

## Adjustment Delay Scheme to Improve Performance IEEE 802.15.4 Networks

Eppy Yundra<sup>\*1</sup>, Bih-Hwang Lee<sup>2</sup>

<sup>1</sup>Universitas Negeri Surabaya, Kampus Ketintang, Surabaya, East Java, Indonesia

<sup>2</sup>National Taiwan University of Science and Technology,  
43, Keelung Rd., Section 4, Taipei 106, Taiwan

\*Corresponding author, e-mail: eppyundra@unesa.ac.id<sup>1</sup>, bhlee@mail.ntust.edu.tw<sup>2</sup>

### Abstract

*The challenges 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 which cause range of blind backoff process also increase. Second, the blind backoff process 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 to predict the probability of successful transmission, network goodput, bandwidth utilization and total network energy consumption. The validity of the model analysis is proven by precisely matching the simulation experiments. ADES performs better than those of other algorithms in term of the probability of successful packet transmission, network goodput, bandwidth utilization as well as energy consumption in the networks.*

**Keywords:** IEEE 802.15.4, Markov chain, blind backoff, energy consumption

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### 1. Introduction

The IEEE 802.15.4 is one of candidates for wireless sensor networks. Wireless sensor networks 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 stipulate the physical sublayer (PHY) and medium access control (MAC) sublayer for low power consumption, short transmission range, and low-rate wireless personal area network (LR-WPAN) [1].

Several problems 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 enter upcoming backoff stage. In addition, the blind of backoff process in the slotted carrier sense multiple access with collision avoidance (CSMA/CA) will lead to reduce channel utilization and more energy consumptions in the networks.

Analysis of IEEE 802.15.4 MAC performance is still include category of the interest research topics in wireless sensor network. A. N. Alvi *at al* [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. K. Ashrafuzzaman *at al* [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 in the contention access period (CAP) of the beacon-enabled mode in IEEE 802.15.4 MAC based on model the slotted CSMA/CA algorithm, which only considers for the saturated mode. However, they do not consider about acknowledgement (ACK).

There are several mathematical models for analysis have been presented to analyze the performance of IEEE 802.15.4 based on Markov chain models, but they do not consider packet retransmissions [4-10]. T.-R Park *at al* [4] have proposed an analyse throughput and energy consumption in saturation conditions based on new markov chain model of 802.15.4 standard. T.-J Lee *at al* [5] have proposed an evaluate throughput limit in order to grasp the

characteristics of IEEE 802.15.4 WPAN for a new model based on the slotted CSMA/CA of IEEE 802.15.4 Medium Access Control. S. Pollin *et al* [6] have proposed an analytical for uplink and acknowledged uplink traffic also evaluation its performance based on star topology network, which are scenarios in both saturated and unsaturated periodic traffic. Y. Zhang *et al* [7] have studied an optimization packet size which take into considering of the CSMA-CA contention, protocol overhead, and channel condition for IEEE 802.15.4 networks. The authors also have proposed new analytical models to calculate the goodput and the energy consumption.

J. He *et al* [8] have studied an analytical model to estimate the slotted CSMA/CA algorithm detailed in the MAC layer of IEEE 802.15.4 standard based on Markov chain. Z. Xiao *et al* [9] have presented an analytical performance to IEEE 802.15.4 Medium Access Control (MAC) based on queuing model to provide a tool especially with sleep mode enabled. C. Buratti *et al* [10] have presented an analytical for the beacon enabled mode of the IEEE 802.15.4 medium-access control (MAC) based on a mathematical model. The multiple nodes are arranged to be a personal area network (PAN), which transmit data pass through directly links or multiple hops to PAN coordinator. Some of the modified Markov chain models have been investigated by considering packet retransmissions but not considering the defer transmission [11-14].

Z. Tao *et al* [11] have proposed precisely seize all the essential features of the IEEE 802.15.4 MAC based on a novel Markov chain, and thus can provide strengths and weaknesses that valuable concept of multiple access scheme. P. Park *et al* [12] have studied of reliability, delay, energy consumption and proposed a generalized analysis of the IEEE 802.15.4 medium access control (MAC). Y-K Huang *et al* [13] have studied duty-cycle operation for comprehensively analyzes IEEE 802.15.4. Specifically, a novel analytical model that accommodates a general traffic distribution is developed. M. Khanafer *et al* [14] have been proposed method to achieve efficient power savings for the sensor nodes with modification the IEEE 802.15.4 standard in order to improve reliability and provided better channel utilization. In [15-19], the authors propose the Markov chain models with considering the postpone transmission.

B. Gao *et al* [15] have presented an analytical of slotted carrier sense multiple access/collision avoidance (CSMA/CA) algorithm with take into considering the newly enabled sleep mode based on extended Markov for IEEE 802.15.4. C.-Y Jung *et al* [16] have been presented analytical with reflect of feature the IEEE 802.15.4 medium-access control (MAC) protocol in term of a superframe duration, acknowledgements, and retransmissions with and without limit based on Markov chain. B. Shrestha *et al* [17] have presented an analytical slotted CSMA/CA for the IEEE 802.15.4 networks considering GTS transmission phenomena together in heterogeneous traffic in term of non-saturation based on general discrete-time Markov chain. B.-H. Lee *et al* [18] have presented an analytical with determine the precise values of beacon order and superframe order for the PAN coordinator, cluster coordinators, and device nodes, and determine the accurate time for the beacon transmission of PAN and coordinator nodes, respectively. M. Martalo *et al* [19] have been proposed 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

H.-K Wu *et al* [20] have also presented an analytical a cluster tree network that is extended with considering acknowledgement, packet retransmission, and defer transmission based on Markov chain model. B.-H. Lee *et al* [21] also proposed a scheme to improve IEEE 802.15.4 medium access control, called superframe duration adjustment scheme (SUDAS), which analyzes the overall of the IEEE 802.15.4 not only CAP but also CFP. SUDAS is expected to effectively allocate guaranteed time slot to the requested devices, it adjusts the length of the slot in superframe duration based on the length of the packet data.

Several authors have been proposed hybrid method MAC protocol combining CSMA with time division multiple access (TDMA) to rectify the slotted CSMA/CA for wireless sensor network [22-24]. K. Sarvakar *et al* [22] have been proposed a streamlined hybrid MAC layer with exploit ZigBee MAC (EZ-MAC), for sensor networks. Sensor in the networks have to manage variety of traffics such as real-time traffics and sensor traffics. H. Deng *et al* [23] have been investigated performance models for CSMA/CA and TDMA systems and compare their performance under both non-saturation and saturation conditions based on the developed performance models. I. Rhee *et al* [24] have proposed a hybrid MAC protocol such as the

design, implementation and achievement evaluation with integrating strengths of TDMA and CSMA while off setting their weaknesses called Z-MAC for wireless sensor networks.

R. K Patro *at al* [25] also presented 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. M.B Rasheed *at al* [26] have proposed 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. B-H Lee *at al* [27] have presented an analytical invorder to improvement performance star networks by using extra carrier sensing for IEEE 802.15.4. However, the authors do not consider about defer transmission and they do not provide retransmission state in Markov chain model. In [29-30], 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.

Ji. Z *at al* [28] have presented an extended for personal area networks in many area industrial applications such as E-Healthcare, environmental monitoring and industrial automation with few complication and major reliability which enable PANs to be greatly applied. Lu ZQ *at al* [29] have studied an manage connectivity and detecting nodes or link failures is difficult in unstructured WSN because there is large number of nodes. The sensor nodes are tiny devices with limited constraints and it is not feasible in deployed scenarios to recharging the batteries. Therefore to decrease energy consumption and prolonging the WSN lifetime is main design objective for sensor based applications and mechanisms. B. Bougard *at al* [30] have studied an apply ultra low power sensor node with exploit potency of an 802.15.4 radio for implementation in a dense network area. C.M Wong *at al* [31] have proposed also using extra adding carrier sensing algorithm based on IEEE 802.15.4 to increase performance in authentic slotted CSMA/CA. However, fail to alleviate collisions.

This article proposes an adjustment delay scheme (ADES) for IEEE 802.15.4 which is the extended work from [18] and [21]. In [18] the authors focus on how to regulate the beacon starting times of personal area network and coordinator nodes in order to decrease the collisions between beacons or even between beacon and data packets for cluster tree topology. In [21], the authors focus how to determine the accurate time for the GTS starting time (GTSstart) and the GTS length (GTSlength) on setting adaptable length of GTS slot based on the length of packet 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 upcoming backoff stage.

ADES focuses on adjustment delay if device node detects the channel in busy condition which can reduce probability of going to entering upcoming backoff stage and blind of backoff process. In addition, this scheme also include addition third CCA for reduce collision. The performance of ADES for star topology is analyzed by the Markov chain model modified from [18] for obtain the probability of success transmissions, network goodput, bandwidth utilization as well as energy consumption which considering packet retransmission, ACK and defer transmission for IEEE 802.15.4 networks. The major contribution of this article is to model the channel access for star network that analyze overall of performance IEEE 802.15.4 to minimize of probability going to upcoming 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 to improve performance networks.

## 2. Research Method

### 2.1. 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 equations (1) and (2), respectively, where  $aBaseSuperframeDuration$  is the minimum duration of the superframe equal to 960 symbols and  $R_s$  is denote symbol data rate equal to 62500 symbol/second.

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

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

According to IEEE 802.15.4 standard for format of the superframe structure is can be shown in Figure 1. Furthermore, the part of active portion of each superframe consist of three arrangements such as beacon, CAP and CFP, which is started 0 to 15 equal length slots. The length of one slot is equal to  $aBaseSlotDuration \times 2^{SO}$  symbols, where  $aBaseSlotDuration$  is equal to 60 symbols.

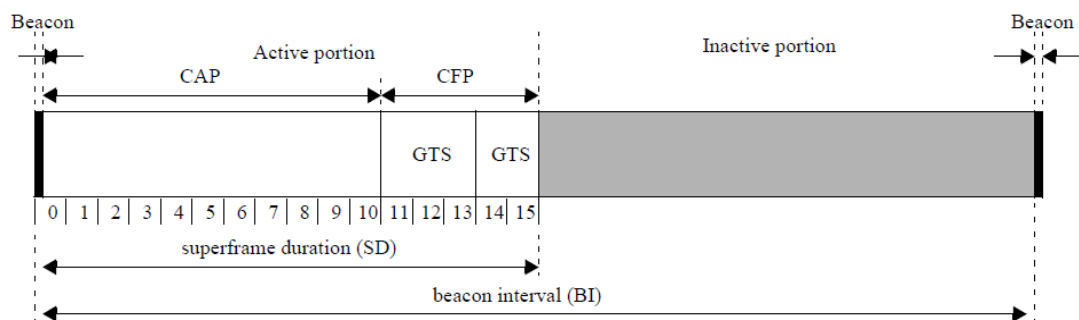


Figure 1. An example of superframe structure

In this CAP, each node will communicate using the slotted CSMA/CA in CAP with the network coordinator. In order to transmit a packet, first each node will delay a backoff period (BP) decided by randomly choosing from 0 to  $(2^{BE} - 1)$  UBP, where BE is a backoff exponent and at the beginning set to the value of  $aMinBE$ , and then it will perform the first CCA to detect channel condition. If the channel condition is detected in busy at the first CCA detection, it will reduce minus one the value of contention window (CW), then it will continue delay for one slot  $T_{delay}$  and then it will perform again the second CCA to detect the channel condition. If the 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 performs again for third CCA. If the third CCA channel is detected by idle condition, the node will try to start transmitting data packet and waits for the acknowledgment packet from the coordinator until finishing transmission.

However, if third CCA channel is detected by busy condition, the device node will do it again a backoff period (BP) between 0 and  $(2^{(BE + 1)} - 1)$  UBP and will try CCA again, where value of BE can be achieved to the maximum of value  $macMaxBE$ . The transmission of system will be failed if the total number aggregation of backoff attempts (NB) outpace the value  $macMaxCSMABackoffs$ . For more detail about the aforementioned description, we can explain ADES with flowchart as shown in Figure 2. We take into consideration a topology use star network which consist of one network coordinator and surrounded several device nodes. By using Equation (2), we can get the value of  $T_{delay}$  for each CCA when channel in busy condition.

Basically, the flowchart of the ADES algorithm can be obtained by somewhat modified the IEEE 802.15.4 standard, which can be shown in Figure 2. While Markov chain model that as shown in Figure 5. The first step set the contention window (CW) to 3 for make sure there are three CCAs and there are two conditional judgment for verify of CCA1 and CCA2 detection. If CW is equal to three after detecting a busy condition, certainly CCA1 failed. If the value of CW is equal to two after detecting busy channel, certainly CCA2 also failed. The system will continue to carry out CCA3 after postpone two of slot durations of  $T_{delay}$ . If verify of CCA3 the

channel in busy again, so the device node has to go to the upcoming backoff stage. An example comparison of ADES with IEEE 802.15.4 standard can be shown in Figures 3 and 4, respectively. The ADES scheme have the probability going to upcoming backoff stage less than IEEE 802.15.4 standard, so that the ADES scheme can improve the network performance.

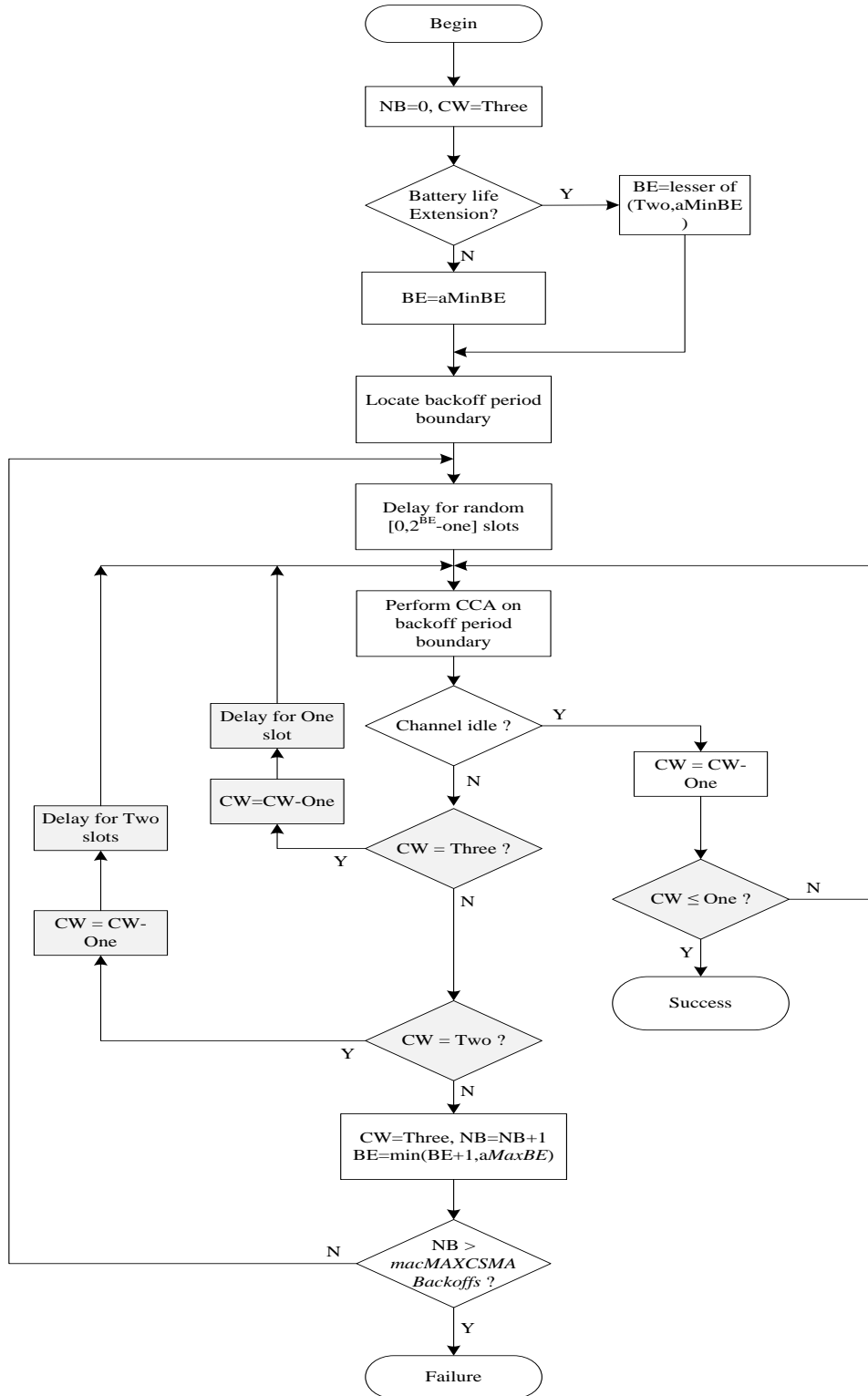


Figure 2. The flowchart of ADES

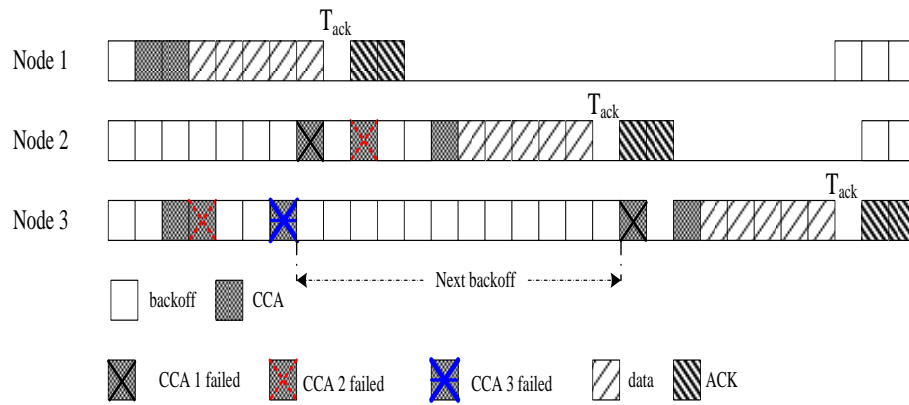


Figure 3. An example of implementation of ADES

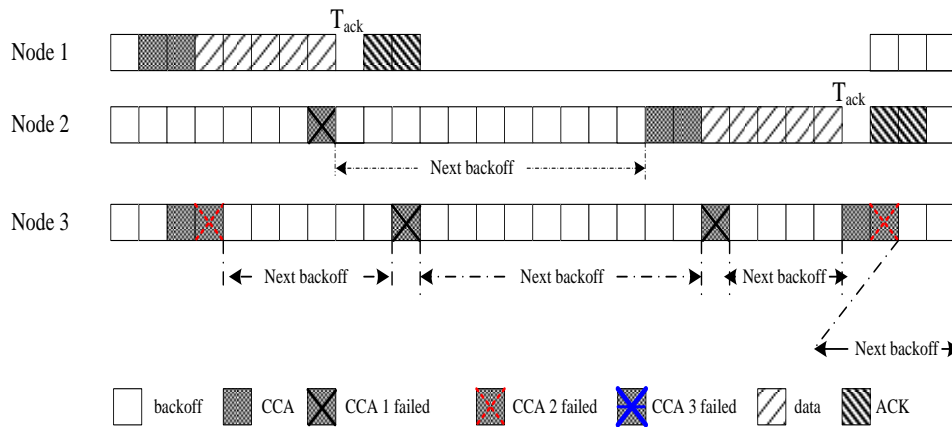
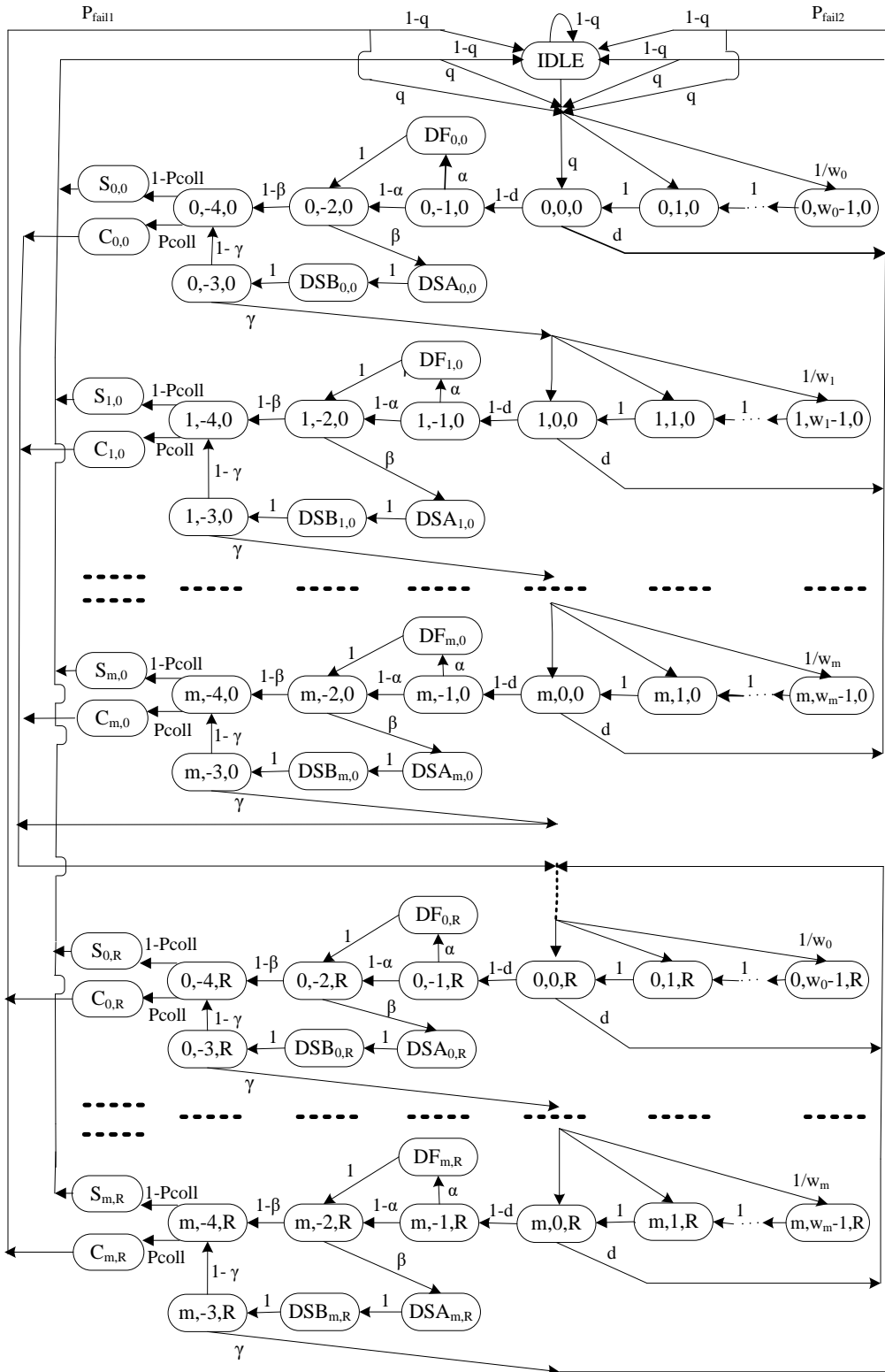


Figure 4. An example of implementation of IEEE 802.15.4

### 2.2. Analysis of ADES

In this subsection, the proposed ADES based on the IEEE 802.15.4 by using CSMA/CA for active portion, part of CAP only, because we only consider about active period, while part of CFP is neglected. This article also take into considering the case of acknowledged uplink data transmission is investigated comprehensively by Markov chain model as shown in Figure 5.

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  $r(t)$  reflect backoff stage, backoff counter, and number of retransmissions, respectively, shown as Equation (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 Equations (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 Equations. (7) to (9), respectively.



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

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

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

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

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

Let us explain the parameters used in the Markov chain model as follows. Let  $w_i = 2^{BE_i}$  be the backoff window at the  $i^{\text{th}}$  backoff stage of a device, where the backoff exponent  $BE_i = 3, 4, 5, 5,$  and  $5$  for  $0 \leq i \leq m$ . An IDLE state means that a device node has no packet to transmit. Let denote  $q$  be the probability a packet come at a node during the active period.

In this CSMA, if the remaining slot, i.e., CCA analysis, the frame transmission, and any ACK can be completed before the end of  $CAP_{ades}$ , then the MAC sublayer should transmit its packet. Conversely, if the current  $CAP_{ades}$  has not enough slots to transmit data packets, it should defer transmission until the beginning of the  $CAP_{ades}$  in the upcoming superframe duration. Let  $d$  be the probability of defer transmission that no enough slot is left in the current  $CAP_{ades}$  to transmit data packet, which can be obtained by equation (10), where  $T_{txCCA}, T_{data}, T_{ack}, T_{Lack}, T_{LIFS}$ , are the time to transmit CCA, time to transmit data packet, time to waiting for ACK packet, time to transmit ACK packet and time duration of IFS, respectively. The value of  $L_{ack}$  is equal to 11 bytes, while the value of  $L_{IFS}$  is equal to *macMinLIFSPeriod* (20 bytes) if the value of packet is greater than *aMaxSIFSFrameSize* (18 bytes), otherwise, it is equal to *macMinSIFSPeriod* (6 bytes).

$$d = \frac{3T_{txCCA} + 3T_{delay} + T_{data} + T_{ack} + T_{Lack} + T_{LIFS}}{CAP_{ades}} \quad (10)$$

Let us denote  $\alpha, \beta$  and  $\gamma$  be the probabilities that  $CCA_1, CCA_2$  and  $CCA_3$  are busy, respectively.  $CCA_1$  busy that means the device node at one of the  $CCA_1$  states while at least one of the other nodes at during packet transmission state, while  $CCA_2$  busy that means the device node at one of the  $CCA_2$  states while at least one of the other nodes at during packet transmission state and  $CCA_3$  busy that means the device node at one of the  $CCA_3$  states while at least one of the other nodes at during packet transmission state. Let us also denote  $P_{coll}$  to be the probability of the collision transmission of packet after  $CCA_2$  or  $CCA_3$ , i.e., the device node at packet transmission state while at least one of the other nodes in during the packet transmission state at the same time, which can be obtained by equation (11). Let us also denote  $P_{fail1}$  and  $P_{fail2}$  to be the probabilities of fail transmission due to the maximum number of retransmissions after collisions and no channel to use after reaching the maximum backoff stage at the maximum retransmission stage, as shown in Equations (12) to (13), respectively.

$$P_{coll} = N \tau (1 - (1 - \tau)^{(N-1)}) \quad (11)$$

$$P_{fail1} = \sum_{i=0}^m b_{C_{i,R}} = b_{0,0,0} (X^R + Z^R) X \quad (12)$$

$$P_{fail2} = b_{m,0,R} (1 - d) \beta \gamma = b_{0,0,0} (Y^m) (X^R + Z^R) (1 - d) \beta \gamma \quad (13)$$



Let denote  $P_{cr}$  to be the probability of collision transmission after  $k$  attempts (Probability of packet being dropped due to collision retransmission), which can be calculated by Equation (14). Let  $P_{dropcoord}$  and  $P_{succoord}$  be the probabilities of drop transmission and successful transmission from device node to its coordinator, which can be obtained by Equations (15) and (16), respectively. Let us also denote  $N_{recvcoord}$  and  $T_{sim}$  to be the number of packets are received by the network coordinator and time of simulation, which can be calculated by Equation (17). Therefore the goodput of ADES in the network which denoted by  $S_{ades}$ , can be calculated by Equation (18).

$$P_{cr} = \sum_{k=1}^R (P_{coll})^k \quad (14)$$

$$P_{dropcoord} = P_{cr} + P_{fail1} + P_{fail2} \quad (15)$$

$$P_{succoord} = 1 - P_{dropcoord} \quad (16)$$

$$N_{recvcoord} = \frac{\lambda_n \times N \times (1 - P_{dropcoord}) \times T_{sim}}{L_{data}} \quad (17)$$

$$S_{ades} = \frac{N_{recvcoord} \times L_{data}}{T_{sim}} \quad (18)$$

Let also denote  $NTq_1$  and  $NTq_2$  be number of packets received by coordinator using  $TQ_1$  and  $TQ_2$ , respectively. Let us denote  $N_{beacon}$  and  $BU_{total}$  be number of beacons and bandwidth utilization in the networks, which can be obtained by Equations (19) and (20), respectively.

$$N_{beacon} = \frac{T_{sim}}{SD} \quad (19)$$

$$BU_{total} = \frac{(NTq_1 \times TQ_1) + (NTq_2 \times TQ_2)}{N_{beacon} \times CAP_{ades}} \quad (20)$$

The energy consumption of device can be shown in Equation (21) and the energy consumption of coordinator node can be shown in Equation (22). Finally, the total energy consumption in networks consist of the energy consumption by devices node and coordinator node can be shown in Equation (23).

$$E_{dev} = \left( PWR_{idle} \sum_{i=0}^m \sum_{j=0}^{w_i-1} \sum_{k=0}^R b_{i,j,k} \times SD_{Coord} \times \frac{Time}{BI_{Coord}} \times N \right) +$$

$$\left( 3PWR_{tx} \frac{(\lambda_n)}{CAP_{ades}} \times \frac{L_{cca}}{R_b} \sum_{i=0}^m \sum_{k=0}^R (b_{i,-1,k} + b_{i,-2,k} + b_{i,-3,k}) \times T_{sim} \times D_{node} \times N \right) +$$

$$\left( PWR_{tx} \frac{(\lambda_h)}{CAP_{ades}} \times \frac{L_{data}}{R_b} \times P_{succoord} \times T_{sim} \times D_{node} \times N \right) +$$

$$\left( PWR_{tx} \frac{(\lambda_n)}{CAP_{ades}} \times \frac{L_{delay}}{R_b} \times P_{deconsec} \times T_{sim} \times N \right) + \left( PWR_{idle} \times P_{idle} \times SD_{Coord} \frac{T_{sim}}{BI_{Coord}} \times N \right) +$$

$$\left( PWR_{rx} \frac{L_{beacon}}{R_b} \times \frac{T_{sim}}{BI_{Coord}} \times N \right) + \left( PWR_{rx} \frac{(\lambda_h)}{CAP_{ades}} \times \frac{L_{ack}}{R_b} \times P_{succoord} \times T_{sim} \times N \right) +$$

$$\left( PWR_{tx} \times Y \times \frac{SD_{Coord}}{BI_{Coord}} \times T_{sim} \times N \right) \quad (21)$$

$$E_{Coord} = \left( PWR_{idle} \times P[IDLE] \times SD_{Coord} \frac{T_{sim}}{BI_{Coord}} \right) + \left( PWR_{tx} \times \frac{L_{beacon}}{R_b} \times \frac{T_{sim}}{BI_{Coord}} D_{node} \right) +$$

$$\left( PWR_{rx} \frac{(\lambda_n)}{CAP} \times \frac{L_{data}}{R_b} P_{succoord} \times T_{sim} \times N \right) +$$

$$\left( PWR_{tx} \frac{(\lambda_n)}{CAP} \times \frac{L_{ack}}{R_b} \times P_{succoord} \times T_{sim} \times D_{node} \times N \right) \quad (22)$$

$$E_{total} = E_{dev} + E_{Coord} \quad (23)$$

### 3. Results and Analysis

In this section, extended Castalia simulator is used to simulate ADES in order to validate analysis and performance evaluation. The performance of ADES is compared with the SUDAS and the IEEE 802.15.4 standard, which include of the analytical (ana) and simulation (sim) results. We take into considering a topology star network with one PAN coordinator is located on center and 20 device nodes are located its surround, where  $D_{node}$  is equal to 10 meters. To perform simulation the performance of power consumption, we take into considering the radio parameters of Chipcon's CC2420 2.4 GHz for the IEEE 802.15.4 RF transceiver [32], where the power transmitting  $PWR_{tx}$ , the power receiving  $PWR_{rx}$ , and the power idle  $PWR_{idle}$ , are 31.32 mW, 35.28 mW, and 712  $\mu$ W, respectively [30]. The BO and SO settings appropriate 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 $\mu$ W
BO=SO	6
$BE_{min}$	3
$BE_{max}$	5

Figure 6 shows the probability of successful transmission arriving at the PAN coordinator against the traffic load by analytical and simulation. The proposed ADES algorithm has higher probability of successful transmissions than those of other algorithms, because adjustment delay and addition third CCA can effectively avoid collision in the network. The average probability of successful transmission of ADES increases by 0.14% and 2.68% compared to SUDAS and IEEE 802.15.4 standard, respectively.

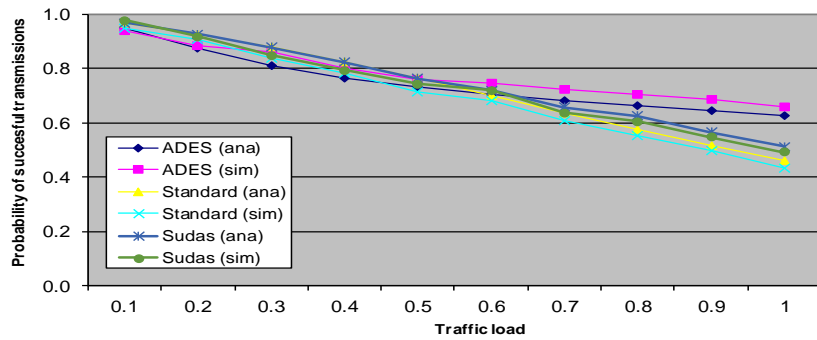


Figure 6. The probability of successful transmission against traffic load

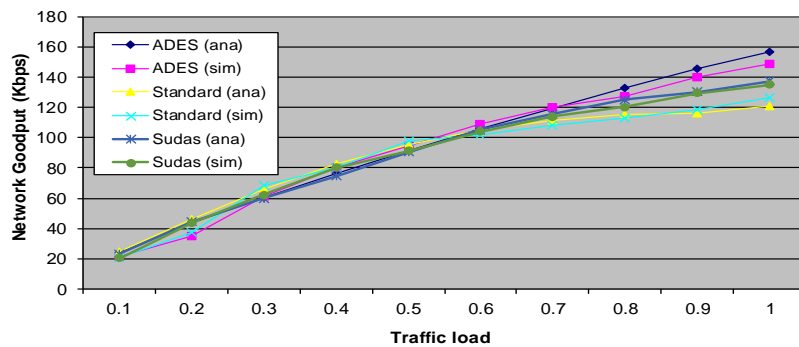


Figure 7. The network goodput against traffic load

Figure 7 shows the network goodput against traffic load. It is obvious the network goodput of ADES is higher than those of the other algorithms. In the light traffic load (i.e., traffic load is started 0.1 to 0.6), the network goodput of ADES is almost the same as those of SUDAS and IEEE standard; however, ADES outperforms to the other algorithms as the traffic load increases (i.e., traffic load is started 0.6 to 1). The average goodput of ADES increases by 5.2% and 7.6% compared to SUDAS and IEEE 802.15.4 standard, respectively

Figure 8 shows the bandwidth utilization (BU) against traffic load. The bandwidth utilization of ADES has better efficiency than those of the other algorithms. The average bandwidth utilization of ADES increases by 1.75% and 5.72% compared to SUDAS and IEEE 802.15.4 standard, respectively. ADES can improve the bandwidth utilization because reduce probability going to upcoming backoff stage, which cause blind of backoff process.

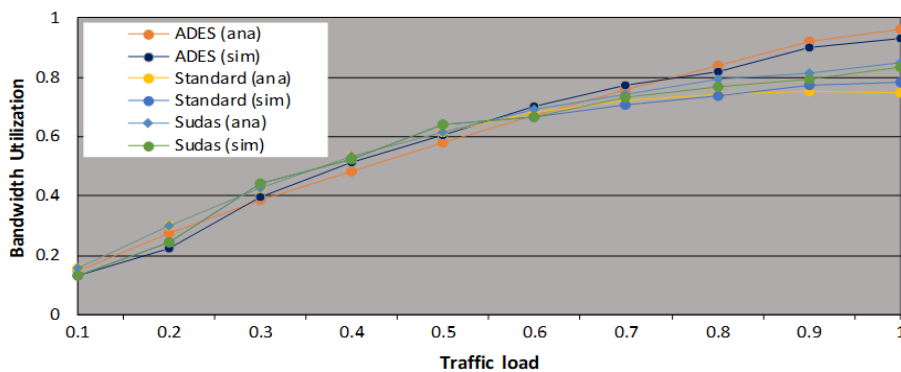


Figure 8. The bandwidth utilization against traffic load

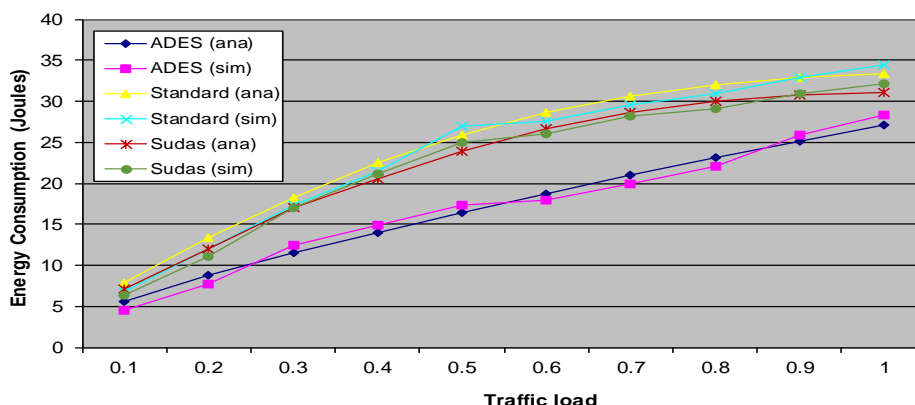


Figure 9. The total of network energy consumptions against traffic load

#### 4. Conclusion

In this article, ADES is presented to improve performance IEEE 802.15.4 networks in order to decrease collision and blind of backoff process which need more energy consumption for random backoff. The proposed ADES algorithm can adjust delay effectively for CCA when channel find in busy condition. Adjustment delay and addition third CCA not only reduce probability collision but also reduce probability going to upcoming backoff stage.

This article also included a comprehensive Markov chain analysis of IEEE 802.15.4, especially for topology star network, to predict the probability of successful transmission, the network goodput, bandwidth utilization as well as the network energy consumption. The validity of the analytical model is shown by precisely matching its predictions of the simulation results. The results of analytical model and simulation experiment show that the performance of ADES is better than those of the other algorithms in term of the probability of successful transmission, network goodput, bandwidth utilization as well as energy consumption.

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