Efficient Layer-2 Multicasting for IEEE 802.11s based Wireless Mesh Networks

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Abstract—**We propose a novel MAC layer multicast scheme for the IEEE 802.11s based multi-hop WLAN mesh networks, where a layer 2 unicast routing protocol (named HWMP - *Hybrid Wireless Mesh Protocol*) is defined. We were motivated by the fact that no multicasting algorithm has been defined in the draft of 802.11s standard. In this paper, we present the two multicasting schemes: Layer2Multicast-Simple (L2M-S) and Layer2Multicast-Enhanced (L2M-E). In the L2M-S scheme, we simply utilize tree-based routing information created and maintained by the HWMP for the purpose of multicasting so no additional path maintenance overhead needs to be generated. Second, in the L2M-E scheme, a distributed tree optimization process is additionally introduced to further improve the performance of the MAC layer multi-hop multicasting. Simulation results using the QualNet simulator show that our protocols can reduce the data transmission overhead and improve the network throughput.**

Keywords; Wireless mesh networks, IEEE 802.11s, MAC layer Multicast

I. INTRODUCTION

In recent years, wireless mesh networks (WMNs) have been deployed in many cities and used in various applications thanks to its various advantages such as scalability, low cost, and easy deployment [1][2][3]. At the same time, various researches on WMNs have been conducted, and the IEEE 802.11s started the standardization of wireless LAN (WLAN) Mesh Networks after becoming a task group in July 2004.

WMNs functioning as backbone networks support the Internet access based on the multi-hop wireless communication. Recently, the demand for multicast TV, video conferencing and multi-player gaming through the internet connection has increased significantly. The multicast is suitable for these applications because it allows transmission of packets to multiple destinations while consuming less network resources [4]. However, the current IEEE 802.11s standard mentions that "*Procedures that enhance the reliability or efficiency of group addressed transmissions are outside the scope of this standard* [5]." Consequently, it does not have an effective multicast algorithm. When a node receives a multicast packet, the node handles it in the same way as it handles a broadcast packet, which leads to problems such as broadcast storm.

Several multicast protocols for mobile ad hoc networks (MANET) have been proposed so far. For instance, MAODV [6] is a typical tree-based protocol while ODMRP [7] is the representative of a mesh-based protocol. However, it is not effective to directly apply the existing ad hoc multicast algorithms to WMNs because these works mostly focus on solving problems caused by mobility, which is not the most significant factor for multicasting in WMNs. There has been an effort to develop some efficient layer 3 multicasting in WMNs. For instance, Ruiz and Gomez-Skarmeta proposed two solutions for constructing minimal cost multicast trees in multi-hop wireless mesh networks [8], and Nguyen tried to compare the performance of two different approaches for multicast routing, i.e., the shortest path tree (SPT) approach and the minimum cost tree (MCT) approach [9]. There is also an interesting work for improving reliability of the layer-2 multicasting in multi-hop wireless networks [10]. However, it is different from our work here in that a traditional single-hop communication was considered in their MAC multicast.

In this paper, we propose two different MAC layer multicast schemes for WMNs based on the IEEE 802.11s standard. The first scheme, named *"Layer2Multicast-Simple (L2M-S)"*, is based on the idea of utilizing the proactive tree path created by the HWMP for both unicast and multicast routing. Not only is it fully compatible with the 802.11s draft, but it also reduces the overhead for a path discovery towards each multicasting group member. In addition, we present the more advanced scheme, called as *"Layer2Multicast-Enhanced (L2M-E)"*. Here, the tree path is constructed and periodically reorganized to reduce the number of nodes that are required to forward multicast data. Such tree optimization technique becomes possible by using one of the characteristics of MAC layer multicasting; when a node transmits a packet through the wireless medium, all neighboring nodes within its transmission range can overhear the packet. It leads to the reduction of the total number of data packet transmission because a packet can be simultaneously delivered to the multiple receivers by a single transmission.

The remainder of this paper is organized as follows. In Section II, we briefly describe the IEEE 802.11s draft standard and the representative unicast routing protocol, HWMP.

This research was supported by the MKE(The Ministry of Knowledge Economy), Korea, under the ITRC(Information Technology Research Center) support program supervised by the NIPA(National IT Industry Promotion Agency" (NIPA-2010-(C1090-1021-0011)) and by the National Research Foundation of Korea Grant funded by the Korea government (2010-0016189)

Section III presents two proposed schemes based on the IEEE 802.11s standard. Section IV shows the simulation results followed by conclusion in Section V.

II. A Brief Overview of IEEE 802.11s

The standardization of WMNs has almost come to the end, and the draft version 4.01 was announced on February 2010. We summarize an overview about a path selection algorithm in the current draft.

The architecture of WMNs is composed of mesh portal, mesh station and mesh access point in the current draft. The mesh portal acts as a gateway connecting the internal mesh network to the exterior Internet. Mesh stations support mesh services and participate in the interoperable formation and operation of the mesh network, such as path selection and data forwarding. Mesh access points provide both mesh functionalities and access point (AP) functionalities.

The standard defines HWMP as the default path selection algorithm. To decide an efficient path, HWMP utilizes airtime link metric which takes both the transmission bit rate and error rate into account. HWMP combines an on-demand path selection mode with a proactive tree building mode. The on-demand path selection mode is always available whether the root mesh station is configured or not. It extends from Ad Hoc On-Demand Distance Vector (AODV) protocol and allows mesh stations to communicate by using peer-to-peer paths. The proactive tree building mode can be performed by configuring a mesh station as the root mesh station. The proactive tree building mode enables tree path maintenance from the root mesh station to every other mesh stations in a proactive manner. The proactive tree path allows to process downstream and upstream flows through the mesh portal without additional delay caused by path discovery.

When the WMNs are established as a backbone network, most of the data is transmitted through the Internet. Under this architecture and environment, it is natural that most of the data should pass via the mesh portal. As explained above, there is only unicast path selection algorithm in the draft, while it does not define any algorithm for multicast packet transmission. Since a demand for the multicast service increases continuously, it is positively necessary to handle the multicast packet efficiently. As a result, we propose an efficient MAC layer multicast scheme for WMNs based on the IEEE 802.11s standard.

III. The Proposed Layer-2 Multicasting Schemes

The goal of this paper is to propose MAC layer multicast routing based on the IEEE 802.11s standard with minimal modification. We cover the multicast services via the Internet such as IPTV and multi-player gaming. Considering these kinds of traffic flows, our proposed schemes create multicast tree paths which configure the mesh portal as the root node. Basically, our algorithms operate as follows: The *Scheme 1* enables nodes to take advantage of the proactive tree path for transmitting multicast data packets. To enhance the performance of MAC layer multicast routing, our *Scheme 2* constructs the multicast tree path and then reorganizes the path for reducing the number of the nodes required to forward the data.

A. Scheme 1: Layer2Multicast-Simple (L2M-S)

When a node wants to join a multicast group, a multicast tree path must be established. The same rule applies to the case when the node wants to transmit the data to the multicast group but does not have the multicast path. To construct a multicast tree path with a minimal overhead, we utilize the proactive tree path which is established and maintained by HWMP in the IEEE 802.11s. Since every node can recognize the next hop neighbor for transmitting its packet to the root node, it can create the multicast tree path without additional path discovery.

In order to inform about join and leave the multicast group, we define multicast path change (MPC). The MPC-JOIN is the message transmitted by a child node to a parent node so that the parent node realizes that it is selected. The MPC-PRUNE message is transmitted when a node wants to invalidate a path.

Multicast group MAC address	Flag	Source MAC address	Destination MAC address

Fig. 1. MPC message format

Fig.1 indicates the MPC message format. *Source MAC address is* the MAC address of the sender and *Destination MAC address* is the MAC address of the root node in the proactive tree. *Flag* field is used to distinguish between MPC-JOIN and MPC-PRUNE messages.

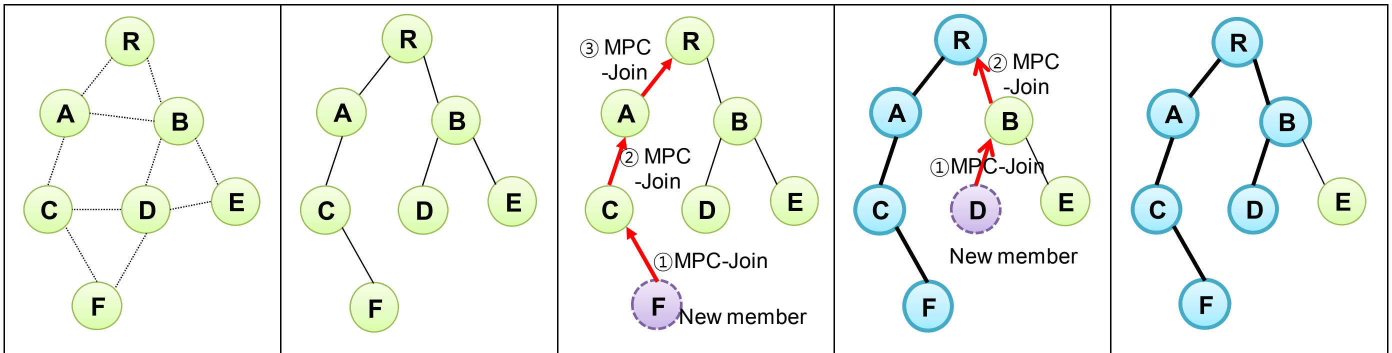
A new member node sends the unicast MPC-JOIN message to the root node. Upon receiving the MPC-JOIN message, a node recognizes that it has a child node joining a multicast group. If the node is not a member of the multicast group, it creates a multicast routing table as shown in Table 1 for transmitting multicast packet. Then, the multicast group MAC address and the child member list is filled with information from the received MPC message. Then, it forwards the message to the root node after changing the source MAC address to itself. Otherwise, if the node already received the MPC-JOIN message from the other node, it only updates the multicast routing table.

Table 1. Multicast routing table in the proposed Scheme 1

Field	Description
Multicast Group MAC address	MAC address of the multicast group
Child Member List	list of multicast member among neighbor nodes

As the same way, if a member node wants to leave the multicast group, it sends the unicast MPC-PRUNE message to the parent node. When a node receives the MPC-PRUNE message, it removes the source MAC address from the child member list. Then, if the node is no longer the multicast member and the child member list is empty, it forwards MPC-PRUNE message to the root node.

For MAC layer multicast, it is unnecessary to make an additional modification to the multicast data created at the upper layer, because it is possible to distinguish MAC address by checking the front part of the MAC address to see whether it is a multicast address or not. When IP layer multicast address



(a) Initial topology (b) Proactive tree path (c) New member join (d) Another member join (e) Multicast tree path

Fig. 2. An example of multicast tree construction in the proposed Scheme 1

is directly mapped to a MAC layer multicast address, the higher 25 bits of the 48-bit MAC address are fixed as follows; the higher 24 bits become 01-00-5E, and the 25th bit becomes zero. The lower 23 bits of the IP multicast address are directly mapped to the rest bits in the MAC multicast address. Therefore, when a node receives a packet, it checks the destination address to distinguish the packet type. In case of the unicast packet, the node forwards or receives it by the destination address of packet. Otherwise, in case of the multicast packet, the node forwards the received packet.

For example, Fig. 2 shows how a multicast tree path is created. We assume that node R is a mesh portal and each node and links are formed as shown in Fig. 2(a). Under the proactive tree building mode, a proactive tree path is established by using airtime link metric as shown in Fig. 2(b). When a new member node F wants to join the multicast group, it sends a unicast MPC-JOIN message to the root node via node C. When node C receives MPC-JOIN message, it creates the multicast tree path and forwards this message to node A because node C is not yet included in the multicast tree path. Eventually, root node R receives the MPC-JOIN message, and then it also creates the multicast routing table. Suppose that another new member node D wants to join the multicast group. It also transmits a unicast MPC-JOIN message to the root node. After all, Fig. 2(e) represents that the multicast tree path is constructed based on the proactive tree path.

B. *Scheme 2: Layer2Multicast-Enhanced (L2M-E)*

Although the proposed Scheme 1 is possible to construct the multicast tree path without additional path discovery, we propose the Scheme 2 to construct more efficient multicast tree path using broadcast feature of MAC layer multicasting. In addition, as the path is occasionally changed by association and disassociation of the member node, the tree path needs to be periodically reorganized to optimize the path based on the degree of the neighbor nodes. If there is a neighboring node that has a higher degree than the current parent node, the multicast tree optimization process is operated sequentially. In this case, the path to the current parent node is invalid so that a new node is selected as the new parent node. Furthermore, multicast trees may be partitioned due to link breakage.

For these operations, we define a new message named multicast root announcement (MANN) to reorganize and optimize the multicast tree path. Fig. 3 shows MANN message format.

Multicast group MAC address	Degree	Airtime link metric	Tree branch information (TBI)	Child list

Fig. 3. MANN message format

Degree is the number of neighboring nodes which belong to the same multicast group. *Airtime link metric* is cumulated value from root node. In order to prevent tree partitions during the optimization in a distributed manner, we define a parameter named *tree branch information (TBI)*. It makes the node to realize whether the message is from the same branch or not. Each node calculates its TBI by multiplying 10 to the TBI of its parent node and adding its own order to the child list. Therefore, if one node realizes that its TBI is the same as the front part of another node's TBI, the node recognizes this node as its own descendant node, so the optimization should not be operated.

In the proposed Scheme 2, each node maintains a multicast routing table with the additional parameters as shown in Table. 2. We define the *Neighbor Group Member List* as the list of the neighboring nodes that participate in the same multicast group. There are three kinds of nodes in the neighbor group member list, which are the parent node, the child node, and the free node. The parent node is the closer node from the root node, and the child node is the farther node from the root node among the neighboring nodes that participate in the same multicast group. The free nodes are the rest of the nodes that are neither the parent node nor the child node. *Degree* is the number of neighboring nodes which belong to the same multicast group.

TABLE 2. MULTICAST ROUTING TABLE IN THE PROPOSED SCHEME 2

Field	Description
Multicast Group MAC address	MAC address of the multicast group
Degree	number of neighboring nodes which belong to the same multicast group
Parent Degree	degree of the parent node
Neighbor Group Member List	list of the neighboring nodes that participate in the same multicast group

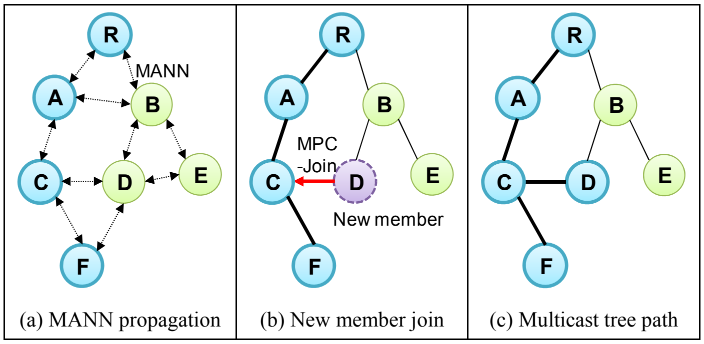


Fig. 4. An example of tree construction in the proposed Scheme 2

One of the differences between two proposed schemes is the way of forwarding the multicast packet. In the Scheme 2, the node forwards the received multicast packet only if any child node exists in the neighbor group member list. Otherwise, the leaf node in the multicast tree without any child node does not forward the received packet any more. Therefore, the total number of data transmission decreases rapidly. Additionally, unlike the proposed Scheme 1, if the root node receives the MPC-JOIN message, it configures itself as the root node of the multicast tree and transmits a MANN message periodically for tree maintenance and optimization. Each node needs to broadcast the MANN message successively, beginning from the root node. If a node receives a MANN message from the parent node, it updates the degree of the parent node and TBI. Then, it broadcasts the MANN message with the information of its own. Otherwise, it modifies the neighbor group member list. Utilizing the MANN message has the double advantages of efficient multicast tree path construction and optimization.

A new member node can collect information about neighbor nodes. If there are any neighbor nodes which are built the multicast tree path, the new member node sends the MPC-JOIN message to the neighbor node which has the biggest degree. If the neighbor nodes have the same degree, the new member node configures the parent node which has a minimum airtime link metric to a root node. Consequently, the proposed Scheme 2 can guarantee reduction of the whole transmission count compared to the proposed Scheme 1.

Fig. 4 represents a difference in the multicast tree construction between the two proposed schemes. Assuming the same topology as Fig. 2(a), node R initially broadcasts the MANN message in the Scheme 2. Upon receiving this message, each node also broadcasts the MANN message to 1-hop neighbor nodes. If a new member node D wants to join the multicast group, Node D recognizes that its neighbor node C already joined the multicast tree path so it can transmit the MPC-JOIN message to node C. Therefore, there is no change in data transmission count. However, in the proposed Scheme 1, node D configures node B as the parent node by exploiting the proactive tree. This in other turn causes an increase in the data transmission count.

When a node receives the MANN message, if the multicast group MAC address in the received MANN message is identical to those stored in the multicast routing table, the optimization algorithm is operated. In order to prevent tree partition and looping, a node operates the optimization process only with the nodes that do not belong to its downstream branch by checking the TBI. If the degree of MANN message sender is larger than the degree of the current parent node or if the degree is the same but the airtime link metric to the root is smaller, the parent node should be modified. To change a parent node, we add the additional function to the MPC message. The node transmits MPC-CHANGE message to the current parent node, then the node redirects the path to the new parent node by sending MPC-JOIN message to it. When the node receives MPC-CHANGE message, it changes the type of the MPC-CHANGE message sender in the neighbor group member list to the free node. If it is not a multicast member and has no more child nodes, the node forwards this message to its parent node to disassociate from the tree.

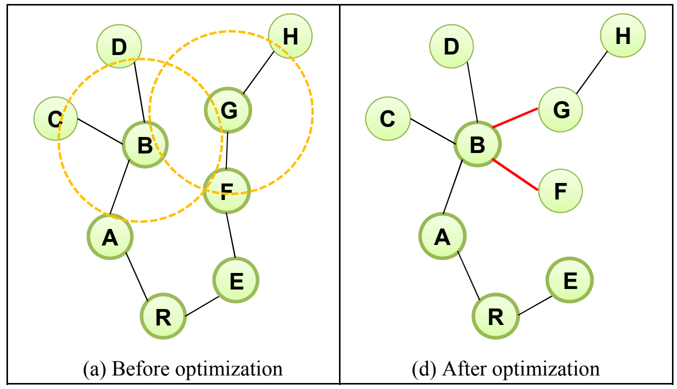


Fig. 5. An example of tree optimization in the proposed Scheme 2

For example, we assume that the multicast tree is established as shown in Fig. 5(a). Since node R, A, B, E, F and G need to transmit a packet, the total transmission count becomes 6. Root node R sends MANN message periodically. Upon receiving this message, node A and E will process and broadcast its own MANN messages. From this process, node F and G will eventually receive the MANN message transmitted by node B. Then, node F will change its parent node from node E to node B because the degree of node B, which is 5, is larger than the degree of node E which is only 2. Moreover, node G will change its parent node from node F to B. As a result of this reorganization process, the multicast tree path is modified as shown in Fig. 5(b). Node E and node F no longer forward the multicast data packet because these nodes do not have any child node. As a result, the transmission count is reduced from 6 to 4.

If a multicast member node does not receive the MANN message from its parent node during the path lifetime, this means that the link is broken due to the change of network environment. Therefore, in order to maintain and recover the multicast tree path, the node selects the new parent nodes as a neighbor node with the largest node degree. At this time, it excludes a neighbor node belonging to its downstream branch from the candidate parent node by using TBI. If there are no parent node candidates, it recovers the multicast tree path using the proactive tree, which is identical to the first proposed method.

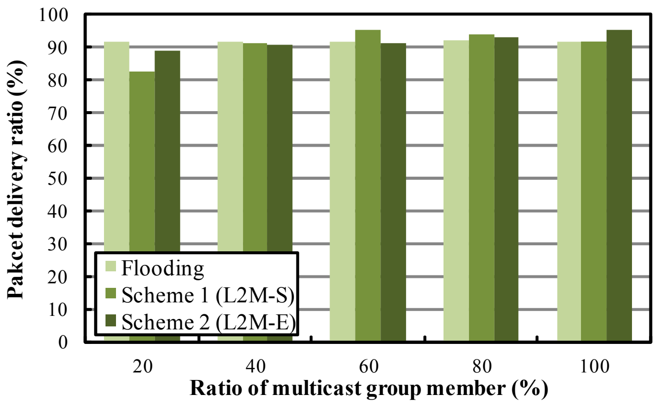


Fig. 6. Average packet delivery ratio

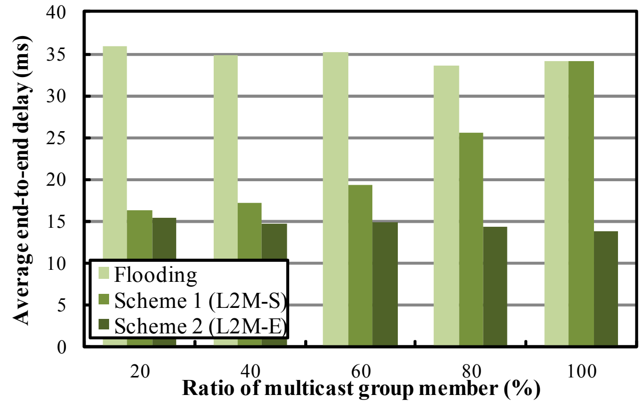


Fig. 7. Average end-to-end delay

IV. PERFORMANCE EVALUATION

For the performance evaluation, we have made simulation studies by using Qualnet 4.5[11] simulator. The simulation was conducted on a 1000m×1000m area in a single-channel single-interface environment for the duration of 300 seconds. Considering that the target size of an IEEE 802.11s WLAN mesh network is up to 32 mesh points [12], we randomly deployed 35 mesh points. We run each random topology ten times with different random seed numbers. The link speed is set to 11Mbps. In order to analyze the performance of video streaming service through the Internet, the mesh portal is set to multicast source node. After all multicast members join a multicast group, the mesh portal transmits 1024 byte MCBR packets for a total of 250 seconds. It transmits 8.4 Mbytes multimedia data with a transmission rate of 300Kbps, which is the average rate of multimedia file at YouTube [13].

As mentioned above, the current WMN adopting the IEEE 802.11s standard handles the multicast packet the same way it handles the broadcast packet, so we compared our scheme with flooding. In the proposed Scheme 2, MANN messages are broadcasted every five seconds. Two types of scenarios were simulated; with the first scenario representing the comparison of the protocols with the change in the number of multicast groups from 7, 14, 21, 28, and 35 in total of 35 nodes. The second scenario is designed to compare the maximum throughput of each protocol. It configures 14 nodes among 35 nodes as the multicast group node, and the amount of multicast data from source node is varied from 25 to 200.

We define five evaluation metrics as follows.

- **Average packet delivery ratio (PDR)** of a multicast group represents the PDR average of all receivers in the group. The PDR of a receiver is the number of data packets actually delivered to the receiver versus the number of data packets that should have been received.
- **Average end-to-end delay** is the average end-to-end delay of each multicast data transmission. The end-to-end delay is the time elapsed from the transmission of the source node to the reception by the destination node.
- **Data transmission count** is the sum of the transmission count of all nodes which generate or receive multicast data.
- **Control message overhead** accounts for all control messages required to transfer multicast data and maintain the path. Since the proposed scheme is based on the HWMP, this metric is the sum of all control messages required to manage HWMP. In the proposed scheme, MCT and MANN will be additionally summed up.
- **Throughput** is computed as the average rate of successful data packet delivery per second.

As shown in the Fig. 6 and Fig. 7, the successful delivery ratio of the proposed Scheme 2 is higher than flooding, and the average end-to-end delay of the proposed Scheme 2 is the lowest compared with others. As the ratio of multicast group member increases, the probability of collision also increases due to the increase of data packets in the network. In case of flooding and proposed Scheme 1, the end-to-end delay is increased even though data packets are delivered because data packets take detours to the destination. On the other hand, the Scheme 2 has less collision according to the reduction of transmission count, so it shows the similar delivery ratio with less delay.

There is no concept of leaf nodes in the Scheme 1, which leads all nodes to forward the received multicast data if it has not yet received the same data. Accordingly as the number of multicast group node increases, the data transmission count also increases, which eventually results as the same with flooding in case all nodes belong to the multicast group. However, in the Scheme 2, the multicast tree path is not only constructed but also reorganized using the maximum degree. Also, since only the parent node that has its own child node transmits the received data, the number of transmission is dramatically reduced compared to the others as shown in Fig. 8. The Fig. 9 shows the comparison of control message overhead. In the Scheme 1, since a proactive tree path of the HWMP is utilized for both unicast and multicast, it is possible to transmit multicast data packet, without additional path discovery. On the contrary, in the Scheme 2, there is an overhead because of

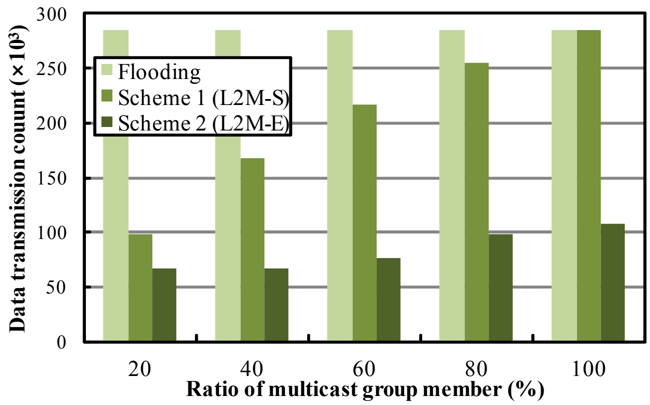


Fig. 8. Data transmission count

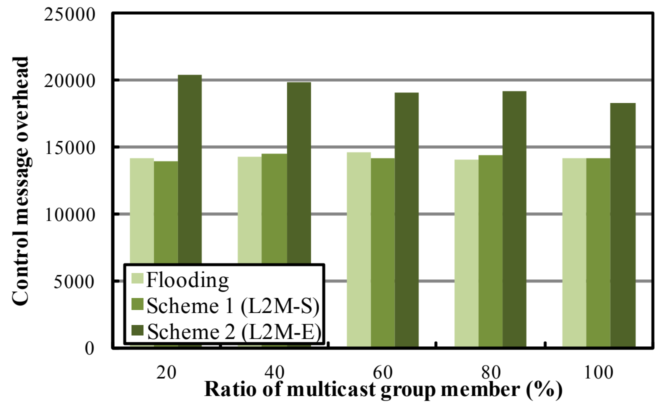


Fig. 9. Control message overhead

periodic broadcast of MANN message for maintaining and optimizing the multicast tree path.

Fig. 10 represents the comparison of throughputs using the second scenario. In flooding and Scheme 1, the throughput increases as the data transmission per second increases until the data transmission count of source becomes 50. After that, the increase stops because of congestion. On the other hand, in the Scheme 2, the saturation point is reached when the amount of data transmission becomes larger than that of others. This is because the multicast data is delivered with the minimum number of transmissions as shown in Fig. 8. Therefore, it guarantees more user connections for the multicast application. In addition, the throughput is higher by maximum of 115%, with an average of 63% compared to the Scheme 1 because of less transmission and efficient path.

V. Conclusion

In this paper, we propose two novel MAC layer multicast protocols based on the current IEEE 802.11s standard for WMN. The proposed Scheme 1 simultaneously utilizes the proactive tree path specified in the standard for unicast and multicast. Furthermore, the proposed Scheme 2 reorganizes the multicast tree path by using the information of neighbor nodes. Therefore, it delivers multicast data with minimal number of transmissions with efficient multicast tree path. The Scheme 1 is effective in case the number of multicast group member is relatively small. As multicast group member increases, the Scheme 2 is more efficient. Future work would include more improvements in the proposed scheme and also analyzing the performance in multi-channel multi-interface environments.

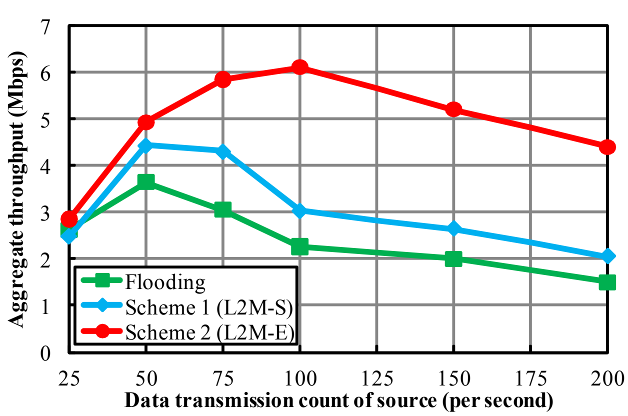


Fig. 10. Throughput

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