Study of Allocation Guaranteed Time Slot Wireless Body Area Networks Based on IEEE 802.15.4

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Abstract. This paper aims to determine the size of the Guaranteed Time Slot (GTS) on the super frame structure required for each sensor as well as to know the performance of the GTS resized system compared to the GTS standard on IEEE 802.15.4. This article proposes a scheme to improve IEEE 802.15.4 medium access control, called allocation Guaranteed Time Slot (ALGATIS). ALGATIS is expected to effectively allocate guaranteed time slot to the requested sensors, it adjusts the length of the slot in super frame duration based on the length of the packet data. This article presents a simulation experiment of IEEE 802.15.4, especially for star network, to predict the throughput of networks and average energy consumption. The simulation experiments show that the performance of ALGATIS is better than that of IEEE 802.15.4 standard in term of the throughput of networks and average energy consumption

1. Introduction
According to the IEEE 802.15.4 standard [1], IEEE 802.15.4 can operate on beacon and non-beacon enabled modes. The network coordinator transmits beacon to synchronize and provide necessary information to the devices in beacon enable-mode, while the unslotted carrier sense multiple access with collision avoidance (CSMA/CA) protocol is used in non-beacon-enable mode. The IEEE 802.15.4 MAC supports both contention-based mechanism in contention access period (CAP) and guaranteed time slot (GTS) in contention free period (CFP) under beacon enable-mode. The limited number of allowable retransmissions and the number of back offs as specified in the standard can reduce energy consumption caused by carrier sensing. However, the performance of CAP and CFP are related each other because the number of request GTS packets successfully received by network coordinator may decrease if the contention level in CAP increases, which will decrease the throughput of CFP and vice versa.

The challenges of the IEEE 802.15.4 beacon-enable mode are how to improve throughput and reduce energy consumption in the networks. The author of [2] present an evaluation of the slotted CSMA/CA of IEEE 802.15.4 based on all of its frequency, which only analyze each frequency and compare with each other but not to propose a method. In [3], the authors analyze the performance of IEEE 802.15.4 MAC by using node state and channel state models that are simple but accurate. The authors also present an analytical model for the slotted CSMA/CA algorithm adopted in the CAP of the beacon-enabled mode in IEEE 802.15.4 MAC, which only considers for the saturated mode but not for acknowledgement (ACK).
The authors of [4] proposed Fibonacci Backoff (FIB) function to compute the backoff interval. In FIB, each node will wait for an increment backoff periods as they need to access channel. This scheme is expected to minimize possibility two or more nodes choose the same backoff period in the networks.

Several mathematical analysis models have been proposed to analyze the performance of IEEE 802.15.4 based on the Markov chain model without considering packet retransmissions [5-9]. However, all of the abovementioned models only consider for the contention-based transmission.

The authors of [10] provide an analysis for channel access during CAP and CFP. However, the purpose of the CFP transmission is to retransmit the packet that is not successful transmitted in CAP to cope with hidden node collisions. A delay bound analysis for an implicit GTS allocation is proposed to analyze the impact on the bandwidth utilization and delay by using numerical network calculus analysis [11]. The authors of [12] proposed a modified superframe structure for supporting immediate emergency data transmission. If any emergency is reported, then a fraction of inactive period is used opportunistically for three new periods for handling emergency events. The authors of [13] analyze the priorities of devices to determine for GTS allocation, while the authors of [14] further propose an adaptive GTS allocation scheme (AGA) using two phases to assign the priorities of devices and schedule GTS.

This article proposed a allocation Guaranteed Time Slot (ALGATIS) for IEEE 802.15.4 to assign adjustable length of GTS slot based on data sensor. ALGATIS is expected to effectively allocate GTS to sensors in order to improve the networks throughput and reduce energy consumption. The performance of ALGATIS for star network is also analyzed by considering packet retransmission, ACK, and defers transmission by modifying the Markov chain model from [14]. The major contribution of this article is to model the channel access for star network that used 7 data sensors for GTS and analyze the overall performance of IEEE 802.15.4 MAC to obtain the networks throughput and energy consumption.

2. The Description of ALGATIS

ALGATIS scheme have been created by a star network consists of one network coordinator and several sensors, while the network coordinator periodically sends beacon frames to the sensors. The network coordinator allocates the dedicated slots for its sensors, if it receives the requests for GTS packets in the CAP period, otherwise the device nodes shall transmit their packets with contention in CAP. This article proposes an allocation Guaranteed Time Slot (ALGATIS), to analyze both CAP and CFP for IEEE 802.15.4 MAC. ALGATIS aims to accurately decide the values of GTS slot based on the length of packet size on the sensors. ALGATIS mainly improves the network goodput and energy consumption by managing the GTS allocation for the requested sensors. ALGATIS can be expanded by considering the length of data packet, the SO value, and packet arrival rate. According to the IEEE 802.15.4 standard, let us denote Tsd to be the time of SD as shown in Eq. (1), where aBaseSuperframeDuration and Rs are the minimum duration of a superframe and data symbol rate with the values of 960 symbols and 62500 symbol/second, respectively. Let us also denote Tslot as the time of one slot duration, which can be obtained by Eq. (2).

\[
T_{sd} = \frac{aBaseSuperframeDuration \times 2^{SO}}{Rs} \quad (1)
\]

\[
T_{slot} = \frac{T_{sd}}{16} \quad (2)
\]

Each sensor with an allocated GTS ensures that the data transmission time, waiting time for ACK, time to transmit ACK packet and interframe spacing (IFS) duration can be completed before the end of its GTS period. Let us denote T_f be the time to transmit one data packet and receive ACK packet, which can be
obtained by Eq. (3), where $T_{\text{data}}$, $T_{\text{Lack}}$, $T_{\text{ack}}$ and $T_{\text{LIFS}}$ are the time to transmit data packet, time to waiting for ACK packet, time to transmit ACK packet and time duration of IFS, respectively. The length of $L_{\text{ack}}$ is equal to 88 bits, whereas the length of $L_{\text{IFS}}$ is equal to $\text{macMinLIFSPeriod}$ (160 bits) if the length of packet is greater than $aMaxSIFSFrameSize$ (144 bits), otherwise, it is equal to $\text{macMinSIFSPeriod}$ (48 bits).

$$T_f = T_{\text{data}} + T_{\text{Lack}} + T_{\text{ack}} + T_{\text{LIFS}}$$

(3)

In CAP, the packet transmission delay cannot be guaranteed, because packets are transmitted by using the CSMA/CA algorithm. Conversely, the packet transmission delay can be guaranteed in CFP, because packets are transmitted by using the allocated GTS without contention. In this article, we assume that each sensor generates time-critical and non-time-critical packets with probabilities $P$ and $(1-P)$, respectively. According to IEEE 802.15.4 standard, the maximum value to allocate the GTS slot duration is seven. Let us denote $\text{adjslot}$ be the integer value that will be used as the adjustment for the $T_{\text{slot}}$ of IEEE 802.15.4 standard become new smaller adjustment time of one slot duration. The value $\text{adjslot}$ can be calculated by Eq. (4). Let us denote $T_{\text{algatis}}$ be the new time of one slot duration in ALGATIS, which can be calculated by Eq. (5)

$$\text{adjslot} = \left[ \frac{T_{\text{slot}}}{T_f} \right]$$

(4)

$$T_{\text{algatis}} = \frac{T_{\text{slot}}}{\text{adjslot}}$$

(5)

We consider star topology network having one network coordinator and seven sensors with different value of packet data. By using Eq. (5), we get the value of $\text{adjslot}$ for each sensor. Based on the IEEE 802.15.4 standard, if each sensor request one slot GTS in IEEE 802.15.4, and its request successfully received by network coordinator. Furthermore, if there are more than seven device nodes in the star network, the device nodes which are not allocated GTS can transmits their data packets more in CAP period because the CAP duration of ALGATIS is increased.

3. Flowchart of Research Stages

In this section, the proposed ALGATIS based on the IEEE 802.15.4 MAC use slotted carrier sense multiple access with collision avoidance (CSMA/CA) for part of CAP and GTS transmission for part of CFP. This article also taking into account the case of acknowledged uplink data transmission is investigated comprehensively via simulation experiment as shown in Fig. 1.
Figure 1. Flowchart of research stages

Figure 1 shows the flow diagram of the research stages. Beginning with an earlier research study then conducts research and collects data. After that, application design on Castalia. Then is tested by simulation. Finally, the result can be obtained and make conclusions then finish stage. Simulation result data in term of network throughput and energy consumption can be obtained by Castalia simulator.

4. Simulation and Analysis Results

In this section, simulation experiments for ALGATIS are performed by using the extended Castalia simulator to validate the analysis and performance evaluation. In simulation model, we consider a star topology with one PAN coordinator and 21 device nodes, where D\textsubscript{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 [15], where the transmitting power PWR\textsubscript{tx}, the receiving power PWR\textsubscript{rx}, and the idle power PWR\textsubscript{idle}, are 31.32 mW, 35.28 mW, and 712 µW, respectively [18]. We compute the network throughput and total network energy consumption, where traffic load varies from 0.1 to 1(full loaded). Table 1 summarizes the simulation parameters.

Table 1. The simulation parameters

| Parameter        | Value    |
|------------------|----------|
| Physical data rate | 250 kbps |
| UBP              | 80 bits  |
| NumSuperframeSlots | 16       |
| MacPacketOverhead | 112 bits |
| ACK length (L\textsubscript{ack}) | 88 bits |
| D\textsubscript{node} | 10 m     |
| PWR\textsubscript{tx} | 31.32mW  |
| PWR\textsubscript{rx} | 35.28mW  |
| PWR\textsubscript{idle} | 712µW    |
| BE\textsubscript{min} | 3        |
| BE\textsubscript{max} | 5        |

Figure 2 shows the throughput against the traffic load by simulation in the networks on 3 nodes position. The proposed ALGATIS algorithm can adjust length of data sensor to allocate for GTS, so that ALGATIS algorithm has higher networks throughput than that of IEEE 802.15.4 standard.

Figure 2. Throughput against traffic load

Figure 3. Throughput against traffic load
In networks consist of 7 nodes as shown on figure 3 shows the throughput against the traffic load by simulation in the networks on 7 nodes position. The proposed ALGATIS algorithm still also can adjust length of data sensor to allocate for GTS, so that ALGATIS algorithm has higher networks throughput than that of IEEE 802.15.4 standard.

Figure 4 shows the throughput against the traffic load by simulation in the networks on 13 nodes position. The proposed ALGATIS algorithm still also can adjust length of data sensor to allocate for GTS, so that ALGATIS algorithm has higher networks throughput than that of IEEE 802.15.4 standard.

Figure 5 shows the network throughput against traffic load. It is obvious the network throughput of ALGATIS is higher than that of IEEE 802.15.4 standard. In the light traffic load (i.e., traffic load is equal to 0.2 – 0.3), the network throughput of ALGATIS is almost the same as that of IEEE standard; however, ALGATIS outperforms to the IEEE 802.15.4 standard as the traffic load increases.

Figure 6 shows the network energy consumption against traffic load. ALGATIS consumes lesser network energy than that of the IEEE 802.15.4 standard, which means that ALGATIS minimizes the energy consumption when retransmitting data packet on number of nodes equal 3.
Figure 8. The total of network energy consumption against traffic load.

Figure 9. The total of network energy consumption against traffic load.

Figure 7, figure 8 and figure 9 respectively, show the network energy consumption against traffic load. ALGATIS consumes lesser network energy than that of the IEEE 802.15.4 standard, because the ALGATIS algorithm can adjust size of data each sensor and allocate to GTS based on its size. Moreover, ALGATIS has greater probability of successful transmission than that of the IEEE 802.15.4 standard, especially in heavy traffic load, which means that ALGATIS minimizes the energy consumption when retransmitting data packet. The energy consumption is obtained by summing the energy consumption of PAN coordinator and all of device nodes in the network.

5. Conclusions
In this article, ALGATIS performs with the adjustable length of the slot in the superframe duration based on the length of sensors, so that it can accurately decide for the starting time, and the GTS length to be allocated for the requested devices to improve networks. ALGATIS is expected to effectively allocate GTS to the requested devices, because the length of CAP on ALGATIS is longer than that of IEEE 802.15.4 standard. This article also presented a comprehensive analysis of IEEE 802.15.4, specifically for star network, to predict the network throughput 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 ALGATIS is better than that of IEEE 802.15.4 standard in term of the networks throughput and energy consumption. As a future work, the proposed scheme will be compared by other algorithms.

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