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Optimization of IEEE 802.15.4: Overview, Theoretical Study and Simulation

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Abstract: In this paper we study, through theoretical analysis and simulation, the impact of Beacon Order (BO) and Superframe Order (SO) parameters of IEEE 802.15.4 on the networks performance and we investigate their optimal values for different classes of traffic. The traffic is dimensioned according to the requirements of the CANet project in which a cane becomes a mean of communication and a surveillance system embedding several sensors to monitor the elderly health and environment (voice, pressure, temperature, etc.). The cane's sensors impose different QoS constraints. Depending on the expected throughput, a sensor's traffic will fall within one of three classes that we defined. Therefore, in order to ease the understanding of our optimization, we introduce a classification scheme which applies to the existing quality of service algorithms. We derive by theoretical study the optimal values of BO and SO that should be used to fit each traffic class QoS requirements and we validate our results by simulation.

Keywords: Wireless Sensor Networks; IEEE 802.15.4; QoS algorithms; MAC protocols; CANet project

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1 Introduction

Wireless Sensor Networks (WSNs) are composed of autonomous sensors to monitor physical or environmental conditions. They can be used in many applications such as health care monitoring, forest fire detection, environment surveillance and monitoring, etc.

Traditional applications of WSNs rely often on homogeneous sensors, having the same characteristics and requirements and performing the same tasks which leads also to common traffic characteristics. Health care applications came with new requirements and new architectures. Various types of sensors can be used within the same application to monitor several physical parameters. For instance, sensors can be embedded on a same patient's body to monitor his blood pressure, cardiac rhythm, movements, fall detection, etc. All these sensors compose the same wireless network but generate different traffics at different rates and periodicity.

Many WSN applications need to ensure that the detected information successfully arrive to their destinations and that it is delivered in a timely manner. In health care applications, the information collected by sensor nodes can be critical when reporting on serious situations, thus, these applications do not tolerate any packets loss or important transmission delays (Aykut et al., 2011).

For this kind of constrained communications, protocols supporting Quality of Service (QoS) algorithms are required. In order to evaluate the QoS requirements of WSNs, authors of (Aykut et al., 2011; Chen et al., 2004) define some metrics such as access delay, collision rate, etc. that can be measured at MAC layer.

CANet (Bougeois et al., 2012) is one of the innovative health care projects which aimed at designing an intelligent cane to monitor, in a non-intrusive way, the environment and health of the elderly in their everyday life. The cane embeds different types of sensors, such as for localization, temperature, movement tracking, or monitoring of different vital signs of old persons. All these sensors have to be implanted on the same cane, which communicates with an access point that plays the role of the network coordinator. The cane is equipped with a single wireless interface that has to serve all types of traffic generated from the embedded sensors.

The choice of a MAC protocol that satisfies a certain level of QoS and that can be flexible and adjustable to the cane requirements (regarding the heterogeneity of the generated traffic) is fundamental. In addition to these QoS requirements, ensuring low energy consumption is important since the cane will operate on battery.

As IEEE 802.15.4 is a widely used standard for WSN, we considered its application within the CANet project. To cope with the different constraints (delay, throughput, etc) of the cane-embedded sensors, we perform in this paper a theoretical and experimental study of different IEEE 802.15.4 parameters that can influence the length of the superframe period and the inter-beacon period in IEEE 802.15.4 protocol within the beacon enabled mode and the star topology.

First, we will present an overview of IEEE 802.15.4, where we explain the important parameters to calculate the length of superframe and the CSMA algorithm for the slotted period. Second, we will propose a classification for the existing QoS mechanisms in WSNs. Third, we will define a classification of traffic types that can exist in WSN, especially in CANet project. After that, we will present a theoretical study of the parameters used to vary the duration of the superframe (SO: Superframe Order) and the duration between two beacons (BO: Beacon Order) and we will finish by presenting some results of simulations.

2 Theoretical choice of BO and SO parameters

2.1 Overview of IEEE 802.15.4 standard

IEEE 802.15.4 standard (Kim et al., 2007) defines the specifications of the *MAC* sub-layer and the *PHY* layer for Low-Rate Wireless Personal Area Networks (LR-WPANs). It defines two types of nodes: Reduce Function Device (*RFD*) and Full Function Device (*FFD*). *RFD* nodes do not implement the entire stack of IEEE 802.15.4 and have limited functionalities. On the other hand, the *FFD* nodes implement all the IEEE 802.15.4 specification and they can be networks coordinators.

In IEEE 802.15.4, two types of architecture are defined: Star or Peer to Peer. In the star topologies, all nodes are connected to one coordinator, which is responsible for synchronizing all nodes, allocating the Guaranteed Time Slots (*GTS*) and the beacon transmission.

The star topology is the one chosen for our application.

Two different modes of transmission are possible: non-beacon-enabled and beacon-enabled modes. In non-enabled-beacon mode, all nodes in the network use *CSMA/CA* access mechanism without any synchronization superframe. In the rest of the paper, we will focus only to the enabled-beacon mode, because it is used with star topologies. In this mode, a beacon is transmitted, by the coordinator, at the beginning of each superframe

to synchronize all nodes. This superframe is divided into two periods: active and inactive period.

The active period consists of 16 slots having an equal duration and it is composed into two parts: Contention Access Periods (*CAP*) and Contention Free Periods (*CFP*).

In the *CAP*, the nodes use *CSMA/CA* access mechanism. In the *CFP*, only *GTS* are defined and has to be reserved in advance. If a node needs to reserve *GTS* in the *CFP* part, it has to send a request to the coordinator. When the coordinator receives the request, it verifies if there are free *GTS* in the *CFP* period and then it satisfies accordingly the requesting node. Therefore, the node can transmit its messages in the reserved slots by using *TDMA* (Time Division Multiple Access).

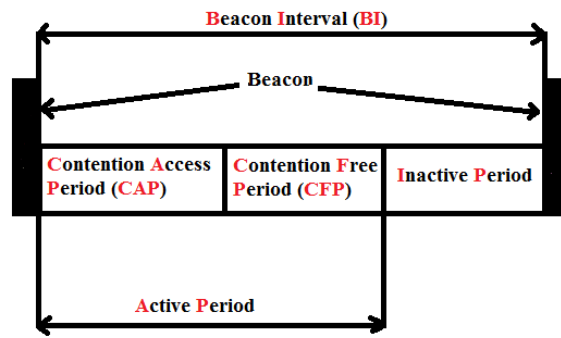


Figure 1 Superframe structure in IEEE802.15.4

The interval between two beacons is named Beacon Interval (*BI*) and represents the total duration of the superframe (figure 1). This parameter is calculated by:

$$BI = aBaseSuperframeDuration \times 2^{BO} [Symbols] \quad (1)$$

With *aBaseSuperframeDuration* is equal to 960 symbols and *BO* is the Beacon Order and it is $0 \leq BO < 15$.

The active period is named Superframe Duration (*SD*) and it is calculated by :

$$SO = aBaseSuperframeDuration \times 2^{SO} [Symbols] \quad (2)$$

With $0 \leq SO \leq BO \leq 14$

Now, we will describe how the *CSMA/CA* operates in the enabled-beacon mode.

In the first step, the parameters *NB* (represents the number of attempts to access to the channel) is set to 0 and *CW* is set to 2. If the node operates with the battery power, the backoff exponent is set to a min (2, *MacMinBE*). In the other cases, the backoff is set to *MacMinBE* (the default value of *MacMinBE* is 3). After that, the algorithm locates the backoff period boundary.

In the second step, the algorithm generates a random period between 0 and 2^{BE-1} . This random value represents the waiting delay before attempting to transmit packets.

After the expiration of the waiting period, the MAC sub-layer performs a Clear Channel Assessment (CCA) procedure (step 3). After this step, the Mac sub-layer verifies the state of the channel:

- If the channel is idle, the algorithm decreases the value of CW by 1. Then the CSMA/CA algorithm verifies if the value of CW is equal to 0, the node can transmit its packets. In the other cases, the algorithm returns to the step 3.
- If the channel is used, CSMA/CA algorithm would set CW to 2 and increase NB by 1 (step 4). If the value of NB is greater than $macMaxCSMABackoff$, the packet cannot be transmitted. In the other case, the algorithm returns to the step 2 and tries again.

In an IEEE 802.15.4 WSN, the coordinator ensures some QoS by allocating GTS in the CFP part of the superframe. The coordinator cannot provide more than 7 GTS which is not sufficient for dense WSN. For this reason, many existing work tried to propose QoS mechanisms in enabled-beacon mode by using CSMA/CA. In another hand, other researches try to improve the GTS reservation method.

2.2 QoS in Wireless Sensor Networks

Many applications in WSNs require a minimum level of transmissions reliability. To satisfy this requirement, many QoS algorithms were proposed. In this section, we classify existing QoS algorithms then we define traffic types in CANet project based on their QoS needs.

2.2.1 Classification of QoS algorithms

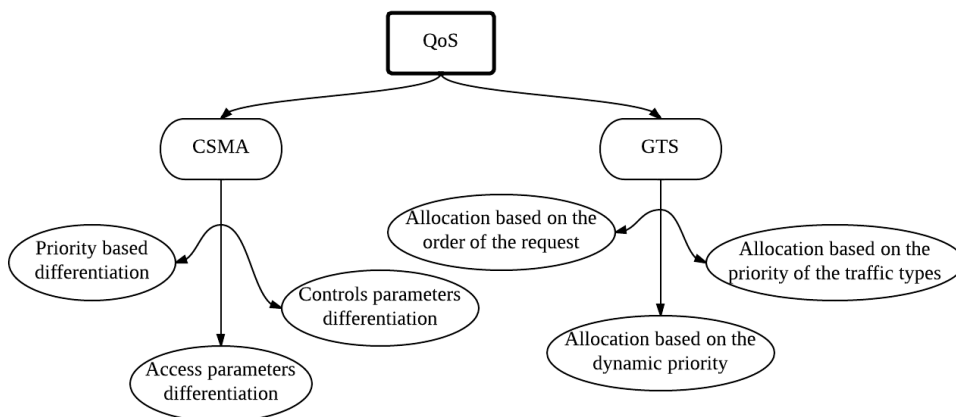


Figure 2 Classification of QoS algorithms

To enhance the performances of IEEE 802.15.4, QoS algorithms (Figure 2) were designed and can be divided into two sub-classes: algorithms intended to support QoS in CSMA mode and others used to improve the GTSs reservation technique. The CSMA sub-class is composed of 3 types of algorithms:

- Priority based differentiation: priorities may be assigned to nodes according to the importance of the information they handle or to classify the generated traffic (Shin, 2013; Severino et al., 2010; Saxena et al., 2008; Firoze et al., 2007).
- Access parameters differentiation: different MAC layer parameters like *CW*, backoffexponet and *SIFS* are tuned for different levels of priority. The aim is to expedite the transmission of packets that have a high priority (Xia et al., 2013; Severino et al., 2010; Kim et al., 2007; Youn et al., 2007;Koubaa et al., 2006; Tae, 2006).
- Controls parameters differentiation: This class contains the *QoS* mechanisms that use parameters such as hop count, life-time of a packet and power control to manage the transfer of packets in the network. In this proposals, these parameters are used to differentiate between the existing traffics and to assign priorities (Aykut et al., 2011; Nguyen et al., 2006; Liu et al., 2005).

GTS sub-class includes algorithms which are proposed to resolve the problem of *GTSs* reservation in IEEE 802.15.4. This sub-class is divided into 3 parts :

- *Allocation based on requests order* : The coordinator reserves slots times to the nodes according to the order of their requests reception. If a node wants to reserve *GTSs*, it has to send a request to the coordinator, which contains the number of desired slots and the direction of the exchange (reception or transmission). Upon a request reception, the coordinator compares the number of requested *GTSs* with the number of available slots in the *CFP* period. If the number of requested slots is lower or equal to the number of available slots, the coordinator allocates the necessary slots to this node. In the other case, the coordinator rejects the request.
- *Allocation based on the dynamic priority of nodes* : *GTS* reservation depends to the priority assigned to each node. In (Huang et al., 2008), this priority changes dynamically according to the use of last reserved *GTS*. The priority change is followed by the reallocation of *GTS* in the network. The algorithm in (Huang et al., 2008) does not support any traffic differentiation. To meet this need, other protocols such as D-SeDGAM (Villarverde et al., 2010) allow the differentiation between services.

This class suffers from several limits. For instance, if many nodes have a strong priority, they will monopolize the bandwidth. Also, this class does not take into account real-time traffics.

- *Allocation based on traffic priority* : In this third class, *GTS* allocation is adapted to real-time traffics. In the initial structure of IEEE 802.15.4 superframe, when a node wants to transmit data during *CFP*, it must send a *GTS* request and wait for the beacon. If the request was accepted, the node will transmit the packets only in the allocated period, which makes the current structure of the superframe inadequate to support the transmission of real-time data. In (Kim et al., 2007), the authors propose a new reservation algorithm based on an extension of the IEEE 802.15.4 *GTS* concept. They suggest to eliminate the inactive period, then *SD* becomes equal to *BI*. Other modifications are proposed in the superframe structure. Therefore, it supports the concept of multi-user at the time of communication.

This class does not take into account the energy consumption and allows the treatment of only one type of traffic.

Algorithms proposed in this classification do not use the length of the information that will be sent in the *GTS* period. Therefore, the authors of (Khssibi et al. (2012); Khssibi et al. (2011)) defined 3 algorithms that use the number of requested *GTS* in the reservation process :

- *FGA (FIFO GTS Allocation)* : In this algorithm, the *GTS* reservation is performed according to the reception order of the *GTS* requests.
- *MFGA (Min First GTS Allocation: MFGA)* : This algorithm is an enhancement of *FGA* algorithm. In this algorithm, the highest priority is assigned to the packet that has requested the lowest number of slots.
- *MWGA (Mean Weighted GTS Allocation)* : In this algorithm, authors propose to balance the access to the channel between nodes by reserving a number of slots that is proportional to their needs.

We focus on the differentiation between existing traffics in the network which should be based on the type and the importance of the transmitted information. For that, we will analyze the characteristics of the generated traffics in CANet project.

2.2.2 Traffic types in CANet

In CANet project, there are many types of sensors used to collect information from the human body and the environment such as heart bit, skin temperature, accelerometer, localization, velocity sensors also a microphone for voice transmission in case of emergency. These sensors generate data with different characteristics (bit rate, priority and periodicity). The bit rate represents the number of bits transmitted from the node to the coordinator. It can be divided into Low and High bit rate. The traffics priority, in CANet project, depends on the type of information. For that, we define 3 priority levels. At last, the detected information can be sent periodically or randomly. The transmission frequency depends on the characteristics of the detected information.

A sensor in the monitoring applications like CANet project can generate and transmit information that belongs to one of the flowing classes :

- *Class 1* : In this class, traffics have low priority and low bit rate and they are generated periodically or randomly. The detected information is transmitted using *CSMA/CA* in the *CAP* period. This class represents the traffic generated by sensors like skin temperature, heart rate, etc.
- *Class 2* : This class contains all traffics characterized by high bit rate and high priority. These traffics will be transmitted continuously. This class represents the real-time traffics generated by the microphone embedded on the cane.
- *Class 3* : this class contains all traffics characterized by low flow, very high priority and generated randomly. The detected information is very important because it represents an urgent case. Therefore, it should be sent as soon as possible. The traffics in this class are generated by heart rate, skin temperature sensors in emergency cases to report on critical health states.

To comply with the requirements of each type of traffic, using the optimal values of IEEE 802.15.4 parameters is necessary. *BO* and *SO* are the most significant parameters that

can affect both bit rate and delays constraints. However, there are no former works that have focused on studying the impact of these parameters on the performances of IEEE 802.15.4 and its ability to meet QoS needs of various types of traffic.

Hence, our goal is to perform a study on the *BO* and *SO* parameters in order to determine the optimal values that can characterize different types of CANet traffics.

2.3 Analysis of *BO* and *SO*

In this section, we will investigate the impact of *BO* and *SO* on the network performances such as theoretical throughput, superframe duration, etc.

Our goal is to find the optimal values of *BO* and *SO* parameters. For that, we use the star topology with enabled-beacon mode of IEEE 802.15.4. The selected values will allow the classification of traffics and satisfy the requirement of all types of traffic.

We calculate the Theoretical Instantaneous Flow (*TIF*) by:

$$TIF = \frac{SD}{BI} Symbols = \frac{1}{2^{BO-SO}} \times 250Kbit/s \quad (3)$$

The figure 3 is created by the use of the equation (3). It represents the theoretical instantaneous flow variation for different *BO* and *SO* values. If *BO* and *SO* are equal to 14 the theoretical instantaneous flow is equal to 250Kbit/s, in this case, the maximal value of flow can be achieved. If the values of *BO* and *SO* increase, the theoretical instantaneous flow increases. Vice versa, if *BO* and *SO* decrease the value of theoretical instantaneous flow decreases.

In the figure 4, the superframe has the largest duration and the highest theoretical instantaneous flow as *BO* = *SO* = 14. In addition, if the values of *BO* and *SO* are equal and different of 14, the superframe has lowest duration and the highest theoretical instantaneous flow. In the other cases, when the *BO* - *SO* is larger, the superframe duration and the theoretical instantaneous flow are shorter (Figure 5) and an inactive period appears. The length of the inactive period is calculated by:

$$InactivePeriod = BI - SD = 960 \times (2^{BO} - 2^{SO}) \times 16 \times 10^{-6} \quad (4)$$

Figure 6 represents the variation of inactive period in terms of *BO* - *SO* and *BO*. The *SO* value is varying from 0 to *BO*. If *SO* value is equal to 0, the inactive period length is equal to the length of the beacon interval. In other cases, the length of the inactive period decreases when the value of *BO* - *SO* increases. Then the length of the inactive period depends essentially on the value of *SO*.

We derive from the previous figures the theoretical optimized values of *BO* and *SO* for the different traffic classes presented in the section 3. These values are represented in Table 1.

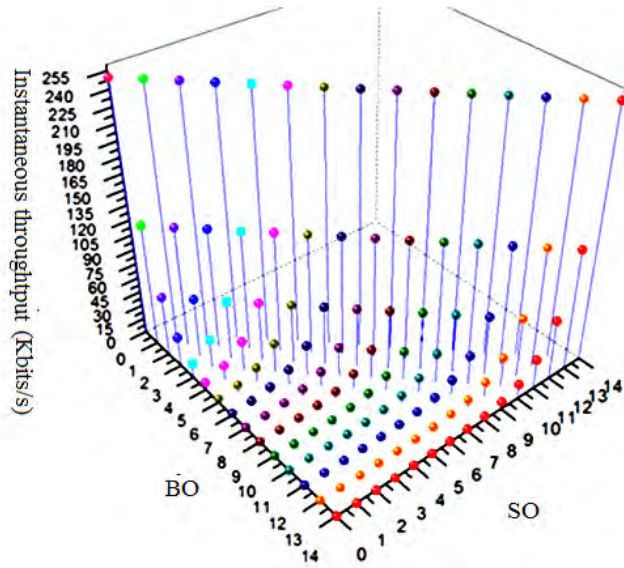


Figure 3 Instantaneous throughput in terms of BO and SO

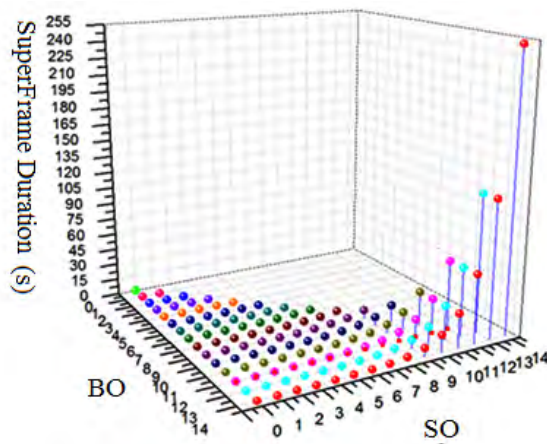


Figure 4 Variation of the superframe duration in terms of BO and SO

For class 1 traffics, the choice of BO and SO values is not important because the nodes can send their information at any time in the CAP . The period length between two frames successively transmitted by the same node is very large. For that, we intend to maximize the inactive period length and minimize the active period length. In the same time, we should ensure to have the necessary period for transmission. If BO and SO values are less than 7, the inactive and the active period are very short. For $BO = 6$ and $SO = 0$, the inactive period is equal to 0,967s and the active period is equal to 15,36ms, and for $BO = SO = 6$ the active period is equal to 0,983s. For these reasons, we should fix 7 as the lowest value for $BO = SO$ to have the shortest length of the active period equal to 1,966s.

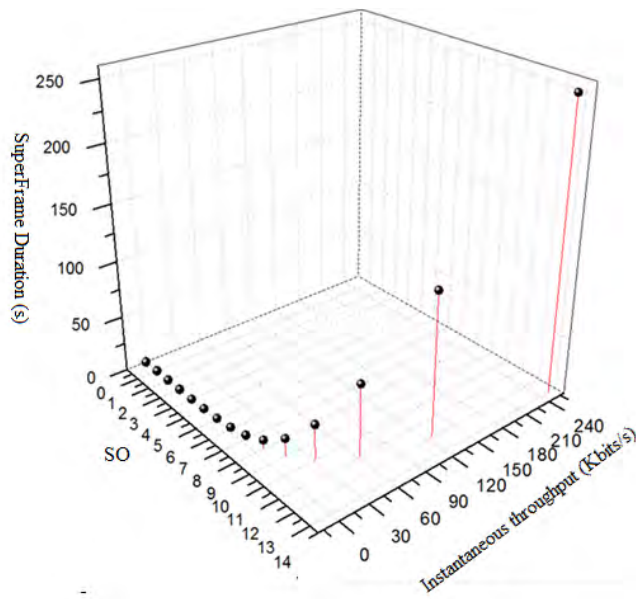


Figure 5 Variation of superframe duration in terms of SO and the instantaneous throughput with $BO = 14$

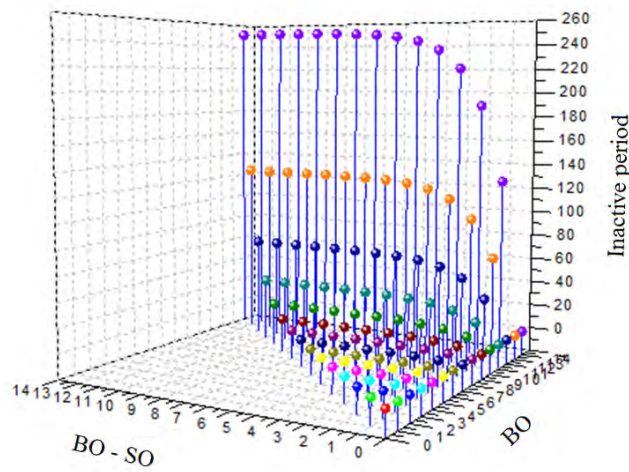


Figure 6 Inactive period in the terms of BO and $BO - SO$

Class	Optimal BO	Optimal SO
Class 1	7..14	7..14
Class 2	0..1	0..1
Class 3	0..14	0..14

Table 1 Different values of BO and SO for the different classes

Parameters	Values
Application packet inter-arrival time	30ms
BO = SO	0,1 ,2 , 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 and 14
Number of nodes	1 and 5 normal nodes and 1 coordinator
Duration of the simulation	1 hour
Length of application payload	70Bytes
Buffer	10 packets
Transmission mode	GTS

Table 2 Simulation parameters for the second class

In class 2, the length of packets is between 20ms and 30ms. For the real-time traffics, the end-to-end delay has an important influence on the QoS . For that, we will remove the inactive period to minimize the delays ($BO = SO$). This class requests a minimum level of QoS , its traffics will be transmitted in CFP . The length of active period will be very small and does not exceed the length of packets generation.

Class 3 covers high priority traffics that must be transmitted in the CFP or CAP periods. The choice of BO and SO values is not important if a packet is timely transmitted.

Table 1 presents the different values of BO (Column 1) and SO (Column 2) that should be used for different classes. These values are the result of our theoretical analysis. We propose in the next section to assess these results by simulation and refine the theoretical proposition.

3 Simulations and Results

In this section, we present the simulations of GTS s allocation in IEEE 802.15.4 while varying the values of BO and SO . These simulations aim at validating the results derived from our previous theoretical analysis.

Two scenarios were simulated with different BO and SO values and different number of nodes. We used the implementation of IEEE 802.15.4 in the OMNeT simulator (OMNet++, 2010) with star topology containing one coordinator and several nodes. The BO and SO values vary between 0 and 14. The number of nodes is equal to 1, 5 and 10. The application packet inter-arrival time is equal to 30ms or 60s and the application payload size is equal to 70 or 10 Bytes.

In the first scenario, we will try to observe the influence of BO and SO variation on the number of transmitted messages in the second class traffics. The number of slots that a node can reserve depends on the length of the first message to transmit. The number of reserved slots is maintained until the end of the simulation. Parameters used for the first scenario are presented in Table 2.

Figure 9 presents the number of successfully transmitted messages in the CFP with GTS s. We note that the number of transmitted messages decreases when BO and SO values increase. The maximal number of transmitted messages is reached when $BO = SO = 0$ for 1 node and $BO = SO = 1$ for 5 nodes.

The raise of the number of successfully transmitted messages in $BO = SO = 1$ for 5 nodes is the result of the slots length increases. Figure 7 illustrates the change of the slots number reserved by each node. For $BO = SO = 0$ the slots number which is necessary for the transmission is equal to 4 slots for each node. For that, only two nodes can transmit their messages. Vice versa, when $BO = SO = 1$, the slots length becomes larger. For that, the necessary slots numbers decreased by 2 for each node and by 2 for the minimal CAP length. The unused slots are reserved to other nodes (figure 7 (a) and (b)).

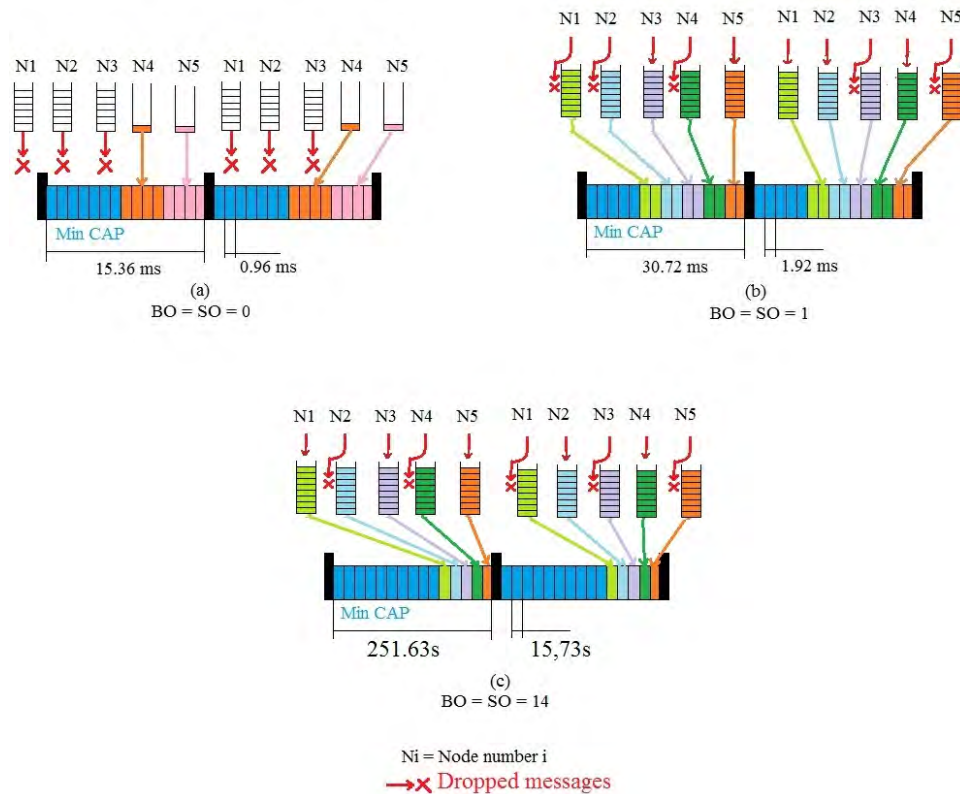


Figure 7 Transmission for $BO = SO = 0, 1$ and 14

If the superframe duration increases, the waiting time for the next transmission period increases for each node. For example, if $BO = SO = 14$, SD becomes equal to 251,66s. Therefore, all nodes must wait 251,66s to achieve their transmission period (figure 8 and figure 7 (c)). From the beginning of the superframe, nodes have generated 8367 messages, but only 10 first packets are conserved and 8357 were dropped. For that, the number of successfully transmitted messages decreases when SD increases.

We note in the figure 9 that we have a similar number of transmitted messages for $BO = SO = 2, 3, 4,$ and 5 , the superframe length for these values is successively equal to 61,44ms, 122,88ms, 245,76ms and 491,52ms. In one superframe, the node generates 1, 4, 8 and 16 messages and the slots' length is equal to 3,84ms, 7,68ms, 15,36ms and 30,72ms,

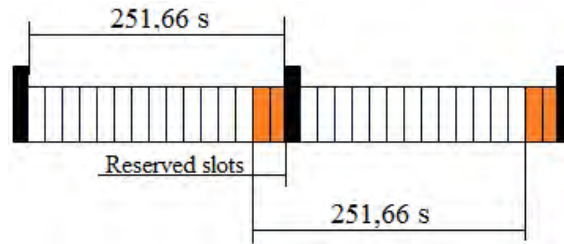


Figure 8 Periodic transmission time for $BO = SO = 14$

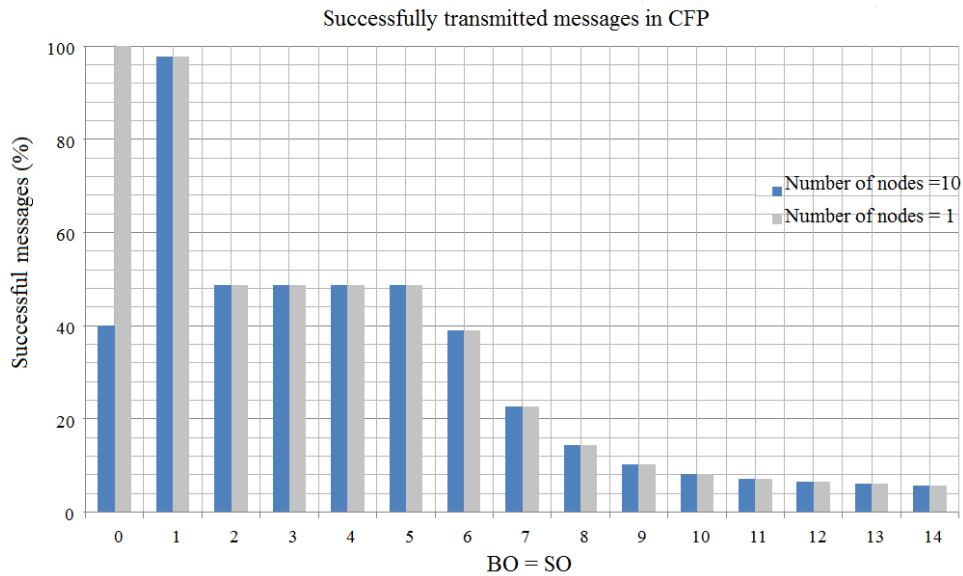


Figure 9 Number of successfully transmitted messages *CFP* with $BO = SO$

successively for $BO = SO = 2, 3, 4$ and 5 .

For these BO and SO values, nodes can transmit only half of generated messages. After some time the buffer will be filled and starts to reject messages.

Finally, the BO and SO optimal values for this class are $BO = SO = 0$ for 1 node and $BO = SO = 1$ for 5 nodes.

In the second simulation, we changed the parameters to adapt them to the characteristics of the first class. The parameters for the second simulation are given in Table 3.

With this configuration, if $BO = SO$, the number of successfully transmitted messages is equal to 100%. It is not influenced by the BO and SO variation because traffics are not heavy.

Parameters	Values
Application packet inter-arrival time	60s
BO	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 and 14
SO	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 and 14
Number of nodes	5 and 10 normal nodes and 1 coordinator
Duration of the simulation	1 hour
Length of application packets	10Bytes
Buffer	10 packets

Table 3 Parameters of the second simulation

In this class, the sensors have a message to transmit every 60s. For this reason, the use of small BO and SO values is not a good solution. If we use the high BO and low SO values, we can enlarge the inactive period to minimize the energy consumption for each node. In one hand, the maximal superframe duration is equal to 251,65s for $BO = SO = 14$ and the maximal inactive period length is equal to 251,64s for $BO = 14$ and $SO = 0$. On the other hand, a compromise between the number of successfully transmitted messages and energy saving must be found.

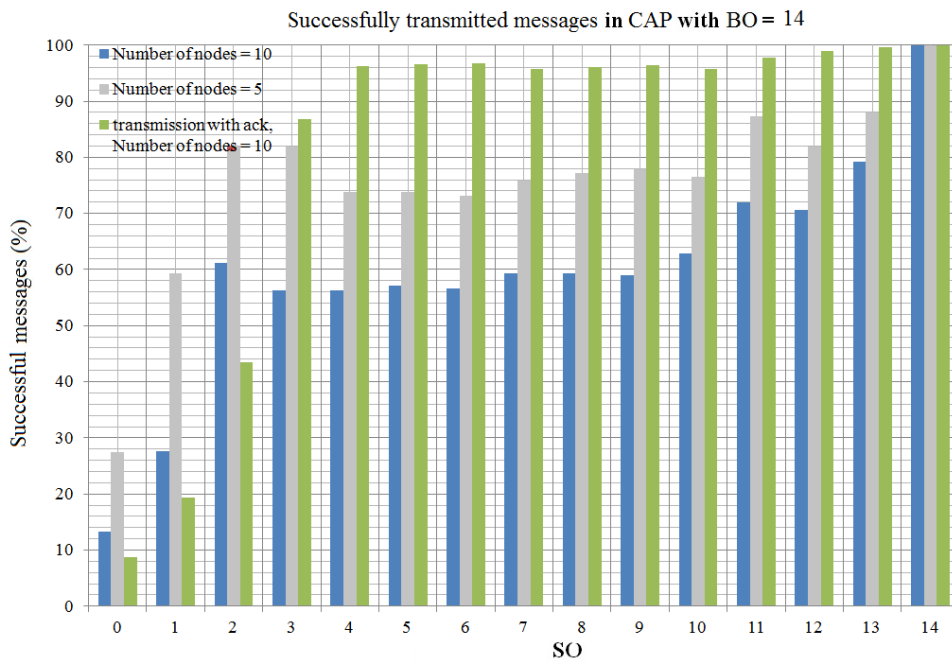


Figure 10 Successfully transmitted messages in CAP with $BO = 14$

In figure 10, the number of successfully transmitted messages without acknowledgement (ACK) for $SO = 2$ is greater than the number of successfully transmitted messages with ACK because when a node transmits a message requiring an ACK , it has to wait to receive this ACK for a fixed delay. If the node does not receive the ACK , it will retransmit the message. In this case, the same message is sent at least for 2 times while the SD length is not very

large, then the node cannot manage to retransmit the old one and transmit new messages in the same SD . If the use of ACK is deactivated, nodes transmit their messages and do not wait the reception of the ACK .

When $SO = 3$, the ratio of successfully transmitted messages with ACK is greater than the ratio of successfully transmitted messages without the ACK . This is explained by the fact that for $BO \geq 3$, the number of collisions is reduced and nodes have a sufficient period for retransmitting and transmitting the messages. If the SD length increases, nodes have more chance to transmit their messages. Also, if the number of nodes increases, the ratio of successful messages decreases because of the collisions. For that, if the number of nodes increases, the SD length must increase then the SO value must increase as well.

In our theoretical study, we fixed the minimum SO value at 7 to ensure that we have a minimum length of active and inactive periods. Our goal is to find the optimal BO and SO values that increase the number of successfully transmitted messages and help nodes to save energy. After these simulations, we can deduce that any values in the interval [7, 14] with requirement of ACK can be used.

Finally, we do not simulate the last class for two reasons. The first reason, nodes do not need to transmit their messages periodically. Therefore, the generated traffic is low and do not have an important influence on the network performances. Secondly, in the classical case, only one node can trigger the emergency phase, in CANet project.

In this part, we simulated transmissions in different periods: CFP and CAP . We configured the network with parameters adapted to each class of CANet traffics. We validated, by simulation, the different values of BO and SO that we derived in our theoretical study. Finally, we can recommend these values to use in WSN applications where generated traffics comply with the classes defined in this paper.

4 Conclusion

The technological advances allowed the application of sensor networks to e-health innovative solutions. In these solutions, several QoS constraints have to be tackled. Within the CANet project, we deal with the problem of combining several types of sensors generating different traffic patterns. In this paper, we investigated the use of IEEE 802.15.4 MAC protocol in this context and its ability to adapt to different traffic types by tuning its BO and SO parameters.

In the first part, we presented an overview of IEEE802.15.4 and its main parameters. After that, we presented our classification of existing QoS mechanisms. At the end of this part, we have classified the different types of generated traffic in CANet project into 3 classes based on their priority. In next parts, our main goal was to conduct a theoretical and experimental study to determine the optimal values that we should use to meet the requirements of each type of traffic generated by the sensors cane.

Our study demonstrated that the first class does not have any QoS constraints and the transmitted messages number is not important. For that, we aimed to find a configuration that ensures the successful reception of an acceptable rate of transmitted messages and that reduces energy consumption by increasing the inactive period. After our simulation and theoretical study, we noticed that the optimal values of BO and SO should be in the interval [7-14].

Moreover, the second class covers real time traffics, thus, we had to look for optimal values that ensure a maximum number of successfully transmitted messages. Two steps were

necessary to find the optimal values. Firstly, we removed the inactive period by setting $BO = SO$. Secondly, we have studied theoretically and by simulation the variation of the number of successfully transmitted messages for different BO and SO values. In the theoretical study, we found that the optimal value must be in the interval $[0-1]$. This result was verified and refined by simulation. The optimal values are: $BO = SO = 0$ for one node with 100% of successfully transmitted messages and $BO=SO=1$ for 5 nodes with 97% of successfully transmitted messages.

In our future work, we aim to define a new mechanism for traffic differentiation in CANet project. This mechanism should adapt dynamically the BO and SO parameters according to the traffic characteristics. We will also analyze the effect of BO and SO variation and the necessary period to return to the stable state as defined by the requirements of CANet project.

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