An Efficient Multicast Routing in IEEE 802.15.5 Networks

Kideok Cho, Munyoung Lee, Dong-il "Diko" Ko, Taekyoung Kwon, Yanghee Choi

School of Computer Science and Engineering
Seoul National University, Seoul, Korea
Email: {kdcho, mylee, diko}@mmlab.snu.ac.kr, {tkkwon, yhchoi}@snu.ac.kr

***Abstract*— The IEEE 802.15.5 standard for WPAN mesh adds mesh links to a tree structure for efficient communications for unicast routing. However, for multicasting, the basic tree routing scheme which does not exploit mesh links is adopted, which leads to inefficient multicasting. In this paper, we propose 'MTM (Multicast Tree with Mesh)' routing scheme which leverages mesh links for multicast routing. The proposed scheme shows better performance than the basic tree routing of IEEE 802.15.5 standard in terms of the number of participating nodes in multicast trees, control message overhead, and the number of data transmissions.**

I. Introduction

The IEEE 802.15 task group 5 (or shortly IEEE 802.15.5) [1] is standardizing mechanisms to enable mesh networking in WPAN environments. The IEEE 802.15.5 standard [2] adopts the adaptive block addressing (ABA) scheme [3] for the logical address allocation and the network auto-configuration. In the course of the 802.15.5 network initialization, an adaptive tree (AT) is constructed by ABA and on top of it, a meshed AT (MAT) which exploits mesh links is formed for unicast routing. With the MAT, a packet can be delivered more efficiently than the AT in terms of the number of hops and single point of failures (SPFs) can be removed thanks to the mesh links [3].

The standard also defines several entities and mechanisms to support multicast routing. However, unlike unicast, the multicast routing scheme in the standard is only based on the AT and uses not mesh links but tree links. Since the multicast routing tries to build a minimal sub-tree which covers all multicast group members on top of the AT, the multicast tree grows very fast when group members are scattered vastly through the branches. And usually it takes more hops to transfer a data while we can transmit it more efficiently if we exploit the MAT instead of the AT. Usually, small devices such as sensors or PDAs constructing WPAN mesh are battery-powered which makes energy saving the primary goal. So, by reducing the number of nodes participating multicast trees, we can reduce the number of transmissions and in consequence the energy consumption [4].

Based on the above observations, in this paper, we propose a novel multicast routing scheme called 'MTM (Multicast Tree with Mesh)' routing scheme. The main idea of the MTM routing scheme is to enhance the multicast tree construction mechanism of the IEEE 802.15.5 standard by exploiting mesh links of the MAT.

The rest of this paper is organized as follows. In section II, we will explain the unicast and multicast routing schemes of the IEEE 802.15.5 standard. After that, the detailed specification of MTM is presented in section III. Section IV presents the simulation results, and finally, we conclude our paper with the future work in section V.

II. IEEE 802.15.5 WPAN Mesh

A. Unicast Routing

The adaptive tree (AT) was proposed in [3] to solve the problems of the cluster tree algorithm [5] which had been adopted by ZigBee [6]. By assigning node addresses adaptively, AT provides flexibility in address assignments while not wasting address spaces. On top of AT, meshed AT (MAT) is formed to exploit mesh links between neighbor nodes in the AT for unicast routing.

Although the AT or the MAT has a self-contained routing mechanism, the 802.15.5 standard also adopts another routing scheme called the 'Topology-guided Distributed Link State (TDLS) [3]' for the purpose of the better performance. In TDLS, every node can utilize *maxHops*-hop link state information to route a packet.

B. Multicast Routing

IEEE 802.15.5 standard defines several entities and mechanisms to support multicast in WPAN mesh (hereafter, we call the multicasting in the standard as the basic tree routing).

1) Multicast Entities: To support multicast routing in WPAN mesh, following entities are defined in the standard.

- Network Coordinator (NC): The root of the tree. It maintains information about all multicast trees so that it can reach any group.
- Group Member (GM): A node participating in a multicast group. It processes packets for its multicast group and rebroadcasts them if it is not a leaf node
- On-Tree Router (OnTR): A node on the multicast tree but not a GM. An OnTR relays multicast packets for a multicast group.
- Group Coordinator (GC): The root of the multicast sub-tree. The lowest tree level GM or OnTR of a multicast group.
- Off-Tree Router (OffTR): A node which is the GC's ancestor or a node resides between the GC and the NC.

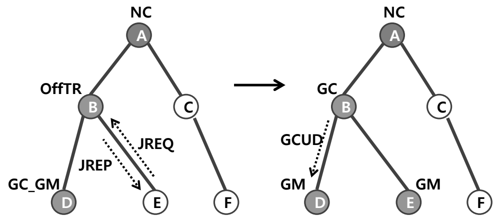


Fig. 1. Join Procedure of Basic Tree: Node E Join

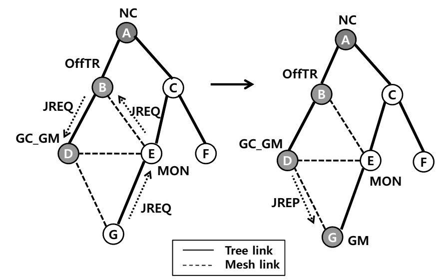


Fig. 2. Join Procedure of MTM: Node G Join

- Non-Member: A node which does not have any information about the multicast group.

2) Join Procedure: When a new node wants to join a multiast group, it will send a join request (JREQ) message to its parent node. On receiving a JREQ from its child node, a node first check whether it has information about multicast group or not. If if has, it responds with a join reply (JREP) message which is forwarded to the joining node through the tree links of AT. If the node does not have any information about the multicast group, the JREQ message will be forwarded to the parent recursively.

Fig. 1 shows an example of the join procedure of the 802.15.5 standard [2]. In this example, node D is the only member of multicast group (it is a GC and GM) while node A, node B are NC and OffTR, respectively. In this situation, Node E sends a JREQ message to its parent (node B) to join the multicast group. Node B happens to be an OffTR, so it responds with a JREP message to node E. Now, node E is a member of the multicast group and changes its status as a GM. Since node B is a common root of the multicast members, it changes its state to GC and send a group coordinator update (GCUD) message to the former GC, node D.[1] On receiving this GCUD message, node D changes it status as a GM and the join procedure is completed.

III. Multicast Tree with Mesh (MTM)

A. Modifications

1) Unicasting JREP: To shrink the size of the multicast tree, MTM is aided by unicast routing protocol. In the basic tree routing, if a node related with the multicast group such as GC, OnTR, GM, NC or OffTR receives a JREQ message, it replies with a JREP message to the joining node. However, in MTM, only the nodes of GC, OnTR, and GM can send a JREP message: NC and OffTR just forward the received JREQ message to the GC. Then, the JREP message will be routed to the joining node with the assistance of unicast routing protocol such as TDLS. By deciding the route of the JREP with the help of the unicast routing protocol, MTM can exploit mesh links of the MAT to forward the JREP, while the JREP is forwarded through the tree links of AT in the basic tree routing. It makes JREP messages traverse smaller hops which results in a smaller multicast tree.

[1] A GCUD message is sent when the GC role has to be changed.

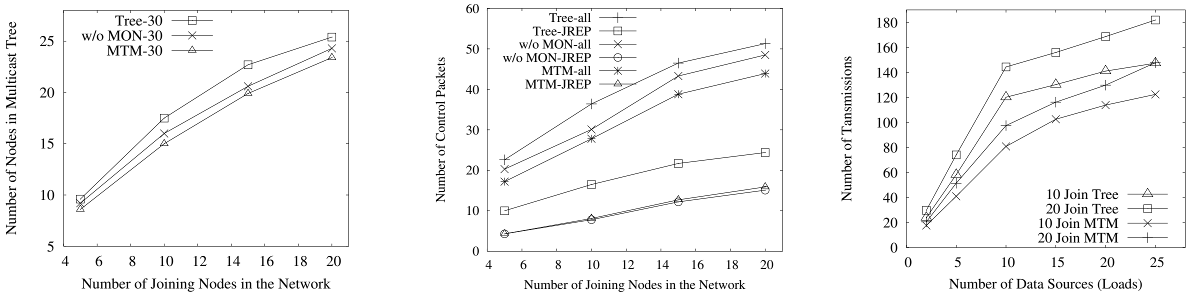
2) Introducing New Entity: To reduce the overhead such as JREQ forwarding, we introduce a new type of multicast entity called ‘Multicast One-hop Neighbor (MON)’. In MTM, a non-GM which overhears a JREP message will change its status from a non-GM to a MON and it maintains multicast group information which it overhears from the JREP. MONs assure that there exists a multicast group within one-hop. Therefore, on receiving JREQ messages or data packets destined to a specific multicast group, MONs can forward them to the group which is within one-hop apart, not forwarding them to their parents. This results in faster message delivery to the multicast group and prevents messages from traversing more hops of the multicast tree.

B. Join Procedure

Fig. 2 shows an example of the join procedure of the MTM. Similar to the basic tree example in Section II-B.2, node D is the GC and GM while node A and node B are NC and OffTR, respectively. Node E has already become a MON by overhearing a JREP from node B when node D joined. In this situation, node G tries to join the multicast group. On receiving a JREQ message from node G, node E can forward it to node B since node E is a MON of node B. Note that the JREQ should traverse E-C-A-B path in the basic tree routing. Since node B is an OffTR, it forwards the JREQ to the GC, node D. Now node D checks the local unicast routing table and sends a JREP message to node G through a mesh link. The resulting tree of MTM has only 2 multicast group members. Note that with the basic tree routing, there are 6 members in the multicast tree: (A: GC), (B, C, E: OnTR), (D, G: GM).

IV. Simulation Results

In this section, we compare the performance of MTM with that of the basic tree routing of the standard using NS2 2.26 [7]. To see the effects of MON entities, we carry simulations with and without MON entities. All experiments are run on top of IEEE 802.15.4 PHY/MAC. We choose non-beacon mode of 802.15.4 and the data rate is 250kbps. We run experiments over randomly generated topologies with 30 nodes. We vary the number of joining nodes in each simulation. Each simulation results are repeated 10 times and we use average values as results. For the unicast routing, we use TDLS routing with 2-hop neighbor information.



(a) Number of Nodes in Multicast Tree (b) Control Overhead (c) Number of Data Transmissions

Fig. 3. Performance Comparison

Fig.3-(a) shows the number of participating nodes in a multicast tree of MTM. In this simulation, we count the number of participating nodes (GC, OnTR, GM) in multicast trees (y axis) as the number of joining nodes (x axis) increases. We varied the number of joining nodes while fixing total number of nodes in network. The simulation results reveal that MTM outperforms the basic tree routing in terms of number of participating nodes. By comparing MTM w/o MON and the basic tree, we can notice that only unicasting the JREP can reduce the number of participating nodes in the multicast tree. By unicasting JREP messages, MTM can exploit mesh links, which results in the reduced number of nodes in the multicast tree. Also, by comparing MTM and MTM w/o MON, we can see that MON can reduce the number of node in the multicast tree by forwarding JREQ messages to the multicast tree earlier.

We also measure the number of control packets including JREQ, JREP and GCUD which will be used for the tree construction. Fig.3-(b) shows that the control overhead of MTM, MTM w/o MON, and the basic tree. In this simulation, we increase the number of joining nodes from 5 to 20.

We can see that MTM produces less control packets than the basic tree. In case of JREP packets, MTM sends almost half compared with the basic tree. This is because that MTM sends JREP messages through unicast routing which exploits mesh links while the basic tree routing only uses tree links. On the other hand, JREQ packets traverse more hops in MTM than the basic tree since they are forwarded to the GC. However, due to the efficiency of JREP packets, the total overhead of MTM is still less than that of basic tree. MTM w/o MON produces almost same number of JREP packets with MTM since reduction of JREP packets is related with unicast routing. However, total overhead of MTM w/o MON is greater than that of MTM. This shows that MONs can reduce JREQ packet overhead by forwarding JREQ packets to the multicast tree earlier. Also, without MON options, MTM still shows less overhead than the basic tree routing.

Since energy consumption is the primary goal of WPANs or sensor networks, it is worth to see the number of data transmissions in the multicast group as the load increases [4]. So, we count the number of data transmissions. Fig.3-(c) shows the number of data transmissions as the load of network increases. In this simulation, there are 10 and 20 joining nodes. Also, we randomly choose from 2 to 25 nodes which generate 10 data packets to the multicast group. As shown in the Fig.3-(c), MTM outperforms the basic tree routing in terms of the number of data transmissions. The number of data transmissions of MTM is about 67% - 80% of the basic tree. From this result, we can conclude that reduced number of participating nodes in the multicast tree results in less multicast data transmissions and low energy consumption.

V. Conclusion

To resolve the inefficiency of the multicasting in IEEE 802.15.5 standard, we propose the Multicast Tree with Mesh (MTM) routing scheme for WPAN mesh. To leverage mesh links for multicasting, MTM sends JREP messages using the unicast routing and introduces a new entity called multicast one-hop neighbor (MON). By doing that, MTM reduces the number of participating nodes in multicast trees. Also, the overall multicast traffics including control messages and data traffics are reduced considerably. As our future work, we will analyze the number of reduced control messages and work on further optimizations.

Acknowledgment

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