ANALYSIS OF ADJUSMENT DELAY SCHEME

by Eppy Yundra

Analysis of Adjustment Delay Scheme Beacon Enabled Mode for Star Networks

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Abstract— **In the contention mechanism used to slotted carrier sense multiple access with collision avoidance (CSMA/CA) on IEEE 802.15.4 standard. Device nodes will perform a backoff process as soon as the clear channel assessment (CCA) detects as busy condition. The challenge of CSMA/CA when the blind backoff process in the slotted CSMA/CA will cause lower channel utilization and more energy consumptions. This article proposes a scheme to improve IEEE 802.15.4 medium access control, called adjustment delay scheme (ADES). This article also presents a comprehensive Markov chain analysis especially beacon-enabled mode to predict the bandwidth utilization and total network energy consumption. The analytical model and simulation experiments show that the performance of ADES is better than that of IEEE 802.15.4 standard in term of the average bandwidth utilization and total energy consumption.**

Keywords: IEEE 802.15.4, Markov chain, energy consumption.

I. INTRODUCTION

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

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.

The problem occur if every device node detect channel assessment (CCA) as busy condition, the device nodes have to increase the value of backoff exponent (BE) and as well as backof stage. This condition not only cause range of backoff process will increase but also more energy consumptions. The performance analysis of IEEE 802.15.4 MAC is still one of the important research topics in wireless sensor network. The authors 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 use node state and channel state models to analyze the performance of IEEE 802.15.4 MAC 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. However, they do not consider about acknowledgement (ACK).

There are some 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[4-6]. A number of the modified

Markov chain models including packet retransmission have been investigated, but those models did not consider the defer transmission[7-8]. In [9-10], the authors propose improved Markov chain models with considering defer transmission. However, all of the abovementioned models only consider for CSMA/CA standard, i.e., not proposed new contention mechanism in CAP

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.

This article proposes an adjustment delay scheme (ADES) 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. ADES focuses on adjustment delay if device node detects the channel in busy condition which can reduce probability of going to entering next backoff stage and blind of backoff process.

The major contribution of this article is to model the channel access for star network that analyze the performance of IEEE 802.15.4 MAC to obtain the average bandwidth utilization and energy consumption based on the proposed Markov chain.

The rest of the paper is organized as follow. Brief overview of IEEE 802.15.4 is given in section 2. The description of ADES is explained in section 3. Analysis of ADES 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 enable mode and non-beacon enable mode. In beacon enabled mode, each node employs two system parameters: beacon order (BO) and superframe order (SO), which define beacon interval (BI) and superframe duration (SD), respectively. Furthermore, the active portion of each superframe consists of three parts: beacon, CAP and CFP. In CAP, a node performs clear channel assessment (CCA) to make sure whether the channel is idle or busy, when the number of random backoff periods is decreased to 0. The value of CW will be decreased by one if the channel is idle; and the second CCA will be performed if the value of CW is not equal to 0. If the value of CW is equal to 0, it means that the channel is idle after twice CCA; then a node is committed the data transmission. On the other hand, in CFP, each node doesn't need compete to transmission of data packet because dedicated slot for transmission. However, a node has to request the usage of GTS by sending GTS request packet to network coordinator in the CAP of the previous superframe. If the network coordinator successfully receives the request packet, and then the network coordinator allocates GTS to the device node, then the device node transmits its packets by using the allocated GTS without contention

III. DESCRIPTION OF ADES

A star network consists of one network coordinator and several device nodes, while the network coordinator periodically sends beacon frames to the device nodes. The network coordinator allocates the dedicated slots for its device nodes, if it receives the requests for GTS packets in the CAP period, otherwise the device nodes shall transmit their packets with contention in CAP.

ADES is expected to adjust delay 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 ADES for star topology is analyzed by the Markov chain 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.

$$SD = \frac{aBaseSuperframeDuration \times 2^{SO}}{Rs}$$

(1)

$$T_{delay} = \frac{1 \times Unitbackoffperiod}{Rs}$$

(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_{ades} be the length of CAP period in second and can be obtained by Eq. (3)

$$CAP_{ades} = \text{SD} - \text{T}_{\text{beacon}} \quad (3)$$

In this article, each node will communicates 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 reduces 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. An example implementation of ADES and IEEE 802.15.4 standard in the network can be shown in figures 1 and 2, respectively.

IV. ANALYSIS OF ADES

In this section, the proposed ADES 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 as shown in Figure 3. 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

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

(4)

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

(5)

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

(6)

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

(7)

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

(8)

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

(9)

V. SIMULATION AND ANALYSIS RESULTS

In this section, simulation experiments for ADES 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 average bandwidth utilization (BU) and the total network energy consumption and also compare the analytical (ana) and simulation (sim) results between the proposed algorithm (ADES) 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 4 shows the average bandwidth utilization (BU) against traffic load. The average bandwidth utilization of ADES has better efficiency than that of IEEE 802.15.4 standard. ADES can improve the bandwidth utilization because reduce probability going to next backoff stage, which cause blind of backoff process. Figure 5 shows the network energy consumption against traffic load. ADES consumes lesser network energy than that of the IEEE 802.15.4 standard, because the ADES algorithm can adjust the delay when CCA in busy condition which not only reduce probability collision but also probability entering next backoff stage. Moreover, ADES has greater probability of successful transmission than that of the IEEE 802.15.4 standard, especially in heavy traffic load, which means that ADES 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.

VI. CONCLUSIONS

In this article, ADES 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 ADES algorithm can adjust delay for CCA when channel find in busy condition.

This article also presented a comprehensive Markov chain analysis of IEEE 802.15.4, specifically for star network, to predict the average 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 analytical model and simulation experiment show that ADES is better than that of IEEE 802.15.4 standard in term of the average bandwidth utilization and energy consumption. As a future work, the proposed scheme will be compared by other algorithms

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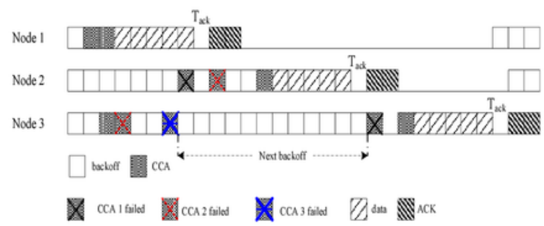

Fig. 1 An example of implementation of ADES

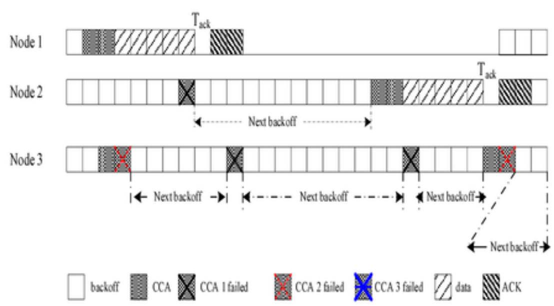

Fig. 2 An example of implementation of IEEE 802.15.4 Std

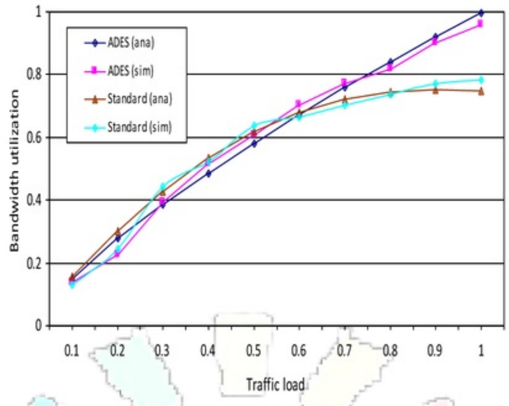

Fig. 4 The average bandwidth utilization against traffic load

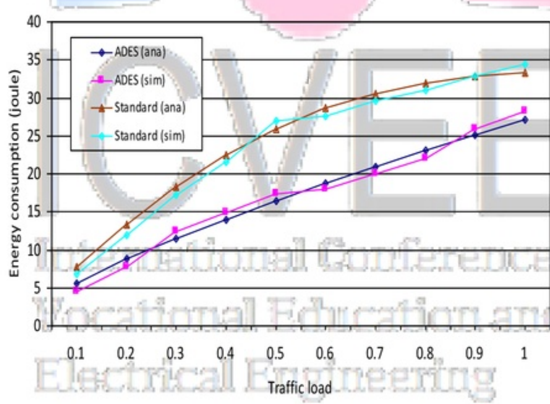

Fig. 5 The total energy consumptions of network against traffic load

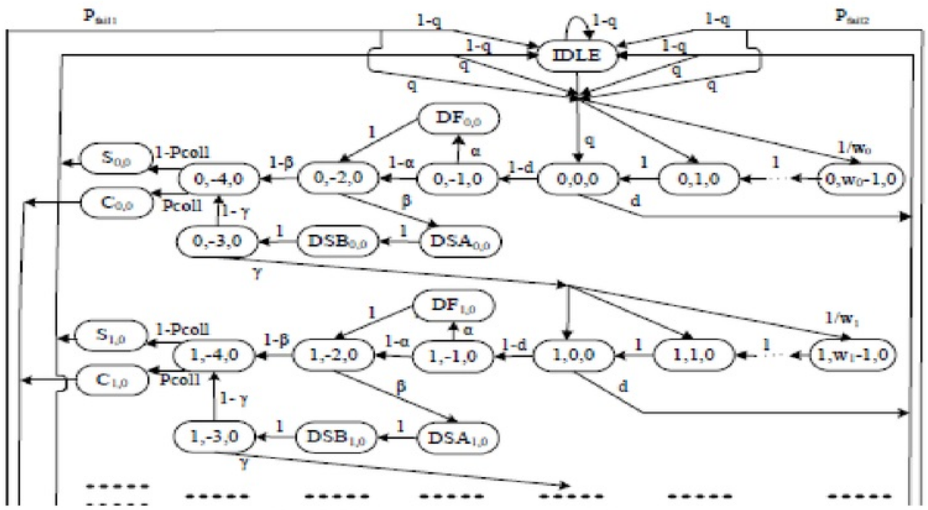

Fig. 3 Markov chain model for ADES

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