

A New Medium Access Control Mechanism for Energy Optimization in WSN: Traffic Control and Data Priority Scheme

Imen Bouazzi^{1,2,*}, Monji Zaidi^{2,3}, Mohammed Usman (Senior Member IEEE)³, Mohammed Zubair M. Shamim (Senior Member IEEE)³

Correspondence: izaidy@kku.edu.sa, Department of Industrial Engineering, College of Engineering, King Khalid University, Saudi Arabia. Member in Electronic and Micro-Electronic Laboratory (E μ E, IT-06) FSM, University of Monastir, Tunisia

Abstract Over the last few years, energy optimization in Wireless Sensor Networks (WSNs) has drawn the attention of both the research community and actual users. Sensor nodes are powered by attached batteries that are considered as a critical aspect of sensor nodes design. Besides, the constraint of the limited battery capacity is associated with the concern on how to reduce the energy consumption of nodes to extend the network lifetime. In this context, the purpose of this study is to implement an adaptive Medium Access Control (MAC) for energy saving and traffic control enhancement. This program was designed to arrange nodes into two priority groups according to their traffic rate and data transmission packet delay. This fuzzy algorithm depends on their queue length where it is implemented into the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) algorithm. However, other types of nodes should send their data during the Contention Free Period (CFP) with a GTS reallocation scheme. Those nodes are classified as low priority access to the medium and their data transmission is scheduled using time division multiple access methods. Moreover, this proposed scheme dynamically adjusts the Contention Access Period (CAP) length to ensure that nodes can complete their data transmission during the same super-frame. Simulation results are done using the Network Simulator tool (NS-2) and it has improved efficiency regarding the IEEE-802.15.4 standard.

Keywords Data transmission, Energy optimization, Priority, Queue, Traffic.

1 Introduction

There has been significant research on the traffic management system using WSNs to optimize the energy consumption and to ensure the priority for an emergency condition. Many researches aim to discuss MAC protocols that involve energy optimization and priority-based allocation. During the last few years, a high number of researches have been concentrated on improving energy consumption and reducing delay for WSNs [1-4]. Furthermore, data transmission management was also being a challenging task for the IEEE-802.15.4 to improve the Quality of Service (QoS) [5-7] by a new slot allocation scheme. The most research optimizes the CSMA/CA method of the IEEE-802.15.4 to improve the quality of service; this method is widely used and recently gained renewed attention. Moreover, there are new techniques applied to schedule the communication and access the medium by using priority schemes. Those protocols optimize energy consumption and improving the QoS, but certainly, there are some expenses of something else.

Various MAC protocols have been developed and studied to improve power saving [8, 9]. In this work, a two-tiered communication between nodes and the Personal Area Network (PAN) coordinator in the network is discussed. Two groups of priority are defined to give priority for nodes to access the channel before other nodes. The first group of nodes is characterized by emergency data in which devices are prioritized to send their data during the CAP period. Each transmission is managed by the PAN coordinator that provides information about the situation of the network, while the second group contains periodic traffic rate and periodic transmission during CFP. The main purpose of this work is to improve the energy consumption in WSNs under the MAC sub-layer. Sensors have a small size in which their batteries cannot be recharged or replaced, for this reason improving their energy consumption can optimize their network lifetime. The motivation behind this work is to propose a dynamic mechanism to adapt nodes for different traffic conditions. This finding implements a new hybrid protocol that combines both the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) and the Time Division Multiple Access (TDMA) methods to schedule the medium access control. Authors use a hybrid mechanism to schedule communication in the network depending on the traffic rate and data packet transmission delay of each node. The dynamic classification is used to perform communication in WSN and optimize energy consumption. This paper is structured as follows: Section 2 cites the recent related works to our work. Section 3 depicted the IEEE-802.15.4 standard overview. Then, section 4 presented the control strategy of the Dynamic Adaptation Mechanism for Traffic (DAMT) algorithm. Section 5 and 6 describe the TC-MAC based algorithm of the GTS reallocation. Next, experimental results are developed in section 7. Section 8 discussed the proposed finding. Finally, section 9 concluded the paper.

2 Related works

WSN is a new research area created to offer economically attractive solutions, to facilitate their deployment, to remote monitoring and for data processing in complex and distributed environments. Many research works use the QoS parameter to improve the efficiency of the WSN, such as optimizing energy consumption. Furthermore, varying the inter-arrival time and allocate different levels of priority for nodes can really minimize energy consumption [10], where, a priority scheme was developed by an arrival priority queue. A dynamic adjustment of data transmission delay was also studied to improve energy consumption and to prolong the network lifetime [11].

Optimizing energy by a modulation method based on computing the consumed energy was developed in [12]. This scheme was specified by the IEEE-802.15.4 to improve the network lifetime. Also, authors in [13, 14] were modified the sleep time to reduce energy consumption, in which they presented a cross-layer solution based on the combined use of duty-cycling MAC protocol. In [15] a hybrid CSMA/CA-TDMA scheme to evaluate the congestion and the collision problem in the network was proposed. They used a Markov Decision Process as transmission strategies to access both the CAP and the CFP period. The proposed method used a queue status to evaluate congestion and provide an offered traffic to do not go beyond the channel capacity.

The authors in [16] suggested an approach to evaluate the IEEE-802.15.4 standard during the CAP and the CFP period. These approaches looked forward to effectively allocate an adequate Guaranteed Time Slot (GTS) for the desired node. Based on the packet data length, the slot duration will dynamically change. A Markov chain model is used to adjust the length and the start time of the GTS slot based on the packet length. In articles [17] and [18], the authors proposed a priority-based MAC protocol to evaluate the IEEE-802.15.4 performance. They dynamically allocated slots time based on traffic priority information to reduce effectively the access delays. Improving energy consumption was also achieved in [19] by introducing a priority level MAC to transmit data. In which, a priority bit was added in the beacon frame to decide the type of data transmission.

A MAC protocol algorithm [20] optimized both the energy consumption and the packet latency. Authors, in this work, proposed a crossing hybrid MAC scheme that dynamically switched the communication channel for MAC protocol between TDMA and CSMA. This algorithm is based on routing information of Ad Hoc On-Demand Distance Vector (AODV). Authors alternate nodes that are not concerned in data transmission to schedule their data using the TDMA method. A backoff enhancement algorithm was developed in [21] to achieve less probability of identical backoffs and to improve the reliability of the received data at the coordinator node. The traffic adaptation algorithm was presented in [22] by an adaptation of the duty cycle using Superframe order (SO) and Beacon order (BO) parameters of the super-frame. Therefore, paper [23] focused on how effectively manage the transmission in a network by an automatically hidden bypass concept. A mechanism that automatically creates or removes a hidden bypass was developed to improve the transmission delay and the throughput. The concept of priority in WSN has become the famous idea that optimizes energy consumption based on the application requirements, many works such as [30] assign tow level of priority for nodes to balance energy consumption in a neighborhood and try to balance theirs to balance their activity. To reduce the contention delay, a priority scheme is settled to nodes that are more active by using adaptive cross-layer design. Several works are discussed in the literature to reduce energy consumption to increase battery life such as [31]. Authors, in this work, examine the idle listening of nodes by using a cross-layer design that has improved the efficiency of the WSN. Low power communication can be ensured also through radio frequency connectivity. Authors in [32-33] deal with the radio frequency module to replenish the battery of a sensor node, through an experimental study; they demonstrate how the placement, the chosen frequency, and several radio frequency energy transmitters impact the sensor charging time. These studies are elaborated to design a MAC protocol to deal with energy consumption and optimize the quality of service. Based on all these studies, the technical contributions proposed in this work aims to more optimize energy consumption and outperform problems that come across sharing functionality between nodes and have equitable energy consumed in the hole networks.

Several methods of energy optimization were developed in the literature. We have introduced a new scheme in WSN using IEEE-802.15.4 technology communication. So, this work aims to implement an adaptive MAC algorithm for energy efficiency and traffic control enhancement. For the intended protocol, information about the situation of nodes must be gathered and transmitted to the Personal Area Network (PAN) and then forwarded in the next super-frame. The transmission procedure will be scheduled according to traffic information and data packet transmission delay of each node. Therefore, the elasticity of the transmission procedure in this proposed contribution can improved energy consumption and allow nodes to send data with a low probability of collision. Thus, the proposed scheme used a hybrid transmission method which uses both CSMA/CA and TDMA method for tow priority groups of nodes.

3 GTS allocation scheme

The IEEE 802.15.4 standard allows the ability to optimize the QoS of the network by a slot reservation mechanism; however, the use of this mechanism is not suitable for all networks due to the limited number of the reserved GTS to seven. Any node wishing to communicate during the CAP must compete with the other nodes using the CSMA/CA mechanism. The communication is done through slots or time slots reserved during the CFP. The GTS mechanism allows a node to operate in a

channel transmission according to the time that is allocated to it by the coordinator. A node must attempt to request and use a GTS if only it is listening for beacon frames. The GTS must be allocated by the PAN coordinator and must be used for communication between the node and the PAN coordinator. The GTS must be released at any time by the coordinator or by the node itself if it no longer wants to use it. For each GTS, the PAN coordinator must record the beginning of the slot, the length, the direction and the address of the node with which it is associated.

A node must request the allocation of a new GTS through a GTS-Request-command with the characteristics provided by the upper layers. When the PAN coordinator receives this request, he must send an acknowledgment. The coordinator then checks if there is enough capacity on the super-frame based on the size of the CAP and on the length of the requested GTS. The super-frame has enough capacity if the maximum number of GTSs to be allocated is not reached or if the allocation of this GTS does not reduce the CAP size unless aMinCAPLength parameter. When the node receives the acknowledgment from the coordinator, it continues to monitor the beacon frames during aGTSDescPersistenceTime. When the PAN coordinator decides to allocate a GTS, he must generate a descriptor with the requested specifications and the address of the node that requested it and inform the upper layers. This descriptor indicates the length and the beginning of the super-frame. In the opposite case, the beginning of the slot must be reset, and the length must be reset to the length of the largest allowed GTS. This descriptor must be sent in aGTSPersistenceTime. Upon receipt of the super-frame, the node processes this descriptor and informs the upper layers of the GTS allocation. The node that wants to release the GTS that has been allocated to it must send a command of type "GTS request". An acquittal is sent by the coordinator and the latter must also begin the release process. The coordinator must ensure that there are no empty spaces in the CFP.

4 Control strategy of the hybrid mechanism

4.1. Traffic control mechanism

In this section, a brief description of the DAMT (Dynamic Adaptation Mechanism for Traffic) algorithm [34] is described. The proposed works classify nodes into two cluster types; first, the author measured the traffic rate and calculated the time needed to transmit one data packet. Then, according to that information collected after several simulations, they assume that nodes which have high traffic rate and random data packet transmission delay are considered as emergency nodes in group one. Those types of nodes will have the priority to access to the medium immediately without reservation of any GTS slots, by scheduling their data transmission using the CSMA/CA method during the CAP period. Those nodes will be classified later according to their queue length using a fuzzy logic rule as described and explained in [24]. The use of fuzzy sets allocated with a priority level guarantees a deterministic power saving, consider the following:

- (i) Inputs parameters: Queue length and traffic rate
- (ii) Output parameter: Priority to access to the medium
- (iii) Rules:
 High priority → BE --, MacMaxCSMABackoffs --;
 Medium priority → BE = 2, MacMaxCSMABackoffs = 2 ;
 Low priority → BE ++, MacMaxCSMABackoffs ++ ;

In the fuzzy logic algorithm presented in [25], nodes are classified into three levels of priority according to their queue length and their traffic rate. This mechanism dynamically adjusts the backoff exponent (BE) value by increasing its value or decreasing it depending on the priority level of nodes. Whenever nodes have a full buffer size and a high traffic rate, the value of BE should be decreased to minimize the time needed to access the medium and vice versa. This mechanism is implemented in the CSMA/CA method of the NS-2 library. On the other hand, the rest of the nodes, that do not satisfy the proposed condition, are considered as normal nodes in the second group. The data transmission phase for the second type of nodes will be done only during the CFP period. The data transmission procedure is illustrated in Fig.1. The hole communication between nodes in group one and the PAN coordinator is done only during the CAP period, otherwise for nodes in group two the channel access and the reservation of GTS slots are done during the CAP period, however, their data transmission is done during the CFP period using their reserved GTS slots. The PAN coordinator is the node in charge who broadcast beacon frames including all the necessary information including the priority type and the parameter presented the CAP length. After each operation, an acknowledgment frame is delivered from either the PAN coordinator or nodes.

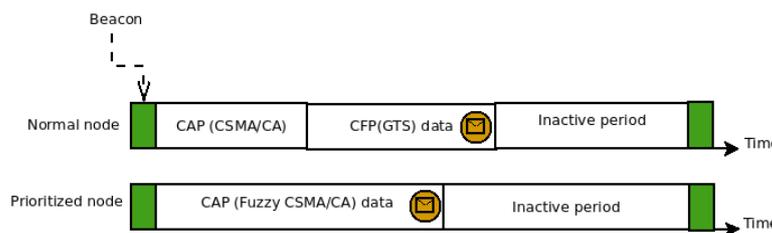


Fig. 1. Data transfer procedure

Hybrid use of both CSMA/CA and TDMA methods to transmit data is used to provide considerable guaranteed transmission. In the first step, we measured the traffic rate of each node and the time needed to transmit one data packet. This information will be sent to the PAN coordinator to be dealt with later, to decide which priority group it is. An indicator of the priority of nodes is appended by adding a one-bit field into the beacon frame to schedule communication; this will be explained in the next subsection. According to the measured information, the PAN indicates that urgent data are considered as a high priority data packet when the bit is set to 1 and non-critical data when it is set to 0. If this bit is set to 1, so transmission will be performed during the CAP period, and if it is set to 0 then the transmission will be performed during the CFP period. If the measured traffic is greater than 50 Kbps and the time needed to transmit data packet cannot be estimated and it is variable from one node to another, in this case, we mentioned that the data will be transmitted during the CAP period. When nodes are appreciated to have an unpredictable wakeup-sleep period, in case of having high traffic in the network, this may have more energy consumed in listening to the channel.

In step number two, the transmission is decided to be in the CAP period, nodes are classified one more time according to their queue size and their traffic rate in the network. As already said, the modified CSMA/CA method is used to transmit data by adjusting the BE value to provide nodes that may have lost packets. Then in step three, an incrementation of the CAP length period is done to prolong this period to support more slots. On the other hand, nodes with less priority will have a GTS slot reserved for data transmission, so we minimized the CAP length to avoid the problem that we cannot transmit data packet during the CFP. This adjustment can improve delay and energy consumption to not defer transmission in the next super-frame. The traffic adaptation algorithm is illustrated below in Fig.2.

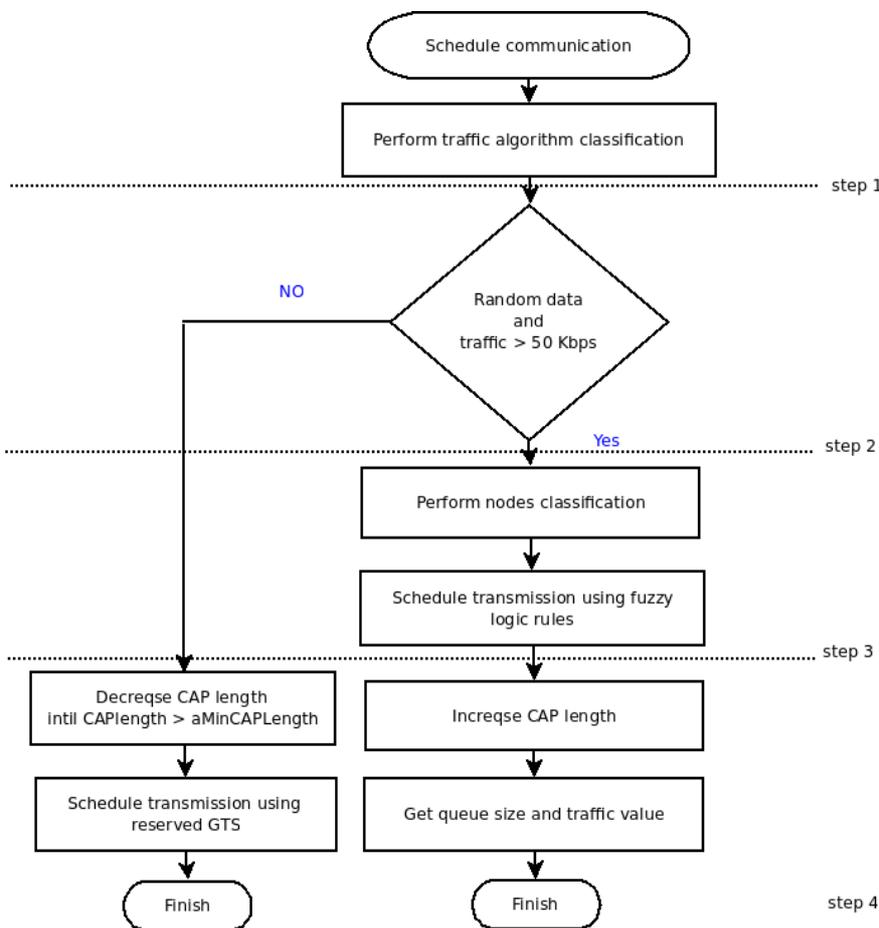


Fig. 2. Traffic adaptation algorithm

4.2. CAP length adjustment

The IEEE-802.15.4 is the most suitable MAC choice for optimizing the energy consumption where he is flexible for any changes. To get information about the slot times duration in a super-frame, the duration is regularly expressed in numbers of symbols, not in second. The 2.4 GHz PHY layer duration of 1 byte= 2 symbols = 32 μ s [27]. A slot frame is a collection of timeslots repeated in time. We define the time needed to transmit a successful data packet as TD. The PAN coordinator stores information about the traffic rate and TD. For high priority nodes, data transmission is performed during the CAP period. The PAN coordinator should not reserve any GTS slot for nodes that will send data using the CSMA/CA mechanism and cancel

any recommendation to send data during the CFP period. The total length of the super-frame is unchangeable but a variation on the duty cycle is required to change the length of the active period. The active period depends on the SO parameter entered by the user, and then according to the traffic condition, it will be changed dynamically. Nodes which transmit their data during the CAP period can increase the number of data packets transmitted due to the increase of the CAP length which can be calculated as given in equation 1:

$$L_{CAP}[S] = Nb_{slot} - B_{duration} - \sum_{n=1}^{Nb_{GTS}} \frac{LGTS}{Slot_{duration}} \quad (1)$$

Where $n \in (1; N_{GTS})$

Algorithm 1. CAP length adjustment

Input: Traffic rate and the required time to send a data packet

Output: CAP duration

At each beacon interval

While (! End of CAP) do

Rate= R.getRate();

For each packet received calculate T_D ;

If ((Rate < 50) && ($T_D[i] == T_D[i-1]$) && $SO > 0$) Then

tcap++;

$SO_{next} = SO_{current} + 1$

Else if (tcap >= aMinCaplength) Then

tcap- -;

$SO_{next} = SO_{current} - 1$

Else

$SO_{next} = SO_{current}$

End if;

End while;

Broadcast beacon frame;

Where Nb_{slot} defines the number of slots in a super-frame, B duration defines the beacon frame duration, Nb_{GTS} defines the number of GTS generated in a super-frame, LGTS defines the duration of one GTS and slot duration define the duration time of one slot in the super-frame. To save more energy consumption, nodes can switch between active and dormant states periodically. This state is controlled by the SO and BO parameters defined in each network area. To update the CAP length, the duty-cycle parameters should be settled to get the new CAP length at each time slot. Figure 3 presents the duty cycle variation. Two types of data transfer transactions exist using the IEEE-802.15.4; they are direct and indirect transmission.

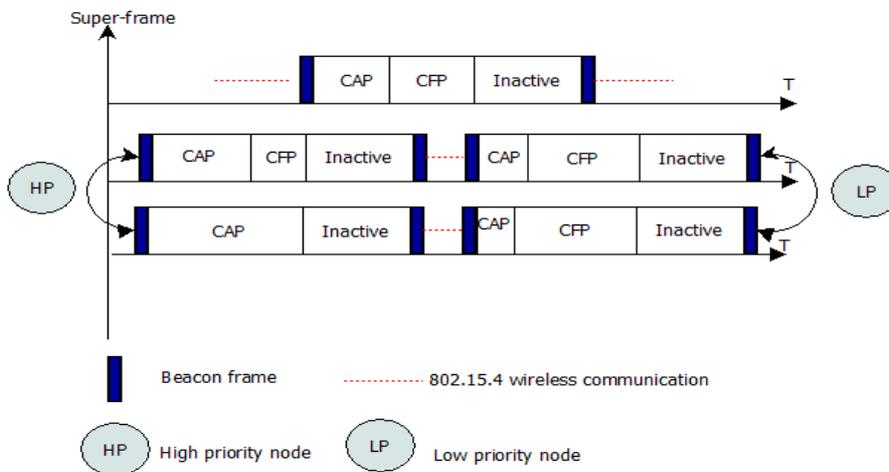


Fig. 3. Set of super-frames using our hybrid scheme

In a beacon-enabled network, a device wishing to send data he should first listen to the network beacon. Let us assume that each time node i needs to transmit data, it should wait for a random BE period in the range of $[0; 2BE-1]$ before performing the CCA (Clear Channel Assessment) and assuming that other super frame parameters are defined as presented in table 1. If the channel is found to be free, and if the backoff exponent BE is set to MacMinBE which has the default value of 3, then the access time can be computed as:

$$\begin{aligned}
 T_{CA} &= \text{InitialBackoffPeriod} + CCA \\
 &= (2^3 - 1) \times a\text{UnitBackoffPeriod} + CCA \\
 &= 7 \times 320\mu s + 128\mu s = 2.37\text{ms}
 \end{aligned}
 \tag{2}$$

Fig.4 shows the packet scheduling delay, we define then the total time needed to transmit one data packet in acknowledged transmission as follow:

$$T_t = T_D + T_{ca} + T_{BE} + T_{ack} \tag{3}$$

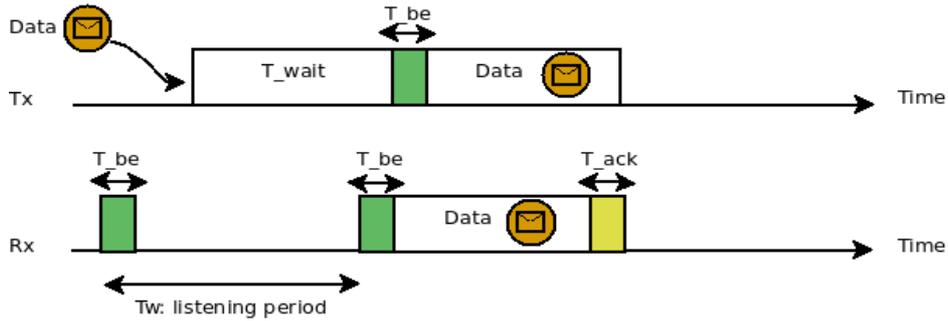


Fig. 4. Packet scheduling delay

Tab. 1. Super-frame parameters

| Parameters | Value |
|-------------------------|-------------|
| SO | 3 |
| BO | 3 |
| Slot time | 0.32 ms |
| Frame size | 128 bits |
| Minimum CAP size | 440 symbols |
| SD | 15,36ms |
| Contention period | dynamic |
| LIFS (for large packet) | 40 symbols |
| SIFS (for small packet) | 12 symbols |
| UnitBackoffPeriod | 20 symbols |

5 TC- MAC traffic classification

To ensure network stability, we are interested in the beacon mode of the IEEE-802.15.4. Indeed, the goal is to reserve network resources using the GTS mechanism. Nodes are classified according to their traffic rate and the data packet delay using a fuzzy logic rule mechanism. We have defined for this fuzzy system two sets of priority groups that will dynamically schedule data transmission during the contention active period or the contention-free period. A group of nodes with an emergency data transmission send data during the first active period of the super-frame using the modified CSMA/CA mechanism presented in our previous work [25]. However, during the CFP period, we are intended to develop dynamic management of GTS to ensure a fairness slot allocation between nodes. We have defined a rigorous fuzzy system that admits traffic rate measurement and the time needed to transmit successfully one data packet as fuzzy input parameters. At each super-frame, the PAN coordinator should collect information about all nodes to define a priority set group. The input linguistic variable admits a triangular membership function however the output parameters will be presented using a singleton function.

$$\text{Traffic_rate} \in \{\text{emergency, on demand, normal}\} \tag{4}$$

$$\text{Packet_delay} \in \{\text{random, continuous}\} \tag{5}$$

A total number of possible combinations arranged as a pair of these states is 6. For each of them we must establish an appropriate state for the output fuzzy variable where P designed priority and NP mean that there is no priority, as shown in table 2:

Tab.2. Fuzzy rules base

| Packet delay Traffic | Emergency | On demand | Normal |
|-------------------------|-----------|-----------|--------|
| Random | P | P | NP |
| continuous | P | NP | NP |

This TC-MAC traffic control-based MAC algorithm address the problem of IEEE-802.15.4 of the unfairness GTS allocation for high traffic network. However, the delay in the DAMT algorithm hasn't been well improved, so, for this reason, we have improved the GTS allocation for nodes according to several conditions. In the proposed work we suppose that the PAN coordinator has allocated seven GTS for seven nodes, then each node desire to allocate another GTS it will share the first GTS allocated for the first incoming node in a condition that they share the same specifications. This management is applicable for just 11 nodes in the network, more than 11 nodes the PAN coordinator decline every GTS reservation until all nodes accomplish their data transmission. The main aim of the TC-MAC algorithm is to reduce contention in the CFP period and provide a fair chance for a low traffic network. The classification of nodes is done for two groups of priority as presented in figure 5; nodes with high priority send their data during the CAP period however the second type of priority of nodes is intended to send their data during the CFP. During the contention access period nodes are also classified into three groups of priority according to their traffic rate and their queue length as explained in our previous work. Besides the second group of nodes transmit their data according to the TC-MAC proposed algorithm by a dynamic GTS request allocation for the PAN coordinator. In this method, priority is assigned for nodes with different status of traffic rate and data transmission delay in order to improve the IEEE-802.15.4 standard and ameliorate the network lifetime.

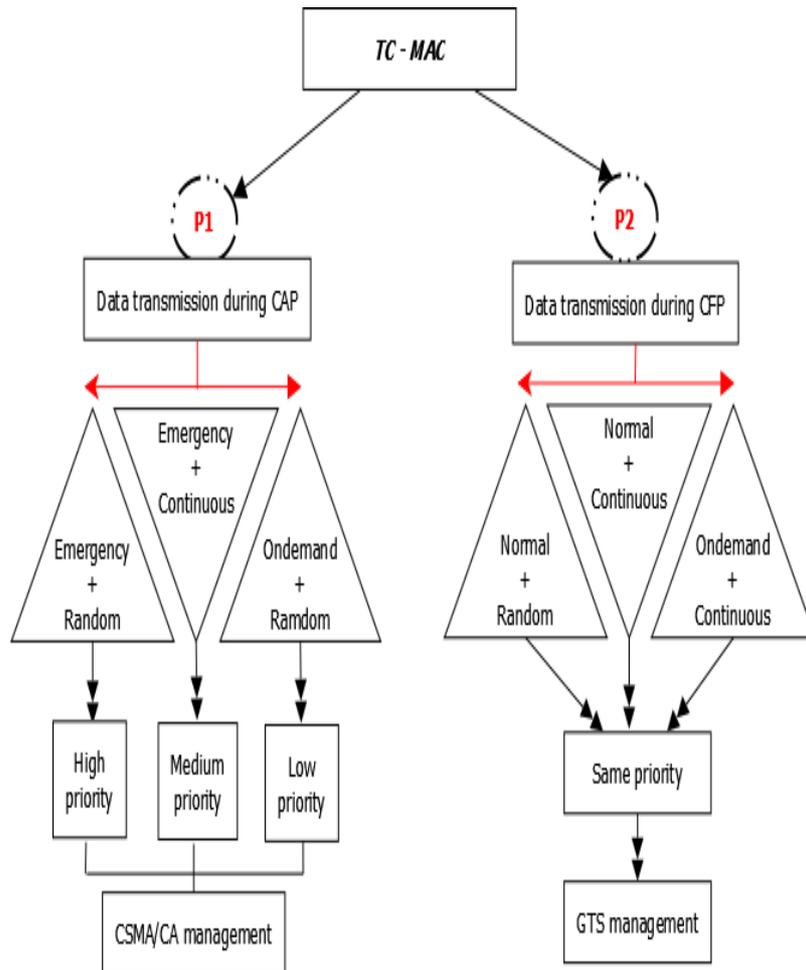


Fig. 5. TC-MAC implementation

6 GTS allocation scheme

The IEEE-802.15.4 standard presents an unfairness GTS allocation for nodes, in this section, the proposed scheme tried to address this problem by a new reallocation of GTS slots duration. To address the problem of the average delay processed in the proposed algorithm described in section 4, we address the CFP period by management in the GTS slot allocation and the slot duration time. However, the rest of the nodes are reorganized into two groups of priority according to the time needed to transmit one data packet. For periodic data transmission delay, we distinguished two range of the traffic rate as presented as follow:

$$P1 = \{Medium, Periodic\} \text{ and } \{Low, Periodic\} \quad (6)$$

$$P2 = \{Low, random\} \quad (7)$$

The proposed scheme deals with periodic data transmission delay and low traffic rate where nodes constantly gather information at periodic slot times. Nodes in this group of priority frequently transmit data in a periodic interval. This proposed scheme is adequate for remote sensing applications where nodes periodically sense and transmit data to the PAN coordinator, so the main aim of this work is to allow more nodes in the network to share GTS and avoid the unfairness in slot allocation. The basic method used to allocate the GTS slot in the IEEE-802.15.4 standard is the method of First in First out (FIFO). The PAN coordinator allocates a maximum number of 7 GTS slot to nodes and it gets quickly consumed in case of low traffic and hold them implicitly or explicitly deallocation. In several cases most nodes don't have data to be sent in each super-frame in case that events transmission is uncommon. However, if the time of implicit deallocation expires then other nodes in the network may be prevented to not allocate GTS due to the unavailability of more slots in the contention-free period; this takes place for unfairness allocation in the GTS. According to the traffic rate information for each sensor node, the PAN coordinator of the network preserves a fairness distribution of GTS between nodes. Hence, every node should identify to the PAN coordinator and send him additional information about the traffic rate and time needed to transmit one data packet. This scheme addresses node that is allocated a GTS and then they abandon it by explicit or implicit deallocation.

In the IEEE-802.15.4 standard, the PAN coordinator awards a maximum number of seven GTS for nodes by using the mechanism FIFO, these seven nodes maintain each reserved slot until holding it. The desired achievement is to allow the PAN coordinator to assign more than seven GTS by a fairness distribution between nodes in the network and allow more than seven nodes to access the contention-free period. The goal of this scheme allows more nodes to share communication in the same super-frame. These groups of nodes have a low average packet arrival rate and they haven't data to be transmitted in each super-frame, for this reason, we have chosen to reallocate the GTS for another node. In this way, the PAN coordinator provides the last GTS to be used by the first six nodes. This can be ensured by a GTS reallocation test if the considerable GTS can be reused or not. The flowchart presented in figure 6 explains the proposed scheme to reallocate GTS slots.

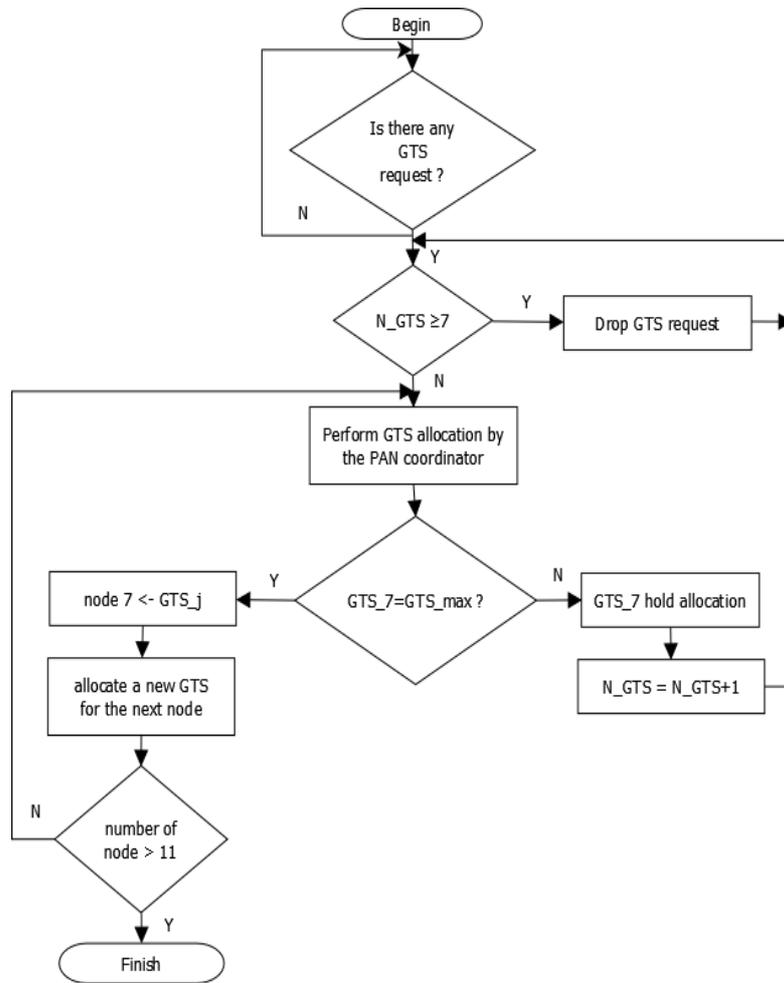


Fig. 6. GTS reallocation scheme

After running this code, if the last node that has been allocated a GTS to transmit its data return true at the end of the code, this last one will share the same GTS with one of the six nodes. Moreover, if the node number one was chosen to share the same GTS with the node number seven, then at each connection attempt of node number seven, the GTS reserved for node number one will be reallocated to the node number seven. After, the PAN coordinator reallocated the GTS reserved for node number seven, because this last one shares the same GTS of the node one and reserve a GTS for a new node wishing to transmit its data as explained in figure 1. Nodes that share the same GTS transmit their data during the contention-free period until they share the same average arrival time and the average time needed to transmit one data packet, else node number one hold the GTS. For the next n super-frame, this process is repeated, and the PAN coordinator checks the test with node number 8 until it satisfies the required condition as shown in the algorithm number 2.

Algorithm 2. GTS reallocation scheme

```

Begin
Nb_GTS = number of allocated GTS
While (GTS request received = TRUE and node number ≤ 11) do
  If (Nb_GTS ≤ 7) Then
    Get nodes information
    For (i=0; i<6; i++) do
      GTS[i] = {GTS1, GTS2, GTS3, GTS4, GTS5, GTS6}
      GTSmax = max GTS[i]
    Return GTSmax
    End for
    If (GTS7 = GTSmax) && (GTSDirection = Transmit) Then
      Return TRUE
    Else Return FALSE
    End If
  Else drop GTS request
  Repeat until (n+1)th super-frame
  End if
End while
  
```

This proposed scheme behaves like a memory as presented in figure 7 where it deals with the unfairness GTS allocation to improve the average delay in the network by avoiding the wasted slots in the super-frame. Therefore, the PAN coordinator of the network allocates the GTS based on the average arrival information for all nodes to make the decision of a predictive model for GTS allocation based on the traffic rate and data delay transmission. This scheme is implemented using the NS-2 tool to evaluate the performance of the proposed scheme compared to the IEEE-802.15.4 standard. In the next section, an experimental result improves the efficiency of our algorithm.

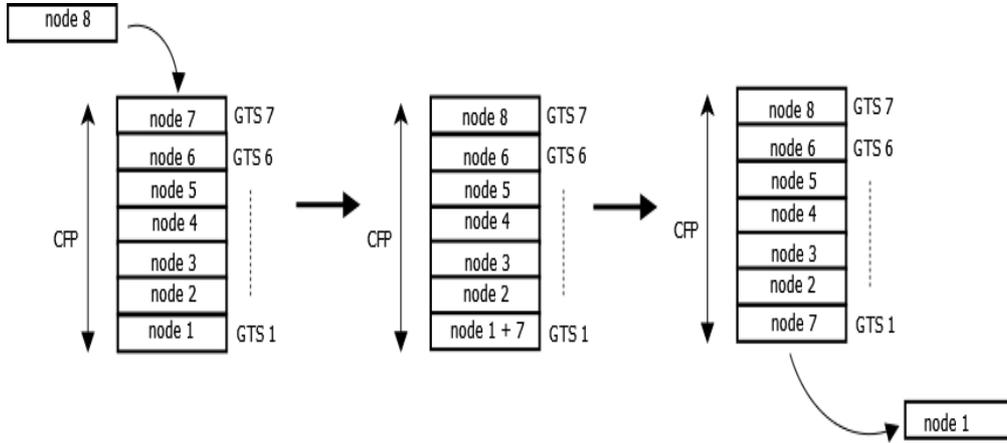


Fig. 7. The new CFP adjustment

7 Experimental results

7.1. Performance Analysis

This paper models energy consumption for beacon-enabled time-slotted media accessing control cooperated with data scheduling in a cluster tree network formulation for IEEE-802.15.4 standard an initial energy equivalent to 1000j. The hybrid access control mentioned earlier has been tested by simulations using the ns2 tool. We developed the simulator using the C++ language to evaluate and compare the performance of the IEEE-802.15.4 in low power consumption. The performance of the proposed scheme based on the beacon-enabled MAC layer is compared with the IEEE-802.15.4 standard. The longest distance of the transmission range in one hop is 30m. To evaluate the performance of the power consumption and the total number of dropped packets. Parameters presented in Table 3 are used for the simulation model:

Tab. 3. Simulation parameters

| Name | Value |
|--------------------|--------------|
| Simulation time | 1000 s |
| Topology | Cluster tree |
| Channel frequency | 2.4 GHz |
| Node number | 11 |
| Network size | 200 * 100m |
| Packet size | 250 bytes |
| Initial energy | 1000 J |
| Queue size | 50 |
| Physical data rate | 250kbps |
| NumSuperframeSlots | 16 |

7.2. Energy consumption

To enhance the energy consumption, we have proposed an algorithm that classifies also nodes into two categories. Nodes with emergency data send their data during the CAP period and nodes with normal traffic should send their data during the CFP period. This classification is accomplished according to the packet transmission delay. Whenever the measured TD parameter is a random value, the transmission is performed during the CAP period. When the required time to transmit one data packet has a periodic value, the transmission should be done during the CFP period.

Suppose that data transmission is done only during the CAP period using our fuzzy proposed scheme. The sleep period will be increased wish leads to improve energy consumption in the networks. In WSN, the acquired power of a receiver node is

extremely less than the power consumption in the active period. In addition, it must be larger than the power consumption in the sleep state, we assume that:

$$P_{tx} > P_a \gg P_{rx} > P_s \quad (8)$$

Where P_{rx} presents the power consumed by the receiver node, P_a defines the power wasted during the active period, P_{tx} is the power harvested during the transmission and P_s present the power consumed during the sleep state. Let us assume that the amount of the consumed energy in the active state is equal to the amount of the harvested energy during the period of the sleep state at the same round:

$$E_a(t) + E_{tx}(t) = E_s(t) \quad (9)$$

E_a and E_{tx} define the amount of consumed energy during the active period. E_s is the amount of charged energy in the sleep state. Therefore, we can derive the following equations from (8):

$$E_a(t) = P_a T_a(t) - P_{rx} T_a(t) \quad (10)$$

$$E_{tx}(t) = P_{tx} T_{tx}(t) - P_{rx} T_{tx}(t) \quad (11)$$

$$E_s(t) = P_{rx} T_s(t) - P_s T_s(t) \quad (12)$$

From this equation, we can have

$$P_a - P_{rx} T_c(t) + P_{tx} - P_{rx} T_{tx}(t) = P_{rx} - P_s T_s(t) \quad (13)$$

Therefore, the duration of the sleep state can be estimated as a linear equation presented below:

$$T_s(t) = a T_a(t) + b T_{tx}(t) \quad (14)$$

$$\text{Where } a = \frac{P_a - P_{rx}}{P_{rx} - P_s} \quad (15)$$

$$b = \frac{P_{tx} - P_{rx}}{P_{rx} - P_s} \quad (16)$$

Energy consumption is a critical issue in WSN. The comparison between the proposed algorithm and the DAMT algorithm and the IEEE-802.15.4 standard is shown in Fig. 8. This figure presented the energy consumption variation against the traffic load. It depicts that the energy rises gradually as a function of traffic load. For low traffic loads of 100 kbps, the maximum energy consumed is 10 J and this occurs in case of the unprioritized network. On the other hand, the prioritized network attains consumed energy of 2J however the TC-MAC algorithm attains a value of 3J. As seen, the average energy consumption of the hybrid and the TC-MAC program are less compared to the IEEE-802.15.4 standard unless the hybrid consumes well the power consumption.

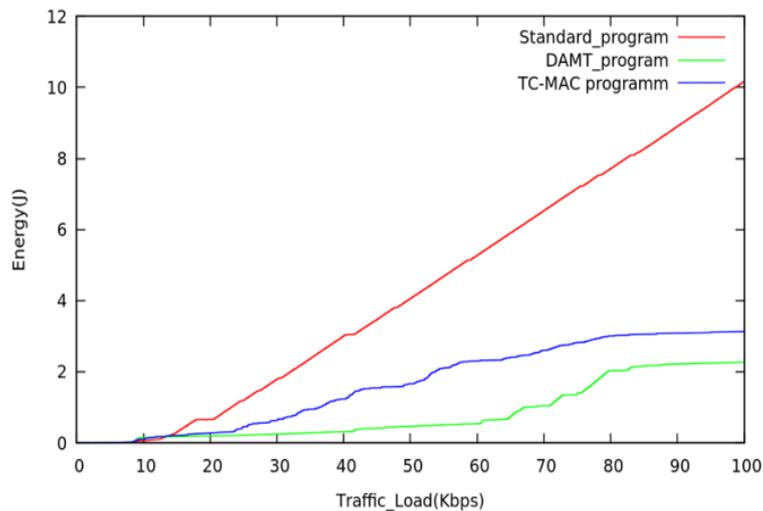


Fig. 8. Average energy consumption

7.3. Throughput performance

Fig.9 presents the throughput variation under different values of BO and SO. We have fixed an equal value of the beacon order and the super-frame order to see the impact of the superframe duration on the throughput. From this figure when the beacon order increases the throughput increase too, this means that more the length of the active period rises this May have an unused channel for long superframe duration. We notice in the upper curve that our proposed algorithm is more significant than the standard IEEE-802.15.4 in which he maximizes the throughput in the network.

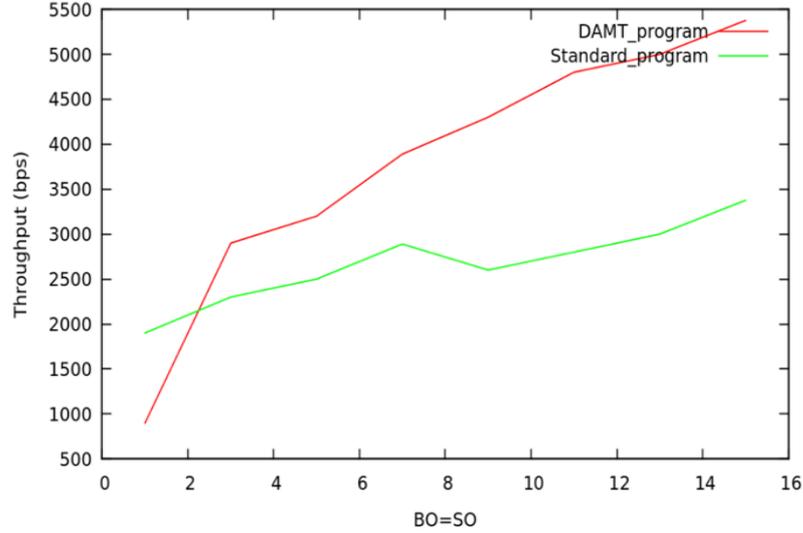


Fig.9. Throughput Vs BO

To evaluate our heuristic approach, we have used the Jain's fairness index to evaluate the fairness in the network. This metric is very important to improve the efficiency of an approach. Fairness of a protocol is its ability to allocate the channel bandwidth equally and it is defined as follow:

$$F = \frac{(\sum_{i=1}^n x_i)^2}{n \times \sum_{i=1}^n x_i^2} \quad ; 0 < F < 1 \quad (17)$$

Here $x_i = \frac{\text{Ratio of actual throughput}}{\text{Optimal throughput}}$ (18)

Where $x_i = \begin{cases} \frac{a_i}{b_i} & \text{if } a_i < b_i \\ 1 & \text{Otherwise} \end{cases}$ (19)

x_i denote an allocated metric that may be throughput, throughput times hops, or response time and n present the total number of flows. An index value of F equal to one is perfectly fair. From the curve we have founded a fairness value equal to 0.8, this means that the useable bandwidth is better enhanced and well distributed between nodes.

7.4. Packet delivery ration

We have evaluated the network performance in three metrics of PDR (packet delivery ratio), throughput and Jain's index which presents the equality in terms of access to the channel of all the nodes in the network. The packet delivery ratio can be defined by the ratio of packets successfully received to packets correctly sent to the node as presented follow:

$$PDR = \frac{\text{TotalPacketsReceived}}{\text{TotalPacketsGenerated} \times 100} \quad (20)$$

Fig.10 presents the PDR variation in the network concerning BO. For the low value of BO, we notice that the PDR increase due to the scheduling of short super-frame without collision. Whenever BO increases, the number of a packet generated will increase which leads to apparition of a collision between nodes. We notice that the DAMT program maximize the PDR instead of the standard who still almost stable which exhibits poor performance. Almost most of the packet does not reach their destination the cause is that the number of packets generated between two periods of activity is too large compared to the size of the active period, exceeding the capacity offered by the network.

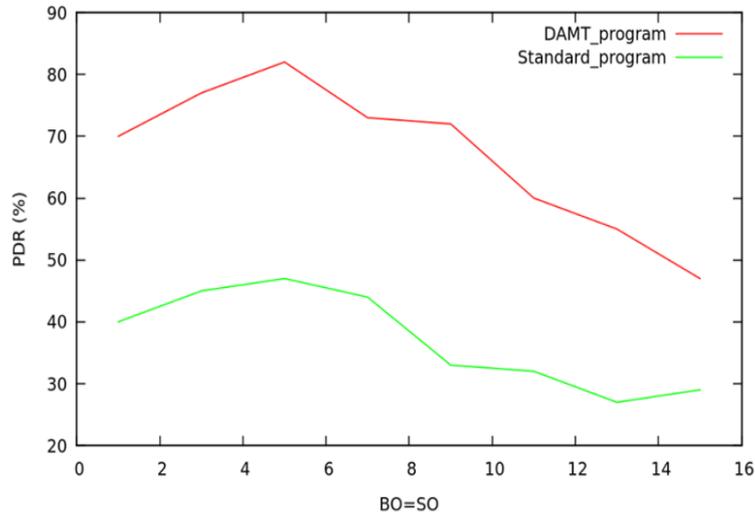


Fig.10. PDR vs BO

7.5. End to end delay variation

The end to end delay in the ns-2 definition is the difference of time between the moment at which the node transmitter generates a packet and the moment at which the receiver node receives successfully the same packet. To evaluate the efficiency of our proposed TC-MAC algorithm, a simulation has been done to trace the delay variation under different traffic load in the network. As we can see in figure 11 the end to end delay variation has been well optimized using the TC-MAC algorithm in comparison with the IEEE-802.15.4 and the DAMT algorithm. The classification of the node to access the channel is well manipulated and it has reduced the wasted time for the communication between nodes and the coordinator.

8 Discussions

Experimental results confirm that this finding well improved the QoS by using an adaptive mechanism to schedule access to the medium. The purpose of this dynamic classification of nodes according to their traffic rate and the time needed to transmit one data packet is to improve the energy consumption in the network. Therefore, this arrangement classifies nodes into two categories of priority to manage the access sequence to the medium. This scheme gives high priority for nodes that have a random flow of data and have a high traffic rate. In this condition, nodes must send their data during the first part of the super-frame using a fuzzy logic rule algorithm applied to the CSMA/CA [24, 25]. Varying the backoff exponent value has been possible to reduce the energy consumption based on priorities. However, other nodes must send their data during the second active period of the super-frame.

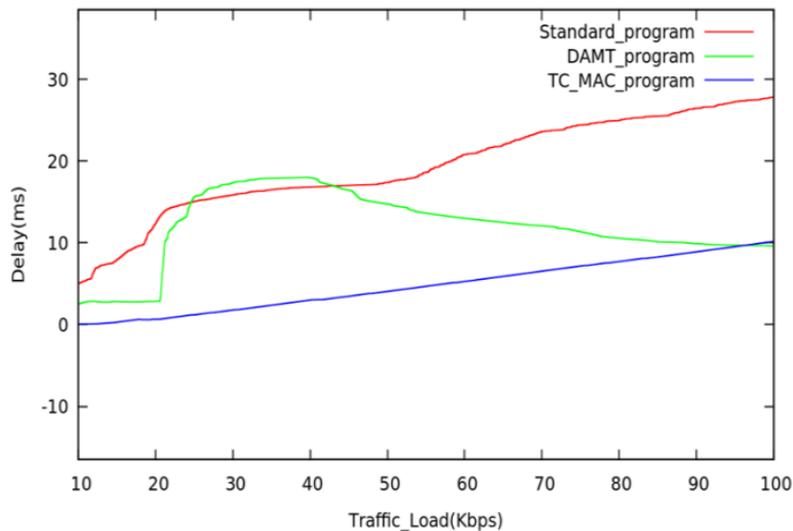


Fig.11. End to end delay variation

Sensors' lifetime and energy consumption have become a critical aspect in WSN in which they influence on its design. The progress of technology in our days depends on the memory cells capable of the electronic devices and its lifetime duration as well as their cost. To implement an algorithm that satisfies those constraints it's not a simple thing to do. Certainly, this

finding performs the energy consumption better by using a classification of nodes. Besides the dynamic modification of the length of the CAP duration has improved the QoS. Experimental results presented a rate difference between the present study and that of [20, 26]. Simulation results of the comparison between this finding and the IEEE-802.15.4 standard show an excellent improvement in energy consumption, better amelioration of the throughput and a significant reduction for the average delay and the packet loss probability. Simulation is tested for a cluster tree topology to evaluate energy consumption. Future research will be applied to the proposed scheme on another type of topology using mobile nodes. One subject that remains to be explored is the dynamic management of the GTS slots which imply the duration of the start and the end of the GTS length.

To compare our study on other works proposed in the literature, we found that this technique of classification of nodes has achieved a good performance in energy in which it has reduced the energy consumption to more than half of the energy consumed of the standard IEEE. Regarding the method of cross-layer applied in [13], our method improves a lot better the energy compared the cross-layer optimization. Also, the work presented in [28,29] where authors propose a traffic-adaptive priority-based super-frame structure to improve the QoS present less improvement compared to our work from the energy consumption point of view.

9 Conclusions

Sensors' lifetime and energy consumption have become a critical aspect in WSN in which they influence on its design. The progress of technology in our days depends on the memory cells capable of the electronic devices and its lifetime duration as well as their cost. To implement an algorithm that satisfies those constraints it's not a simple thing to do. Certainly, this finding performs the energy consumption better by using a classification of nodes. Besides the dynamic modification of the length of the CAP duration has improved the QoS. Experimental results presented a rate difference between the present study and that of [20, 26]. Simulation results of the comparison between this finding and the IEEE-802.15.4 standard show an excellent improvement in energy consumption, better amelioration of the throughput and a significant reduction for Energy efficiency is a key issue in WSN; it is known that energy efficiency is a conflicting design objective. Hence, power control and rate adaptation need to be carefully considered used to achieve energy efficiency. Traffic rate adaptation to achieve energy efficiency is particularly a challenging task in the MAC-based IEEE-802.15.4 protocol. In this paper, a novel scheduling mechanism for data transmission packet delay and traffic rate management has been proposed in order to optimize energy consumption in WSN. Various methods of improving the network lifetime by optimizing energy consumption in WSNs have been discussed so far. The self-reorganization of nodes has well improved the network performance and has archived good results for the QoS. This reorganization is primordially based on the traffic in the network and according to this condition a GTS management-based priority condition schedule the GTS allocation.

List of Abbreviations

| | |
|---------|--|
| WSNs | Wireless Sensor Networks |
| MAC | Medium Access Control |
| CSMA/CA | Carrier Sense Multiple Access with Collision Avoidance |
| CFP | Contention Free Period |
| CAP | Contention Access Period |
| QoS | Quality of Service |
| PAN | Personal Area Network |
| TDMA | Time Division Multiple Access |
| GTS | Guaranteed Time Slot |
| DAMT | Dynamic Adaptation Mechanism for Traffic |
| AODV | Ad Hoc On-Demand Distance Vector |
| TC-MAC | traffic control-based MAC algorithm |
| BE | Backoff Exponent |
| FIFO | First in First out |
| BO | Beacon order |
| SO | Super-frame order |
| PDR | Packet delivery ratio |

Availability of data and materials

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Acknowledgements

Not applicable.

Funding

The authors gratefully acknowledge the support by the College of Engineering Research Center under the Deanship of Scientific Research of King Khalid University, Saudi Arabia. (Grant number R.G.P.1/194/41)

Competing Interest

All authors declare that there is no competing of interest.

Authors Contribution

All authors contributed to this work. The authors read and approved the final manuscript.

Author details

1Department of Industrial Engineering, King Khalid University, Abha, Kingdom of Saudi Arabia

2Electronic and Micro-Electronic Laboratory (E μ E, IT-06) FSM, University of Monastir, Tunisia

3Department of Electrical Engineering, King Khalid University, Abha, Kingdom of Saudi Arabia
izaidy@kku.edu.sa

Mobile number: 00966531575724

Orcid Id: 0000-0001-7418-2212

* The author for correspondence

References

- [1] Ramya, R., Saravana kumar G., Ravi, S., MAC Protocols for Wireless Sensor Networks. *Indian Journal of Science and Technology*, Vol 8(34), (2015) DOI: 10.17485/ijst/2015/v8i34/72318.
- [2] Korhan Cengiz, Tamer Dag, A review on the recent energy-efficient approaches for the Internet protocol stack. *Journal on Wireless Communications and Networking*, 2015:108 (2015).
- [3] Zhang, H., Cheng, P., Shi, L., Chen J., Optimal denial-of-service attack scheduling with energy constraint. *IEEE Trans Autom Control* 60(11), 3023–3028 (2015).
- [4] Jamalabdollahi, M., Zekavat, R., Seyed, A., Joint neighbor discovery and time of arrival estimation in wireless sensor networks via OFDMA. *IEEE Sensors J.* 15(10), 5821–5833 (2015).
- [5] Wang, H., Chi, X., Energy adaptive MAC protocol for IEEE 802.15.7 with energy harvesting. *L. Optoelectron Lett.* (2016) 12: 370. DOI:10.1007/s11801-016-6163-6.
- [6] Hoon Oh, Md Abul Kalam Azad, A Big Slot Scheduling Algorithm for the Reliable Delivery of Real-Time Data Packets in Wireless Sensor Networks. *Wireless Communications, Networking and Applications, Lecture Notes in Electrical Engineering* 348, (2016) DOI 10.1007/978-81-322 2580-5_2.
- [7] Sreejith, V., Suriyadeepan, R., Anupama, K.R., Lucy, J., DS- MMAC: Dynamic Schedule based MAC for Mobile Wireless Sensor Network. (2016) DOI:10.1145/2851613.2851999.
- [8] Guerroumi, M., Pathan, AS.K. Derhab, A. et al: MMSMAC, A Multi-mode Medium Access Control Protocol for Wireless Sensor Networks with Latency and Energy-Awareness. *Wireless Pers Commun* DOI:10.1007/s11277-016-3726-610.1007/s11277-016-37266.
- [9] Wang, J., Ren, X., Chen, F. et al., On MAC optimization for large- scale wireless sensor network. *Wireless Netw* (2015) 22:1877. DOI: 10.1007/s11276-015-1073-2.
- [10] Subramanian, A.K. & Paramasivam, I. *Wireless Pers Commun* (2017) 92: 863. <https://doi.org/10.1007/s11277-016-3581-5>.
- [11] Chen, Z., Liu, A., Li, Z. et al., Distributed duty cycle control for delay improvement in wireless sensor networks. *Peer-to-Peer Network. Appl* (2016). DOI: 10.1007/s12083-016-0501-0.
- [12] Deepak, K. S., Babu, A. V., Energy consumption analysis of modulation schemes in IEEE 802.15.6-based wireless body area networks. Deepak and Babu *EURASIP Journal on Wireless Communications and Networking*. (2016) DOI 10.1186/s13638-016 0682-5.
- [13] Luca Mainetti, Vincenzo, M., Luigi Patrono, HEC-MAC: A Hybrid Energy-Aware Cross-Layer MAC Protocol for Wireless Sensor Networks. *International Journal of Distributed Sensor Networks*. Article ID 536794, 12 pages (2015).
- [14] Sherly, L., Puspha Annabel and Murugan, K., Energy-Efficient Quorum-Based MAC Protocol for Wireless Sensor Networks. *ETRI Journal*, 37(3) (2015).
- [15] Rajesh, B. Shyamala, D., George, A., HYBRID CSMA/CA-TDMA BASED MAC PROTOCOLS FOR WIRELESS SENSOR NETWORKS. *ARPN Journal of Engineering and Applied Sciences*. 10(4) (2015).

- [16] Bih-Hwang Lee, Eppy Yundra, Huai-Kuei Wu, M Udin Harun Al Rasyid, Analysis of superframe duration adjustment scheme for IEEE802.15.4 networks. *Journal on Wireless Communications and Networking*. 2015:103 (2015).
- [17] Mohamed, B., Houria, R., Tahar, E., A Comprehensive Performance Study of the Contention Access Period of the Slotted IEEE 802.15.4. *The International Conference on Advanced Wireless, Information, and Communication Technologies (AWICT 2015)*.
- [18] Sabin Bhandari, Sangman Moh, A Priority-Based Adaptive MAC Protocol for Wireless Body Area Networks. *Sensors* (2016), 401; DOI:10.3390/s16030401.
- [19] Varsha, J., Shweta, A., Kuldeep, G., Energy Consumption Improvements by Priority based MAC Protocol for WSN. *International Journal of Computer Applications® (IJCA) (0975 – 8887) National Seminar on Recent Advances in Wireless Networks and Communications, NWNK* (2014).
- [20] Tsung-Han Hsieh, Kuei-Ying Lin, Pi-Chung Wang, A Hybrid MAC Protocol for Wireless Sensor Networks. *Proceedings of 2015 IEEE 12th International Conference on Networking, Sensing and Control* (2015).
- [21] Mouzehkesh, N., Zia, T., Shafigh, S. et al., Dynamic backoff scheduling of low data rate applications in wireless body area networks. *Wireless Network* 21: 2571. (2015) DOI:1007/s11276-015-0929-9.
- [22] Hassan, M.N., Murphy, L., Stewart, R., Traffic differentiation and dynamic duty cycle adaptation in IEEE 802.15.4 beacon enabled WSN for real-time applications. *Telecommun Syst* 62: 303. (2016) DOI:10.1007/s11235-015-0074-x.
- [23] omżał, J., uliński, Z., Rzaśa, J. et al., Automatic Hidden Bypasses in Software-Defined Networks. *J Netw Syst Manage* (2016).
- [24] Bouazzi, I., Bhar, J. and Atri, M. (2017) 'New CSMA/CA prioritisation based on fuzzy control mechanism', *Int. J. Intelligent Engineering Informatics*, Vol. 5, No. 3, pp.253–266.
- [25] Imen B., Jamila B. and Mohamed A., Priority-based queuing and transmission rate management using a fuzzy logic controller in WSNs. *ICT Express* 3(2), 101-105 (2017).
- [26] Raja P., Dananjayan P., A Game Theory-Based Hybrid Medium Access Control Protocol for Congestion Control in Wireless Sensor Networks. K. Hausken and J. Zhuang (eds.), *Game Theoretic Analysis of Congestion, Safety and Security*, Springer Series in Reliability Engineering, (2016). DOI 10.1007/978-3-319-13009-5_1.
- [27] Hamid Reza Sharif, Yousef S. Kavian - 2015 - Technology & Engineering. *Technological Breakthroughs in Modern Wireless Sensor Applications*.
- [28] L. Chongqing, Y. Wang, and al., Duty-Cycling MAC Protocol for Low Data-Rate Medical Wireless Body Area Networks. *Sensors* 2017, 17(5), 1134; doi:10.3390/s17051134.
- [29] S. Henna,†, M. Sajeel, and al., A Fair Contention Access Scheme for Low-Priority Traffic in Wireless Body Area Networks. *Sensors* 2017, 17(9), 1931; doi:10.3390/s17091931.
- [30] Akhavan, M.R., Choobkar, S., Aijaz, A. and Aghvami, A.H., 2014. Adaptive preamble-sampling techniques for receiver-based medium access control protocols in lossy wireless sensor networks. *IET Wireless Sensor Systems*, 5(1), pp.31-41.
- [31] Kuo, Y.W. and Liu, K.J., 2015. Enhanced sensor medium access control protocol for wireless sensor networks in the ns-2 simulator. *IEEE Systems Journal*, 9(4), pp.1311-1321.
- [32] Naderi, M.Y., Nintanavongsa, P. and Chowdhury, K.R., 2014. RF-MAC: A medium access control protocol for re-chargeable sensor networks powered by wireless energy harvesting. *IEEE Transactions on Wireless Communications*, 13(7), pp.3926-3937.
- [33] Agrawal, N., Milner, S.D. and Davis, C.C., 2014. Design and performance of a directional media access control protocol for optical wireless sensor networks. *IEEE/OSA Journal of Optical Communications and Networking*, 6(2), pp.215-224.
- [34] Imen Bouazzi, Jamila Bhar, Mohamed Atri. A Dynamic Adaptation Mechanism for Traffic Conditions in Wireless Sensor Network. *Int. J. wireless personal communication*. Issue 4, 2018.

Figure Title

- Figure 1: Data transfer procedure
 Figure 2: Traffic adaptation algorithm
 Figure 3: Set of super-frames using our hybrid scheme
 Figure 4: Packet scheduling delay
 Figure 5: TC-MAC implementation
 Figure 6: GTS reallocation scheme
 Figure 7: The new CFP adjustment
 Figure 8: Average energy consumption
 Figure 9: Throughput Vs BO
 Figure 10: PDR vs BO
 Figure 11: End to end delay variation

Authors Information



IMEN BOUAZZI obtained her PhD degree in Science and technology from the Faculty of Science in Monastir, Tunisia in 2018; she obtained her engineering degree in Applied Science in Technology (speciality - Electronic Microelectronics, July 2013) from the higher institute of Computer and Mathematical of Monastir. Her interest's research is concentrated on computer science, network communication and electronic wireless devices. She is currently working within the college of engineering King Khalid University, Saudi Arabia. Email: izaidy@kku.edu.sa



MONJI ZAIDI was born in Kairouan, Tunisia on January 1, 1982. He received his Dipl.-Ing. in Electrical Engineering for automation and processes control and Master's degree in Nanostructures, devices and micro-electronics systems in 2005 and 2007 from the National engineers school of Sfax and from the University of Monastir respectively. He received his Doctorate in Electronics and Communication from the Faculty of Science of Monastir, Tunisia. He is currently working within the college of engineering King Khalid University, Saudi Arabia. His research interests include Management of the Wireless technologies. Email: amzaydi@kku.edu.sa



Mohammed Usman was born in Chennai, India on May 24, 1980. He received B.E in Electronics and Communication Engineering from Madras University, India in 2002. He then joined the University of Strathclyde in Glasgow, United Kingdom as a graduate student and was awarded Master of Science in Communications, Control and Digital Signal Processing in 2003. In 2008, he was awarded the PhD degree for his research on Fountain codes for wireless communications. He is a Senior Member of IEEE, USA and Member of IET, UK. He serves as Editor for several books and as Organizing/TPC Chair for IEEE International conferences.



A. Dr. Mohammed Zubair Mohammed Shamim was born in India on 27 March 1981. He received his M.Eng degree in electronics and electrical engineering from the University of Dundee, Dundee, United Kingdom in 2003. Further he received his Ph.D. degree in electronics engineering and applied physics from the same university in 2008. From 2005 to 2009 he was a Research and Development Engineer with Quantum Filament Technologies Ltd, United Kingdom. From 2009 to 2011 he was a Senior Research Scientist at the University of Stuttgart, Germany. His current research interests include fabrication of functional micro-nanostructured surfaces using pulsed excimer laser crystallization for field emission applications and GPU accelerated deep learning. He is a recipient of several international awards and scholarships and has published several papers in internationally renowned journals and conferences.