Indonesian Journal of Electrical Engineering and Computer Science
Vol. 5, No. 2, February 2017, pp. 376 ~ 382
DOI: 10.11591/ijeecs.v5.i2.pp376-382

Performance Evaluation of Different Backoff Algorithms in IEEE 802.15.4 Using Double Sensing

Md. Mohibur Rahaman*[1], Mohammad Khairul Islam[2], Kazi Ashrafuzzaman[3], Mohammad Sanaullah Chowdhury[4]
[1, 2, 4]Department of Computer Science and Engineering, University of Chittagong, Chittagong-4331, Bangladesh
[3]Department of Electrical Engineering and Computer Science, University of Calgary, Canada
*Corresponding author, e-mail: mohib.csecu@yahoo.com

Abstract
The IEEE 802.15.4 is the standard for Low Rate Wireless Personal Area network (LR-WPAN). It is widely used in many application areas. The standard uses Slotted CSMA/CA mechanism in its contention access period (CAP) for the beacon enabled mode. The protocol has two modes - single sensing (SS) and double sensing (DS). The protocol also adopts a binary exponential backoff (BEB) algorithm. In this paper, we explore the saturation throughput, delay and energy consumption of this standard with doubles sensing (DS) using the existing BEB algorithm. We also investigate three other backoff schemes-exponential increase exponential decrease (EIED), exponential increase linear decrease (EILD) and exponential increase multiplicative decrease (EIMD). From simulation results, it is found that the EIED, EILD, EIMD perform better than the BEB for higher loads. It shows that the EIED, EILD, EIMD have better throughput and lower delay than the BEB. The EIED outperforms the other schemes in terms of throughput, delay and energy for the higher loads.

Keywords*: IEEE 802.15.4, backoff algorithms, contention access period, CSMA/CA*

1. Introduction

The IEEE 802.15.4 is meant for Low Rate Wireless Personal Area network (LR-WPANs) [1]. This is a well-known light, cost effective communication network standard. The standard allows wireless connectivity in applications with confined power. The primary objectives are cost effective wireless communication with moderate data rates, feasible data transfer, ease of installation, smaller-range operation and a legitimate battery life. It sustains a light and yieldable protocol. The standard supports light weight devices that consume subtle power.

The IEEE 802.15.4 standard with its medium access control (MAC) protocol for the contention access period (CAP) draws great interest from academia.The protocol follows two variants of either single sensing (SS) or double sensing (DS). The only difference between SS and DS is that SS requires one successful clear channel assessment (CCA) before the node can transmit but DS requires two consecutive successful clear channel assessments (CCA) before the node can transmit.

The standard IEEE 802.15.4 Medium Access Control (MAC) allows two types of channel access mechanisms. The first one is non-beacon and the second one is beacon enabled mode. The first mode employs an un-slotted carrier sense multiple access with collision avoidance (CSMA/CA). On the other hand, the second mode, the beacon enabled mode uses superframes separated by periodic beacons. The superframe consists of contention access period (CAP) which works non-persistent slotted CSMA/CA in a distinguished manner. This protocol employs a channel access mechanism and binary exponential backoff (BEB) scheme. The saturation throughput and delay (or mean frame service time) results for the CAP with SS using this protocol of the standard can be found in the reference [2].

The BEB are also vastly used in many standards, for example, in IEEE 802.11. The purpose of BEB is to set the medium but it responds rapidly to the tokens of network congestion. It is achieved by doubling the channel intercession time (backoff period) every time a node tastes a failure to deliver a frame. For every successful transmission of packets, the

Received November 2, 2016; Revised January 16, 2017; Accepted January 30, 2017

channel intercession time reduces quickly to its minimum value. The effect of cutback in the backoff period can conduct to performance degeneration when there are large amount of contending nodes, as it causes excessive collisions latterly an effective transmission. As a consequence, two types of schemes that point out a gradual curtailment in a backoff period latterly any effective transmission. One of the schemes is exponential increase exponential decrease (EIED) [3]. EIED increases the backoff period by power of 2 latterly a collision and halves it after a successful transmission. The second scheme is exponential increase linear decrease (EILD) algorithm. EILD also increases the backoff period by power of 2 after collision, but linearly decreases the backoff period latterly a significant transmission. Also there exists a third scheme known as exponential increase multiplicative decrease (EIMD) [4]. EIMD increases the backoff period by power of 2 after collision and decreases the backoff period by a factor (here 1.5) after a successful transmission. In reference [4], the authors analyzed and compared the performance of the three-backoff algorithms for IEEE 802.11 – BEB, EIED, and EILD.

But the backoff scheme proposed in IEEE 802.15.4 is BEB [5]. Hence, it is significant to inquire the performance of the other backoff algorithm for this standard. In other words, we would like to find and propose a better backoff scheme for IEEE 802.15.4. To the best of our knowledge, the performances of other backoff algorithms are yet to be found for this standard.

In this paper, we investigate and compare the performances (that is throughput, delay and energy) of different backoff mechanisms - EIED, EILD and EIMD along with the BEB of the slotted CSMA/CA protocol in the IEEE 802.15.4 MAC using the DS. The organization of residual of the paper is as follows. IEEE 802.15.4 MAC protocol is explained in section 2. The different backoff algorithms are described in section 3. The results are discussed in the next section. Finally, we conclude the paper in section 5.

2. The IEEE 802.15.4 MAC Protocol

In this section, we briefly discuss the MAC protocol in the IEEE 802.15.4 standard. More details of the protocol can be found in [1] and [6]. The IEEE 802.15.4 MAC specifies two modes: non-beacon-enabled mode and a beacon-enabled mode. Non-beacon mode uses a non-slotted CSMA with collision avoidance (CSMA/CA) for channel access. If the channel is idle, the transmission of a frame will begin immediately, otherwise the node will backoff and try to access the channel in a future slot. This mechanism has been widely studied in the literature [7]. In the beacon-enabled mode, a coordinator transmits a beacon periodically to form the superframe as shown in Figure 1. The superframe can have an active and an inactive portion and it consists of a beacon, contention access period (CAP), contention free period (CFP), and an optional inactive portion. The CAP and CFP together form the active portion of the superframe. All communication among the nodes should take place during the active portion. In the CFP, the coordinator controls the contention free channel access by assigning guaranteed time slots (GTS) to those nodes with their GTS requests granted. The assignment of the GTS to those nodes is determined by the scheduling scheme decided by the coordinator.

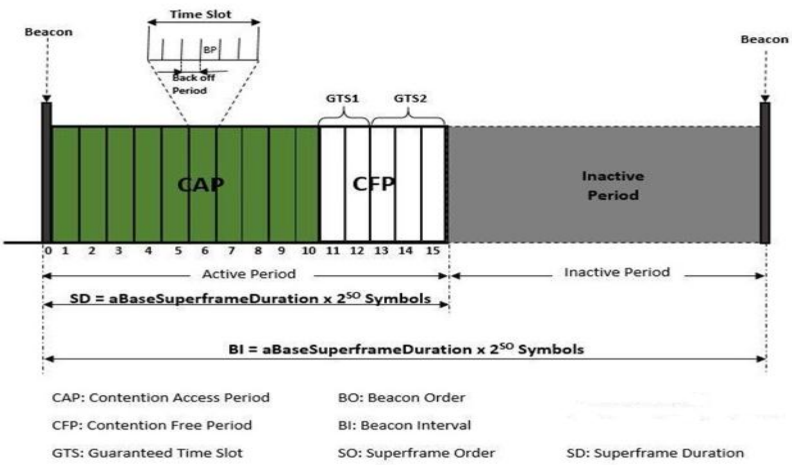

Figure 1. IEEE 802.15.4 superframe and Backoff period in CAP

In the CAP, a slotted CSMA/CA with binary exponential backoff protocol is used. Each frame need to maintain three variables before it is transmitted successfully. They are - the number of random backoffstages experienced (NB), the current backoff exponent (BE), and the contention window (CW). NB is the number of times the node requires to delay while attempting the current transmission. It is initialized to 0 before every new transmission. CW defines the number of slot periods that need to be clear of activity before the start of transmission. It is set to 2 before each transmission attempt and reset to 2 each time the channel is assessed to be busy. BE is related to how many slot periods a device must wait before attempting to assess the channel.

The slotted CSMA/CA of IEEE 802.15.4 works as follows and is depicted in Figure 2.

1. Step 1: NB, CW and BE are initialized.
2. Step 2: The node delays for a random number of complete slot periods drawn from a uniform distribution over$[0, 2^{\mathrm{BE}} - 1]$.
3. Step 3: Perform two successful clear channel assessments (CCA) for DS. Then the MAC sub-layer proceeds provided that the remaining steps (frame transmission and acknowledgement) can be completed before the end of the CAP. If it cannot proceed, it must wait until the start of the CAP in the next superframe.
4. Step 4: If the channel is busy, both NB and BE are incremented by one, ensuring that BE is not more than aMaxBE, and CW is reset to 2. If the value of NB is less than or equal to macMaxCSMABackoffs, the CSMA/CA must return to step 2, else the CSMA/CA end with a Channel-Access-Failure status.
5. Step 5: If the channel is idle, the CW is decremented by one. If CW is not equal to 0, it must goto step 3, else start transmission on the boundary of the next slot period.

The standard specifies the following default parameter values – amacMinBE=3, aMaxBE=5 and $\mathrm{NB}_{\max} = 5$. If the node succeeds in accessing the channel during the backoff procedure, it will reset the parameters NB, BE and CW to the default values for initial transmission of the next frame.

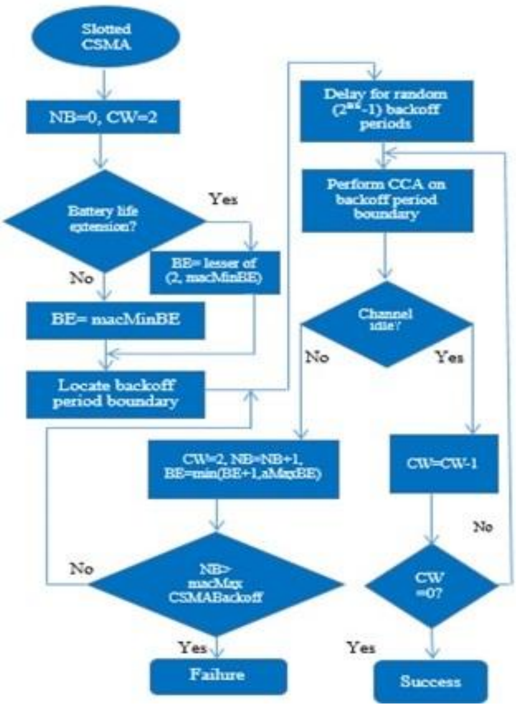

Figure 2. Slotted CSMA/CA mechanism for IEEE 802.15.4

3. Different Backoff Algorithms

In previous section, we have described about the backoff algorithm for the IEEE 802.15.4 which is known as BEB. In this section, we briefly discuss three more backoff algorithms namely EIED, EIMD and EILD[3][4]. Then we adopt these algorithms in the slotted CSMA/CA of IEEE 802.15.4.

3.1. Exponential Increase Exponential Decrease Algorithm

Step1: Initialization-minimum backoff exponent, maximum backoff exponent, maximum number of backoffstages.

Step2: At the First Transmission Attempt
Set: Backoff Period Set to the Minimum.
Step3: For Each Collision or Unsuccessful Transmission
EIED doubles the Backoff Period
It retries until maximum number of backoff occurs
Step4: For Each Successful Transmission
EIED halves the Backoff Period
Step5: End

3.2. Exponential Increase Multiplicative Decrease Algorithm

Step 1: Initialization-minimum backoff exponent, maximum backoff exponent, maximum number of backoffstages.

Step 2: At the First Transmission Attempt
Set: Backoff Period Set to the Minimum.
Step 3: For Each Collision or Unsuccessful Transmission
EIMD doubles the Backoff Period
It retries until maximum number of backoff occurs
Step 4: For Each Successful Transmission
EIMD decrease the Backoff Period by a Factor(here 1.5).
Step 5: End

3.3. Exponential Increase Linear Decrease Algorithm

Step1: Initialization-minimum backoff exponent, maximum backoff exponent, maximum number of backoffstages.

Step 2: At the First Transmission Attempt
Set: Backoff Period Set to the Minimum.
Step3: For Each Collision or Unsuccessful Transmission
EILD doubles the Backoff Period
It retries until maximum number of backoff occurs
Step4: For Each Successful Transmission
EILD decrease the Backoff Period Linearly, that is current Backoff period=Backoff period -1.
Step5: End

4. Simulation Results and Discussion

We In this part, we present simulation results and compare the saturation throughputs, mean frame service time or delay and energy by applying the four backoff algorithms in slotted CSMA/CA of IEEE 802.15.4.

The simulation results presented in this section are obtained using the same simulator used in [2] for the BEB.By comparing with existing BEB [2],we found the same performance for BEB in our simulation. We extend the simulator adding other backoff algorithms. It is a discrete event simulator using C++ programming language that closely follows the MAC layer procedure of the IEEE802.15.4.We have used two scenario – the first one is the using the default values in the standard and other one is using different parameter values as shown in the Table 1.

Table 1. Simulation parameters

Parameters	Scenario 1 (Default Values)	Scenario 2
amacMinBE	3	4
aMaxBE	5	9
NB_{max}	5	5
Packet Size	8	8

The Figure 3, Figure 5, and Figure 7 show the normalized throughput, mean frame service time or delay and energy respectively for all the four backoff algorithms using the scenario 1. The EIED algorithm outperforms the other three. As the load (number of nodes) increases, the relative performance of the EIED increases. That is, it has better throughput (showed in Figure 3), lower delay (Figure 5) using low energy (Figure 7) than the others. However, other schemes – BEB, EIMD show almost similar throughputs (Figure 3) for the default parameters. EILD performs better than BEB. But EIED performs much better than all other schemes. This implies EIED would be better choice among all for this scenario (default parameter values).

On the other hand, the Figure 4, Figure 6, Figure 8 shows the performance results scenario 2 as the values are given at the Table 1. The throughputs of BEB are better up to a certain number of nodes (around 25)(Figure 4). As a consequence, the BEB has less delay and low energy consumption for the lower number of nodes. After that, the performance is decreased. This concludes that for higher load, BEB would not be good choice. However, the EIED, EILD and EIMD performed less than BEB up to the first 25 nodes and takes lead afterwards. Moreover, EIED has better throughput (Figure 4), lower delay (Figure 6) and minimal energy used (Figure 8) when the number of nodes (after 35) increased. It outperforms other backoff algorithms for higher number of nodes. The EILD and EIMD also has better throughput than the BEB (Figure 4) for higher amounts of nodes. The EILD and EIMD also has less delay (Figure 6) and low energy (Figure 8) than the BEB for higher number of nodes. It happens because of taking a random number from a small distribution range yield a higher collision probability. In BEB, after a successful transmission, it decreases the backoff window into the minimum. Hence, the distribution range is small and collision probability is higher. But in the cases of EIED, EILD and EIMD, it decrease the backoff window into halves, linearly, and by a factor (here 1.5) respectively. As a result, a larger distribution range produced and collision probability become lower. If collision probability is less, that result less delay and if less delay occurs which leads to minimal energy used. Therefore, the throughputs, delay and energy of EIED, EILD, and EIMD algorithm are better than that of BEB algorithm after certain amount of nodes.

We compare the throughput of all the proposed algorithms with that of the BEB using the scenario 2 parameters (amacMinBE = 4, aMaxBE = 9 and NB_{max} = 5), which is shown in Figure 4. It is evident that the BEB performs well only for lower amount of nodes. But as the number of node increases (after 25) EIMD, EILD performs much better than BEB algorithms.For higher loads (here 45 to 60) EIED yield the highest throughput among all other schemes. As a consequence, EIED has less delay and subtle energy consumption for higher loads shown in Figure 6 and Figure 8 respectively.

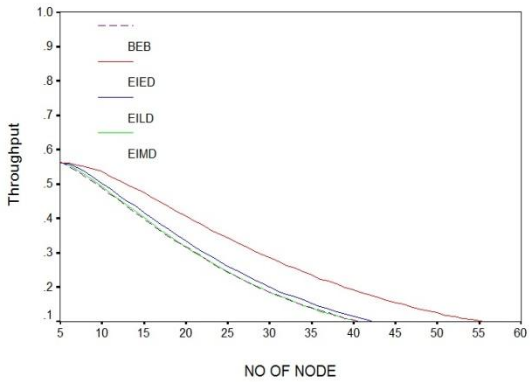

Figure 3. Normalized Saturation Throughput (amacMinBE=3, aMaxBE= 5 and NB_{max} = 5)

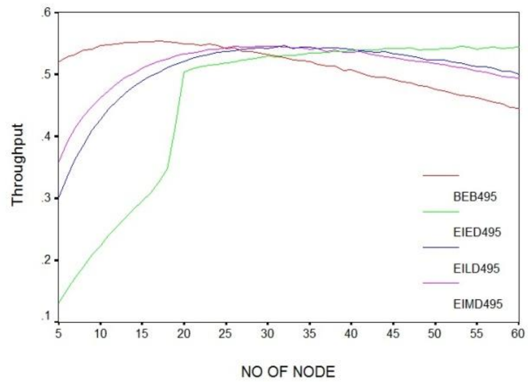

Figure 4. Normalized Saturation throughput (amacMinBE = 4, aMaxBE = 9 and NB_{max}=5)

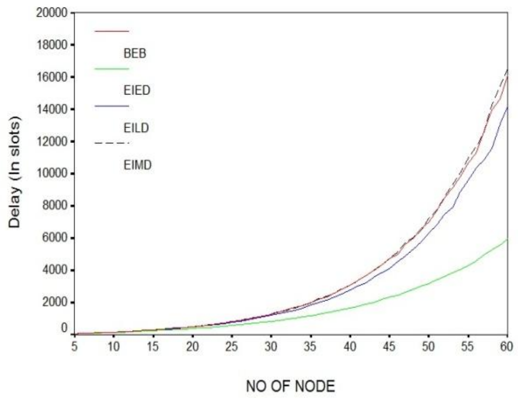

Figure 5. Delay vs no. of nodes (amacMinBE = 3, aMaxBE = 5 and $\mathrm{NB_{max}}$=5)

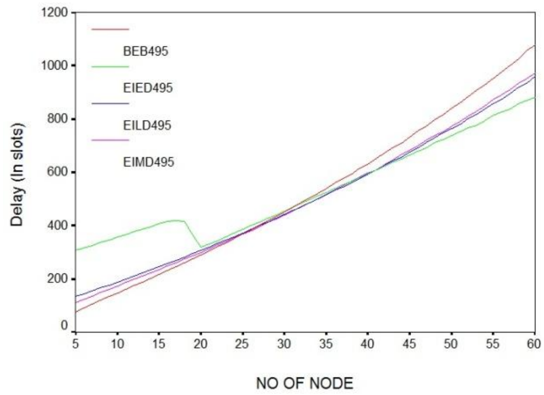

Figure 6. Delay vs no. of nodes (amacMinBE = 4, aMaxBE = 9 and $\mathrm{NB_{max}}$ = 5)

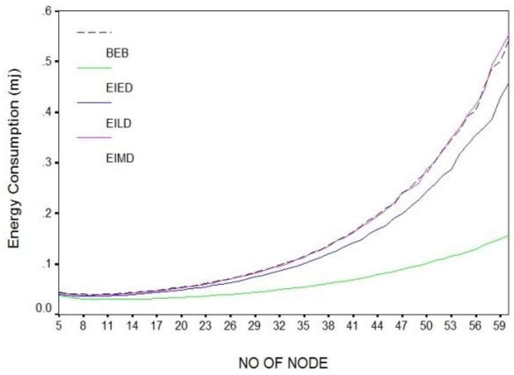

Figure 7. Energy vs no. of nodes (amacMinBE = 3, aMaxBE = 5 and $\mathrm{NB_{max}}$ = 5)

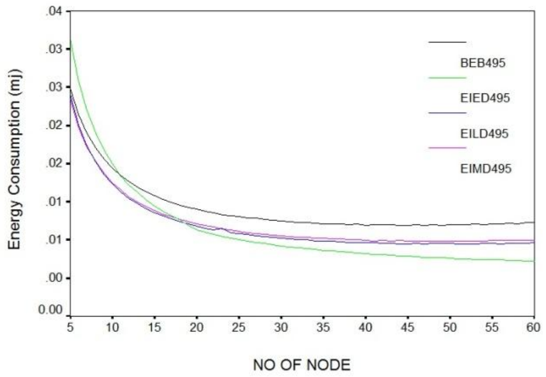

Figure 8. Energy vs. Number of Node (amacMinBE = 4, aMaxBE = 9 and $\mathrm{NB_{max}}$ = 5)

6. Conclusion

Throughput considered as one of the most important aspects for MAC performance metrices. The other aspects are delay and energy. We have compared the throughput, delay and energy of existing BEB algorithm with three other backoff algorithms - EIED, EILD, EIMD for the slotted CSMA/CA in IEEE 802.15.4 MAC using the standard variant DS. Simulation results showed that for default parameter EIED, EILD algorithms give better throughputs, lower delay and low energy over the BEB and EIMD. For the higher load, the EIED, EILD, EIMD perform better than that of the BEB algorithm using the proposed parameter. The EIED outperformed the other three algorithms for the higher loads. The EIED, EIMD, EILD would be the better choice for dense WPAN.

Acknowledgements

In this research work I am grateful to my honorable Supervisor Dr. Mohammad Khairul Islam, Professor Department of Computer Science & Engineering, University of Chittagong, Chittagong-4331, Bangladesh for his Guidance.I am also thankful to, two of my honorable teacher Mr. Kazi Ashrafuzzaman and Dr. Sanaullah Chowdhury, Associate professor Department of Computer Science & Engineering, University of Chittagong, Chittagong-4331, Bangladesh for their technical support continuously.

References

[1] LAN/MAN Standards Committee. Part 15.4: wireless medium access control (MAC) and physica layer (PHY) specifications for low-rate wireless personal area networks (LR-WPANs). IEEE Computer Society. 2003.

[2] Kazi Ashrafuzzaman, Sup Kwak Kyung. On the performance analysis of the contention access period of IEEE 802.15. 4 MAC. *IEEE communications letters*. 2011; 15(9): 986-988.

[3] Song Nai-Oak, et al. *Enhancement of IEEE 802.11 distributed coordination function with exponential increase exponential decrease backoff algorithm*. Vehicular Technology Conference, 2003. VTC 2003-Spring. The 57th IEEE Semiannual. 2003; 4.

[4] Vukovic Ivan N, Natt Smavatkul. *Saturation throughput analysis of different backoff algorithms in IEEE802. 11*. Personal, Indoor and Mobile Radio Communications, 2004. PIMRC 2004. 15th IEEE International Symposium on. 2004; 3.

[5] Ling Xinhua, et al. A renewal theory based analytical model for the contention access period of IEEE 802.15. 4 MAC. *IEEE Transactions on Wireless Communications*. 2008; 7(6): 2340-2349

[6] Zheng Jianliang, Myung J Lee. Will IEEE 802.15. 4 make ubiquitous networking a reality?: A discussion on a potential low power, low bit rate standard. *IEEE Communications magazine*. 2004; 42(6): 140-146.

[7] Kleinrock Leonard, Fouad Tobagi. Packet switching in radio channels: Part I-carrier sense multiple-access modes and their throughput-delay characteristics. *IEEE transactions on Communications.* 1975; 23(12): 1400-1416.