Performances Comparison of IEEE 802.15.6 and IEEE 802.15.4

Optimization and Exploitation in Healthcare and Medical Applications

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***Abstract*—In this paper, we simulate the energy consumption, throughput and reliability for both, Zigbee IEEE 802.15.4 Mac protocol and BAN IEEE 802.15.6 exploited in medical applications using Guaranteed Time Slot (GTS) and polling mechanisms by CASTALIA software. Then, we compare and analyze the simulation results. These results show that the originality of this work focuses on giving decisive factors to choose the appropriate MAC protocol in a medical context depending on the energy consumption, number of used nodes, and sensors data rates.**

Keywords*—*Guaranteed Time Slot (GTS); polling; WBAN; IEEE 802.15.6; IEEE 802.15.4; energy consumption

I. Introduction

Continuous Monitoring of patient's vital signs by Wireless Sensor network WSN can help in the diagnosis and can also monitor the patient's history in everyday life activities so as to provide accurate diagnosis simulation results compare.

Doctors can check the complete details of patients from a remote location and can then recommend a suitable medication. The main purpose of this technology is to presents reduce the load at hospitals and provide efficient healthcare facility remotely.

Recently, WBANs are becoming more and more studied and developed by research organizations. In 2003 IEEE has standardized IEEE 802.15.4 for industrial applications, but with the increasing of WBAN demand, this protocol was adopted as the main solution in several WBAN projects [1]. Then Bluetooth Low Energy, have been proposed as likely candidates to lead the development and extended deployment of WBANs, but his small network scalability was a handicap. In 2012 the IEEE 802.15 Task Group 6 (BAN) [2] standardized the IEEE 802.15.6 communication standard optimized for low power devices and operation on, in or around the human body to provide a variety of applications including medical, personal entertainment and others [3].

In the literature, we notice that a big importance is given to WBAN and especially the comparison between IEEE 802.15.6 and old WBAN protocols, starting with the authors in [4] that provide a comprehensive survey on Wireless Body Area Network. Others in [5] attracted a review paper on the recent advances in MAC protocols for WBANs. In [6] authors presents the specifications and characteristics of medium access protocols for WBAN. Based on this comparison many researches were done to improve WBAN performances especially in terms of physical layer and energy consumption [7].

However, all these papers compare WBANs protocols in a thigh sense without taking into consideration neither the application field, nor the sensors constraints. In this paper our contribution aims to compare the IEEE 802.15.4 and IEEE 802.15.6 from a medical point of view taking into consideration the practical medical sensors data rate. For this purpose, this paper is presented into three sections: Section 1 introduces an overview of IEEE 802.15.4/6 MAC layers specifications; in Section 2 we investigate the power and throughput compromise between the two protocols access mechanisms namely Guaranteed Time Slot (GTS) and polling; in Section 3 we present our simulation results to compare between the two protocols under the same simulation conditions, then the paper gives some proposals how to improve WBANs efficiency in the medical field.

II. An Overview of the IEEE 802.15.4 and IEEE 802.15.6 Medium Access Control Sub-Layer

A. IEEE 802.15.6 MAC Specifications

IEEE 802.15.6 is the standard developed by the IEEE 802.15 task group 6 (BAN) to face several wireless technologies challenges especially ultra-lower power constraint, lower device complexity, higher transfer data rate, shorter range communication and security [2]. The last draft of this standard was published in 2012 and specified the three IEEE 802.15.6 physical layers such as the Narrowband (NB), Ultra wideband (UWB), and Human Body Communications (HBC) layers. It defines also the MAC layer specifications that facilitate the control operation of the entire system. The Nodes that communicate are organized into logical sets controlled by a collective hub. The hubs are responsible for coordinating channel access by establishing one of the following three access modes: Beacon mode with beacon period superframe boundaries, Non-beacon mode with superframe boundaries, Non-beacon mode without superframe boundaries using polling access method which is the most important advantage of the standard. Polling process begins with the nodes getting connected to the hub. The hub sends a polling packet to the node that is being polled. The node that receives the polling packet transmits data packets stored in its buffer. When the transmission of data is over, the polled node sends a poll finish packet to the hub [8]. The hub on receiving the packet starts polling the next consecutive node in the cycle and the process is repeated. If no packets are present in a node's buffer, the hub switches the poll to the next node immediately. Polling is, in fact, in between TDMA and CSMA/CA [9]. The base station retains total control over the channel, but the frame content is no more fixed, allowing variable size packets to be sent. The base station sends a specific packet (a poll packet) to trigger the transmission by the node. The latter just waits to receive a poll packet, and upon reception sends what it has to transmit. Polling can be implemented as a connection oriented service (very much like TDMA, but with higher flexibility in packet size) or connection less-service (asynchronous). Fig. 1 well-describes the polling process.

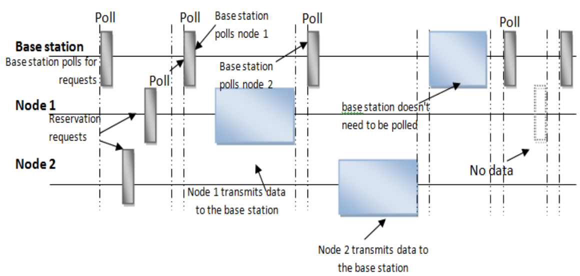

Fig. 1. IEEE 802.15.6 polling process.

B. *IEEE 802.15.4 MAC Specifications*

IEEE 802.15.4 [10] defines the physical layer (PHY) and MAC sublayer specifications for Low Rate WPAN (wireless personal area network) devices. The standard is defined for devices with short-range operation and low energy consumption. The IEEE 802.15.4 LR-WPAN uses two types of channel access mechanism, depending on the network configuration:

- Nonbeacon-enabled PANs use an unslotted CSMA-CA channel access mechanism.
- Beacon-enabled PANs use a slotted CSMA-CA channel access mechanism using The Guaranteed Time Slot (GTS) mechanism. GTS allows devices to access the medium without contention for nodes requiring guaranteed bandwidth, based on special superframe structure.

As shown in Fig. 2, the superframe is defined between two beacon frames and has an active period and an inactive period [11]. The active portion of the superframe structure is composed of three parts, the Beacon, the Contention Access Period (CAP) and the Contention Free Period (CFP):

- ✓ Beacon (BCN). The beacon frame is transmitted at the start of slot 0. It contains the information on the addressing fields, the superframe specification, the GTS fields; the pending address fields and other PAN related data.
- ✓ Contention Access Period (CAP). The CAP starts immediately after the beacon frame and ends before the beginning of the CFP, if it exists. All transmissions during the CAP are made using the Slotted CSMA/CA mechanism. However, the acknowledgement frames and any data that immediately follows the acknowledgement of a data request command are transmitted without contention.
- ✓ Contention Free Period (CFP). The CFP starts immediately after the end of the CAP and must complete before the start of the next beacon or the end of the superframe. Transmissions are contention-free since they use guaranteed time slots (GTS) that must be previously allocated by the Zigbee Coordinator.

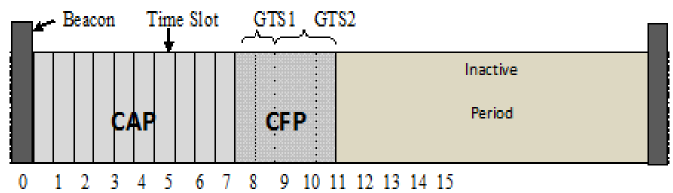

Fig. 2. IEEE 802.15.4 MAC superframe structure.

III. Pooling and GTS: Power and Throughput Compromise

With IEEE 802.15.6 polling mechanism, sensors sleep most of their lifetime. They wake up only to transmit Data. As soon as transmission is finished, they sleep again. The node getting uptime is determined by the coordinator [8]. The hub sends a poll packet to a node according to the poll schedule stored in the hub. Ideally, a node need to wake up just at the moment it should receive the poll packet from the hub. If the node wakes up earlier, it will have to stay awake to receive the poll packet from the hub causing unwanted energy losses. If the node wakes up after the poll packet is sent by the hub, the poll packet will be lost and the polling mechanism fails. The hub has to ensure that the node receives the poll packet. The coordinator therefore sets a sleeping time for each node after the transmission of the packets. The node should sleep for the time specified by the hub after which it wakes up at the right moment to receive the poll packet. However, because of clock synchronization problems, and due to variations in times for which packets are transmitted, the sensor may wake up before or after the stipulated time for sending the poll packet by the hub [12]. All this explains why the polling mechanism is less efficient in terms of energy consumption.

IEEE 802.15.4 standard allows for dedicated bandwidth allocation to devices through GTS mechanism. The Contention Free Period (CFP) of the superframe consists of GTS slots which the devices can use for contention free data transmission. The devices request for GTS allocation through GTS request command by specifying the number of slots needed and direction of GTS transmission (from or to the coordinator). The GTS slots are allocated in every superframe so they consume a significant bandwidth of the superframe duration. Therefore, inefficient allocation of GTS can lead to significant loss of bandwidth and degradation of the overall system performance. According to the IEEE 802.15.4 standard, the size of a GTS slot is the same as a CAP slot (i.e. 1 GTS slot = 1 CAP slot = Superframe Duration (SD) / 16). The maximum bandwidth available by GTS should also be higher than the packet arrival rate of a device for data transmission to be complete. However, the packet transmission duration during GTS is much lower than the available bandwidth and thus a significant amount of bandwidth is wasted for every slot allocated in every superframe [13]. Thus, the GTS Mechanism is less efficient in terms of throughput.

IV. Simulations and Results Analysis

In this section, and based on Castalia simulator and OMNET++ [14], we proceed to analyze the performance of protocols ZigBeeMAC IEEE 802.15.4 and IEEE 802.15.6 (BaselineMAC).

A. Sensors Data Rates

Table 1 details data rates required for some known sensors used in medical and health care applications [15].

TABLE I. Data Rates of Some Medical and Healthcare Sensors

Health information	**Data rate**
ECG	36 kbps
EEG	98 kbps
Pulse rate	2.4 kbps
Respiratory rate	1.0 kbps
Blood pressure	1.92 kbps
Heart rate	1.92 kbps

B. Simulation Parameters

Simulations are realized by CASTALIA-3.3 software based on Zigbee/IEEE 802.15.4 and BAN BaseLine IEEE 802.15.6 MAC protocols, the parameters used for these simulations are shown in Table 2.

TABLE II. Simulation Parameters

Number of Nodes	**6**
Radio Output Power	-15dBm
Sensors data rates	{20kbps to 260kbps for 802.15.4} {20kbps to 1Mbps for 802.15.6}
Frequency band	ISM 2.4GHz

C. IEEE 802.15.4 Simulations and Results Analysis

1) Throughput and reliability

During 50 s, which is the time set at the code for the simulation, we vary parameters of the MACs related to random access (CSMA/CA) and guaranteed access (GTSon) and the nodes data rates. If the communication is ideal we would achieve 12500 packets when the data rate is 250 kbps, as the packet size is 1kbit [14]. However, in fact, we just receive1600 packets according to Fig. 3.

In Fig. 3, the y-axis is the average packets received per node (only node 0 receives packets but it receives them from multiple nodes, this is what the “per node” means). The x-axis represents the data rate of nodes. We notice that the number of received packets is low for high data rates (>40 kbps) compared to the number of sent ones, and in the best case (GTSon, noTemporal) the maximum of received packets don't exceed 1600 packets.

For the same mode (GTSon, noTemporal), the graph shows that the number of received packets is saturated for rates over 40 kbps which conforms to theoretical suppositions. That is because every node uses (250kbps/5) =50 kbps assuming that the maximum Zigbee PAN data rate is 250kbps [10]. So as to show explicitly the dependence of the saturation data rate to the number of nodes, we vary the number of nodes from 2 up to 32 using the mode (GTSon, noTemporal), which is the best simulation scenario; therefore, we illustrate results in Fig. 4.

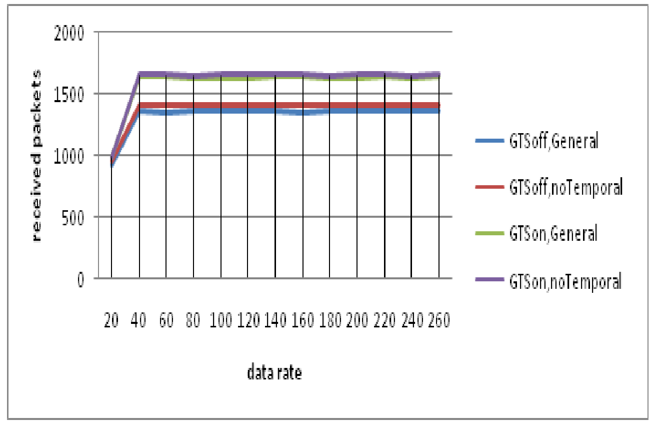

Fig. 3. Packets received per node 0 in function of sensors data rates.

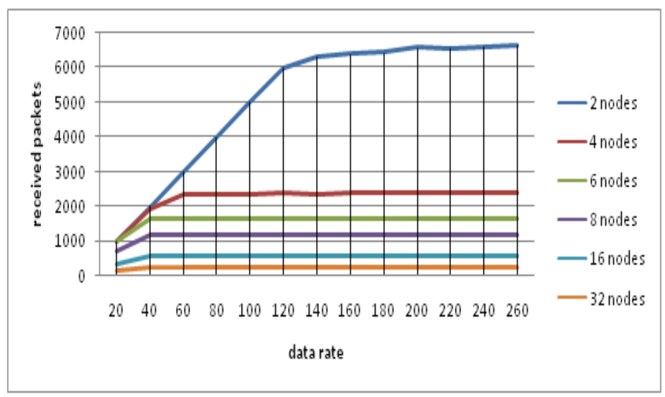

Fig. 4. IEEE 802.15.6 received packets per node 0 in function of sensors data rates for various numbers of nodes.

Fig. 4 is a plot between the number of nodes and throughput for various data rates. This plot shows that the more the number of nodes in the PAN (star topology) increases, the more the throughput of sensors decreases.

This curve gives also an idea about "Saturation Throughput" defined as the limit reached by the system throughput when the offered system load increases [16]. We observe that throughput linearly increases with the load to a certain point and achieves a constant saturation throughput. This is an important observation that contradicts the assumption used in the literature for the analytical modeling of the IEEE 802.15.4 MAC protocol. We demonstrate this fact in the table hereunder.

TABLE III. COMPARISON BETWEEN SIMULATION AND THEORETICAL SATURATION DATA RATE IN FUNCTION OF NODES NUMBER

Number of nodes (without node 0)	Saturation Throughput(packets)	Saturation data rate(kbps)	Theoretical nodes uplink data rate(kbps)
1	6500	240	250
3	2400	60	83.3
5	1600	40	50
7	1175	40	35.7
15	540	40	16.6
31	250	40	8

The results in Table 3, significantly means that nodes cannot reach their maximum data rate due to the saturation throughput. Moreover, they also show that we cannot exceed 6 nodes (including node 0) in a coordinated 802.15.4 PAN otherwise we reach the saturation data rate of 40 kbps.

We translate these results into reliability, which is the number of received packets divided by the number of transmitted ones.

According to Fig. 5, we observe that reliability is less than 80% for cases over 6 nodes, and taking into consideration that accepted value of reliability should be over 80% [17], we conclude that a coordinated Zigbee 802.15.4 PAN (star topology) can't be scalable over 6 nodes. We also observe that the best case of reliability (2 nodes), the data rate couldn't exceed 160 kbps.

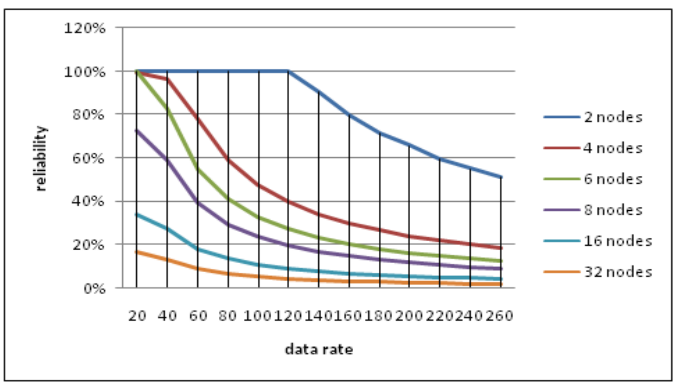

Fig. 5. IEEE 802.15.4 received packets per node 0 in function of sensors data rates for various numbers of nodes.

2) Energy consumption

To define the main operating parameters of a radio, Castalia follows a specific format. Castalia defines 2 radios: CC1000 and CC2420, they define the real radios of the same name by Texas Instruments. To evaluate simulation performance, we used CC2420 radio.

Fig. 6 illustrates the energy consumption histogram. We notice that when the GTS is active, the energy doesn't exceed 0.09 j. However, when GTS is OFF, the consumption is higher and can reach 0.11 j. These results are conforming to the theoretical supposition, because with the inactive period in the superframe, all sensors radios are in sleep mode, which saves an important amount of energy [18]. As a result, the applied mechanism conserves an important amount of energy and consequently increases the node life time.

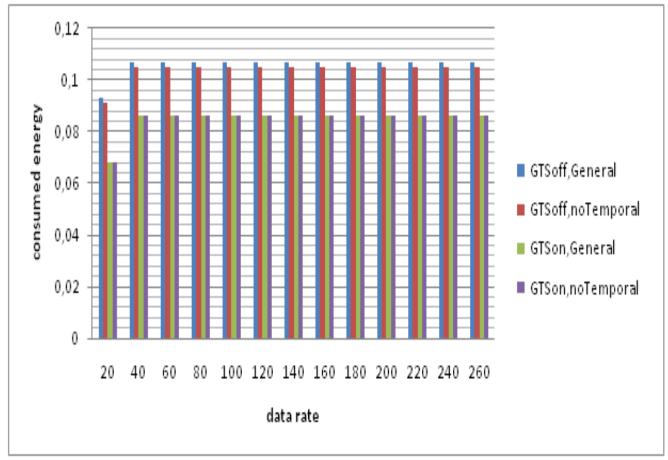

Fig. 6. IEEE 802.15.4 energy consumption (J) in function of nodes data rates.

Based on these results above, we conclude that GTSon mode is better than GTSoff mode when it comes to throughput and reliability. In terms of energy consumption, GTSon saves up to 20% of the supposed energy to be consumed. Thus, the results respond to the economic energy consumption criteria of Zigbee.

D. IEEE 802.15.6 Simulations and Results Analysis

1) Throughput and reliability

In this section we keep the same conditions of the first simulation, we change the Zigbee Mac protocol by BaselineMAC IEEE 802.15.6 protocol and we vary parameters of the MACs related to scheduled access, random access and improvised access (polling) mechanisms. We also choose data rates interval to attend 1Mbps (theoretical IEEE 802.15.6 data rate).

From Fig. 7, we notice that the optimal case is obtained when polling is activated without channel time variations. Particularly for data rates over 40kbps, and in the best case (pollingON, noTemporal) the maximum of received packets reached 6300 packets.

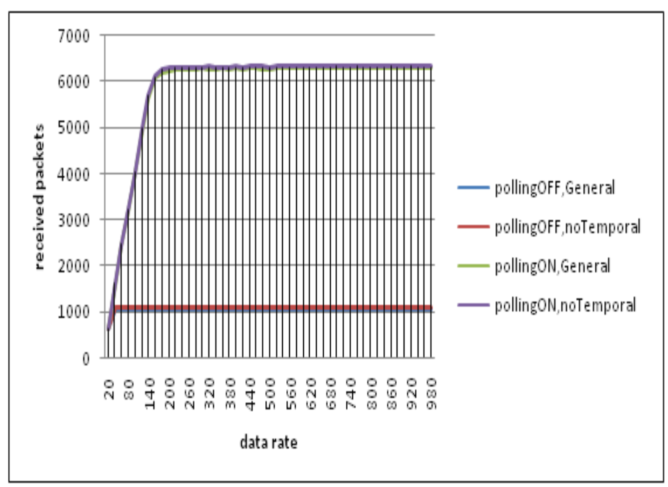

Fig. 7. IEEE 802.15.6 packets received per node 0 in function of sensors data rates.

As shown in Fig. 7, the number of received packets is saturated for rates over than 170 kbps, which conform to theorical suppositions. That is because every node uses (1024kbps/5) = 204 kbps, assuming that the maximum WBAN area data rate is 1024kbps when the modulation DQPSK is used [15]. As done for GTS in the first simulation, and in the purpose of clarifying the number of nodes impact on the saturation data rate we have varied the number of nodes from 2 up to 32 using the mode (pollingON, noTemporal), which is considered the best simulation scenario.

Fig. 8 gives an idea about "Saturation Throughput». We observe that throughput linearly increases with the load to a certain point and achieves a constant saturation throughput. We also notice that the more the number of nodes in the PAN (star topology) increases, the more the saturation data rate decreases. Unlike GTS where the saturation data rate blocks at 40 kbps for more than 6 nodes, pollingON saturation data rate is relatively dependent on the number of nodes. Table 4 resumes the results shown in Fig. 8.

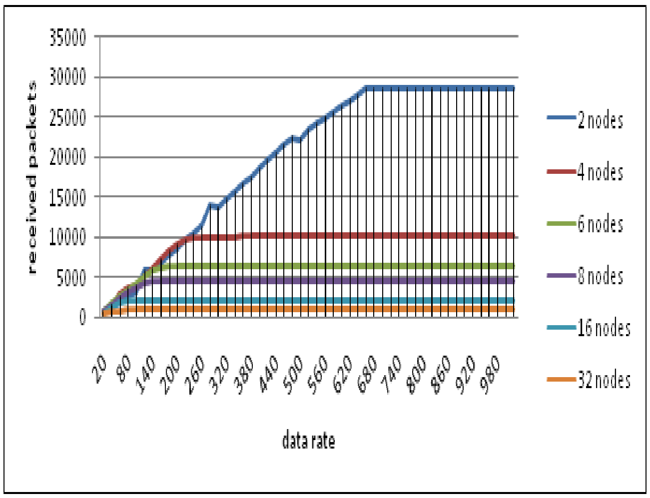

Fig. 8. IEEE 802.15.6 received packets per node 0 in function of sensors data rates for various numbers of nodes.

TABLE IV. COMPARISON BETWEEN SIMULATION AND THEORETICAL SATURATION DATA RATE IN FUNCTION OF NUMBER OF NODES

Number of nodes (without node 0)	**Saturation Throughput (packets)**	**Saturation data rate(kbps)**	**Theoretical nodes uplink data rate(kbps)**
1	28500	660	1024
3	10200	280	341
5	6300	180	204
7	4500	140	146
15	2100	80	68.2
31	790	40	33

As done in the first simulation and to evaluate IEEE 802.15.6 scalability, we translate throughput results into reliability and we obtain results in Fig. 9.

We notice that reliability is optimal when we use 6 (including node 0) or less than 6 nodes already recommended by authors in reference [15]. We also observe that the best case of reliability (2 nodes) data rate shouldn't exceed 720kbps.

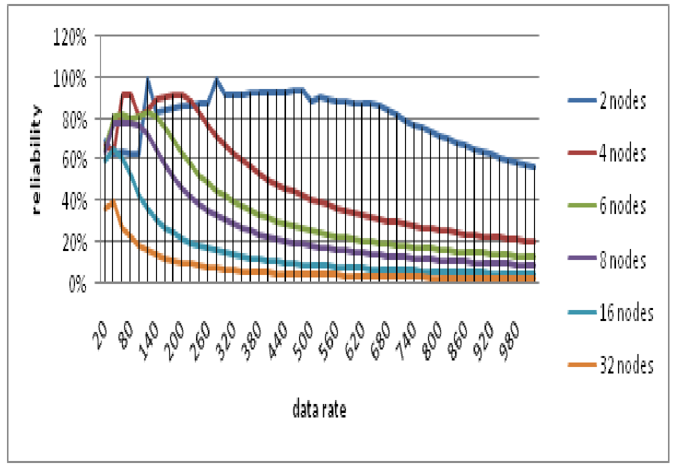

Fig. 9. Coordinated 802.15.6 reliability in function of sensors data rates for various numbers of nodes.

2) Energy consumption

From Fig. 10, we remark that when the polling is active the consumed energy achieves 0.29 joule for data rates higher than 40kbps. However, for data rates fewer than 40 kbps, the consumption is lower and doesn't exceed 0.16 j. That is, because the polling process bases on nodes synchronization, if the node wakes up earlier, it will have to stay awake to receive the poll packet from the hub causing unwanted energy loss [12]. If the node wakes up after the poll packet is sent by the hub, the poll packet will be lost and the polling mechanism fails.

Based on results, and as far as throughput and reliability are concerned, we conclude that pollingON mode is better than pollingOFF mode. In terms of energy consumption, in one hand, pollingON mode is more exigent and 45% of battery saved energy will be consumed only to activate this mode, on the other hand, pollingOFF mode is energy saving, but its low reliability is the major disadvantage as it deprives it from the overuse in WBANs.

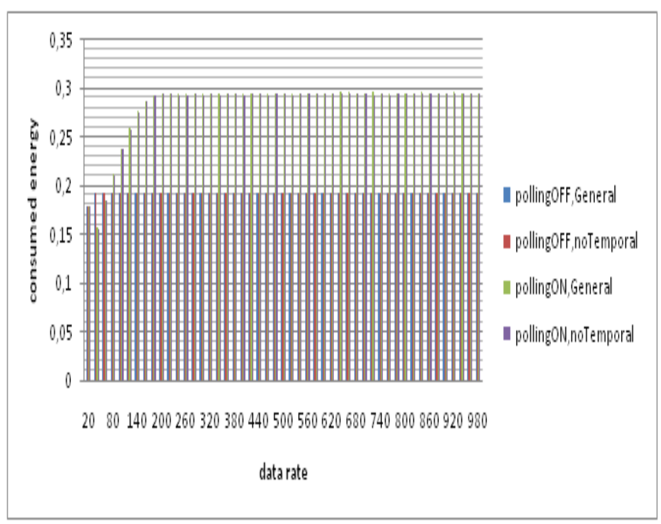

Fig. 10. IEEE 802.15.6 Energy consumption (J) in function of nodes data rates.

E. GTS and Polling Comparison and Discussion

Given that IEEE 802.15.4 (GTSon,noTemporal) and IEEE 802.15.6 (pollingON,noTemporal) are the best scenarios the simulations above, in this section of this paper we compare their results and performances.

Fig. 11 shows that in terms of throughput, the polling offers better results than GTS and especially for high data rate (>40kbps). Thus, the use of GTS is more beneficial if data rates are fewer than 40 kbps.

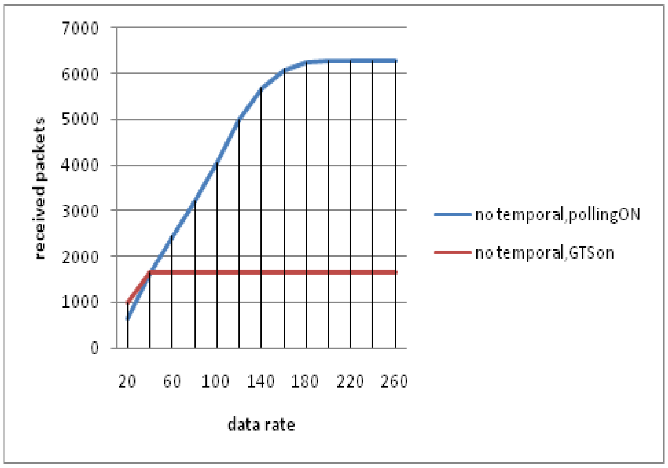

Fig. 11. IEEE 802.15.6 vs. IEEE 802.15.4 received packets performance.

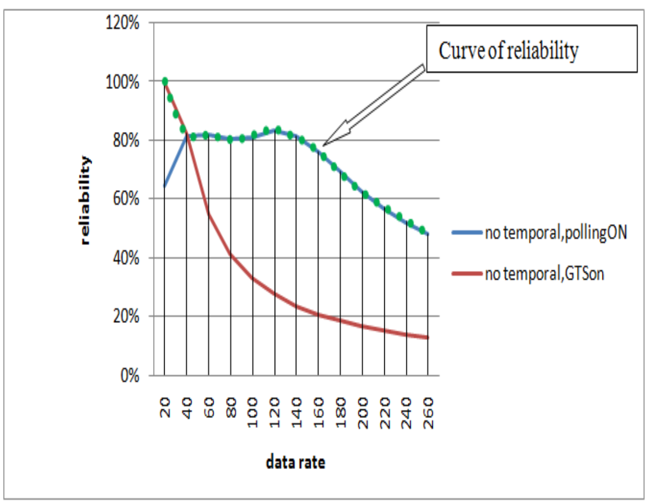

Fig. 12. IEEE 802.15.6 vs. IEEE 802.15.4 reliability performance.

In Fig. 12 and In terms of reliability, we can observe the complementarity of the two protocols. The graph shows that up to 40 kbps GTS gives more than 80% of reliability, and from 40 kbps to 150 kbps polling takes over and the reliability is around 80%. Consequently, the painted area in the graph is the new curve of reliability obtained when we use GTS for sensors data rates less than 40 kbps and polling for sensors data rates between 40kbps and 150 kbps.

In terms of energy consumption, Fig. 13 shows that GTS consume less energy than polling saving up to 72% of supposed energy to be consumed, especially for data rates less than 40kbps.

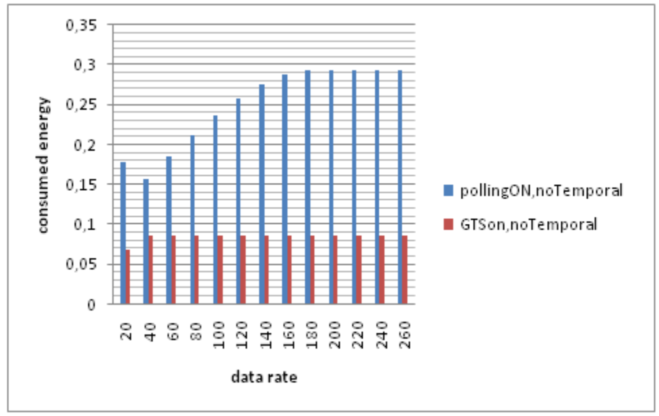

Fig. 13. IEEE 802.15.6 vs. IEEE 802.15.4 energy consumption performance.

We conclude that as far as medical exploitation is concerned, the use of IEEE 802.15.4 is more beneficial for sensors with minimum data rate requirement (less than 40 kb/s) like temperature and glucose sensors, profiting from its important reliability for low data rates, and increasing our sensor lifetime by saving up to 72% of required energy as resumed in Table 5.

TABLE V. GTS AND POLLING ENERGY CONSUMPTION COMPARISON

	Min. energy	**Max. energy**
GTS	0.06	0.08
polling	0.16	0.29
Gain	62%	72%

For sensors enquiring high data rates like ECG and Endoscopy the use of BAN IEEE 802.15.6 is more beneficial profiting from its reliability for high data rate (>40 kbps) even though the constraint of energy consumption still exit.

V. CONCLUSION

In this paper we presented an overview of WBANs IEEE 802.15.4 and IEEE 802.15.6 performances especially on the MAC Layer. Then we compared their communication modes and access mechanisms namely GTS and Polling. Thereafter we analyzed their performances in terms of throughput, reliability and energy consumption using OMNET++ with Castalia simulator. Based on the simulation results we synthesize that:

- In terms of throughput and reliability, GTSon mode gives better results than GTSoff mode. In terms of energy consumption, GTSon mode is energy saving and the gain is 20% of the supposed energy to be consumed.
- In terms of throughput and reliability, IEEE 802.15.6 pollingON mode gives better results than pollingOFF mode. However, In terms of energy consumption, on one hand, pollingON mode is more demanding and 45% of battery saved energy will be consumed only to activate this mode, on the other hand, pollingOFF mode is energy saving, but it's of limited use because of its low reliability.

- In regard of medical exploitation, the use of Zigbee technology is more beneficial for sensors with minimum rate requirement (less than 40 kb/s) profiting from its important reliability for low data rates, and increasing our sensor lifetime by saving up to 72% of required energy. For sensors requiring high data rates (>40kbps) the use of BAN 802.15.6 is more beneficial profiting from its reliability for high rate.

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