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Dynamic GTS Allocation Scheme in IEEE 802.15.4 by Multi-Factor

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Abstract—**IEEE 802.15.4 is a standard of Low-Rate Wireless Personal Area Network (LR-WPAN), which provides the communications in short distance, low data rate, low power consumption. In IEEE 802.15.4 a guaranteed time slot (GTS) structure is defined to support high quality of service (QoS) to time-critical traffic. However, the transmission bandwidth of GTS may be wasted because of the inefficient allocation. Moreover, the coordinator in the PAN allocates the GTSs by first-come-first-serve (FCFS) scheme, which decreases the system performance, such as delay time and throughput. In this paper, we proposed a Multi-Factor Dynamic GTS Allocation Scheme (MFDGAS) to improve the utilization of GTS bandwidth. The MFDGAS scheme determines allocation of GTS by taking the data size, delay time and the utilization of GTS time slot into consideration. The numerical results show that the proposed MFDGAS improves the performance of system throughput.**

Keywords-IEEE 802.15.4; GTS; LR-WPAN

I. INTRODUCTION

In recent years, the development of wireless network has been rapidly growth. IEEE 802.11 is the one of the wireless network standards, which is designed for Wireless Local Area Network (WLAN) and applied to the transmission services in high data rate and long distance. On the contrary, IEEE 802.15.4 standard is designed for low Rate Wireless Personal Area Network (LR-WPAN), which is suitable for the transmission services in low data rate, short distance and low power consumption. The IEEE 802.15.4 specifies the protocols of medium access control (MAC) layer and physical (PHY) layer [1]. In the PHY layer, the IEEE 802.15.4 supports various data rates for transmission. In the MAC layer, IEEE 802.15.4 supports two operation modes, including beacon-enable and nonbeacon-enable. In beacon-enable mode, all wireless devices transmit data in the structure of the superframe. There are two portions of a superframe, including active portion and inactive portion. The active portion is consisted of contention access period (CAP) and contention free period (CFP). During CAP, all devices contend the channel access to transmit data with Carrier Sense Multiple Access / Collision Avoidance (CSMA/CA) method. In CFP, the coordinator in the PAN allocates the Guaranteed Time Slot (GTS) for the device. The device can transmit data without contending the channel access with other devices during the CFP.

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In the LR-WPAN, the allocation of GTS bandwidth affects the performance of wireless devices. First, the active portion of a superframe is equally split into 16 time slots. A GTS is consisted of at least one time slot and allocated to the wireless device. The transmission bandwidth may be wasted when the allocated GTS time slots is larger than the required bandwidth of the device. Second, the coordinator in the PAN allocates the GTSs to the devices base on the First Come First Serve (FCFS) method. The order of GTS allocation is disaccording to the QoS requirement by the wireless devices. The inefficient allocation decreases the performance of bandwidth utilization and system throughput. This paper proposes a Multi-Factor Dynamic GTS Allocation Scheme (MFDGAS) to improve the utilization of GTS bandwidth. In the MFDGAS, the PAN coordinator determines the allocation of GTSs by taking the data size, delay time and the utilization of GTS time slot into consideration.

The rest of this paper is organized as follows： Section 2 describes the background of IEEE 802.15.4 standard. Section 3 introduces the proposed MFDGAS scheme. Section 4 demonstrates the performance of the proposed MFDGAS and the related schemes. Finally, Section 5 presents some brief concluding remarks and indicates the intended direction of future research.

II. BACKGROUD

A. IEEE 802.15.4

The IEEE 802.15.4 standard specifies the PHY and MAC layer for LR-WPAN. There are two communication modes supported in IEEE 802.15.4, including beacon-enable and nonbeacon-enable. In beacon-enable mode, the PAN coordinator periodically broadcasts the beacon to all the devices in the network. In the communication, the beacon provides the information of synchronization function and superframe format. On the contrary, the superframe structure is unadoptable in the nonbeacon-enable mode.

As shown in Fig.1, there are two portion in the superframe, including active portion and inactive portion. The active portion of a superframe is equally split into 16 time slots and all time slots are arranged among the contention access period (CAP) and contention free period (CFP). During the inactive portion, the wireless devices are unable to transmit data and in an energy saving mode.

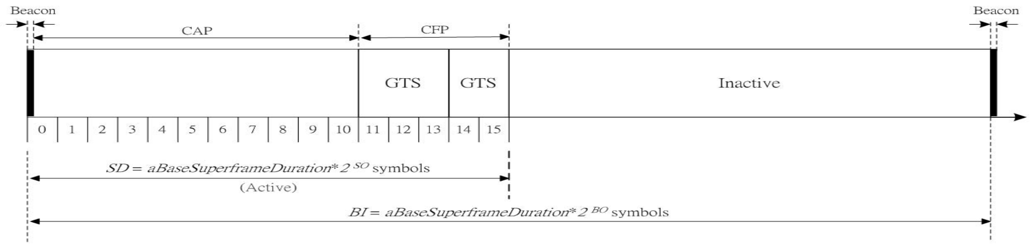

Figure 1. **Sperframe structure in IEEE 802.15.4.**

Octets: 2	1	4/10	0/5/6/10/14	2	variable	variable	variable	2
Frame Control	Sequence Number	Addressing fields	Auxiliary Security Header	Superframe Specification	GTS fields (Figure 45)	Pending address fields (Figure 46)	Beacon Payload	FCS
MHR				MAC Payload				MFR

Bits: 0–3	4-7	8-11	12	13	14	15
Beacon Order	Superframe Order	Final CAP Slot	Battery Life Extension (BLE)	Reserved	PAN Coordinator	Association Permit

Octets: 1	0/1	variable
GTS Specification	GTS Directions	GTS List

Figure 2. **The specification of the sperframe.**

In the CAP period, all devices contend the channel access for data transmission by the slotted CSMA/CA method. In CFP, the PAN coordinator allocates the GTS for the devices, so the devices can transmit data without contending the channel access. A GTS is consisted of at least one time slot and allocated to the specific wireless device. In a superframe, the upper bound of the number of the allocated GTSs is 7. As shown in Fig. 2, the PAN coordinator specifies the structure of the superframe, such as the length of superframe, active portion and CAP, through the specification fields in the beacon frame. The Beacon interval (BI) and Superframe Duration (SD) are defined as follow:

$$\begin{aligned} BI &= aBaseSuperFrameDuration \times 2^{BO} \text{ (symbols)} \\ SD &= aBaseSuperFrameDuration \times 2^{SO} \text{ (symbols)} \end{aligned} \quad for \quad 0 \le SO \le BO \le 14$$

where values of the Beacon Order (BO) and the Superframe Order (SO) are both from 0 to 14. Accordingly, the minimum length of a superframe is 960 symbols, which is specified in the field of the beacon frame (aBaseSuperFrameDuration).

B. GTS Allocation

In IEEE 802.15.4 network, the PAN coordinator specifies all parameter values of the superframe in the fields of the beacon frame and broadcast to all devices in the PAN. The device in the network sends a GTS allocation request to PAN coordinator when the device wants to transmit data in the CFP period. When receiving the GTS allocation request, the PAN coordinator will checks if the available GTS resources are sufficient for the GTS request from the device. If the available GTS resources are sufficient, the PAN coordinator will allocate GTS time slots to the device based on the first come first serve (FCFS) method. The whole CFP period could be divided into at most 7 GTSs in a superframe. Then, the PAN coordinator will broadcast the information of GTS allocation, such as GTS start time, GTS length and numbers of available GTS, to the devices in the network by setting the GTS fields in the beacon frame. The Fig.2 shows the specification of the sperframe.

The procedure of the GTS deallocation is also specified in the IEEE 802.15.4 standard. There are two conditions for the GTS deallocation. First, when the device sends the request of GTS deallocation to the PAN coordinator, the GTS sources will be released by the PAN coordinator. Second, when the timer of the allocated GTS is expired and no data sent by the device. The PAN coordinator will deallocate the GTS resource to increase the utilization of the GTS. The expiration of GTS timer is defined as that the device is allocated GTSs but without transmitting data for the period of 2 × k superframes. The k is defined as follows:

$$k = \begin{cases} 2^{8-BO} & , \quad \text{for } 0 \le \text{BO} \le 8 \\ 1 & , \quad \text{otherwise} \end{cases}$$

III. THE MFDGAS SCHEME

The main objective of the proposed Multi-Factor Dynamic Allocation Scheme (MFDGAS) scheme is to dynamically allocate GTSs to the devices based on the priority of the GTS requests. In order to improve the system performance, the MFDGAS determines the priorities of the GTS requests based on the QoS requirements of the device, including the largest allowed delay times, the transmission data size and the utilization of the GTS slot. After the determination of the priority value, the PAN coordinator allocates GTSs to devices for data transmission.

A. Priority Definition

In the MFDGAS scheme, the priority of the GTS request is determined by three factors, including the data size, the largest allowed delay times and the utilization of GTS time slot. First, the GTS_Slot_Ratio of the ith device in nth superframe is calculated by the size the transmitted data.

$$GTS\_Slot\_Ratio_i[n] = \frac{GTS\_Slot_i[n]}{Avalilable\_GTS\_Slot_i[n]} \quad (1)$$

where $Available\_GTS\_Slot_i[n]$ is the available length of GTS slot for ith device in nth superframe. The $GTS\_Slot_i[n]$ is the GTS length of the i^{th} device in nth superframe and represented as below:

$$GTS\_Slot_i = \frac{Data\_Length_i[n]}{60 \times 2^{SO}} \quad (2)$$

In the Eq. (2), the *Single_Slot* is the length of a base slot which is calculated as below:

$$Single\_Slot = \frac{SD}{16} = 60 \times 2^{SO} \quad (3)$$

According to the Eq. (1), the longer length of the transmission data will lead to the higher priority of the GTS allocation because of the effect on the throughput performance.

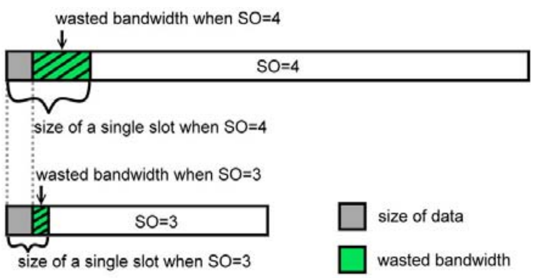

Figure 3. **The bandwidth waste in different size of time slot.**

Second, in order to avoid the starvation problem, the proposed MFDGAS scheme considers the delay time of each devices. The starvation happens if the determination of the priority is only based on the ratio of data size. The ratio of the delay times of the i^{th} device in nth superframe is shown as follow:

$$Delay\_Times\_Ratio_i[n] = \frac{Delay\_Times_i[n]}{Delay\_Times\_Sum[n]} \quad (4)$$

where $Delay\_Times_i[n]$ is the delay times of the i^{th} device in nth superframe and $Delay\_Times\_Sum[n]$ is the sum of delay times of all devices in nth superframe.

The last factor of the GTS allocation is the utilization of GTS time slot. In IEEE 802.15.4 standard, the bandwidth of allocated GTS may be wasted due to the value of SO. As shown in Fig.3, when the value of SO is from 3 to 4, the length of a base slot is double. Base on the Eq. (3), the longer length of the GTS time slot, the more serious of the bandwidth waste.

In the MFDGAS scheme, The order of data transmission for each node is also taking the bandwidth utilization into consideration. The ratio of utilization is calculated as follow:

$$Utilization_i[n] = \frac{Data\_Length_i[n]}{GTS\_Slot_i[n] \times 60 \times 2^{SO}} \quad (5)$$

In the MFDGAS scheme, the priority of the GTS allocation is adopt to replace the FCFS method to decrease the bandwidth waste. After the calculation of the ratios of the data size, the delay times and the utilization of GTS time slot, the PAN coordinator determines the priority of each device in network. The priority of the i^{th} device in n^{th} superframe is:

$$P_i[n] = \alpha(GTS\_Slot\_Ratio_i[n]) + (1-\alpha)Idle\_Times\_Ratio_i[n],\ 0 \le \alpha \le 1 \quad (6)$$

B. GTS Scheduling

After the determination of the priority for each device, the PAN coordinator schedules the GTSs according to the available source of the superframe. In the beginning of the CAP period, the PAN coordinator calculates the priority value of each device by the Eq. (6). The GTS requests of the devices are received by the PAN coordinator in the last superframe. Then, the PAN coordinator sorts the priorities of data transmission for the devices and broadcasts the information in the network. The procedure of the priority sorting is specified in Fig. 4.

```
1： K：Total devices in the WPAN
    P：The set of priority
    Pn_h：The largest priority value
    R：Remain GTS capacity
    M：Total number of time slot be allocated
2：P = { Pn_1 ，Pn_2 ，Pn_3 ，… ，Pn_k }
3：Sort P from large to small and the largest P is Pn_h
4： if Pn_h =Pn_h+1 then
5：  compare slot utilization; the device with the higher slot
     utilization has the higher priority
6：else
7：end if
8：if device i's data_size < R && M < = 7 then
9：GTS is allocated to Pni Remove Pni from P
10：else if device i's data_size > R || M > 7
11：Remove Pn_i from P
12：else
13：break;
14：end if
```

Figure 4. **The MFDGTS algorithm.**

IV. Performance Evaluation

The performance of the proposed MFDGAS method is evaluating by the simulations. In the simulations, there are N devices communicate with the PAN coordinator in the star topology. The data transmission rate is 250 kbps. The values of BO and SO are both 3. The simulation time is 1000 seconds. The model of packet arrivals from devices to the PAN coordinator is Poisson stream with the arrival rate (λ=0.3). The exponential moving average weight (α) of the Eq. (6) is set to 0.8. The simulation parameters used in the simulation are shown in Table I.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Networks topology	Star topology
Simulation duration	1,000 sec
Frame size	15bytes
BO=SO	3
Transmission rate	250kbps
λ	0.3
Buffer size of each device	150bytes
α	0.8

Fig. 5 and 6 represent the performance of the conventional IEEE 802.15.4 and the proposed MFDGAS under different data packet size. Fig. 5 shows the throughput of the both schemes when N=10. Fig. 6 shows the throughput of both schemes when N=20. As shown in the Fig. 5 and 6, the proposed MFDGAS scheme provides better performance of throughput than conventional IEEE 802.15.4 whether N=10 or N=20. As a result, the proposed MFDGAS scheme improves the system performance by decreasing the bandwidth waste.

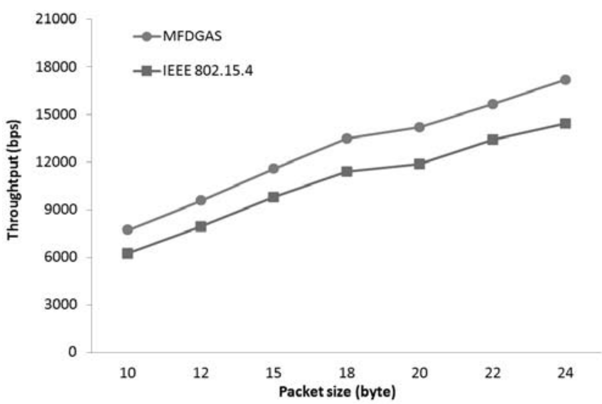

Figure 5. **Variation of throughput with packet size given n = 10.**

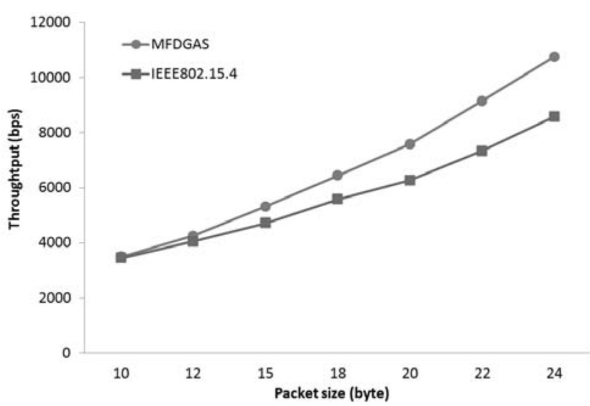

Figure 6. **Variation of throughput with packet size given n = 20.**

V. CONCLUSION

IEEE 802.15.4 standard provides the superframe structure for the communication of the PAN coordinator and wireless devices. In the CFP portion, the GTS slots are allocated to the devices to transmit data without the contending of the channel access. However, there exists the problem of the bandwidth waste for the GTS allocation in IEEE 802.15.4. In order to improve the performance, this paper proposed a Multi-Factor Dynamic GTS Allocation Scheme (MFDGAS). In the MFDGAS, the GTS allocation is based on the priority which is determined by the data size, delay time and the utilization of GTS time slot. Instead of the FCFS adopt by the IEEE 802.15.4, in the MFDGAS the PAN coordinator uses the priority of the GTS allocation to schedule the GTS allocation to decrease the bandwidth waste. From the simulation results, we have verified our proposed scheme has better performance than conventional IEEE 802.15.4 standard in terms of throughput for data transmission.

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