tree construction while the nodes connected to networks with dynamic topologies maintain a SPT tree structure for determining the multicast tree. The mesh routers use HTNI for locating the mobile nodes when the mobile nodes change their locations from one BR to another.

In the future, we plan to extend this framework to include protocols which can take care of cross layer interactions, provide QoS guarantees for real time applications. Also, develop algorithms for efficient flow and congestion control to keep the network stable even when the network load is very high.

REFERENCES

[1] I. F. Akyildiz, X. Wang, and W. Wang, "Wireless mesh networks: a survey," *Computer Networks*, vol. 47, pp. 445-487, 2005.

[2] Y. Zhang, J. Luo, and H. Hu, "*Wireless Mesh Networking, Architectures Protocols and Standards*," Auerbach Publications.

[3] K. Nahrstedt, S. Shah, and K. Chen, "Cross-Layer Architectures for Bandwidth Management in Wireless Networks," *Resource Management in Wireless Networking, Springe*r, vol. 16, pp. 41-62, 2005.

[4] U. Varshney, "Multicast over wireless networks," *Communications of the ACM*, vol. 45, No. 12, pp. 31 – 37, 2002.

[5] A. Kumar K. S, and S. Hegde, "Multicasting in Wireless Mesh Networks: Challenges and Opportunities," in *Proc. International*

Conference on Information Management and Engineering (ICIME), 2009.

[6] X. Zhen, "A QoS Multicast Routing in Wireless Mesh Networks," 3rd *IEEE International Conference on Computer Science and Information Technology (ICCSIT)*, vol. 9, pp. 260-264, 2010.

[7] L. Zhao, A. Yassin Al-Dubai, and G. Min, "A QoS Aware Multicast Algorithm for Wireless Mesh Networks," *23rd IEEE International Symp. On Parallel and Distributed Processing (IPDPS)*, pp. 1-8, 2009.

[8] H. Wu and X. Jia, "QoS multicast routing by using multiple paths/trees in wireless ad hoc networks," *AdHoc Networks*, vol. 5, pp. 600-612, 2007.

[9] M. Iqbal, X. Xang, S. Li, and T. Ellis, "QoS scheme for multimedia multicast communications over wireless mesh networks," *IET Common*. vol. 4, pp. 1312 – 1324, 2010.

[10] B. An and S. Papavassiliou, "A mobility-based clustering approach to support mobility management and multicast routing in mobile ad-hoc wireless networks," *International Journal of Network Management*, vol. 11, pp. 387–395, 2001.

[11] W. Kieb, H. Fubler, J. Widmer, and M. Mauve, "Hierarchical location service for mobile ad-hoc networks," *ACM SIGMOBILE Mobile Computing and Communications Review*, vol. 8, pp. 47–58, 2003.

[12] De-Nian Yang and Ming-Syan Chen, "Efficient Resource Allocation for Wireless Multicast," *IEEE Transactions on Mobile Computing*, vol. 7, no. 4, pp. 387-400, 2008.

[13] Y. Wei, R. Maosheng, T. Zhao, and L. Xiaoming, "A bandwidth management scheme support for real-time applications in wireless mesh networks," in *Proc. of the ACM Symp. on Applied computing (SAC)*, pp. 2063-2068, 2008.

[14] U. T. Nguyen, "On multicasting in wireless mesh networks," *Computer Communications*, vol. 31, pp. 1385–1399, 2008.

[15] S. Zeng and H. Zheng, "Multicast Architecture for Wireless mesh networks," US Patent Pub. no. 2006.

[16] W. A. Shittu, Aisha-Hassan A. Hashim, F. Anwar, and W. Al-Khateeb, "A Proposed QoS Multicast Routing Framework for Next-Generation Wireless Mesh Network," *IJCSNS International Journal of Computer Science and Network Security*, vol.8, no.9, 2008.

[17] P. V. Krishna, N. Ch. S. N. Iyengar and S. Misra, "An efficient Hash Table Node Identification method for bandwidth reservation in hybrid cellular and ad hoc networks," *Computer Communications*, vol. 31, no. 4, pp. 722-733,2008.

[18] C. S. R. Murthy and B. S. Manoj, "*Ad Hoc Wireless Networks – Architectures and Protocols*," Pearson Education.

Manaswi Saha was born in New Delhi, India in 1989. She received her B.Sc. in Information Technology (IT) from Mumbai University, India, in 2009.

Currently, she is pursuing her Master in Computer Applications (MCA) from VIT University, Vellore, India. Her research interests include wireless mesh network problems like routing, network architectures, efficient bandwidth utilization etc.; mobile computing and developing technologies appropriate for emerging regions.

P. Venkata Krishna received his B. Tech in Electronics and Communication Engineering from Sri Venkateswara University, Tirupathi, India, M.Tech. in Computer Science & Engineering from REC, Calicut, India and he received his Ph.D. from VIT University, Vellore, India.

Currently, he is a Professor at the School of Computing Sciences, VIT University, Vellore, India. His research interests include Mobile and wireless systems and Grid Computing.

He has published several papers in national and international refereed journals and conferences. He was the editor for 2003, 2004 and 2006 ObCom International conference proceedings and he is the founding member for ObCom International Conference. He has authored few books on Computer Networks and Programming Languages. He is the reviewer for many reputed journals like IET Journal on Communications, International Journal of Security and Networks (IJSN) etc.