A Queue based Enhanced Backoff Algorithm for IEEE 802.15.4 Wireless Sensor Networks

Imen Bouazzi, Jamila Bhar, Mohamed Atri
Electronic and Micro-electronic laboratory (IT-06), FSM, University of Monastir, Monastir 5000, Tunisia
imen.bouazzi@gmail.com

**Abstract— T*he IEEE 802.15.4 standard defines a new wireless personal area network (WPAN) used for applications of wireless monitoring and control. In this article, a study of the backoff exponent (BE) management in CSMA/CA in the MAC layer is conducted. Where BE determines the number of backoff periods the device must wait before access to the channel. In this paper, we aim to prolong maximum possible the life time of sensor nodes by optimizing the energy consumption. We propose an algorithm in which we can adjust dynamically the MAC parameters based on the queue length of each sensor node. We have then defined a parameter to obtain instantaneously information about the queue size. We use network simulator ns-2 to implement the network. The performance metrics of the comparison are energy consumption, average delay and throughput.*

Keywords: WSN, MAC layer, energy consumption, queue length, Backoff Exponent, NS-2.

I. INTRODUCTION

In recent years, the use of Wireless Sensor Networks (WSNs) has increased tremendously and gained worldwide interest. Medium Access Control (MAC) protocol plays a vital role to improve the performance of WSNs. IEEE 802.15.4 MAC protocol is designed to achieve the characteristics of low power and low rate wireless personal area networks (LR-WPANs) [1]. Furthermore, IEEE 802.15.4 defines the specifications of both PHY and MAC sub-layer to meet the requirements of sensor networks. It can operate with two different channel access methods; a beacon-enabled mode and a non beacon-enabled mode. In this paper, we evaluate the beacon-enabled based IEEE 802.15.4 MAC due to its simplicity for WSNs applications compared to non beacon-enabled mode [2]. Beacon-enabled mode utilizes the slotted version of CSMA/CA mechanism for contention mechanism and channel access.

In CSMA/CA, a long random backoff time causes longer average delay, while a small one gives high collision rate [3–5]. Therefore, this paper examines two main drawbacks of slotted CSMA/CA algorithm; the first problem is that during CSMA/CA mechanism, a node tends to delay for a very limited value of backoff exponent (BE). The probability of collisions when two or more nodes choose the same value of backoff period is high. This insufficient distribution of backoff time causes more collisions among the contending nodes and affects system performance. The second problem is that CSMA/CA updates the contention window length without considering the number of contending nodes in the communication medium. Thus, CSMA/CA is proven to be inefficient in terms of system throughput, reliability and energy efficiency.

In this paper, we propose an efficient backoff algorithm based on the IEEE 802.15.4 MAC protocol that resolves the aforementioned problems. To evaluate the performance of our algorithm, the network simulator (NS-2) has been conducted. Simulation results demonstrate that the proposed mechanism minimized energy consumption especially for higher traffic load.

The rest of this paper is organized as follows. Section2 introduces a description of related literature that has targeted by modifying the 802.15.4 standard. Section3 provides a brief overview of the IEEE 802.15.4 MAC protocol. Section4 analyses and formulates the queue management algorithms to be evaluated and how to configure their key parameters. Sections5 and 6 gives the performance analysis and the simulation results to validate our proposed model, respectively. Finally, section 7 summaries our conclusion.

II. RELATED WORK

IEEE 802.15.4 is considered a new promising technology for WSNs. Many researchers have been studied the performance of CSMA/CA algorithm and introduced different backoff algorithms. Some propositions done by given authors who are related to our research work are studied and related information is given as under.

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Mohit Agrawal and al [6] presents that in the field of computer networks, the implementation management and the performance analysis of queues is one of the foremost issues. The selection of the various queues totally depends upon the need of data transmission. Safe and Reliable propagation of data is a basic requirement of any computer network.

Queues performance assessment requires a concrete research effort in the measurement and deployment of router mechanisms, which advances to protect the Internet from flows that are not sufficiently responsive to congestion notification.

Saman Afrasiabi and al [7] aimed to evaluate the computer networks behavior by NS simulator version 2 (NS-2) and particularly the implementation of the network by this simulator. It draws attention to the investigation of the effect of queuing systems in the network performance.

Thus, various queuing systems such as CBQ, SFQ, DRR, FQ, RED and Drop Tail are implemented by the purpose simulator. Elementary scenarios are compared with each other and network throughput is calculated for each of them. It can be said that the purpose of this paper is to depict the effect of queuing disciplines in the network and to select a good system. As the selection of the type of optimized queue discipline depends upon the network topology, results introduced in this paper are dedicated for special network topology and are not generalized.

Moreover, two mechanisms are proposed in [8]: the enhanced collision resolution (ECR) and the enhanced backoff (EB). The ECR adjusts the backoff exponent depending on the busy results of clear channel assessment (CCA) while the BE is based on shifting the range of backoff period to reduce redundant backoffs based on the results utilized by the CCA. In this scheme, the expected number of shifting range hasn't a clearly computation; the average delay may increase due to shifting range of BP. In addition to this mechanism, we can still use the information CCA1 and CCA2 efficiently to detect channel condition. Therefore, authors proposed the additional carrier sensing (ACS) algorithm based on the IEEE 802.15.4. ACS detects the channel status whenever the CCA2 detects a busy channel. In this case, ACS can provide accurate information that the busy channel is caused by data or acknowledged packet transmission in the CCA2 detecting. The mathematical model is developed to analyze the ACS algorithm.

Zahraa Dahham and al [9] propose an efficient backoff algorithm, called EBA-15.4MAC that enhances the performance of slotted CSMA/CA algorithm. EBA- 15.4MAC is based on two new techniques; firstly, it updates the contention window size based on the probability of collision parameter. Secondly, EBA-15.4MAC resolves the problem of access collision via the deployment of a novel Temporary Backoff (TB) and Next Temporary Backoff (NTB).

III. OVERVIEW OF IEEE 802.15.4

IEEE 802.15.4 defines the characteristics of the PHY and MAC layers for low rate wireless personal area networks (LR-WPANs). Two basic network topologies, star (single-hop) and peer-to-peer (multi-hop), are supported in IEEE 802.15.4 [12]. In the star topology, communications are possible between nodes and PAN coordinator to establish and maintain the transmission. In the peer-to-peer topology, a coordinator is also used and nodes can communicate with any other nodes within its transmission range.

Moreover, the IEEE 802.15.4 MAC layer devices are classified into full function device (FFDs) and reduced function device (RFDs).

An FFD is a complete functional device of IEEE 802.15.4 that supports all MAC layer functions and primitives while the RFD is equipped to support a sub set of them [13]. Also an FFD can be act as a network coordinator or as a network end-device. When FFDs is acting as a coordinator, it can send a beacon defined as a special synchronization frame which is used then for communication between network services. On the other hand, RFDs is only can be act as end-devices and can interact with a single FFD.

A. SUPERFRAME SRTUCTURE

The IEEE 802.15.4 network can work in either a beacon-enabled mode or non beacon enabled mode. Super frame structure is imposed in the beacon-enabled mode as shown in Fig. 1.

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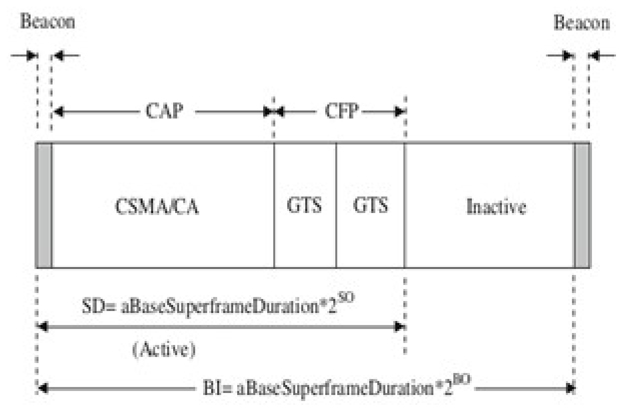

Fig1. IEEE 802.15.4 super frame structure [14]

The super frame is bounded by a network beacons; a special synchronization frames send periodically by the coordinator. A super frame begins and ends with the beacon frame. The length of the super frame is called the Beacon Interval (BI) and it is size defined within the Beacon Order (BO) parameter as follows:

$BI = aBaseSuperframeDuration * 2^{BO}$ symbols (1)
Where $0 \leq BO \leq 14$

Furthermore, each super frame consists of active and inactive period. During the active period, the sensor nodes communicate with coordinator and enter a low-power state to save energy in the inactive period. The active period is referred to as Super frame Duration (SD), and is defined through the Super frame Order (SO) parameter as follows:

$SD = aBaseSuperframeDuration * 2^{SO}$ symbols (2)
Where $0 \leq SO \leq BO \leq 14$

In our simulation scenario, we used an equal value of SO and BO (i.e., S D = B I) to keep the super frame active at all times. In addition, the active period (SD) is also divided into three parts; a beacon, a contention access period (CAP), and a contention free period (CFP). Any device wants to access the channel and communicates during the CAP; a slotted CSMA/CA mechanism is used. Meanwhile, the CFP contains a number of Guaranteed Time Slots (GTS), which is locates at the end of the active period. In CFP, communication occurs in a time-division multiple access (TDMA) technique. There is no super frame in the non beacon-enabled mode, devices are always active and slotted CSMA/CA algorithm is utilized for channel access.

B. SLOTTED CSMA/CA ALGORITHM

CSMA/CA algorithm is used in both beacon-enabled mode and non beacon-enabled mode. In this paper, we focus on the beacon-enabled mode where a slotted CSMA/CA mechanism is used and its flowchart is shown in Fig. 2.

In the contention access period (CAP), each node communicates with the coordinator using the slotted CSMA/CA. Transmission can start at the boundaries of units of time called backoff slots and indicated by aUnitBackoffPeriod = 20 symbols. Each node has a packet to transmit. A delays for a random value of backoff period (BP) is chosen in the range of $[0, 2^{BE} - 1]$ slots, where BE is the backoff exponent who will be dynamically changed in order to optimize the energy consumption.

The backoff is applied to reduce the probability of collision among the contending nodes. Once the backoff timer expires to reach zero, two CCAs are performed to detect the channel condition and to ensure the channel is clear of activities. If the channel is found idle, the node starts to transmit its data and wait the coordinator to send acknowledgment packet.

Conversely, if either the first check of channel busy (CCA1) or the second scan of the channel (CCA2) detects a busy channel, the value of BE and NB will be increased by one. BE and NB have their maximum values which are aMaxBE, and macMaxCSMABackoffs respectively.

If BE exceed its maximum value, it will reassign again in range $[0, 2^{BE}+1 - 1]$, while the transmission will fails and the packets will discard if NB reach to macMaxCSMABackoffs. In this case, failure result will declare to the upper layer.

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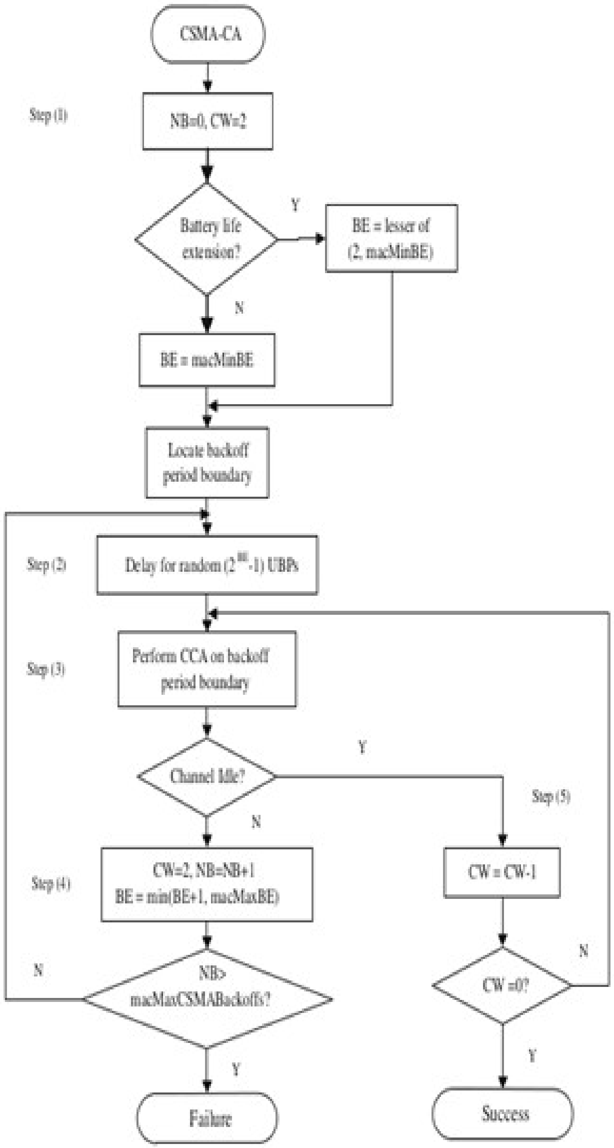

Fig2. Slotted CSMA/CA algorithm[15]

IV. Description of the algorithm

In this section, we will give a brief introduction of our proposed algorithm and an explanation of the basic idea of our proposed model.

A. ALGORITHM PRESENTATION

The motivation of this work is to enhance the performance of the IEEE 802.15.4 slotted CSMA/CA at the MAC layer. These enhancements should take into consideration the power consumption issues to be as low as possible in order to not affect the network lifetime. Also, we wish ameliorate our considered algorithm in order to avoid packet loss and shares the traffic load between all nodes with fairly.

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The algorithm avoids the problem that a node can paralyze before another and lost communication with their neighbors. So in some parts of the algorithm we have defined a parameter who measure instantaneously the length of the queue of each node. Therefore, to have a best scheduling and a high traffic between all nodes, we must give the priority for nodes that have a queue length greater than a given threshold.

Whereas, the channel access priority in CSMA/CA is controlled by macMinBE and macMaxCSMABackoff parameters. So we will add, in the algorithm, a variable called curq_ that gives us the queue length of each sensor nodes, then we are going to vary the value of macMinBE relatively to the state of curq_. The tuning strategy is defined as follows:

```
If curq_ <= qlim-
        Then macMin BE++;
        macMaxCSMABackoffs ++;
        Else if  qlim- < curq_ < qlim+
                Then    macMin BE--;
                macMaxCSMABackoffs --;
                        Else if curq_ >= qlim+
                                Then macMin BE=2;
                                macMaxCSMABackoffs=2;
```

Energy consumption is wasted on account of many reasons, our idea to reduce this wastage energy is to defined three level of priority for nodes and classify them us follows:

(i) Nodes with high priority: define nodes who has a queue length very high and their packet will be automatically dropped. In this condition information will be loosed and a wasteful energy will be consumed to retry to resend the dropped packets. So it is necessary to allow the first priority to these nodes to access channel immediately.

(ii) Nodes with medium priority: define nodes where the queue length has a critical value but haven't a high priority to access the channel at the first range.

(iii) Nodes with low priority: define nodes who hasn't detect any collision and who consume less energy to send their packets. Nodes in this cluster access the channel normally with no urgent condition.

The new parameter used in the algorithm are:

- Curq_: measure the queue length of all nodes and helps to trace queue during arrival packets.
- Qlim- and qlim+: are respectively the minimal value of the queue size and the maximal value of the queue size, it can be used to see the category of the queue size level.

This tuning strategy depends on the situation of the queue length, so we keep *macMaxBE* to a fixed value and we dynamically vary the value of macMinBE and *macMaxCSMA*.

However, when a node has a full queue length we must assign it the smallest value of BE to access to the channel quickly before the others nodes and vice versa.

Note that a high and a fixed value of *macMaxBE* is not detrimental, since it becomes relevant only after several backoff attempts. In addition, it gives opportunity to meaningful variations of macMinBE.

B. NEW MAC ALGORITHM

This algorithm aims to minimize energy consumption, to minimize also packet loss and queuing delay and maintain high link utilization between nodes. This algorithm is applied in the CAP period of IEEE 802.15.4. When a node wish to send a packet, it first initializes the variables NB to 0. and the maximum window size CW to 2, this will let the node to wait for an extend period of time.

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Then we have to monitoring the value of curq_ and check if there are nodes in a saturation condition, this phase will not affect the system performance since nodes will have the priority to access the channel and to minimize the number of dropped packets.

In the proposed algorithm's design, the backoff period BE has been defined as mentioned before. We adapt the backoff period according to the level of priority detected by the queue size of node. Hence, when the queue size decreases in the communication medium, the backoff period can be extended for more durations of time. This effectively decreases the probability to access to the channel. On the other hand, as the queue size increases in the network due to the high traffic, nodes tend to delay for shorter backoff duration. This reflects in better system performance by reducing packet delay due to short backoff period. After setting the appropriate duration of BE. We notice that the whole operation of defining the backoff period differs from that of the existing CSMA/CA mechanism. The idea here is that nodes consume less energy and to not lost information. The program flowchart of our Queue Enhanced Backoff Algorithm (QEBA) is shown in Fig.3

V. SIMULATION

A. PERFORMANCE ANALYSIS

In this section, we analyze the performance of the proposed algorithm based on beacon-enabled IEEE 802.15.4 slotted CSMA/CA. In our simulation, we consider a cluster-tree network topology consisting of a coordinator and N sensor nodes. We assume that each data packet has a fixed length of 70 bytes. We also assume that the system consist of active period without CFP or inactive period.

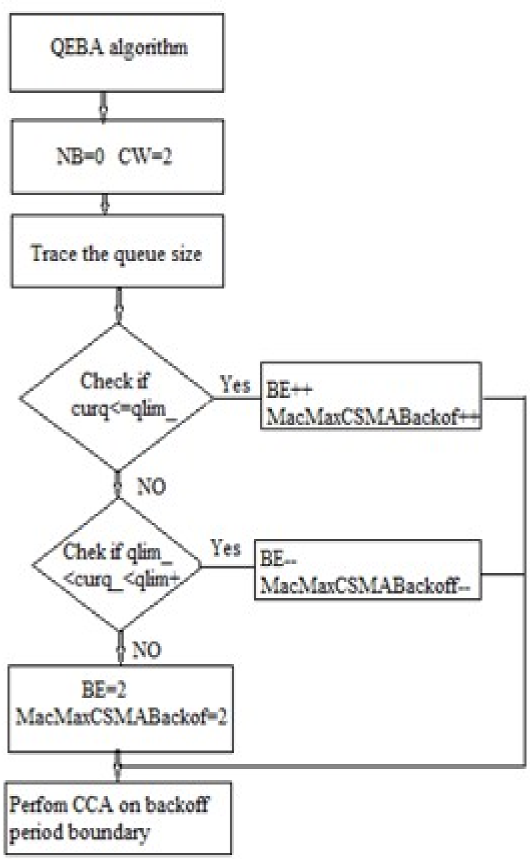

Fig3: The flowchart of the QEBA-IEEE802.15.4MAC algorithm

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By using only the active period, the nodes can follow the slotted CSMA-CA mechanism for channel access. We also considered that all nodes work within the carrier sensing of each other in order to avoid any interruption in a current transmission by other node.

B. PERFORMANCE PARAMETERS

The performance parameters used in this study are energy, throughput, packet drop, and end-to-end delay.

- ***Throughput***

It is defined as the total number of packets delivered over the total simulation time.

To calculate the throughput value we assume p_S and $p_{c,q}$ be the likelihood of a successful transmission.

$$p_s = n \sum_{l=0}^{Q} \frac{\tau_l}{1-\tau_l} \prod_{Q \neq l}^{Q} (1 \qquad (3)$$

Let p_B be the probability that the channel is sensed busy in a time slot. Then it is given by

$$p_B = 1 - P_I = 1 - \prod_{l=0,}^{Q} (\qquad (4)$$

Then $p_B - p_S$ is the probability that the channel is sensed busy by collisions occur from any priority class. In addition, the probability that a collision occurs in a time slot for the priority q class which is denoted by $p_{C,q}$ is given by

$$p_{C,q} = 1 - (1-\tau_q)^{n_q - 1} \qquad (5)$$

Let S_q be the normalized throughput for the priority q class. Let, L, T_S and T_C be the duration of an empty time slot, the payload size, the average time that the channel is sensed busy because of a successful transmission, and the average time that the channel has a collision, respectively.

Note that T_S and T_C are given by

$$T_S = T_H + T_{E(L)} + 2\,SIF \qquad (6)$$

And

$$T_C = T_H + T_{E(L)} + SIFS \qquad (7)$$

Where T_H, $T_{E(L)}$, SIFS, L, t_{ACK}, and γ denote the time to transmit the header (including MAC header, PHY header), the time to transmit the ACK, the time of SIFS, the length of the frame in a collision, the time to transmit a payload with length E (L), and the time of the propagation delay, respectively. Then we can express the normalized throughput S_q as the following ratio:

$$S_q = \frac{E(payloadtrans}{E(length}$$

(8)

- ***Average delay***

In this paper, the delay of a packet is defined as the time elapsed from the instant of the generation of the packet to the instant of the successful reception or drop of it. Let $D_{i,j,k}$ be the time needed to successful transmission or dropping of the packet starting from the state (i, j, k). Note that $D_{i,j,k}$ is a random variable depending on the priority q. Then E ($D_{i,0,0}$) and E ($D_{m+1,0,0}$) are given by:

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$$E(D_{i,0,0}) = P_{S,q} T_S + P \quad (9)$$

$$E(D_{m+1,0,0}) = 0$$
(10)

- ***Packet drop probability***

Throughout the paper, we are assuming that if a collision occurs, the packet is dropped. Therefore, for the priority q class, the probability to be dropped in a time slot equals to the probability to be collided, which can be expressed as follows:

$$p_{D,q} = p_{C,q} = 1 - (1 - \quad (11)$$

$$q \in [0, Q]$$

- ***Energy***

The energy consumption: define the energy consumed while sending or collecting data.

The power consumption of sending or receiving packets in a network mainly consists of two sources: the power consumption state defined as P_{cons} in watt, the power consumption of sending or receiving packets which is defined as P_{spk} in watt and the power consumption to send or receive packets dropped P_{dp}, so it can be reformulated as follows:

$$\mathbf{P_{cons} = P_{spk} + P_{dp}} \quad (12)$$

VI. PERFORMANCE ANALYSIS AND RESULTS

In this section, we compare the results of the new MAC algorithm of IEEE 802.15.4. We simulate the proposed algorithm where 30 sensor nodes with one PAN coordinator are deployed as shown in fig.4(it is a caption of the NS2 tools where it define our cluster tree topology). The range of traffic load has been chosen from 0 to 3 packet/s. We further compare the results of the proposed algorithm with IEEE 802.15.4 according to the network throughput, power consumption and average packet delay. The results show the performance of each metric of a device under a saturation condition, i.e., every device always has a packet to transmit. The results are presented with a 95 % confident level.

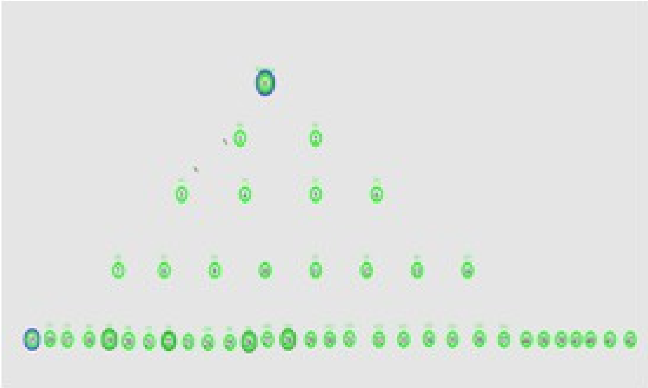

Fig4. Cluster tree architecture

To study how effectively our algorithm is able to dynamically adjust the macMinBE parameter, we define an experiment of medical application. We consider traffic condition of a medical application, where the traffic in the network is dynamically altered in terms of both generation rate and the message size.

Table 1 summarizes the parameters of the simulation model.

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Tab1: The parameters of the simulation model

Parameter	Value
aBaseSlotDuration	60 symbols
macMinBE	3
macMaxBE	8
aUnitBackoffPeriod (UBP)	20 symbols
Topology	Cluster tree
Sensor nodes (N)	30
Packet length	70 bytes
Routing type	AODV
Traffic load	0–3
Data rate	20 kbps
Simulation time	1000 s
BO = SO	3

A general network structure is shown in Fig.5. The network consists of a coordinator, multiple routers and end devices. There is only one coordinator in each network. The coordinator is responsible for the network formation. The routers and end devices can be medical devices such as oxygen saturation monitor, blood pressure monitor, Electrocardiography (ECG), and non-medical devices such as gateway, light and surveillance system etc. In this application, the coordinator and routers are deployed at a fixed location while end devices serve as mobile nodes.

There is no doubt that such a structure is definitely a catalyst to the development of ZigBee Personal Home & Hospital Care applications. For example, the panic button for senior citizen is one of the typical examples of potential ZigBee applications in mobile health. When the senior citizen is not feeling well, he/she may press the on-body panic button, and the call center will receive the help signals and so timely aids/services can be offered. More importantly, ZigBee Personal Home & Hospital Care applications demand that the body status of users must be monitored from time to time.

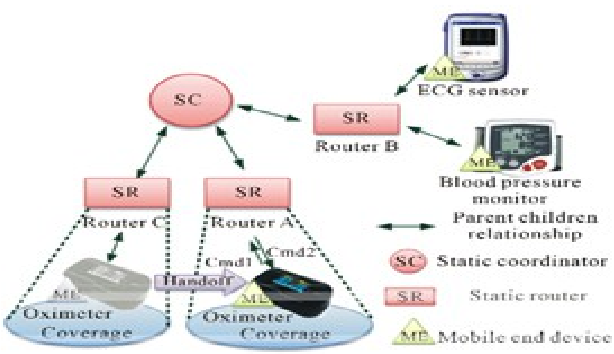

Fig5. ZigBee Fixed-Mobile Network (ZFMN).

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The network structure of the simulation models is illustrated in Fig.6 and the simulation model parameters are shown in Table 1.

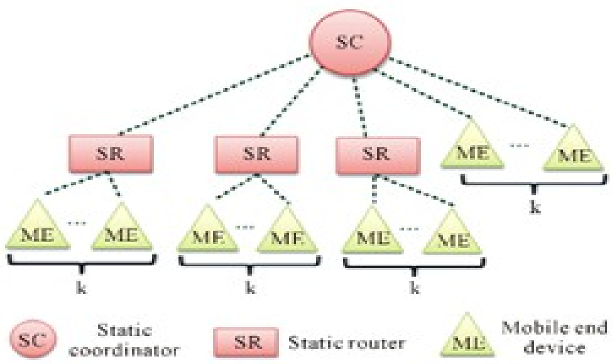

Fig 6. Network structure of simulation model

A. MACMINBE EFFECTS

To explore the impact of this algorithm on the throughput, we show the impact of MacMinBE for a saturation condition

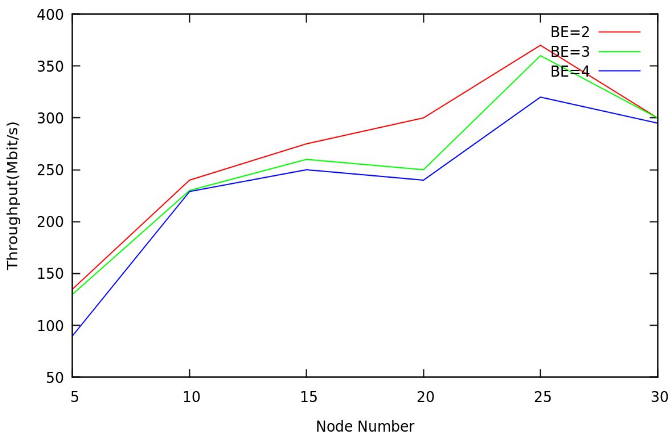

Fig 7.Throughput variation

in Fig.7. As shown in this figure, when the number of nodes in simulation becomes small and for a high value of Backoff Exponent, the throughput of the whole network led to a high value.

Therefore, in a scenario where we have a low collision probability and only few nodes, it is necessary to adopt a longer backoff window (i.e., large BE), which leads to time wasting and worsened throughput.

However, when the number of nodes increases, a large backoff window could help to decrease the collisions probability between the nodes, thus leading to higher throughput.

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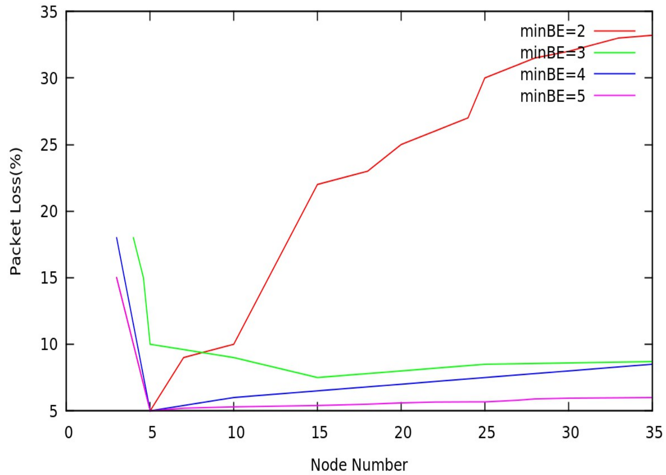

Fig 8 .Network structure of simulation model

Simulation results shows the impact of increasing the BE value on different performance metrics as the number of observed nodes. In these simulations, the macMaxCSMABack and macMaxFrameRetries parameters are maintained to their default values (4 and 3 respectively).

It means that at very high traffic loads, the packet loss probability becomes very high irrespective of the BE value. It is clearly shown that the increase in the number of nodes has a wasteful impact on the performance irrespective of the BE value.

To verify the formula for energy consumption, we show in Fig.9 the energy consumed to successfully transmit one bit of data under different parameters in the saturation condition. Firstly, it is observed that as the number of nodes increases, a successful transmission of every bit of data requires more energy.

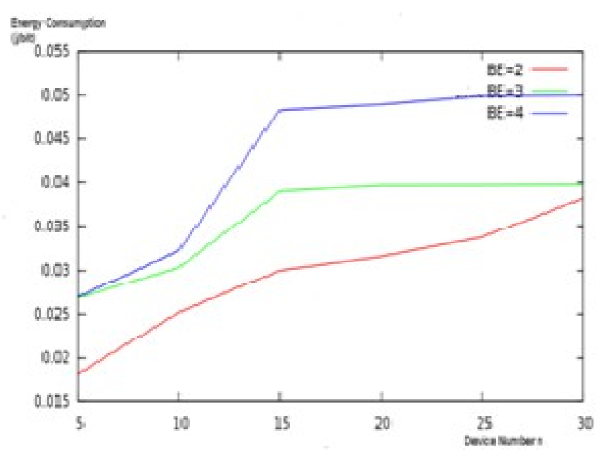

Fig 9. Average energy consumption per bit

For a high number of nodes, energy consumption becomes also so high. It is the large collision probability that deteriorates the transmission process and results in the increase of energy consumption. Secondly, as in the throughput analysis, parameter BE has a strong impact on energy consumption than another parameters. In fact, a longer backoff window can avoid frequent CCA detection, thus resulting in lower energy consumption.

To further verify the impact of BE for access delay, we show in Fig.10 the average access delay for successfully transmitting one packet in the saturation condition. The results show that as the number of nodes increases, the delay decreases slowly at the beginning and then increase gradually when n > 15.

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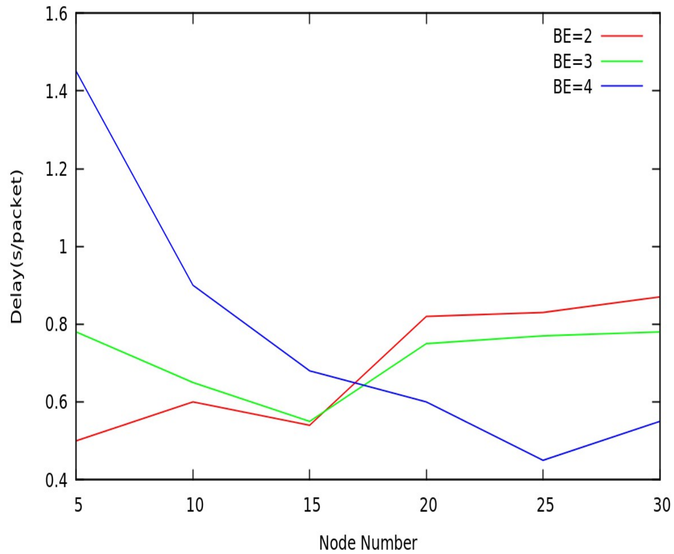

Fig 10. Average delay per packet

Moreover we note that when the number of device is small (n<10), the smaller the value of BE, the lower the delay. This is due to the fact that in the low collision probability scenario when there are only a few nodes present, less time is spent in a backoff period, thus leading to lower delay. However when the number of nodes increase (n > 25), the collision probability is so high that a low backoff period cannot guarantee successful transmission and triggers a new backoff cycle. Therefore the average access delay under smaller value of BE is higher. Finally, it is observed again that parameters BE has a stronger impact on delay performance.

C. *Impact of macMaxCSMABackoffs*

As we see in fig.11, it is clearly shown that for a few numbers of nodes in traffic who wish access to the channel we can see that we have a low packet loss. Hence higher macMaxCSMABackoffs value decreases the packet loss probability.

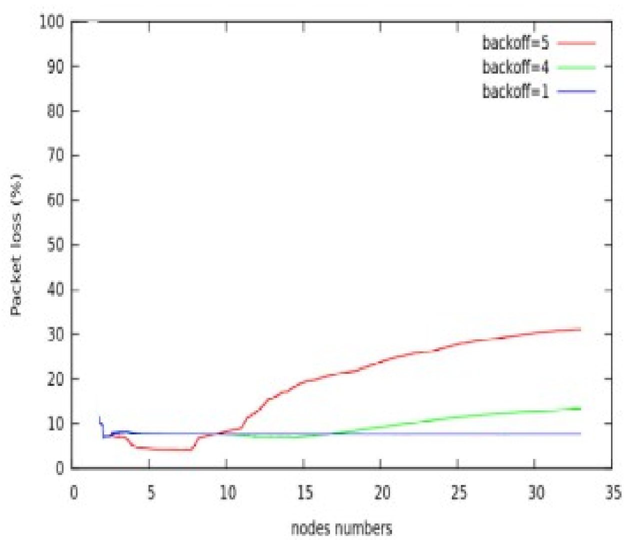

Fig 11. Impact of MacMaxCSMABackoff

With an increase in the number of nodes, collision failure becomes the reason for packet loss and hence higher macMaxCSMABackoffs value increase the packet loss probability. Normally a value of 0 for macMaxCSMABackoffs essentially means that a packet is abandoned as soon as a CCA failure is encountered.

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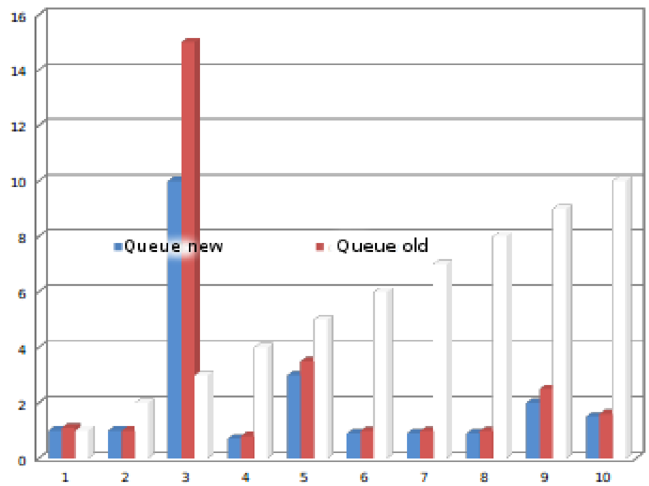

Fig *12.* Average queue length of each node

D. NEW MacMinBE PARAMETER

In our topology node number 3 is considered as a rooter node for which he still active for the whole time. In Fig.12 we can see clearly that our modification has down the queue length of node 3, so the probability of packet loss have been fell due to the minimization of the queue length because we have increasing its chance to access the channel and it has the priority to send its data before the other node.

Also we can see clearly in fig.13 that the length of the working period felled, in this condition nodes tends to enter in the inactive period quickly. Therefore, nodes switch between active and dormant states, and each node may determine its active/dormant schedule independently without wasteful time. This can extremely save the energy consumption.

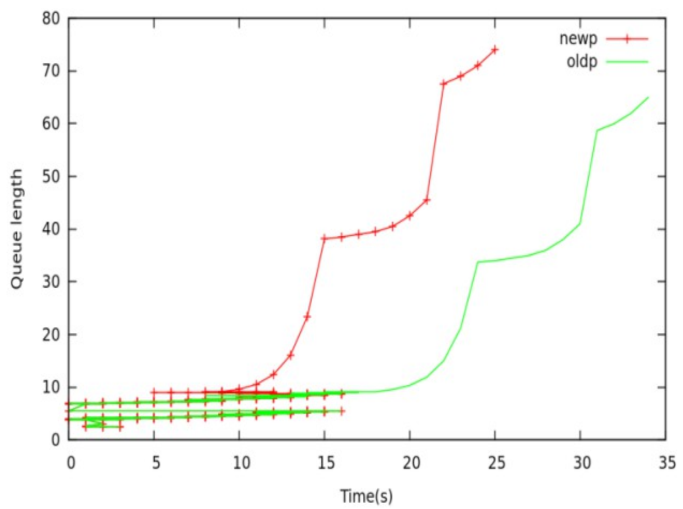

Fig13.queue length of node 3

Fig.14 shows the performance of IEEE 802.15.4 and the new MAC protocol in terms of power consumption. Both 802.15.4 and the new MAC protocol show similar performance and consumed the same level of power for low traffic loads as they work within the congested area and the nodes sent data at much acceptable rates.

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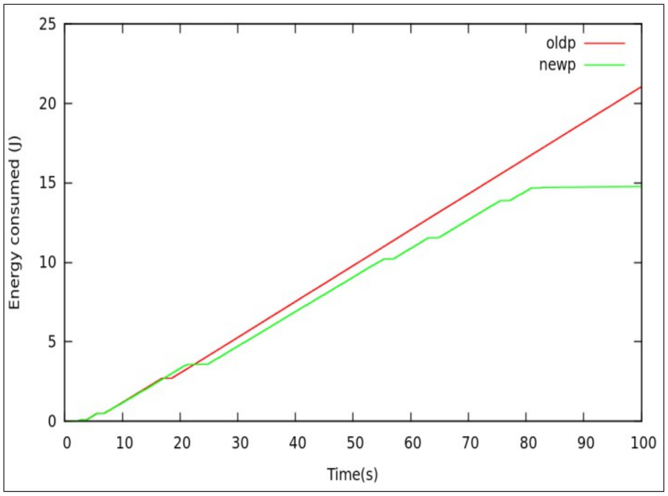

Fig 14. Energy consumption

However, at a higher traffic load, the IEEE 802.15.4 illustrates a jump in the amount of energy dissipation. This arises as a result of network congestion that can be marked by a higher number of packet drops. It is a common problem of all CSMA-CA based MAC protocols when the traffic in a given network increases; the probability of two nodes choosing the same backoff periods is high. Hence, this leads to a packet collision that causes a higher increase in energy consumption.

Furthermore, by applying our proposed algorithm, the power consumption of sensor nodes will not increase rather it becomes stable and less than that of using the traditional CSMA/CA. This improvement in power performance is attributed to the reduction in the probability of minimizing the backoff slots and reducing the probability of lost of packet and its retransmission when it's required to retransmit it.

Fig.15 shows the results of the old MAC program and our new protocol versus time simulation. In Fig.15, we see the effectiveness of our proposed algorithm in terms of throughput compared with that of IEEE 802.15.4. At first the IEEE 802.15.4 and the new MAC algorithm have the same amounts of throughput. However, when the traffic increase in the network, the throughput increase too due to copying the BE's value of nodes that sends their data successfully.

The other nodes will try to access the channel using the same value of BE. Hence, the level of collisions will increase in the network causing degradation in the throughput of 802.15.4 at the end of simulation. In the case of the proposed algorithm, the throughput of the new MAC program is better than that the old one. The main reason is that, the MAC protocol updates the backoff duration according to the level of collision detected.

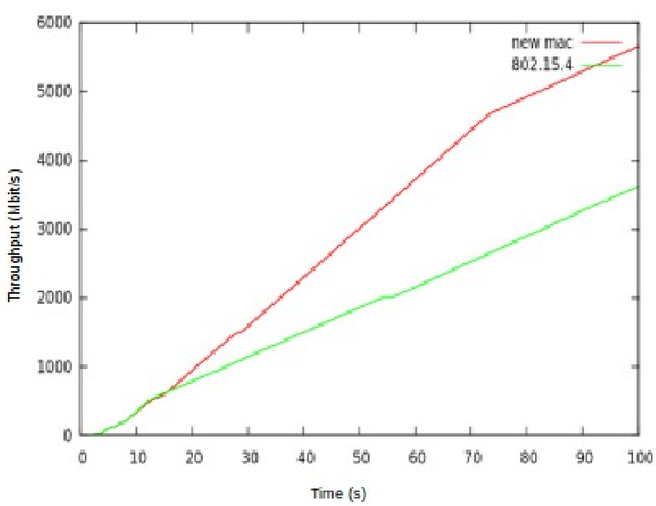

Fig 15. Throughput versus time of simulation

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Fig.16 plots the average delay for IEEE 802.15.4 and the new MAC protocol under different traffic loads. As seen earlier, all the previous graphs show similar performances at low traffic rates since the network can service more packets and the transmission to the destination occurs successfully. However, at higher traffic loads, packets have to wait longer in order to be serviced by the network. This will bring more collisions with a lot of packet drops. In IEEE 802.15.4, a sudden increase in the amount of packet delay traffic load will occur while in the new MAC protocol.

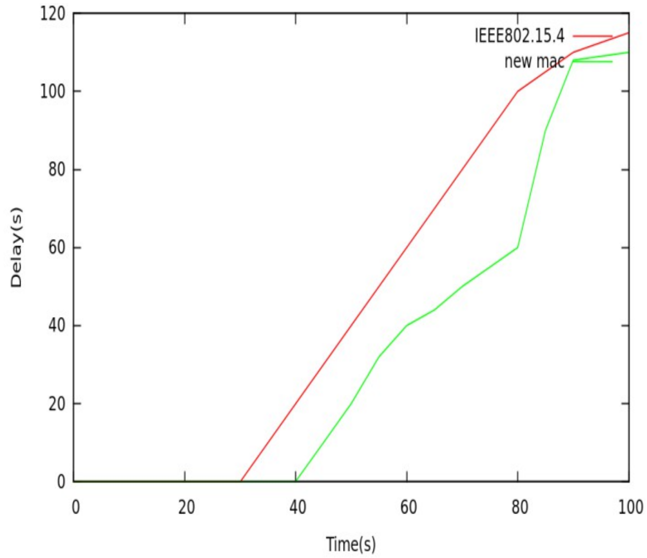

Fig 16. Delay as function of time

This is because a node in 802.15.4 allocates small values of backoff exponents and delays for this limited random number indicated in the range of backoff periods. This method increases the number of packet drops and causes more collisions. Our proposed algorithm decreases the number of packet drops due to the selection of higher values for backoff exponents when the queue is full.

V. CONCLUSION

In this paper, the new MAC algorithm based on the IEEE 802.15.4 beacon-enabled mode is proposed. The idea of our work is to control the backoff duration according to the queue size. In this case, when the shared medium expects a high length of the queue, nodes tend to backoff for a tight duration of time to decrease the number of packet dropped. On the other hand, as the energy starts to decrease, an idle medium is avoided by decreasing the backoff time.

By applying the proposed techniques, possible substantial improvements are shown in the overall system performance. Simulation results confirmed our expectations and demonstrated that monitoring of the queue length outperforms the original IEEE 802.15.4 MAC protocol.

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