Scheduling Beacon Transmissions in Receiver-Initiated MAC Protocols for Low-Delay Wireless Sensor Networks

Akihiro Fujimoto*, Yukari Masui† Takuya Yoshihiro† and Fumitaka Uchio*
*Center for Information Science, Wakayama University
Email: {fujimoto, uchio}@center.wakayama-u.ac.jp
†Faculty of Systems Engineering, Wakayama University
Email: {s1710432, tac}@sys.wakayama-u.ac.jp

***Abstract*—Receiver-initiated MAC protocols are promising protocols for wireless sensor networks due to their energy efficiencies. This paper proposes a method to schedule beacon transmissions for receiver-initiated MAC protocols to improve data collection delay. The proposed method divides a beacon period into slots. Each sensor node selects a slot to send beacon in distributed manner so that their beacon timing are sorted in descending order of their distances (i.e. hop counts) from the sink node. In addition, in order to avoid collisions, each node adjusts its beacon timing within the selected slot. Computer simulations show that the proposed method can collect data in a shorter time with less energy consumption than conventional receiver-initiated MAC protocols.**

I. Introduction

In recent years, wireless sensor networks (WSNs) have attracted a lot of attention in both of research and industry fields. In general, WSNs consist of a large number of low-cost battery-powered devices (called "nodes") having sensing and wireless communication functions. Since WSNs can be easily deployed in various environments, they are expected to be applied in various monitoring applications.

Energy saving is one of the key issues in the WSNs. A major solution for energy saving is scheduling active/sleep mode adequately, called "duty-cycling" [1], [2]. Receiver-initiated MAC protocols [3], [4] are promising approaches that can achieve good duty-cycling properties. In these protocols, receiver nodes lead sender nodes to send their data frames by small beacon frames. Senders just listen to the channel until the beacon is received only when they have data frames in their transmission queues. In addition, receivers can return to sleep mode quickly when no data frame is transmitted in response to the beacon. However, most of these works did not consider the data collection delay, which is a duration from sensing data is generated till the data is received to the sink node. For the emerging delay-sensitive applications in WSNs, it is required to establish energy-efficient duty-cycling mechanisms which can provide the fast data collection.

To improve both of data collection delay and energy efficiency, this paper proposes a method to schedule beacon transmissions for receiver-initiated MAC protocols. The key idea of the proposed method is to give transmission opportunities to more distant nodes from sink nodes prior to closer ones. By this strategy, each node can quickly forward data frames from its children to its parent. In addition, in order to avoid frame collisions, each node adjusts its beacon timing.

II. Related Work

Several receiver-initiated MAC protocols considering the data collection delay have been proposed in [5], [6]. In particular, REA-MAC [6] schedules beacon timing in a similar way with our proposed method. The main difference between REA-MAC and the proposed method is the beacon collision avoidance: timing randomization and timing adjustment, respectively. Since the senders can easily predict receivers' beacon timings in the proposed method, they can sleep until just before the predicted timings. As a result, the proposed method can save more energy.

III. Proposed Scheduling Method

We propose a method to schedule beacon transmissions so that the more distant nodes are, the earlier they transmit beacon frames. In this paper, we suppose that sensor nodes communicate with each other according to some kind of receiver-initiated MAC protocol. We also suppose the sensor nodes construct a data collection tree using a given tree routing protocol.

Figure 1 shows an example of frame transmissions in the proposed method. At first, each node roughly determines its beacon transmission timing based on its depth on the data collection tree. Nodes share a common network-wide "operation cycle" and divide it into N time slots. Each node determines the rough beacon timing by selecting the time slot $S_i, 0 \leq i < N$ corresponding to its depth d. The index of time slot i is calculated by Eq. (1).

$$i = N - 1 - (d \bmod N). \quad (1)$$

Then, each node adjusts its beacon timing so as not to collide with neighbors' beacons. This beacon timing adjustment also prevents the children's frame transmissions from collisions. Since the number of retransmission is decreased,

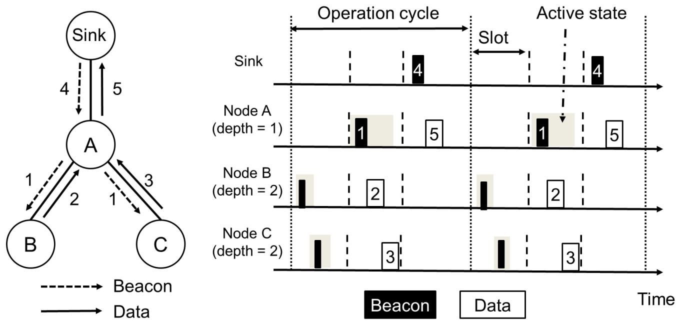

Fig. 1: Frame transmission order of the proposed method.

TABLE I: Simulation parameters.

Parameter	Value
Bandwidth	250 [kbps]
Data frame length	25 [Byte]
ACK frame length	variable
Beacon frame length	6 [Byte]
Beacon listening time	1 [s]
Data listening time after beacon	0.3 [s]
Sensing interval	300 [s]
Operation cycle length	20 [s]
Number of slots N	10

nodes can save their energy. In addition, in order to increase children's transmission opportunities, beacon timings of relay nodes are placed in the first half of the slot. After the adjustment is completed, each node has only to periodically wake up and transmit a beacon frame.

In order to communicate with parent nodes, nodes have to recognize when their parent nodes transmit beacon frames. For this reason, in the proposed method, nodes wake up at the start times of their parents' time slots (i.e. next time slots of themselves), and listen to the channel to record their parents' beacon timings during the slots. Note that nodes normally transmit data frames in response to parents' beacons, even when they are in recording phase. After having recorded the beacon timings, nodes can wake up just before the recorded beacon timings to receive their parents' beacons, instead of the start times of the parents' time slots.

IV. Performance Evaluation

We evaluated the performance of the proposed scheduling method by the computer simulations. We used a handmaid simulator written in Java. To evaluate the performance of the proposed method, we compared the proposed method with "REA-MAC [6]" in terms of data collection delay and energy consumption. Both of the transmission range and the interference range are set to 100 m. One sink node and sensor nodes are randomly placed in a 1000 m $\times$ 1000 m field. After a data collection tree is constructed, nodes start to schedule their beacon timing. The parameters of the proposed method are listed in Table I. Under the above conditions, we repeated the simulation 30 times.

Figure 2 shows the average delivery delay per hop under the different numbers of nodes. The delay per hop slightly increases as the number of nodes increases in both methods.

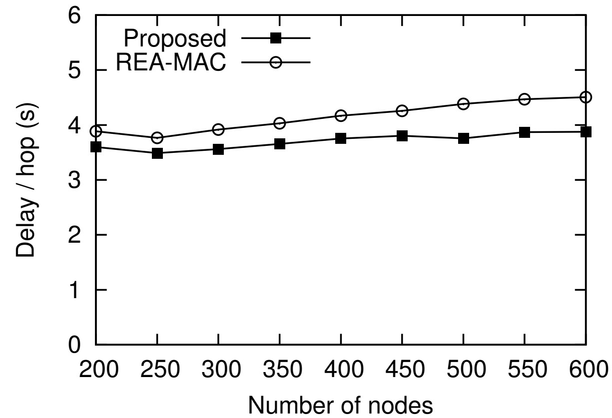

Fig. 2: Average delivery delay per hop in various number of nodes.

This is because that some data frames could not be transmitted within one operation cycle when nodes were densely placed. However, the proposed method can improve the performance than REA-MAC in terms of the increase rate of the delay per hop. The proposed method assigns beacon timings of relay nodes in earlier stage of their slot. Since they have more opportunities to receive data frames, more data frames are smoothly forwarded than REA-MAC. We also confirmed that the proposed method reduced nodes' active periods by 40% than that of REA-MAC.

V. Conclusion

In this paper, we proposed a method to schedule beacon transmissions for receiver-initiated MAC protocols to improve data collection delay and energy efficiency. By selecting time slots for beacon transmission based on the nodes' depths, the proposed method smoothly forwards data frames from leaf nodes to a sink node.

Acknowledgment

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