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Submission date: 10-Jan-2019 11:53AM (UTC+0700)

Submission ID: 1062740536

File name: 7_Study_of_Adjustment_Delay_Scheme_on_IEEE_802.15.4_Networks.pdf (403.23K)

Word count: 3983

Character count: 19320

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To cite this article: E Yundra 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **288** 012065

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Study of Adjustment Delay Scheme on IEEE 802.15.4 Networks at Beacon Enabled Mode

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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 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) 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 which cause more energy consumptions for entering next backoff stage. This article proposes a scheme to improve IEEE 802.15.4 medium access control, called adjustment delay scheme (ADES). ADES not only reduce probability of collision but also reduce probability of going to next backoff stage. The validity of study is proven by simulation experiments. ADES performs better than IEEE 802.15.4 standard in term of the probability of successful packet transmission, network goodput, bandwidth utilization as well as energy consumption in the networks

1. Introduction

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. 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 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 several mathematical analyses based on Markov chain models have been proposed to analyze the performance of IEEE 802.15.4, but they do not consider packet retransmissions [4-10]. Some of the modified Markov chain models have been investigated by considering packet retransmissions but not considering the defer transmission [11-14]. In [15-18], the authors propose the Markov chain models with considering the postpone transmission. In [19], the analytical model based on Markov chain for multi-hop cluster network has been studied without considering ACK to confirm the successful of data packet 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 [21-23]. In [24], the authors present the analysis correctly for contention access period, but they do not consider about defer transmission if the current superframe is not enough to accommodate transmission. The authors of [25] 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 [26] 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.

This article proposes an adjustment delay scheme (ADES) for IEEE 802.15.4 which is the extended work from [18] and [20]. In [18], 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. In other words, they did not consider the blind of backoff and probability going to next backoff stage. The performance of ADES for star topology is analyzed by the Markov chain model modified from [18] for considering packet retransmission, ACK and defer transmission, which is to obtain the probability of success transmissions, network goodput, bandwidth utilization as well as energy consumption for IEEE 802.15.4 networks. The major contribution of this article is to model the channel access for star network that analyze the overall performance of IEEE 802.15.4 MAC to reduce probability of going to next backoff stage which can increase probability success packet transmission with adjustment delay at first CCA and second CCA if channel find in busy condition also including addition third CCA to reduce collision in order for improve performance networks.

2. The description of ADES

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. 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 R_s denote the minimum duration of the superframe and symbol data rate are equal to 960 symbols and 62500 symbol/second, respectively.

$$SD = \frac{aBaseSupeframeDuration \times 2^{SO}}{R_s} \quad [\text{in second}] \quad (1)$$

$$T_{delay} = \frac{1 \times Unitbackoffperiod}{R_s} \quad [\text{in second}] \quad (2)$$

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

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

An example implementation of ADES in the network can be shown in figures 1. The ADES scheme have the probability going to next backoff stage less than IEEE 802.15.4, so that the proposed scheme can improve the network performance.

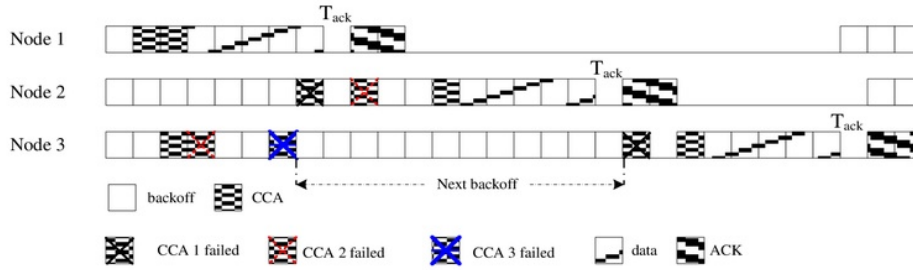


Figure 1. An example of implementation of ADES

3. 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 2. 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 (CCA_3) and packet transmission, respectively, at the i^{th} backoff stage and the k^{th} retransmission. Let $b_{S_{i,k}}$ and $b_{C_{i,k}}$ 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 $b_{DF_{i,k}}$, $b_{DSA_{i,k}}$ and $b_{DSB_{i,k}}$ 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.

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

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

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

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

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

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

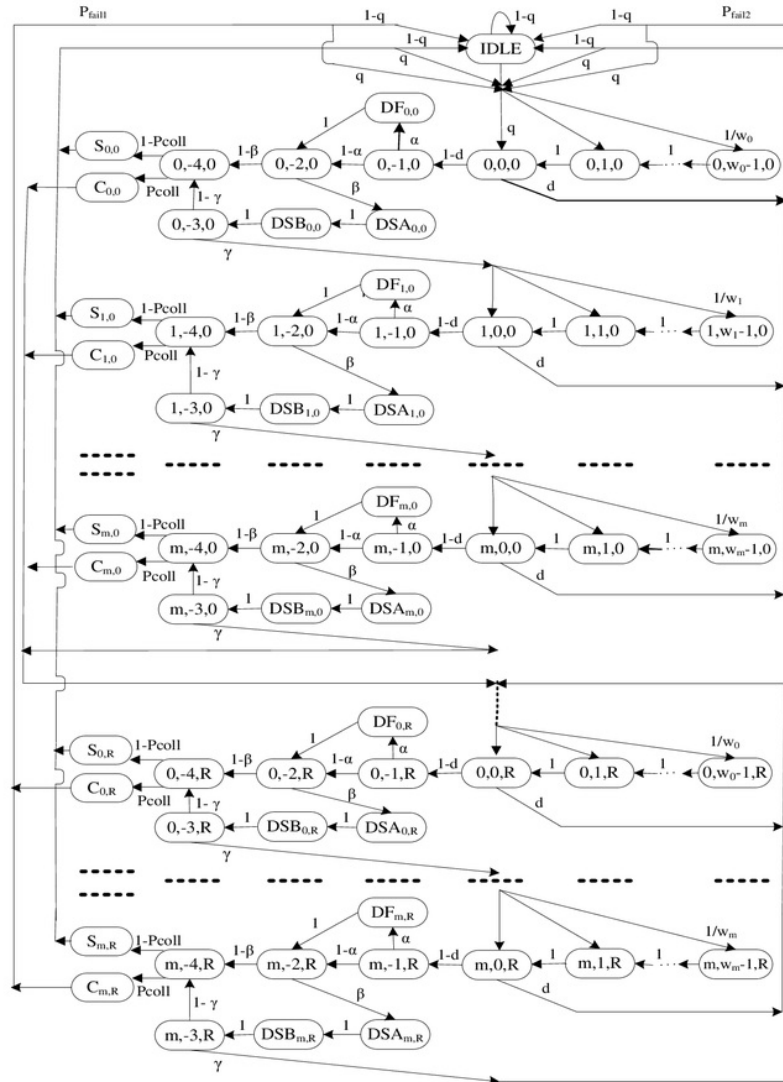


Figure 2. Markov chain model for ADES

4. 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 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 [27], 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 μ W, respectively [28]. The BO and SO settings follow the IEEE 802.15.4 standard and the proposed ADES algorithm, which are fixed to be six. We compute the probability of successful packet transmission, network goodput, bandwidth utilization 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
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}	712 μ W
BO=SO	6
BE_{min}	3
BE_{max}	5

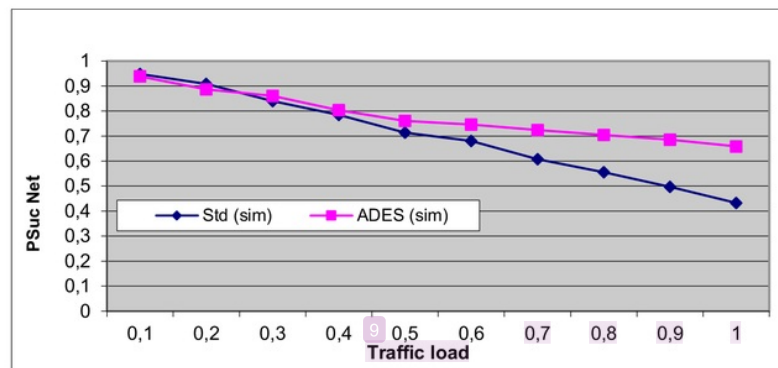


Figure 3. The probability of successful transmission against traffic load

Figure 3 shows the probability of successful transmission arriving at the PAN coordinator against the traffic load by simulation. The proposed ADES algorithm can adjust delay for CCA when in busy condition. Adjustment delay and addition third CCA can effectively avoid collision in the network, so that ADES algorithm has higher probability of successful transmissions than that of IEEE 802.15.4 standard.

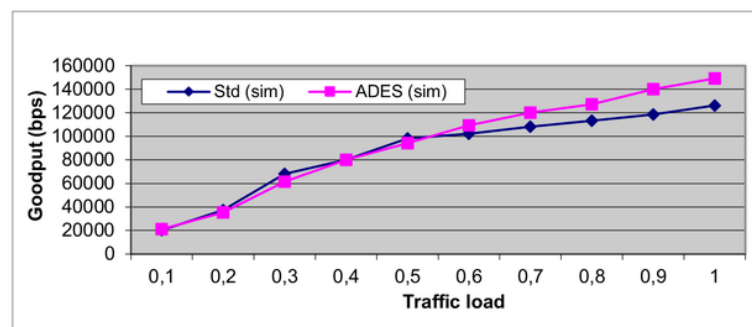


Figure 4. The network goodput against traffic load

Figure 4 shows the network goodput against traffic load. It is obvious the network goodput of ADES is higher than that of IEEE 802.15.4 standard. In the light traffic load (i.e., traffic load is equal to 0.1 to 0.6), the network goodput of ADES is almost the same as that of IEEE standard; however, ADES outperforms to the IEEE 802.15.4 standard as the traffic load increases (i.e., traffic load is equal to 0.6 to 1).

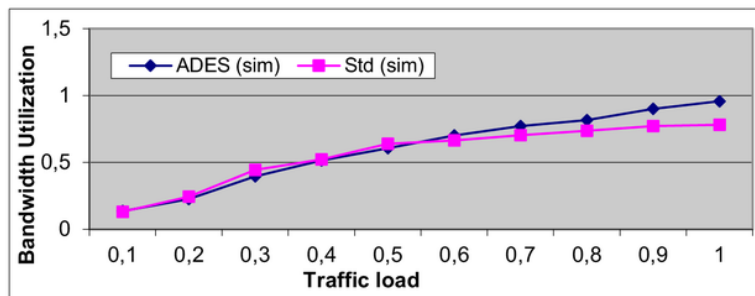


Figure 5. The bandwidth utilization against traffic load

Figure 5 shows the bandwidth utilization (BU) against traffic load. The bandwidth utilization of ADES has better efficiency than 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.

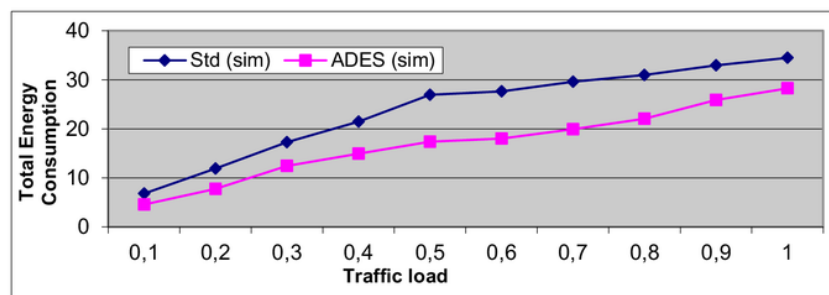


Figure 6. The total of network energy consumption against traffic load

Figure 6 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.

5. Conclusion

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. Adjustment delay and addition third CCA not only reduce probability collision but also reduce probability going to next backoff stage.

This article also included a comprehensive Markov chain analysis of IEEE 802.15.4, especially for star topology, to predict the probability of successful transmission, the network goodput, bandwidth utilization as well as the network energy consumption. The simulation experiment results show that the performance of ADES is better than that of the IEEE 802.15.4 in term of the probability of successful transmission, network goodput, bandwidth utilization as well as energy consumption.

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