An Efficient Superframe Algorithm for IEEE 802.15.4 Cluster Tree Networks

#Bih-Hwang Lee[1] and M. Udin Harun Al Rasyid [1, 2]
bhlee@mail.ntust.edu.tw
[1]Department of Electrical Engineering
National Taiwan University of Science and Technology, Taiwan
[2]Electronics Engineering Polytechnic Institute of Surabaya (EEPIS), Indonesia

Abstract – A cluster tree network is a special case of a peer-to-peer network in which most devices are full function devices (FFDs). Any FFD may serves as a coordinator and implements synchronization services to other devices or other coordinators. However, if the coordinator nodes send periodic beacon frames at inappropriate time, the beacon transmission will be collide each other and prevent children nodes to synchronize to their coordinator. In this paper, we propose an efficient superframe algorithm to overcome the above mentioned problem. The values of beacon order and superframe order for coordinators and device nodes are chosen by considering the interarrival time, the number of children nodes and the depth of coordinator.

Index Terms – IEEE 802.15.4, cluster tree network, coordinator, beacon order, superframe order

1. Introduction

The IEEE 802.15.4 low-rate wireless personal area network (LR-WPAN) medium access control (MAC) standard [1] is proposed for low data rate and low power communication network applications. The standard may operate in either star topology or peer-to-peer topology. In the star topology, a personal area network (PAN) coordinator and several sensor nodes build a communication. A sensor node serves as either initiation node or termination node (sink node) in the network communication. PAN coordinator is the main controller of the network. It can be used as initiation, termination or router node in the network. A cluster tree topology is a special type of the peer-to-peer communication topology in which most devices are full function devices (FFDs). The advantage of the cluster tree topology is increasing coverage area, while the disadvantage is increase message latency.

Some algorithms have been proposed to deal with superframe order and beacon order. In [2], the authors propose a burst traffic adaptation algorithm for IEEE 802.15.4 beacon enabled networks. The length of active period will be extended dynamically based on the request from device, while the value of beacon order is always the same. In [3], the authors propose an algorithm for beacon order adaptation. The value of beacon order is increased or decreased based on the data traffic, while the value of superframe order is fixed to 0 during simulation. In [4], a MAC status index (MSID) is proposed to represent the queue occupancy and queuing delay, after that, the coordinator will estimates the number of packets and adapt the value of superframe order based on MSID, while the value of beacon order is constant. In [5], the authors propose a new traffic adaptation scheduling scheme based on the traffic volume and pattern. At that scheme, the value of superframe order will be adapted based on channel contention state, while the value of duty cycle always constant. In [6], the interval of sleep mode is adjusted by varying the value of beacon order based on the arrival rate of packets, while the value of superframe order is equal to 0. In [7], the authors propose individual beacon order adaptation which can adapt the value of beacon order based on the waiting time in each node, while the value of superframe order is constant. However, the papers [2-7] are working on star topology network. In [8], the authors propose an efficient duty cycle management in case of unbalanced and balanced cluster tree WSN. In case of balanced cluster tree, the author proposes a scheme to obtain duty cycle for cluster tree coordinator.

A cluster tree network is formed by several coordinators that regularly send beacon frames to the devices of their cluster. However, if the coordinators sent periodic beacon frames in the same time, collision will happens among these beacon frames. Consequently, the children nodes in their cluster cannot synchronize and communicate to their coordinator node. In order to overcome this problem, we propose a scheme to decide the value of superframe order and beacon order for PAN coordinator and every coordinator and devices around the cluster tree topology network. It will describe how to assign the number of active/inactive portion to achieve the effective throughput and the energy efficiency in the IEEE 802.15.4 cluster tree sensor network.

2. An efficient superframe algorithm

IEEE 802.15.4 defines two operating modes: beacon-enabled and nonbeacon-enabled. In beacon-enabled mode, the coordinator periodically sends a beacon to define the superframe. The coordinator transmit beacon frame in the beginning slot of each superframe. The beacons are used to synchronize the attached devices, to identify the PAN, and to describe the structure of the superframe. The coordinator may enter low-power mode during inactive portion in order to save energy. A superframe is bounded by the transmission of beacon frame and can have an active portion and an inactive portion. The active portion of each superframe is further divided into 16 equal time slots and consists of three parts: the beacon, a contention access period (CAP) and a contention free period (CFP). The CAP shall start immediately following the beacon and complete before the beginning of the CAP on a superframe slot boundary. If the CFP is zero length, the CAP shall complete at the end of active portion of the superframe. A device requiring dedicated bandwidth or low-latency transmission can be assigned a guaranteed time slot (GTS) in CFP by the PAN coordinator.

Cluster tree network consists of clusters, each cluster have a coordinator as a cluster coordinator and several device nodes. The PAN coordinator which initiates the network and serves as root forms the first cluster and broadcasting beacon frames to neighboring devices to form the whole networks. As problem above mentioned in section 1, we propose an algorithm to assign superframe for different coordinator in order to avoid beacon collision problem. In this section, we describe a proposed algorithm to decide beacon order and superframe order for PAN coordinator, cluster coordinator and device nodes.

A. Determining Beacon Order

For LR-WPAN at 2.4 GHz, we have the symbol rate and the bit rate of 62.5 ksymbol/s and 250 kb/s, respectively. In this algorithm, we derive three kinds of beacon and superframe orders for the coordinator node at the highest depth (PAN coordinator), the coordinators that is not PAN coordinator and device nodes, respectively.In order to guarantee the data traffic transmission, the beacon interval of the network should be the round function to the interarrival time (λ). Let denote BO_0 be the beacon order for PAN coordinator, which can be obtained by Eq.(1), where B_{sd} and N_s denote *aBaseSlotDuration* and *aNumSuperframeSlots* and is equal to 60 symbols and 16 slots, respectively. In order to reduce beacon collision from vicinity coordinators, we derive the following equation to get different beacon order between coordinators at different depth shown as Eq.(2), where BO_i and BO_{i-1} are the beacon orders at coordinator depth i iand i-1, respectively. Beacon order of device node is decided by its coordinator node. Therefore, the beacon order of device node is equal to beacon order of its coordinator node.

$$BO_0 = \left\lfloor (Log_2(\frac{\lambda}{Bsd * Ns * 0.000016})) \right\rfloor \quad (1)$$

$$BO_i = BO_{i-1} - 1 \quad (2)$$

B. Determining Superframe Order

PAN coordinator might often be powered; therefore, in this scheme we set superframe order is equal to its beacon order, i.e., $SO_0 = BO_0$, where SO_0 is denoted as the superframe order for PAN coordinator. We assume there is no CFP, hence the estimated CAP that nodes need to transmit their traffic is equal to beacon interval of coordinator divided by the number of its children nodes and children coordinator nodes shown as Eq.(3), where N_{ch} is the number children node and N_{cr} is the number of coordinator node. Superframe order of device node is decided by its coordinator node.

Therefore, the superframe order of device node is equal to superframe order of its coordinator node shown as Eq.(4), where SO_i and SO_{i-1} is the superframe orders of device nodes at depth i and i-1, respectively.

$$EstimatedCAP = \frac{BI}{Nch + Ncr} = \frac{Bsd * Ns * 2^{BO_i}}{Nch + Ncr} \quad (3)$$

$$SO_i = SO_{i-1} \quad (4)$$

3. Performance evaluation

In this section, the proposed algorithm is validated by using NS2 simulator. Let us assume that the number of nodes and the maximum depth of coordinator node are equal to 13 and 1, respectively. Note that the depth of coordinator start from zero that is PAN coordinator. We assume that the signal range is 15 meters, simulation time is 1500 seconds, packet traffic is Poisson traffic, interarrival time is between 0.1 – 1 and packet size is 70 bytes. In order to analyze the energy efficiency, we consider the radio parameters of Chipcon's CC2420 2.4 GHz for IEEE 802.15 [9], where the transmitting power, the receiving power and the idle power are 31.32 mW, 35.46 mW and 766.8 µW, respectively. If the PAN coordinator and other coordinator nodes send beacon in the same time, the beacon will be collide each others. Thus we need to choose the suitable BO and SO for PAN coordinator and every cluster coordinator such that reduce collision between beacon frames from different nodes or reduce collision between beacon frames and data packet. Furthermore, we need to choose the best suitable BO and SO to increase goodput and decrease energy consumption.

Fig. 1 shows the comparison of interarrival against goodput among proposed scheme, duty cycle management which the value of BO equal to 8 for its duty cycle combination, standard BO = SO = 8, and standard BO = SO = 4. We can see that the proposed scheme obtains the highest goodput than others from $\lambda = 0.9$ to $\lambda = 0.1$. It means that the proposed scheme obtain higher goodput in the high traffic load. Fig. 2 shows the comparison of interarrival against energy efficiency among proposed scheme, duty cycle management which the value of BO equal to 8 for its duty cycle combination, standard BO = SO = 8, and standard BO = SO = 4. We can see that the proposed scheme achieves the best value than others from $\lambda = 0.9$ to $\lambda = 0.1$. It means that the proposed scheme obtain lower energy consumption in the high traffic load.

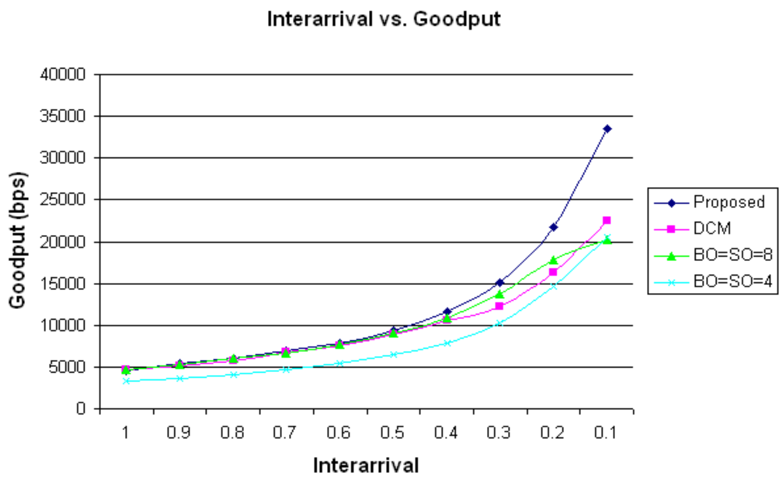

Fig. 1 Goodput for different interarrival.

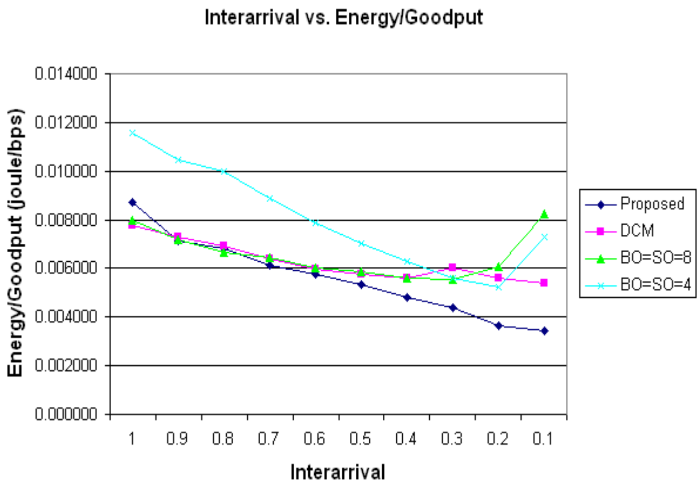

Fig. 2 Energy efficiency for different interarrival.

4. Conclusion

Beacon collision is important issue in the cluster tree topology. If the coordinator nodes sent periodic beacon frame in the same time, the collisions will happen among these beacon frames. Consequently, the children nodes in their cluster cannot synchronize and communicate to their coordinator node. In order to overcome this problem, we propose a scheme to decide the value of superframe order and beacon order for PAN coordinator, every coordinator and device nodes around the cluster-tree topology networks. The value of beacon order and superframe order is chosen by considering the interarrival time, the number of children node and the depth of coordinator. The simulation results of this study have shown that the proposed algorithm increase the goodput and performs better in term of energy efficiency. As future work, we will study on beacon scheduling further especially for adjacent coordinators in order to reduce beacon collision and increase the probability of packet delivery ratio.

REFERENCES

[1] IEEE Std. 802.15.4, "Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LRWPANS)," Sept. 2006.
[2] Jongwook Lee, Jae Yeol Ha, J. Jeon, Dong Sun Kim, Wook Hyun Kwon, "ECAP: A bursty traffic adaptation algorithm for IEEE 802.15.4 beacon-enabled networks," IEEE Vehicular Technology Conference, pp. 203-207, April 2007.
[3] M. Neugebaur, L. Plonnigs, K. Kabitzsch, "A new beacon order adaptation algorithm for IEEE 802.15.4 networks," In Proc. the Second European Workshop on WSNs, pp. 302-311, 2005.
[4] Joseph Jeon, Jong Wook Lee, Jae Yeol Ha, Wook Hyun Kwon, "DCA: Duty Cycle Adaptation algorithm for IEEE 802.15.4 beacon-enabled networks," IEEE Vehicular Technology Conference, pp. 110-113, April 2007.
[5] Indong Yeo, Jonghyune Kim and Sunshin An, "Performance enhancement in Low Rate Wireless PAN," Second International Conf. on Sensor Technology and Applications, pp.474-479, Aug. 2008.
[6] Dong-Hoon Cho, Jung-Hoon Song, Ki-Jun Han, "An adaptive energy saving mechanism for The IEEE 802.15.4 LR-WPAN," Springer Lecturer Notes in Computer Science, vol. 4138, pp. 38-46, 2006.
[7] Bo Gao and Chen He, "An individual beacon order adaptation algorithm for IEEE 802.15.4 networks," IEEE International Conference on Communication Systems, pp. 12-16, Nov. 2008.
[8] A. Koubaa, A. Cunha, M. Alves and E. Tovar, "A Time Division Beacon Scheduling Mechanism for IEEE 802.15.4/Zigbee Cluster-Tree Wireless Sensor Networks," Springer Real-Time Systems Journal, vol. 40, pp. 321-354, October 2008.
[9] Chipcon corporation, "Chipcon AS SmartRF® CC2420 datasheet (rev 1.2)," 2004.