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Hend Fourati, Hanen Idoudi, Thierry Val, Adrien van den Bossche, Leila Azzouz Saidane. Performance evaluation of IEEE 802.15.6 CSMA/CA-based CANet WBAN. 12th International Conference on computer Systems And Applications (AICCSA 2015), Nov 2015, Marrakech, Morocco. pp.1-7. hal-01327091

HAL Id: hal-01327091

<https://hal.science/hal-01327091>

Submitted on 6 Jun 2016

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To cite this version : Fourati, Hend and Idoudi, Hanen and Val, Thierry and Van den Bossche, Adrien and Azzouz Saidane, Leila *Performance evaluation of IEEE 802.15.6 CSMA/CA-based CANet WBAN*. (2015) In: 12th International Conference on computer Systems And Applications (AICCSA 2015), 17 November 2015 - 20 November 2015 (Marrakech, Morocco).

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Performance evaluation of IEEE 802.15.6 CSMA/CA-based CANet WBAN

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Abstract—In the recent few years, Wireless Body Area networks (WBANs) showed what can be done remotely to greatly improve healthcare systems and facilitate the life to elderly.

One of the recent ehealth projects is CANet which aims at embedding a WBAN into a cane to monitor elderly/patients. Our main goal in this paper is to evaluate the performances of the emerging standard IEEE 802.15.6 when applied on different sensors from CANet eHealth project.

At this end, we defined a small scenario extracted from CANet, and we assigned IEEE 802.15.6 priorities to the selected cane sensors according to their inherent characteristics. We considered further the mandatory RAP period of IEEE 802.15.6 superframe under the beacon period with superframes mode since it supports both normal and urgent traffic.

Our results showed that the contention access behavior of this considered model of simulation depends on several constraints (including the nature of the studied application and the traffic types and frequency). This would be necessarily taken into account to get the most advantage of all features offered by WBANs standard IEEE 802.15.6.

Keywords—Medium Access Control (MAC), wireless body area networks (WBANs), E-health, CANet project, wireless sensor networks (WSN), IEEE 802.15.6.

I. INTRODUCTION

The demographic profile of the world is constantly submitted to fast changes, mainly due to the number of elderly which keeps increasing while the number of young people is in constant decrease. During the last decade, the pace of change has accelerated, involving an increasingly urgent challenge for society. Thus, aging and inherent pathologies require from now on a high level of social, familial, technical and financial resources. Knowing that, for example, more than 33% of 65-and-over aged persons fall every year [13] is not very reassuring, since it is impossible to have a qualified personnel alongside each one of them 24 hours a day and 7 days/7. This risks to explode healthcare costs especially as a majority of the elderly prefer to receive the medical care at home while benefiting from quality conditions and from optimal safety.

That's why, the need for a solution of easy and low-cost use (custom), handled remotely, is felt and the domain of e-health, has brought answers. E-health covers several activities such as the telemedicine, electronic health records, medical

remote monitoring, cybermedicine (the use of the internet to deliver medical services), etc.

E-Health systems are destined to provide several services to the monitored persons and their main features cover essentially two types: safety services (detection of gas, fire, etc.) and healthcare services such as remote medical diagnosis and detection of emergency situations [2].

The implementation of the provided services is often based on two elements:

- A *WSN* : is defined as a network of tiny sensor nodes, which are spatially distributed to communicate information gathered from the monitored field through wireless links. The data collected by the different nodes is sent to a sink which is connected to other networks, for example, the Internet (through a gateway) [2, 14];
- A *gateway* : which allows the collection of data and its transmission through a network of larger bandwidth (to the smartphone of the family doctor, for instance) [2].

In this context, CANet [1], an innovative project launched in 2011, aims at allowing an efficient monitoring of the elderly by the mean of a WBAN [15, 19] (Wireless Body Area Network), which can be defined as a short-range WSN embedded into a cane. To carry out this project and better take into consideration the different QoS requirements of this kind of health monitoring applications, we need communication protocols specially designed for ehealth systems using WBANs [20].

In this paper, we propose to use IEEE 802.15.6 as a communication protocol for a CANet scenario. We analyze different IEEE 802.15.6 parameters that should be adjusted according to the cane sensors characteristics and priorities. We discuss the choice of the most adequate modes, frame structure and priorities. Then, we simulate our scenario and study its performances under Castalia simulator.

The remainder of this paper is organized as follows. Section 2 gives an overview of the main specificities of CANet project, then, the general characteristics of IEEE 802.15.6

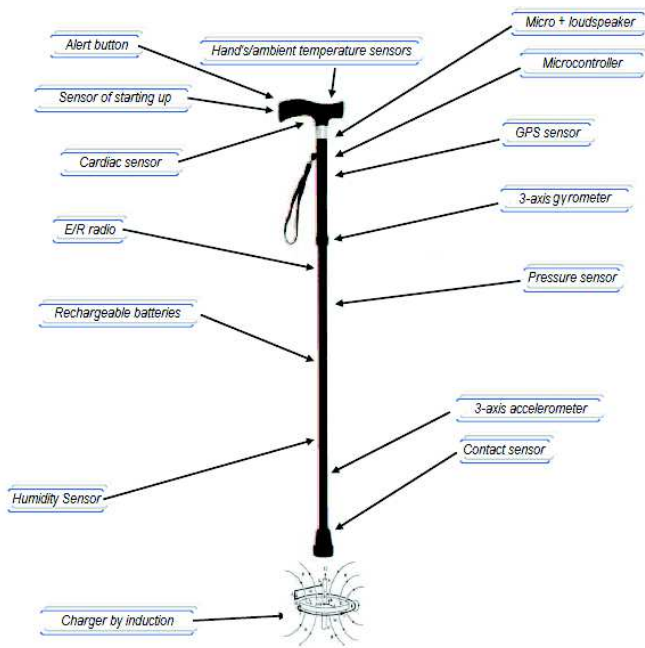


Fig. 1. Various sensors proposed in CANet project [1]

MAC layer. In section 3, we describe in detail the considered study case, which is part of CANet project. The exhibition of the IEEE 802.15.6 performances evaluation once applied to the studied case and the analysis of the obtained results of simulation are developed at the section 4. We will finish by the conclusion and perspectives in section 5.

II. RELATED WORK

A. CANet project

CANet (Cane Network) project [1] aims at designing and implementing a monitoring system of elderly integrated into an equipment which is usable during the everyday life: their walking cane. The smart cane would thus allow leading an easier life (it will not be necessary any more to stay in a hospital or a medical center to be watched all the time) while avoiding possible risks to which is exposed the concerned elderly person (falls, suffocation, fire, etc.). In order to grow old serenely and healthy, a collection of embedded sensors in/on the cane will ensure an active and optimized monitoring of the elderly, according to the health state of the concerned person (figure 1). To better understand the characteristics of different sensors and their requirements in terms of quality of service, data rate, frequency, etc., we will present a general definition of some selected sensors that are proposed within the CANet project:

- *A starting up sensor* : Allowing to start up (to activate) the monitoring system, embarked on the cane;
- *A hand's temperature sensor* : Measuring periodically the temperature of the user's hand and making sure it does not exceed a certain range of values;
- *A battery charge sensor* : integrated into the body of the cane;

- *Digital sensor AON (all or nothing) for detecting the action of the cane on the ground* : It reports on the frequency of cane contact with the ground when walking, to estimate the traveled distance, the rest periods, etc.;
- *The combination (microphone, loudspeaker)* : A couple of microphone / loudspeaker for the interactive dialogue with the concerned person. It is intended as an emergency call tool;
- *A 3- axis accelerometer* : Assisting in the location and detection of falls;
- *A 3- axis gyrometer* : The 3-axis gyrometer, coupled with a magnetometer, measures the angular speed and gives interesting informations about the rotation movements of the cane;
- *An emergency call button* ;
- *A localization sensor* : A sensor intended for the localization of the cane indoor/outdoor (via the wireless network);
- *Cardiac sensor* : This sensor records and watches the heart rhythm;

Health monitoring applications, such as CANet, need service differentiation since data and traffic generated by different sensors are heterogenous and should have different priorities in the network. For this reason, the authors of [18] proposed a novel architecture for service differentiation in CANet based on IEEE 802.15.4. Authors based their proposals on the characteristics of the here defined sensors and they further defined 2 virtual sensors to take into account specific types of high priority traffics :

- *Alert state* : An alert frame is sent in the case of extreme urgency;
- *Critical state* : Any sensor can be in this state in case of detection of abnormal, or even alarming values of a given vital sign to be watched [1].

Service differentiation was not officially considered by the major technologies used for WPANs (wireless personal area networks) as IEEE 802.15.4 std [6] and BLE [17], until IEEE 802.15.6 was defined. Since this standard was specifically designed to give a solution to service differentiation, we aim in our work to study the feasibility of using the native priority system of IEEE 802.15.6 within CANet project.

B. IEEE 802.15.6 standard

With the aim of supplying a personalized standard providing a great use flexibility of WBANs in the field of ehealth, the latest version of IEEE 802.15.6 appeared in 2012. Network topologies supported by IEEE 802.15.6 are one-hop and two-hop star topologies. In the most common case (single hop), an IEEE 802.15.6-based WBAN is composed, as illustrated in figure 2, of one and only one coordinator (or hub) and a number of connected nodes, which varies from 0 to 64 nodes. The two-hop star topology is typically used to increase the range of the network, if needed, and ensures thus a better QoS.

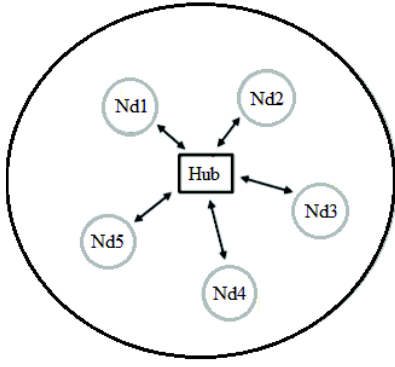


Fig. 2. IEEE 802.15.6 one-hop star topology

This standard operates on the first two layers of the OSI model: PHY and MAC. It proposes a unique MAC layer which can be used for one of the three following PHY layers: Human Body Communications (HBC), Narrowband (NB) PHY and Ultra wideband (UWB) PHY. The differences between these layers reside essentially in the defined data rates and the considered frequency bands as shown in table I. Each PHY layer is also characterised by the contention access mechanism, according to the standard:

- For HBC PHY : the slotted aloha is used;
- For NB PHY : the CSMA/CA access mechanism is adopted;
- For UWB : Either slotted aloha or CSMA can be used [3];

To allow various network nodes to access efficiently to the medium, three modes were defined by the standard: beacon mode with superframes, non-beacon mode with superframes and non-beacon mode without superframes. In each of these access modes, a different superframe structure has been defined to better serve the various requirements of each traffic type that may exist within the targeted application. The choice of the mode depends on the nature of sensors and their traffic.

When the IEEE 802.15.6 is used for a vital ehealth application such as CANet, the time base definition and the traffic differentiation through various periods of appropriate properties for each type of traffic is paramount.

In such applications, different mixed frames (for emergency or regular traffic, etc.) are sent frequently. The beacon mode with beacon periods would be thus the most adequate choice since it defines high-flexible superframe periods presented in the figure 3. That's why we'll opt for this mode in our CANet study case.

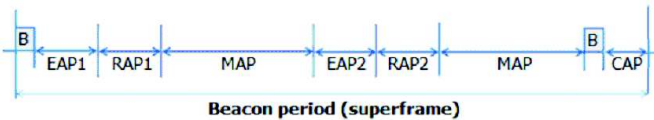


Fig. 3. IEEE 802.15.6 superframe structure in Beacon mode with superframes

The IEEE 802.15.6 superframe, in the beacon mode with beacon periods, consists of n slots (such as $1 \leq n \leq 255$

TABLE II. CLASSIFICATION OF IEEE 802.15.6 STD SUPERFRAME PERIODS [3, 4,10]

Period	Traffic type	Access mode
MAP	Regular traffic	Scheduled access
	Unscheduled and improvised access	On-demand (Polling/Posting)
EAP	Urgent high priority traffic only	Contention access
RAP	Random traffic (urgent or classic)	
CAP	Regular traffic only	

medium access slots) which we allocate to the various superframe parts. EAP phases (Emergency Access Phases) are destined exclusively to high priority traffic and Random Access phases (RAP) can be used for both urgent and regular traffics. MAP (Managed Access phase) is proposed essentially for request-based traffic and CAP (Contention Access phase) is defined only for regular traffic. But why to define two EAP, RAP and MAP periods in a same superframe ? In the case of coexistence, in the same network, between heterogeneous sensors for medical surveillance and others for purposes of entertainment, fixing RAP1 for medical traffic and RAP2 for entertainment traffic with $RAP1\text{-duration} > RAP2\text{-duration}$, allows the medical traffic to be more likely to access the channel during RAP phases. It is also useful to precise that only the RAP1 period is mandatory in this mode, all other superframe periods can be of zero length. The table II above shows the main characteristics of the differents parts of IEEE 802.15.6 superframe.

To meet the emerging needs in the e-health field, optimizing the existing medium access algorithms is henceforward a priority. For that purpose, an effective traffic management is imperative. This requires among other things the development of dynamic differentiation strategies during data collection (in real time as in delayed mode) as intelligently and precisely as possible. It's in this context that the IEEE 802.15.6 TG introduced the notion of priority as detailed in table III.

TABLE III. PRIORITY MAPPING PROPOSED BY IEEE 802.15.6 [3]

User priority	Traffic designation	Frame type
0	Background (BK)	Data
1	Best effort (BE)	Data
2	Excellent effort (EE)	Data
3	Video (VI)	Data
4	Voice (VO)	Data
5	Medical data or network control	Data or management
6	High-priority medical data or network control	Data or management
7	Emergency or medical implant event report	Data

The standard did not set clearly the quantitative details for each traffic of a particular priority. Only delays were defined for priorities 3 and 4. For priority 4 (which targets voice), by way of example, the delay must be less than 10 ms [5].

Within the contention access periods such as EAP, RAP and CAP, the respect for the priorities given by the IEEE 802.15.6 is guaranteed through the considered access mechanism. In our case study, the assigned priorities to the sensors will be managed thanks to the CSMA/CA access mechanism by choosing the backoff value among the intervals $[CW_{min}, CW_{max}]$ (contention window) defined by the standard for each priority class as illustrated in the following table (table IV).

TABLE I. DATA RATES DEFINED BY IEEE 802.15.6 (WHERE RSV MEANS RESERVED OR UNDEFINED) [3]

PHY layer	Frequency band (MHz)	Data rate (kb/s) for UP0	Data rate (kb/s) for UP1	Data rate (kb/s) for UP2	Data rate (kb/s) for UP3	Data rate (kb/s) for UP4	Data rate (kb/s) for UP5	Data rate (kb/s) for UP6	Data rate (kb/s) for UP7
HBC	5 to 50	164	328	656	1312.5	Rsv	Rsv	Rsv	Rsv
NB	402 to 2483.5	75.9 to 121.4	151.8 to 242.9	187.5 to 485.7	455.4 to 971.4 or Rsv	Rsv	Rsv	Rsv	Rsv
UWB	3100 to 10 600	202.5 to 487	789.7 to 975 or Rsv	1579 to 1950 or Rsv	3159 to 3900 or Rsv	6318 to 7800 or Rsv	12 636 to 15 600 or Rsv	557 or Rsv	1114 or Rsv

TABLE IV. CSMA/CA CONTENTION WINDOW BOUNDS PER PRIORITY CLASSES-IEEE 802.15.6 STD [3]

User priority	[CW _{min} , CW _{max}] interval
0	[16, 64]
1	[16, 32]
2	[8, 32]
3	[8, 16]
4	[4, 16]
5	[4, 8]
6	[2, 8]
7	[1, 4]

In the next sections, we define and study an IEEE 802.15.6-based case from the CANet project.

III. STUDY CASE AND ANALYSIS

To better examine the feasibility of using IEEE 802.15.6 for CANet, we focused on three sensors from those presented in section II.A, having the most different characteristics. Our objectives are:

- To define a small scenario for a cane as specified by CANet project and apply IEEE 802.15.6 as a communication protocol;
- To discuss and assign IEEE 802.15.6 priorities to different used sensors;
- To analyze different IEEE 802.15.6 parameters to be used in our scenario (superframe structure, data rates, frequency band, etc.).

As illustrated in figure 4, the hub (node 0) is placed on a necklace worn by the concerned person to prevent it from loss while all the other nodes are integrated into the cane.

We consider the use of three sensors (nodes).

The battery charge sensor (node 1) indicates if the battery of the system works well and if it is well charged. This sensor can be considered as a part of the network control mechanism because without load, the entire system becomes non-functional. In particular the extremely urgent situations can no longer be detected in this case, which can put the life of the person in danger. As a consequence, we assigned the priority 5 to the battery charge sensor.

The 3- axis accelerometer (node 2) measures essentially the movements of the cane along 3 axes (X, Y and Z). There is no need for a high priority for this sensor since as soon as there is detection of an emergency situation (such as

a risk of fall), this sensor passes to the maximal priority (User Priority UP7).

For this reason, we assigned priority 2 to this sensor.

Pushing the sensitive area of the emergency call button (node 3) allows to turn on immediately the microphone and the loudspeakers and call a family member or a doctor regardless of the transmission channel state at that moment. Once it collected the data from each sensor, the hub sends the received information through a broadband network in order to transmit them to the family doctor or the person charged of the patient e-health control.

Thus, we assigned the highest priority (User Priority 7) to this sensor.

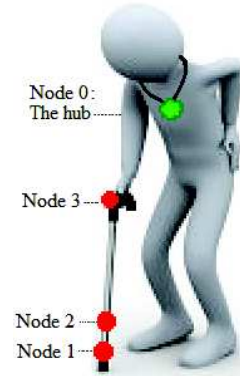


Fig. 4. The considered WBAN network scenario

The general description of the studied sensors in our scenario is summarized in the table V below and organized according to the priority classes and the specificities of superframe periods introduced in the IEEE 802.15.6 standard.

TABLE V. GENERAL CHARACTERISTICS OF THE STUDIED SENSORS

Sensor	Priority (IEEE 802.15.6)	Period (IEEE 802.15.6 superframe)
Sensor of the load of battery	5	EAP, RAP, MAP
A 3- axis accelerometer	2	RAP,MAP, CAP
Emergency call button	6	EAP, RAP

Since the RAP period can tolerate contention access of regular and urgent traffics and all the other IEEE 802.15.6 superframe parts are optional, and considering that (because) those kinds of traffic are the only needed ones in CANet

TABLE VII. PARAMETERS OF THE STUDIED SENSORS

Parameter	Node 1: Charge sensor	Node 2: 3-axis accelerometer	Node 3: Emergency call button
Number of sensing devices per sensor	1	1	1
Power consumption per device(mJoules)	0.01455 [7]	0.02	0.0576 [9]
Sensor type	Battery	Acceleration	Emergency
Device sensitivity (Volt)	0 [7]	0.02 [8]	0
Device resolution	0.047nC [7]	0.004 [8]	0,001
Device saturation	5V [7]	2g [8]	1b [9]
maxSamples rate	1	1	1
Data rate (kbps) according to IEEE 802.15.6 UP [3]	971.4	485.7	971.4

project, our IEEE 802.15.6 performance evaluation will be based on the basic superframe structure shown in figure 5.

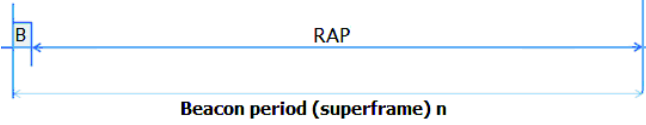


Fig. 5. The considered beacon period in our scenario

IV. SIMULATION RESULTS

To examine closer the yield of IEEE 802.15.6 MAC, we conducted a study of its various eventual implementing simulators. To our best knowledge, Castalia [11] is currently the most adequate simulator since it provides already a basic IEEE 802.15.6 MAC implementation named: BaselineMAC.

A. Simulation context

Most of recent articles studying the performances of IEEE 802.15.6 did not consider modifications brought to the standard after the first version [12] particularly in term of MAC layer parameters. We therefore brought the necessary code additions and improvements for BaselineMAC according to the last version of the standard [3] (Which is so far the only official version). The general parameters of the performed simulation are detailed in table VI. The distribution of different sensors details are then mentioned in table VII.

B. Simulation results

Taking into account the different simulation parameters, we evaluated the CSMA/CA access mechanism according to three metrics: Data packet breakdown, latency and energy consumption.

1) *MAC sublayer metric: Data Packet Breakdown:* In this study, we observed the efficiency of IEEE 802.15.6-MAC in term of packet outcome breakdown for a chosen scenario based on CANet project concept. Figure 6 shows different data packet breakdown for each node of the WBN network and for different data rates starting with 20 packets/sec/node to 140 packets/sec/node. The vertical axis represents packets transmission states in different colors.

Transmission failure due to channel unavailability presents the lowest rate in all the graphs especially for node 3 (fig6-c) which has the highest priority (6) and 0% of this failure category.

Packet transmission failure due to buffer overflow was null for low data rates and began to be significant just from 100 packets/sec/node for all the nodes.

However, the rate of success from the first try, inappropriate to the nodes priorities, reminds us of the CSMA/CA drawbacks. Nodes with high priorities are therefore not sufficiently benefited by the values of CWmin and CWmax set by the IEEE 802.15.6 standard. These CSMA/CA weaknesses are accentuated when it's a matter of managing a fairly heterogeneous traffic and considering important data rates.

2) *Application metric: Latency:* We also evaluated the end-to-end delay of successfully transmitted packets, taking into account the differentiation of service through the priority system proposed by the IEEE standard. These latency results are presented in figure 7. The horizontal axis represents latency intervals in ms and the vertical one indicates success packages percentage for different data rates (from 20 to 140 packets/sec). Since in our application, we are manipulating medical data, the data reception delay is extremely important: in case of long delay, this could put the patient's life in danger. the latency histograms obtained from the simulation of our present network is satisfactory since more than 80% of packets are transmitted during the first 20ms for data rates up to 100 packets/sec. However, the performance in term of latency begins to degrade when the data rates become high (such as 120 and 140 packets/sec). This degradation of latency performance is most clearly visible for 140 packets/sec data rate. For this packets rate, less than 60% of packages percentage are successfully sent during the first 20ms, and almost 7% are sent in an interval of [380 ms, 400ms] (which corresponds to the second increase of the black curve in figure 7).

TABLE VI. SIMULATION PARAMETERS

	Parameter	Value
General Parameters	Transmitter Power	0.037mW
	Frequency	2400MHz
	PHY layer	NB
	Duration of the simulation	51 sec
MAC Layer parameters	MAC protocol	CSMA/CA
	Data rate	Up tp 971.4 kb/s
	Transmission Power	-10 dBm
	pTiFS(time to start TXing a frame after a RX of another one)	0.075 msec
	MAC buffer	48 packets
	Time slot duration	10ms
	Number of time slots in a beacon period	32slots
	RAP length	32slots

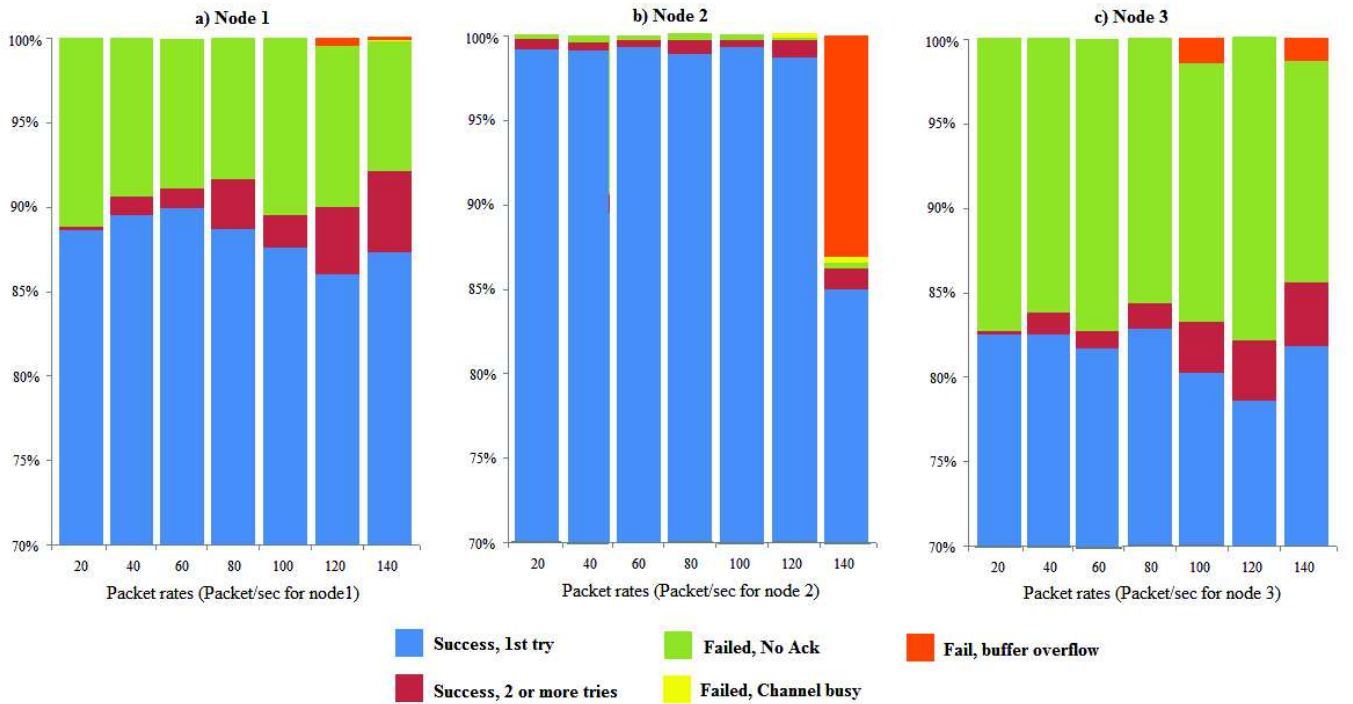


Fig. 6. Data packet outcome breakdown for different nodes and variable packet rates

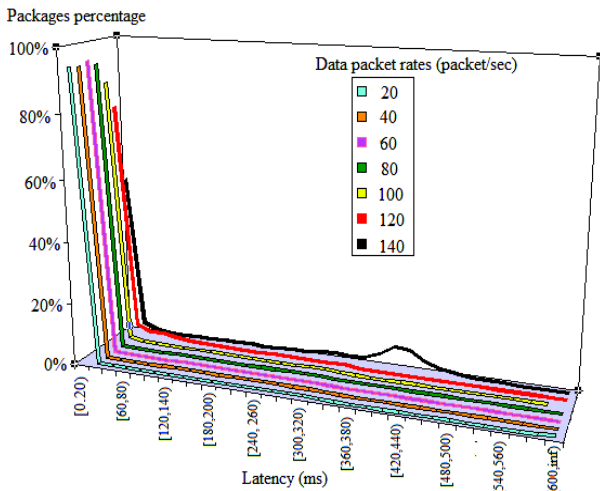


Fig. 7. Latency intervals for different packet rates

3) *Energy Consumption*: Figure 8 shows the consumed energy (in joules) for all the nodes of our scenario including the hub. This considered metric depends mainly on the sleep periods and activity periods fixed for each node. The CSMA/CA method, known to be greedy in terms of resources, affects also this result. However, the different sensor priorities do not have a significant effect on energy consumption.

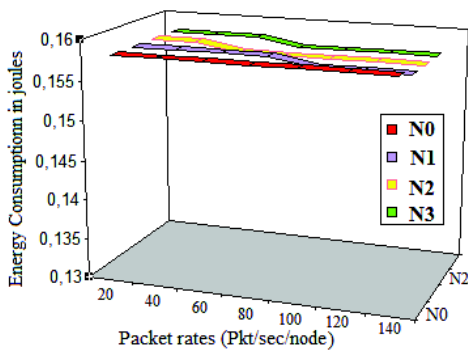


Fig. 8. Consumed energy for different nodes and variable packet rates

V. CONCLUSION AND PERSPECTIVES

IEEE 802.15.6 is an emergent standard specifically designed for low power and high efficient e-health applications. Through this work, we used the emergent standard intended for body area networks to investigate its performances when applied to a prototype cane of CANet project.

Thus, we essentially discussed the benefit of IEEE 802.15.6 priority system and how it can be adapted to differentiate priorities of some sensors proposed for CANet. We analyzed different IEEE 802.15.6 parameters choice which could be more adequate to our scenario. We evaluate and the end the performances of our CANet scenario with IEEE 802.15.6 as a communication protocol.

In a future work, we aim at estimating the performances of the studied network once the superframe structure changed (such as introducing the use of EAP et CAP periods, testing the efficiency of slotted ALOHA access mechanism rather than CSMA / CA, etc.).

Through this approach, we will be able of determining the ideal structure of the superframe, the values of the parameters and the choice of the mode and the appropriate access method that ensures an optimal differentiation of the traffic in the considered WBAN.

It would be also interesting to prototype and test the CANet scenario on a real testbed such as Wino prototypes [16].

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