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GTS size adaptation algorithm for IEEE 802.15.4 wireless networks

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ABSTRACT

IEEE 802.15.4 standard specifies the Medium Access Control (MAC) and Physical (PHY) layer for wireless sensor networks (WSN) applications with limited power and low data rate. This standard supports time critical applications by allowing TDMA based access in beacon enabled networks. In these networks, the PAN coordinator exchanges data with the end devices through guaranteed time slots (GTS). The PAN coordinator can allocate GTS on a first come first serve (FCFS) basis in response to the requests by end devices. In original standard, the coordinator can assign up to the maximum seven GTSs. This fixed number of GTS allocation may result in inefficient utilization of channel bandwidth. In this paper, we propose a new GTS allocation scheme that will set the GTS size adaptively in accordance with the data size of the end device. We call it as GTS Size Adaptation Algorithm (GSAA) and it will optimally use the GTS resources. Simulations have been performed to validate the proposed GSAA.

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1. Introduction

Over the last decade, wireless sensor networks (WSNs) have become quite popular because they are potentially low cost solutions to a variety of real world problems [1]. The application areas include home automation, health-care monitoring, military investigation, environment surveillance, and so on. Moreover, they have applications in future communication, control, intelligence, reconnaissance, and targeting systems in the military field. In the health industry, sensor nodes in the WSNs have been used to monitor and help patients [2]. There are also environmental applications, like real time volcano monitoring [3] and temperature control of museums [4] etc. In recent years, home automation has emerged significantly; it has been accomplished by combining sensor nodes with other mobile devices like smart phones and PDAs [5].

To fulfill the needs of these emerging applications, IEEE has created a standard called IEEE 802.15.4 for LR-WPAN. This standard is considered as one of the communication candidates for wireless sensor networks [6,7] and wireless control networks [8]. It focuses on short range wireless communication.

IEEE 802.15.4 supports several network types, such as star topology, cluster-tree topology and peer-to-peer topology. In some cases, the applications are time sensitive [11–13]. In this situation, the standard allows the use of GTS in beacon-enabled mode that ensures real-time guarantees for data frame exchange among the network devices.

In the beacon-enabled 802.15.4 network, end devices may request GTSs during the CFP. An end device may be allocated a GTS consisting of more than one superframe slot. If the total time for data transmission for an end device is shorter than the total allocated GTSs duration then a portion of GTS is wasted. The unused portion of each GTS is similar to the fragmentation problem in memory allocation of an

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operating system [9]. Moreover, the original standard allows only seven end devices in CFP that may leave many other end devices unserved that have requested service in CFP due to time sensitive nature of their data. In some situations, it would be disastrous. For example, in military investigation, the target will not be detected, and some disastrous situations will appear.

In this paper, we propose a GTS Size Adaptation Algorithm (GSAA) based on IEEE 802.15.4 standard [10] to improve GTS utilization efficiency, reduce average end-to-end delay and to improve throughput. In this technique, the GTS size and number of Guaranteed time slots (GTSs) are adaptively set in accordance with the data size of the end device. The GSAA proposed three different sized GTSs. In order to implement GSAA, modifications have been made to the Beacon frame and the GTS Request Command frame. The end device first calculates the required GTS resources; the time duration required to transmit its data to the coordinator. It then decides about the GTS type and number of desired GTSs. The coordinator, after receiving the GTS allocation request from the end device, evaluates the availability of GTS resources. If the resources are available, the coordinator informs the concerned end device through the beacon frame. Finally, the end device will find out the starting time of its allocated GTSs by running an algorithm. With this technique, more than seven end devices can be serviced in the CFP during one superframe.

The contribution of this paper is that by using GSAA, the GTS resources can be optimally allocated in accordance with the packet size of the end device that it needs to transmit to the coordinator. It also ensures accommodation of more than seven end devices in CFP for time-sensitive applications. Our extensive simulation results demonstrate that GSAA has better performance as compared to the standard. In worst-case scenario, the performance of GSAA is equal to original standard.

The rest of the paper is organized as follows. Section 2 presents the overview of IEEE 802.15.4 standard. In Section 3, the proposed GTS Size Adaptation Algorithm is presented in details. The performance evaluation is given in Section 4. Finally, the conclusions are given in Section 5.

Although the standardization for IEEE 802.15.4 has developed over some years, some issues are still needed to be resolved before WPAN can be efficiently deployed. The limitations of the standard include these aspects: inefficiency in energy consumption, bandwidth under-utilization, high latency, unfairness in allocation of GTSs in CFP and so forth.

Some work on IEEE 802.15.4 CFP focused primarily on the fairness of the scheduling algorithm, best utilization and allocation of GTSs among participating nodes [14–16]. In [14], an adaptive GTS allocation scheme is proposed to gain low latency and fairness of data transmission. The proposed scheme decreases the latency and improves the fairness of GTS allocation by providing a starvation avoidance mechanism. GSA in [15] is an optimal GTS scheduling algorithm for applications with strict delay requirements. This algorithm reduces the average delay and also allows more transactions to meet the delay constraints of time-sensitive applications. In [16], the authors use the idea of sharing one GTS among several nodes to reduce the wastage of medium resources.

Although the GTS allocation algorithm can improve GTS utilization, the GTS resources may still not be fully engaged. Because of this, the work in [17,18] have proposed a scheme to split the standard GTS. In [17], the authors split the CFP into 16 equally sized slots. In [18], the authors proposed scheme by reducing the GTS size to half. Our GTS Size Adaptation algorithm expands upon the work in [17,18] and the GTS size is defined by the data size of the transmitting nodes that results in efficient GTS allocation.

While [17,18] just split the standard GTS, this will sometimes lead to low GTS utilization efficiency as compared with the standard protocol. As compared with [17,18], our proposed method GSAA will allocate GTS resources according to the end devices packet size and will solve this drawback. Moreover, GSAA accommodates more end devices in CFP for time sensitive data transmission as compared with all above discussed algorithms.

2. An overview of IEEE 802.15.4 standard

The IEEE 802.15.4 standard defines the MAC sub-layer and the physical layer for Low-Rate Wireless Personal Area Networks (LR-WPANs). This standard allows two channel-access methods: beacon-enabled and non beacon-enabled mode. In non beacon-enabled mode, medium access is only based on CSMA/CA. However, in beacon-enabled mode, the coordinator transfers the beacon frames periodically to all the other end devices in the network within its transmission range so that the end devices are synchronized by these beacon frames [10].

The time interval between two Beacon frames is called the beacon interval (BI), and is divided into an active period and an optional inactive period. During the inactive period, nodes can be kept in sleep mode to conserve their energy. The length of the active period is superframe duration (SD) and contains 16 equal length time slots. The active period comprises Contention Access Period (CAP) and Contention Free Period (CFP). The CFP, which is managed by the coordinator, is used for low latency applications and contains at most seven guaranteed time slots(GTSs). During the CAP, nodes access the medium resources with a slotted CSMA/CA method [10].

In order to specify the BI and SD, beacon order (BO) and superframe order (SO) values are defined in the superframe specification by the coordinator. These two parameters follow the following constraint:

$$0 \le SO \le BO \le 15 \tag{1}$$

The relation between BI and BO is defined as follow:

$$BI = aBaseSuperframeDuration \times 2^{BO} \tag{2}$$

And the relation between SD and SO is defined as follow:

$$SD = aBaseSuperframeDuration \times 2^{SO} \tag{3}$$

According to the above, the general superframe structure in beacon-enabled mode is shown in Fig. 1.

3. Proposed GSAA technique

In this paper, we assume a star network with PAN coordinator acting as FFD and all other end devices are RFD. We further assume that PAN coordinator is the sink node and all the end devices send data to it. In proposed GSAA technique,

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