IMPLEMENTATION ADJUSTMENT GUARANTEE

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Implementation Adjustment Guaranteed Time Slot Method Based on Data Size for IEEE 802.15.4

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Abstract. The IEEE 802.15.4 was designed for physical layer and medium access control that was used for low power consumption and low data rate in the networks. The challenges in allocate guaranteed time slot are how to improve size data in contention free period (CFP) and reduce power consumption, respectively. This article proposes a scheme to improve performance IEEE 802.15.4, called guaranteed time slot allocated based on data size (GABAS), which analyze performance of the IEEE 802.15.4 networks. This article presents a comprehensive simulation for GABAS, especially for star topology to improve throughput, average bandwidth utilization as well as total energy consumption in the networks. The simulation results are proven that GABAS can be allocated in the IEEE 802.15.4 networks. GABAS performs better than the standard algorithm in term of throughput, average bandwidth utilization and total energy consumption in the networks.
Keywords: IEEE 802.15.4, guaranteed time slot, energy consumption.

I. INTRODUCTION

The IEEE 802.15.4 was designed for physical layer and medium access control that was used for low power consumption and low data rate in the networks. The IEEE 802.15.4 is one of candidates for wireless sensor networks, which consist of large number of sensors that are densely deployed to some physical phenomena for wide variety applications.

The IEEE 802.15.4 standard has been designed to specify the physical layer (PHY) and medium access control (MAC) sublayer for low power consumption, short transmission range, and low-rate wireless personal area network (LR-WPAN) [1]. The super frame structure in IEEE 802.15.4 standard consist of active portion and inactive portion. The active portion comprised of beacon frame, contention access period (CAP) and contention access period (CFP). While inactive portion used to sleep mode for saving energy. During CAP that mean contention mechanism, all of nodes have to compete each other to access the channel using slotted carrier sense multiple access with collision

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avoidance (CSMA/CA). Whereas in CFP used to guaranteed time slot (GTS) for application that need specific requirement because device occupied as dedicated slot. [1]

In the contention mechanism used to slotted carrier sense multiple access with collision avoidance (CSMA/CA). Device nodes will perform a backoff process as soon as the clear channel assessment (CCA) detects as busy condition. The challenge of CSMA/CA as following: first, when the device nodes detect the channel in busy condition, the device nodes have to increase the value of backoff exponent (BE). However, which cause range of blind backoff process also increase. Second, when the device nodes detect the channel in busy condition, the device nodes have to increase number of backoff stage. However, which cause more energy consumptions for entering next backoff stage. In addition, the blind of backoff process in the slotted carrier sense multiple access with collision avoidance (CSMA/CA) will cause lower channel utilization and more energy consumptions in the networks. [2]

Several authors have been proposed to improve the slotted CSMA/CA using hybrid MAC protocol integrating CSMA and time division multiple access (TDMA) for wireless sensor network [11-13]. The authors of [14] propose an analysis for slotted CSMA/CA for energy consumption, but they only consider about idle condition for the standard and do not propose a new scheme. The authors of [15] propose an enhanced backoff (EB) mechanism shifts the range of backoff period (BP) to reduce redundant backoff and clear channel assessments (CCAs). However, the average delay also possibly increases. In [16] the authors present an additional carrier sensing (ACS) for IEEE 802.15.4 in order to improvement performance star networks. However, the authors do not consider about defer transmission and they do not provide retransmission state in Markov chain model. In [17-18], sensor nodes use different mechanisms to reduce the waiting time before they have successfully transmitted packets, which makes it possible to decrease the backoff time between packet transmissions. They can improve channel utilization. However, fail to alleviate collisions.

The performance analysis of IEEE 802.15.4 MAC is one of the important research topics in wireless sensor network. The challenges in allocate guaranteed time slot are how to improve size data in contention free period (CFP) and reduce power consumption, respectively. [3]

This article proposes aguaranteed time slot allocated based on data size (GABAS) for IEEE 802.15.4 which is the extended work from [19] and [20]. In [19], the authors focus on how to decrease the collisions between beacons or even between beacon and data packets by adjusting the beacon starting times of PAN and coordinator nodes for cluster tree topology. In [20], the authors focus on assigning adjustable length of GTS slot based on the length of packet and also deciding the precise time for the GTS starting time (GTSstart) and the GTS length (GTSlength) for star topology. However, all of the aforementioned models only consider CSMA/CA standard for contention mechanism.

The major contribution of this article is to model the channel access for star network that allocate guaranteed time slot (GTS) based on data size to obtain the average throughput, the bandwidth utilization and energy consumption based on simulation method. That is important contribution in this article.

The rest of the paper is organized as follow. Brief overview of IEEE 802.15.4 is given in section 2. The description of GABAS is explained in section 3. Analysis of GABAS is derived in section 4. Simulation and analysis results is given in section 5. Final section are conclusions of the paper.

II. OVERVIEW OF IEEE 802.15.4

The IEEE 802.15.4 standard can operate in beacon-enabled mode and non-beacon-enabled mode. In beacon-enabled mode, each node employs two system parameters: beacon order (BO) and SO. The parameter BO decides the length of beacon interval (BI), where BI = *aBaseSuperframeDuration* $\times 2^{BO}$ symbols and $0 \leq BO \leq 14$; while the parameter SO decides the length of superframe duration (SD), where SD = *aBaseSuperframeDuration* $\times 2^{SO}$ symbols and $0 \leq SO \leq BO \leq 14$. The value of *aBaseSuperframeDuration* is fixed to 960 symbols. The format of the superframe is defined by the network coordinator as shown in Figure 1. Furthermore, the active portion of each superframe consists of three parts: beacon, CAP, and CFP, which is divided into 16 equal length slots. The length of one slot is equal to *aBaseSlotDuration* $\times 2^{SO}$ symbols, where *aBaseSlotDuration* is equal to 60 symbols.[4]

GABAS is expected to adjust time slot if the device node detects the channel in busy condition. If the device node detects channel in busy condition which cause blind of backoff process. In this case can cause degradation of performance networks not only lower bandwidth utilization but also more energy consumption. The performance of GABAS for star topology is simulated by model modified from [19] for considering packet retransmission, ACK and defer transmission, which is to obtain the bandwidth utilization and as well as energy consumption for IEEE 802.15.4 MAC in the networks. Let us denote SD and T_{delay} be the supeframe duration in second and the time interval of waiting due to CCA busy in second, which can be obtained by Eqs.(1)and (2), respectively, where *aBaseSuperframeDuration* and Rs denote the minimum duration of the superframe and symbol data rate are equal to 960 symbols and 62500 symbol/second, respectively.

$$SD = \frac{aBaseSuperframeDuration \times 2^{SO}}{Rs} \quad (1)$$

$$T_{delay} = \frac{1 \times Unitbackoffperiod}{Rs} \quad (2)$$

Let us also denote L_{beacon} and T_{beacon} be length of beacon in symbol and time interval of beacon in second, respectively; e.g., L_{beacon} is equal to 190 symbols. Let denote CAP_{gabas} be the length of CAP period in second and can be obtained by Eq. (3)

$$CAP_{gabas} = SD - T_{beacon} \quad (3)$$

In this article, each node will communicate with the network coordinator by using the slotted CSMA/CA in CAP. To transmit a packet, a node first delays a backoff period (BP) determined by randomly choosing from 0 to (2^{BE} – 1) UBP, where BE is a backoff exponent and initially set to the value of aMinBE, and then performs the first CCA to detect channel condition. If the channel is founded in busy at the first CCA detection, it will reduce minus one the value of contention window (CW), then continue delay for one slot T_{delay} and then perform the second CCA to detect the channel again. If the result of second CCA channel is detected by busy condition, the node will reduce again with minus one for value of contention window (CW), then continue delay for two slot T_{delay} and then perform again for third CCA. If the result of third CCA channel is detected by idle condition, the node will starts to transmit its data packet and waits for the acknowledged packet from the coordinator after finishing the data packet transmission. However, if the result of third CCA channel is detected by busy condition, the device node will reassign a backoff period (BP) between 0 and ($2^{(BE+1)}$ – 1) UBP for delay and attempt CCA again, where BE can be increased to the maximum value of macMaxBE. The transmission will fail if the number of backoff attempts (NB) exceeds the value macMaxCSMABackoffs.

We consider star topology network having one network coordinator and twenty device nodes with the same value of six for SO and BO.

IV. ANALYSIS OF GABAS

In this section, the proposed GABAS based on the IEEE 802.15.4 use slotted carrier sense multiple access with collision avoidance (CSMA/CA) for part of CAP only, because we only consider about active period, while part of CFP is neglected. This article also taking into account the case of acknowledged uplink data transmission is investigated comprehensively via Markov chain model. Let $b_{i,j,k}$ be the stationary probability at the stochastic state (s(t) = i, c(t) = j, and r(t) = k), where s(t), c(t), and r(t) represent backoff stage, backoff counter, and number of retransmissions, respectively, shown as Eq. (4), where $b_{i,-1,k}$, $b_{i,-2,k}$, $b_{i,-3,k}$ and $b_{i,-4,k}$ are the stationary probabilities for the first CCA (CCA_1), the second CCA (CCA_2), the third CCA (CCA3) and packet transmission, respectively, at the i^{th}backoff stage and the k^{th} retransmission. Let $b_{Si,k}$ and $b_{Ci,k}$ be the stationary probabilities of the successful transmission and collision at the states of $S_{i,k}$ and $C_{i,k}$ as shown in Eqs. (5) and (6), respectively, where m and R are the maximum NB stage and retransmissions, i.e., they are equal to 4 and 3, respectively. Let $b_{DFi,k}$, $b_{DSAi,k}$ and $b_{DSBi,k}$be the stationary probabilities of delay one slot at first CCA busy, delay one slot for second CCA busy for first and delay one slot for second CCA busy for second at the states of $DF_{i,k}$, $DSA_{i,k}$, and $DSB_{i,k}$for the i^{th}backoff stage and the k^{th} retransmission as shown in Eqs. (7) to (9), respectively. Finally, the total energy consumption of the network can be obtained.

$$b_{i,j,k} = \lim_{t\to\infty} P\{s(t) = i, c(t) = j, r(t) = k\}, \text{for } i \in (0,m), j \in (-4, w_i - 1), k \in (0,R) \quad (4)$$

$$b_{S_{i,k}} = \lim_{t\to\infty} P\{S_{s(t)} = S_i, r(t) = k\} \; i \in (0, m), k \in (0, R) \quad (5)$$

$$b_{C_{i,k}} = \lim_{t\to\infty} P\{C_{s(t)} = C_i, r(t) = k\}, i \in (0, m), k \in (0, R) \quad (6)$$

$$b_{DF_{i,k}} = \lim_{t\to\infty} P\{DF_{s(t)} = DF_i, r(t) = k\}, i \in (0, m), k \in (0, R) \quad (7)$$

$$b_{DSA_{i,k}} = \lim_{t\to\infty} P\{DSA_{s(t)} = DSA_i, r(t) = k\}, i \in (0, m), k \in (0, R) \quad (8)$$

$$b_{DSB_{i,k}} = \lim_{t\to\infty} P\{DSB_{s(t)} = DSB_i, r(t) = k\}, i \in (0, m), k \in (0, R) \quad (9)$$

V. SIMULATION AND ANALYSIS RESULTS

In this section, simulation experiments for GABAS are performed by using the extended Castalia simulator to validate the analysis and performance evaluation. In simulation model, we consider a star network topology with one PAN coordinator and 20 device nodes, where D_{node} is equal to 10 meters. To simulate the performance of power consumption, we consider the radio parameters of Chipcon's CC2420 2.4 GHz for the IEEE 802.15.4 RF transceiver [22], where the transmitting power PWR_{tx}, the receiving power PWR_{rx}, and the idle power PWR_{idle}, are 31.32 mW, 35.28 mW, and 712 μW, respectively [21]. Table I summarizes the simulation parameters. We compute the throughput, average bandwidth utilization (BU) and the total network energy consumption and also compare between the proposed algorithm (GABAS) and IEEE 802.15.4 standard (Std).

Table I the simulation parameters

Parameter	Value
Physical data rate	250 kbps
Packet length (L_{data})	720 bits
UBP	80 bits
NumSuperframeSlots	16

MacPacketOverhead	112 bits
ACK length (L_{ack})	88 bits
D_{node}	10 m
PWR_{tx}	31.32mW
PWR_{rx}	35.28mW
PWR_{idle}	712µW
BO=SO	6
BE_{min}	3
BE_{max}	5

Figure 2 shows the network throughput against traffic load. The network throughput obtained by simulation is very close to that obtained by the analytical model. It is obvious the network throughput of GABAS is higher than those of the other algorithms. In the light traffic load (i.e., traffic load is equal to 0.1 and 0.2), the network throughput of GABAS is almost the same as those of IEEE standard; however, GABAS outperforms to the standard algorithm as the traffic load increases. The average goodput of GABAS increases by 18 %, compared to IEEE 802.15.4 standard.

. Figure 3 shows the average bandwidth utilization (BU) against traffic load. The average bandwidth utilization of GABAS has better efficiency than that of IEEE 802.15.4 standard. GABAS can improve the bandwidth utilization because reduce probability going to next backoff stage, which cause blind of backoff process and also allocated time slot accurately. The average bandwidth utilizationt of GABAS increases by 45%, compared to IEEE 802.15.4 standard

Figure 4 shows the network energy consumption against traffic load. GABAS consumes lesser network energy than that of the IEEE 802.15.4 standard, because the GABAS algorithm can adjust the delay when CCA in busy condition which not only reduce probability collision but also probability entering next backoff stage. Moreover, GABAS has greater probability of successful transmission than that of the IEEE 802.15.4 standard, especially in heavy traffic load, which means that GABAS minimizes the energy consumption when retransmitting data packet. The average energy consumption of GABAS decreases by 28.67%, compared to IEEE 802.15.4 standardTheenergy consumption is obtained by summing the energy consumption of PAN coordinator and all of device nodes in the network.

VI. CONCLUSIONS

In this article, GABAS is proposed to improve performance IEEE 802.15.4 networks in order to reduce collision and blind of backoff process which need more energy consumption for random backoff. The proposed GABAS algorithm can adjust size of time slot accurately based on data size that allocated by coordinator so that can avoid waste bandwidth utilization of superframe structure.

This article presented a comprehensive simulation analysis of IEEE 802.15.4, specifically for star network, to predict the average throughput networks, bandwidth utilization as well as the network energy consumption. The validity of the analytical model is shown by closely matching its predictions of the simulation results. The results of simulation experiment show that GABAS is better than that of IEEE 802.15.4 standard in term of the throughput networks, average bandwidth utilization and energy consumption. As a future work, the proposed scheme will be compared by other algorithms

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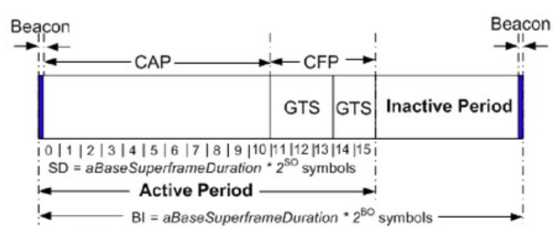

Fig. 1 an example superframe structure

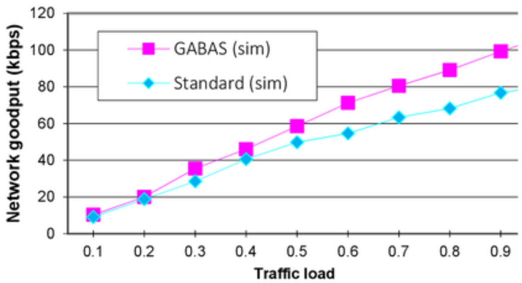

Fig. 2 The throughput networks against traffic load

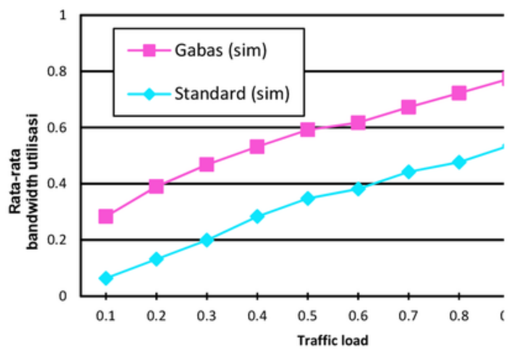

Fig. 3 The average bandwidth against traffic load

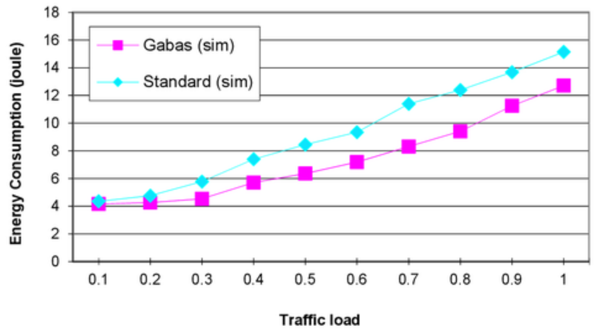

Fig. 4 The energy consumption against traffic load

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