Optimization in Backoff Technique for IEEE 802.15.4/ ZigBee Networks

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***Abstract*—Zigbee/IEEE 802.15.4 is a high level communication and short range standard in Wireless Sensor Networks (WSN), where each node can send and receive data with high security, reliability, low complexity, low power consumption and low cost. It is utilized by industry leaders, such as Samsung, Motorola, Siemens, Philips, etc., and used in industrial, medical purposes, control and monitoring applications. ZigBee supports two operation modes; beacon enabled mode and beaconless enabled mode. In this paper, we present the optimal values of two parameters used in the Zigbee standard, namely, BO (Beacon Order) and SO (Superframe Order), to enhance the network performance, which can be obtained by increasing the network throughput as well as decreasing the total energy consumption and end-to-end delay. The experiment was applied on a star topology, along with an improved backoff mechanism for ZigBee networks. The results showed that the best BO and SO values that increases the throughput, decreases the end-to-end delay as well as decreases the total energy consumption is (8, 8).**

Keywords-IEEE 802.15.4; zigBee; backoff; beacon; superframe.

I. INTRODUCTION

The IEEE 802.15.4 standard (Zigbee) [1] is a technological standard for high level communication in WSN, which approved to assign protocols for the data link, Mac and physical layers. This standard is essentially based on IEEE Low Rate Wireless Personal Area Networks. It connects between two devices in the lower level of communication that makes it useful for low data rate, low power and low cost networks, such as WSN [1][2]. It is developed by the ZigBee Alliance [5], and its name came from a zigzag type of dance, which is used by the honeybee to inform the other bee hive members that a new source of food is detected [6]. ZigBee protocols are directed towards earning remote control applications, like wearable health monitoring systems [4].

The MAC layer of IEEE 802.15.4 standard deals with two kinds of network topologies; star and peer to peer networks, and it supports two work modes; beacon mode, and beaconless mode [3].

To avoid a collision that appears in the network while transmitting in the same time and cause loss of data when using beacon mode, a popular approach is used, called slotted Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) that determines the devices which can rival with the other devices during the access of the channel [8].

There are two ways for channel access: the first way is Contention Free Period (CFP), where the Personal Area Network (PAN) coordinator assigns small period of time for each node in the Superframe to do whatever it needed without contention or latency, this time is called Guaranteed Time Slot (GTS). The second way is Contention Access Period (CAP). In the beaconless mode the un-slotted CSMA/CA approach is preferred [3][13]. In both modes, the nodes which depend on IEEE 802.15.4 standard try to send their data, and, if the collision happens when more than one node sends in the same time, the user waits for a little period of time, called backoff time; then, it tries to resend its data again after that time is finished.

Backoff time is computed through a linear function selected randomly from the range of [0-2BE-1], where BE symbolizes the backoff exponent that is required to determine the amount of time that a node have to wait before trying to send again [4].

The Beacon is a message with a particular form used to synchronize the clock of the node in the network. Two sequential beacons include among them one superframe, which is splatted into 16 active periods of time slots as well as an elective idle amount of time, where all nodes can weight if the sleep mode is enabled as shown below in Figure 1.

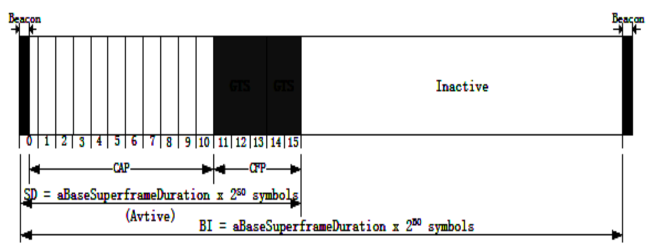

Figure 1. E SuperFrame Structure.

The process of using the beacon message can be clarified as follows: A coordinator sends the beacon signals to the node to start sending its data (beacon enabled PAN). On the other hand, the beaconless mode has no GTS time, but it has CFP, which makes an advantage for it because it saves the battery life unlike the beacon mode [2].

The paper presents the optimal BO and SO value to improve the network performance. The network improvements are gained by increasing network throughput, as well as decreasing the end-to-end delay and total energy consumption. The rest of the paper is organized as follows; Section II presents a literature review of several techniques used in ZigBee networks. Next, Section III shows the simulation and obtained results. Finally, the paper is concluded in Section IV.

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II. RELATED WORK

Many researches have been performed in the domain of the ZigBee networks; mostly, these researches are about how to improve the network throughput as well as decreasing the total energy consumption and average end-to-end-delay, that can be summarized as improving the network performance.

Rao et al. [4] have suggested an Adaptive Backoff Exponent (ABE) algorithm, where BE amount was administered depending on device's participation to the network passing. ABE executes a variable macMinBE and approved it just by devices participated in the transference activity. Moreover ABE leads to solve the potentiality of the devices to choose amounts as same as the BE amounts raised essentially by the little quantity of potential BEs. Thus, devices will backoff a corresponding period of time producing collisions. Hence ABE cannot back PANs with great scales.

Rohm et al. [6] have studied the impact of changing fundamental backoff values, such as macMaxBEs, macMinBEs, and macMaxCSMA, on the efficiency of beaconless ZigBee networks; the study was performed under several traffic loads by suggesting a dynamic scheme for estimating the best backoff values. Where the new dynamic scheme continuously observes different network traffic indicators and change backoff parameters, according to it. Furthermore, they evaluated the traffic loads by observing the packet loss and latency averages at every node to avoid extra communications for nodes, which are needful in the centrally managed algorithm. Also, they ensured that there are no invisible nodes in the whole radio range of nodes. The simulations were implemented by using several packet sizes, such as 133 byte long packets.

Huang et al. [7] have combined two types of wireless technologies, which are: (WLAN) Wireless Local Area Network (IEEE 802.11b) and ZigBee (IEEE 802.15.4) in the health monitoring field They have suggested a cooperative existence scheme based on dynamic GTS allocation with preemptive technique for the Wearable Health Monitoring systems. They suggested two-layer-architecture: the first layer was released by Body Area Network (BAN) that controls the communication between sensors on the body with the controller on the wrist. The second layer sends the information received from ZigBee devices to the infrastructure network through WLAN. The new pattern works as follows: at first it quantifies the RSSI and Channel Utilization (CU) to locate the status of the channel, so if ZigBee channel is empty the PAN coordinator will choose it, otherwise the new approach will be called and start by calculating GTS through active period in each superframe.

Ha et al. [10] have studied how to increase the throughput and decrease the energy consumption for Zigbee CSMA/CA. They have suggested two techniques; the first one was depended on the collision and Clear Channel Assessment (CCA) values, where they increases and decreases the backoff exponent (BE) value regarding to transmission status. The second technique benefits from the CCA results by shifting the scope of backoff counters. They performed their simulation using the NS-2 simulator with 25 nodes and one coordinator, where there are no invisible nodes and all nodes forward data packets to the coordinator. And although that most Zigbee applications use a little amount of traffic load, each node may suffer from the saturating of the network and radio congestion. The simulation shows that the proposed techniques improved the throughput by 29.9% and energy efficiency by 86.8%.

Ko et al. [11] have presented a new State Transition Scheme to increase the network performance by modifying the BE values depending on the moving scheme base on the transmission conditions. In their simulation they have used the NS-2 simulator as well as modified NS-2 MAC simulator. From their experiment they observed that the throughput and network performance increased after changing the minBE values to 1 rather than the original values that were chosen from the range between 3 and 5.

Lee et al. [12] have adjusted the amount of BE in the slotted CSMA/CA to an effective EBE value that is being set regarding to the volume of devices available in the PAN in the network. The backoff delay time of the nodes decreased regarding to the lack of nodes that joined the network. So, they initialized the EBE to the least value in the range between 2 and macMinBE value, and setting the battery life extension (BLE) in the beacon frame to 1 that increases the necessity to long backoff periods due to the increase of nodes that joins to the network.

Khan et al. [14] have suggested the Improved BEB (IBEB) algorithm. Which decreases the potentiality that devices may choose amounts like BE amounts and waits for the same time of backoff. Devices uses a different value to compute the backoff time instead of the random choose of BE only. They pick temporary Backoff value greater than 10% and less than 40% of the computed backoff period of time, either they hired the unit temporary Period (IP) to reduce the potential of picking both IB and BE. The outcomes of simulation exposed that IBEB is better than the BEB scheme while examined on various network scales and loads.

III. SIMULATION SETUP AND RESULTS DISCUSSION

The optimal BO and SO value that achieves the best network performance were investigated through an improved linear backoff mechanism, because using linear function is more suitable for ZigBee network to minimize the collision between different nodes in the network as well as minimizing the packets delay sustained by the backoff technique.

Simulation evaluation was performed using QualNet v5.2 simulator. QualNet is a simulator based on C/C++ programming language, derived from GloMoSim simulator that was first issued in 2000 by Scalable Network Technologies (SNT) [9]. QualNet is designed to back simulation of large scale and different networks. It has a smooth graphical user interface that supports a lot of tasks, such as network scenario creation, protocol design, and animated implementation.

Simulation was implemented using an IEEE 802.15.4/Zigbee network, depending on star topology that contains one PAN coordinator with 6 reduced functional devices (RFDs) one hop away from the PAN coordinator, where RFD nodes send CBR traffic of 70 bytes to the PAN coordinator during the simulation period. The nodes were uniformly distributed in 25m×25m of the area as shown in Figure 2, in addition to an inter arrival time, which is equal to of 1 second, as shown below in table 1.

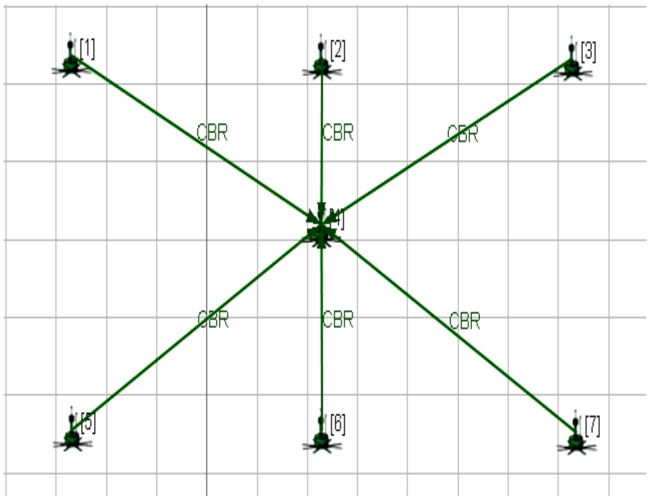

Figure 2. 7 nodes (star topology) implemented on QualNet 5.2 simulator.

TABLE I. QUALNET SIMULATION PARAMETERS USED IN THE SIMULATION.

Parameter	Value
Used Simulator	QualNet 5.2
Radio Type & MAC Type	IEEE 802.15.4
Area (x, y)	25m * 25m
Number of devices	7
Transmission range	5 m
Simulation time	1000 s
-Channel Frequency	2.4 GHZ
Start Time	15
End Time	0
Energy model	MICAZ
Antenna Height	0.08
Traffic	VBR
Item size	70 byte
Channel Access Mechanism	CMSA
Traffic Generator	CBR
Items to send	0
Interval	1 Second
BO and SO	Shown in Table 2

Many experiments were conducted to help researchers to pick up the best BO and SO value that represent the best network performance, where each experiment differed from the others in the value of BO and SO used, as shown below in table 2. BO and SO values were chosen from the range of [1-9] considering the following conditions:

- BO should be greater than or equal to SO.
- If BO is greater than 5, SO also should be greater than 5.

TABLE II. BO AND SO VALUES USED IN THE SIMULATION.

No	BO,SO	Throughput	Average End-to-End Delay	Total Energy Consumption
1	(1,1)	1529.2	0.1664944	12.663684
2	(2,1)	639.8	0.122474	8.298964
3	(2,2)	1993.4	0.2727686	9.0926402
4	(3,1)	330.2	0.508394	6.3243268
5	(3,2)	993.2	0.2942532	6.998513
6	(3,3)	2331	0.4144662	8.3540372
7	(4,1)	172.8	1.064789	5.2675614
8	(4,2)	507	0.394051	5.9119196
9	(4,3)	1170.4	0.4332626	7.4540344
10	(4,4)	2520.2	0.5172802	7.7634934
11	(5,1)	2592	0.6953788	8.4686058
12	(5,2)	361.4	1.3256918	5.0616906
13	(5,3)	620.6	1.440292	6.8974716
14	(5,4)	1301.2	1.409788	8.325229
15	(5,5)	2592	0.6953788	8.4686058
16	(6,6)	1978.4	3.068698	6.5669064
17	(7,6)	918	2.159328	6.077315
18	(7,7)	1666.2	2.043424	6.7881978
19	(8,6)	691.2	4.484266	7.455299
20	(8,7)	1025.6	2.346314	7.579415
21	(8,8)	1681.8	1.893714	4.7075258
22	(9,6)	620.4	16.44958	12.6877532
23	(9,7)	642	11.61832	11.7020778
24	(9,8)	757	4.912716	7.87586
25	(9,9)	910.6	1.2472382	4.5487218

The Performance metrics investigated in our study are:

- Throughput: volume of bits passes through the PAN per second.
- Average End-to-End delay: The average time, which the packet spends to move from the source device to the target PAN coordinator.
- Total Energy Consumption: The total amount of sending, receiving, sleeping and idle energy used by the PAN nodes.

In the following, there are presented three groups of results that show the variance of network performance depending on the BO and SO values. Where the first group of results shown in Figure 3 indicates that the throughput increases to reach its maximum value 2592 Bit/Sec at (BO, SO) =

(5, 1) as well as at (5, 5) and decreases to reach the minimum value 172.8 Bit/Sec when (BO, SO) = (4, 1).

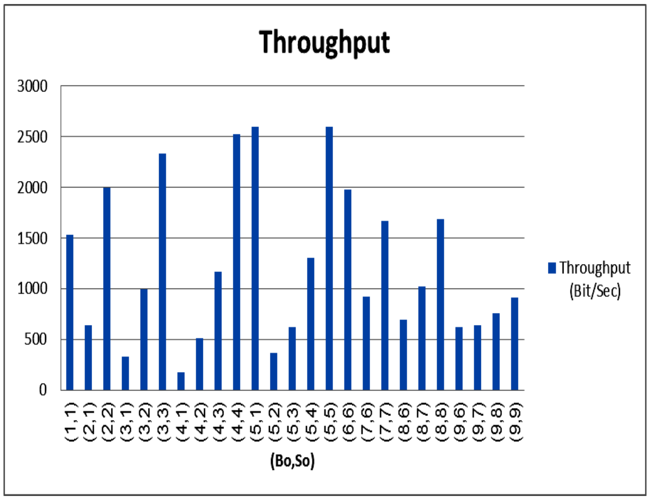

Figure 3. Throughput performance metric using different (BO,SO) values.

The second group of results shown in Figure 4 indicates that the average end-to-end delay increases to reach its maximum value, which is 16.44958 Sec when (BO, SO) = (9, 6) and decreases to reach the minimum value 0.122474 Sec when (BO, SO) = (2, 1).

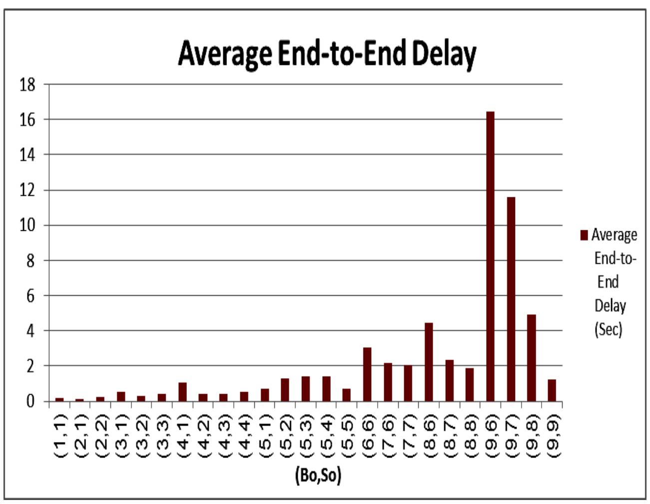

Figure 4. Average end-to-end delay performance metric using different (BO,SO) values.

The third group of results shown in Figure 5 indicates that the total energy consumption increases to reach its maximum value, which is 12.6877532 at (BO, SO) = (9, 6) and decreases to reach the minimum value 4.5487218 when (BO, SO) = (9, 9).

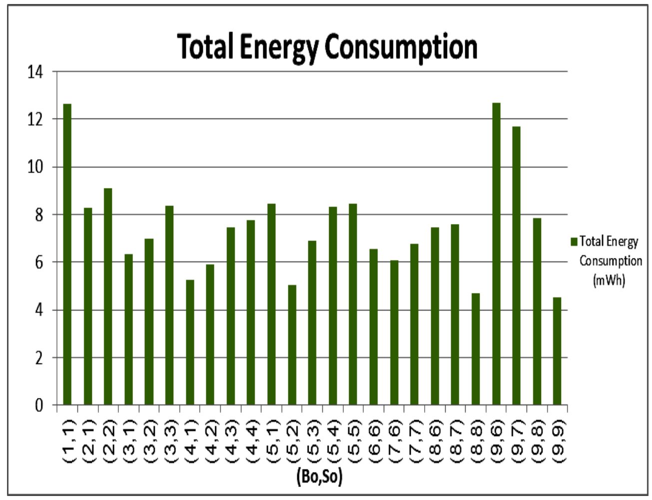

Figure 5. Total energy consumption performance metric using different (BO,SO) values.

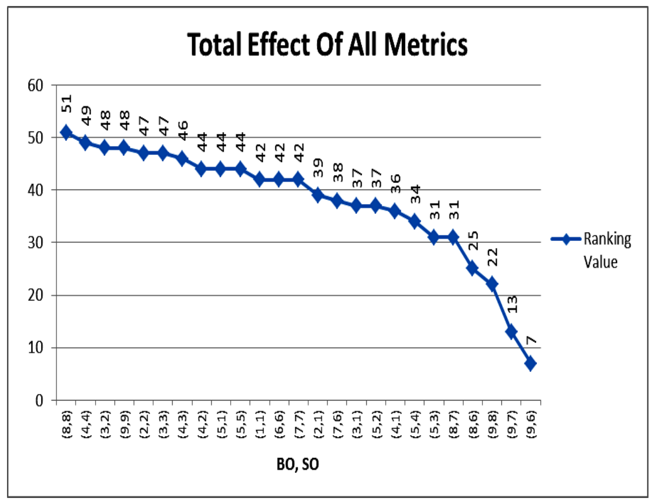

Figure 6. Total effect of all metrics using different (BO,SO) values.

Figure 5 best summaries the results obtained from the previous figures. It was constructed by giving the all BO and SO values suitable ranks according to the results obtained from each studied metric, i.e., (8, 8) has the highest value, that make it the best (BO, SO) values, where (4, 4) comes on the next stage by presenting high amount of throughput, balanced with low amount of end-to-end delay and total energy consumption. Furthermore, the value (9, 6) comes at the end of the list by presenting the worst amount of end-to-end along with the worst total energy consumption value.

IV. CONCLUSION AND FUTURE WORK

Zigbee is a high level communications and short-range standard in WSN, it consumes little power (small batteries) and low cost than alternative networks, such as Bluetooth or Wi-Fi. When more than one node tries to send data in the same time, collision and packets delay happens then, they have to wait for a little period of time, called backoff time. In order to cope with these problems, the optimal BO and SO values that achieve best network performance on star topology were presented, as the network improvements were gained by increasing network throughput as well as decreasing the end-to-end delay and total energy consumption, considering the use of improved backoff mechanism for ZigBee network that minimizes the collision and packet delay between various nodes in the network. The results show that the best BO and SO value that increases the throughput, decreases the end-to-end delay as well as decreases the total energy consumption to is (8, 8). As a future work, we plan to study the effect of the BO and SO values on the same algorithm using other topologies instead of the star topology; and then to compare the network performance in all studied topologies to find out which one is the best. Another proposed work is to study the impact of the data traffic load and data traffic type on the performance of the Linear backoff algorithm by changing the number of packets sent from the nodes to the PAN coordinator per each experiment under different traffic types.

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