Performance Analyses and Improvement of the IEEE 802.15.6 CSMA/CA using the Low Latency Queuing

Tariq Benmansour[1,2], Toufik Ahmed[2], and Samira Moussaoui[1]

[1]Computer Science Department, University of Science and Technology (USTHB)
P.O. Box 32 USTHB, El-Alia, Bab Ezzouar, Algiers, Algeria
tbenmansour@usthb.dz, s_moussaoui@usthb.dz

[2]CNRS-LaBRI, University of Bordeaux / Bordeaux INP
P.O. Box 99, Talence Cedex, 33400, France
tad@labri.fr, tbenmans@labri.fr

Abstract—Recent advances in wireless communication and electronic manufacture have allowed the creation of a variety of bio-sensors to be used for Wireless Body Area Networks (WBANs). These devices operate in close vicinity to, on or inside a human body. WBANs have gained much interest and became emerging technology in health monitoring due to its wide range of use in improving the human health. Many earlier wireless standards were used for the transport of medical data both to and from medical devices but these standards were not appropriate for wireless communication around the human body. The first international WBANs standard was established by the Task Group 6 and called IEEE 802.15.6. The standard defines a Medium Access Control (MAC) layer that supports several Physical layers. To ensure a high quality of services (QoS), the standard defines many user priorities (UPs) for different types of data. This prioritization allows nodes with emergency packets to access the channel with high probability. Under saturation condition, the standard doesn't provide the manner in which the packets are queued and selected at MAC layer to be sent. In this paper, we study the performances of the IEEE 802.15.6 CSMA/CA in monitoring of an individual cardiac patient while using many queues strategies. To meet the objectives of the standard, we propose an adapted Low Latency Queuing (LLQ) scheme in order to improve the QoS. Over Castalia simulator based on OMNeT++, a comparative performances analysis between queuing strategies over the IEEE 802.15.6 standard has been conducted. Results of expanded simulations show that our queuing scheme performs the standard in terms of latency, energy consumption and packets delivery rate.

Keywords—WBAN, IEEE 802.15.6, Low Latency Queuing

I. Introduction

WBANs are a sub-class of Wireless Sensor Networks (WSNs) characterized by a limited energy resources, a reduced number of nodes with no redundancy, an extremely low transmission range (to minimize interference and health effects) and a heterogeneous nature of nodes. A typical WBAN consists of tiny sensor nodes that monitor human physiological signs such as heart rate, body temperature, glucose level, etc. and forward that information to a central device called the Body Network Coordinator (BNC) [1].

Initially, many earlier standards such as IEEE 802.11[2], IEEE 802.15.1[3] and IEEE 802.15.4 [4] were used to ensure communications in WBANs, but these standards are not suitable for WBAN applications. The power consumption of 802.11 is too high to satisfy WBANs requirements with a low power. IEEE 802.15.4 is the most used in WBANS, but it doesn't support high data rate applications (data rate > 250 Kbps). The IEEE 802.15.6 TG6 group was formed to standardize the Media Access Control (MAC) layer for WBAN, which works in short-range wireless communications within the vicinity of, or inside, a human body. This standard supports QoS and allows devices to operate on very low transmission power ensuring safety by minimizing the Specific Absorption Rate (SAR) into the body and increasing the battery life time[5].

Compared to the IEEE 802.15.4, several improvements have been made by IEEE 802.15.6 to provide high QoS and extreme high power efficiency. The IEEE 802.15.6 designs three different Physical Layers (PHYs) to adapt the broad range of possible applications and constructs a more flexible frame structure that supports multiple access modes. The main difference is the assigning of different UPs based on the traffic type, which allow to guarantee for the high priority data to be transmitted on timely and reliably[6].

Using WBANs in healthcare systems has been widely studied over the last decade. Most of the existing researches in this networks paid attention to studying of the MAC layer and the QoS performance evaluations. However, there is few studies assessing the queuing and scheduling while evaluating QoS in WBANs. To illustrate our contribution and situate our study, we categorize relating researches into two classes:

The first class represents all works that treat the queuing in WBANs nodes without referring to the IEEE 802.15.6 standard. In [7], authors proposed a class based QoS model for multi-hop topology by defining three classes of services (i.e. guaranteed service, real time service, and best effort services). Packets are categorized into classes by the classifier and en-queued and de-queued in the adequate priority-queue based on its priority. In [8], M Iftikhar and al. proposed an analytical model for a WBAN system where different classes of bursty traffic are placed in various priority queues. They defined three different priority queues to improve the QoS in the network but they concentrate only on bursty traffic. In [9], authors proposed a differentiated traffic and scheduling scheme for WBAN based on patients' data classification and prioritization. Through queues scheduling and path choice issues, the urgent packets are delivered on time to provide a QoS guarantee for the WBAN. After the data classification phase, packets are added to three queues depending on their classes. The scheduling module is used to select data from queues referring to their priority; data in a queue is scheduled only when there is no data in queues that have higher priorities. Authors in [10] proposed the deploying of queuing on emergency care of patients in hospital-centered system. They categorized packets into normal and emergency and supposed that the WBAN uses three tier heterogeneous networking method for communication. The first tier of the network consists of ZigBee nodes. The second tier has Wi-Fi router acting as server for the packets queues generated by ZigBee radio module. In the third tier, hospital information system is connected using Ethernet. In the second tier, authors deployed two priority queuing models M/G/1 and M/G/N to handle deliverance of packets to the next tier.

The second class that we defined focus on the queuing in WBANs over the IEEE 802.15.6 standard. In [11],authors defined a bridging between the IEEE 802.15.6-based WBANs and the IEEE 802.11e EDCA-based WLAN. The bridge operates as a BNC in the WBAN and as a station in the WLAN. At bridges, the eight different user priorities defined by the IEEE 802.15.6 are mapped to four Access Categories (AC) where each AC has its own queue and channel access differentiation parameters. In [12] and [13], S Rashwand and al. provided many performance evaluations of the IEEE 802.15.6 standard under various channel conditions and traffic regimes. They proposed a formal model for the CSMA/CA scheme using three dimensional Discreet Time Markov Chain (DTMC). In their model, they assumed that each node has only one type of user priority data, in fact they supposed that each node has only one queue with infinite capacity at MAC layer. In [14], authors evaluated the IEEE 802.15.6 by simulations and by an analytical model. They suppose that each node has of only one queue with infinity length. By taking into account the effect of the traffic load, payload of MAC frames, modulation and coding modes, and priorities on the network performance, they show that IEEE 802.15.6 supplies nodes of high UPs with better performance, but it starves nodes of lower UPs such as non-medical traffics. In [15], authors proposed the use of the length of queues to provide a novel contention probability dynamism to improve the IEEE 802.15.6 slotted-ALOHA protocol where each node has only one queue at MAC layer with finite length. In [16], authors provided a prioritized queuing mechanism on the IEEE 802.15.6 standard by defining three priority queues at MAC layer. The goal of this prioritization is to guarantee minimum delay and more reliability. Results showed that the latency of the emergency packets is highly improved. In [17] authors proposed a queue length and channel quality based EDT adaptation algorithm in the IEEE802.15.6 CSMA/CA to combat performance degradation in multiple adjacent BANs scenarios. Simulation results indicate potential benefits in performances and warrant future investigation of queue size and channel quality based EDT adaptation in IEEE 802.15.6 CSMA/CA.

The IEEE 802.15.6 standard offers a prioritization mechanism to handle high emergency packets to be sent timely and reliably. Whoever, as shown previously the most of existing evaluations and improvements of the standard supposed that at MAC layer only one queue for all types of packets is used. On the other hand, some proposed works use many queues but without mapping the user priorities defined by the standard with the queuing strategy at MAC layer.

In this paper, we will evaluate the standard IEEE 802.15.6 to show how the queuing strategy has an effect on the standard performance. In the second step, we will propose an adapted Low Latency Queuing (LLQ) strategy which meet the requirements of emergency applications and improve the QoS of the standard in terms of reception rate, latency and energy consumption. In this paper, we will concentrate our studies on the EAP and RAP phases which use the CSMA/CA with priority as access schemes.

The remainder of this paper is organized as follows. In Section II, we give an overview of the IEEE 802.15.6 Mac layer focusing on the CSMA/CA access scheme. In section III, we introduce the adapted LLQ strategy to the IEEE 802.15.6 standard. In section IV and V, simulations parameters, performances evaluation and results are described and analyzed. Finally, we conclude in Section VI.

II. Overview of IEEE 802.15.6 MAC

The IEEE 802.15.6 standard is developed to accommodate the growing demand for short range, wireless communication in the vicinity of, or inside a human body (but not limited to humans) and to accelerate diversified applications of WBAN worldwide. The standard organizes networks into sets of body area networks (BANs) each of them is expected to have only one BNC and multiple nodes. A BNC may operate in a beaconed mode with super-frame, non-beaconed mode with super-frame or non-beaconed mode without super-frame. The first mode offers synchronization between the BNC and all BAN nodes. This makes the network more reliable and more energy efficiency; nodes go to the sleep mode and wakeup periodically when they have data to send. Hence it is the most used in medical applications. As shown in Fig.1, the super-frame structure with beacon mode has seven (7) access phases; two Exclusive Access Phases (EAP), two Random Access Phases (RAP), two Managed Access Phases (MAP) and one Contention Access Phase (CAP). The BNC transmits a beacon at the start of the super-frame to define the size of each access phase and another optional beacon before the start of the CAP. The access phases EAP 1, EAP 2, RAP 1, RAP 2, and CAP are used for contended allocation by nodes to initiate communication using CSMA/CA or S-ALOHA access scheme. EAP is used only by highest priority data, UP 7, for emergency and medical event report.

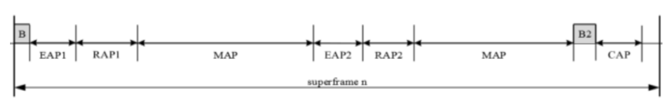

Fig.1. Superframe structure of Beacon mode with Superframes.

a. IEEE 802.15.6 CSMA/CA

In this protocol, the node sets its Backoff Counter (BC) to a random integer uniformly distributed over the interval [1, CW] where $CW \in [CW_{min}, CW_{max}]$ is called the Contention Window, which depends on the number of failed data transmissions. The values of CW_{min} and CW_{max} are selected according to the priority classes presented in TABLE 1. These priority classes are assigned based on the type of data traffic, ranging from best-effort data traffic to the most critical emergency traffic.

TABLE 1. CW BOUNDS AND UP MAPPING FOR CSMA/CA

Priority	User priority	Traffic designation	CWmin	CWmax
Lowest	0	Background	16	64
	1	Best effort	16	32
	2	Excellent effort	8	32
	3	Video	8	16
	4	Voice	4	16
	5	Medical data or network control	4	8
	6	High-priority data or network control	2	8
Highest	7	Emergency or medical implant event report	1	4

Initially, the CW is set to CW_{min} for each priority class and remains the same for each successful data transmission. The node decrements the BC by one for each idle CSMA/CA slot. Once the BC reaches zero, the data is transmitted.

The node locks the BC because of the following reasons: a) the channel is busy because of a frame transmission of another node. b) The current time is outside of EAP, RAP, or CAP phases. c) The current time left in the EAP, RAP, or CAP is not enough to complete the data transmission.

The node unlocks the BC when the channel is sensed idle for Short InterFrame Space (pSIFS) duration or when the current time left in the EAP, RAP, or CAP is enough to complete the data transmission. If the contention fails, the node doubles the CW for even number of failures, and keeps it unchanged for odd number of failures. If doubling the CW exceeds the CW_{max}, the node sets the CW to CW_{max}.

III. LOW LATENCY QUEUING IN IEEE 802.15.6

WBAN is one of emerging technology that has the potential to significantly improve healthcare delivery, diagnostic monitoring, disease-tracking and related medical procedures. However, QoS and reliability of successful communication must be handled to preserves patient life in critical scenarios. The standard IEEE 802.15.6 offers physical layers and medium access control layer to ensure a high reliability and a timely transmission of emergency packets. By using packets prioritization mechanism, the standard assigns the high user priority to emergency data which correspond to short contention window to ensure there timely sent. On the other hand, the standard allows a dedicated EAP phase in the super-frame for the transmission of only high priority packets. As we showed in the introduction the most of works treating queuing in IEEE 802.15.6 suppose that each node has only one type of data which is not valid in many realistic scenarios where WBANs incorporate nodes that sense different vital signs with different user priority. In such cases, nodes must define a priority to send their packets and eventually node's events report to the BNC. Without an adequate queuing and scheduling strategies to send high priority packets, the standard will not ensure a timely notifying of high emergency crisis. In this work, we will propose an adapted Low Latency Queuing to improve the QoS in networks using the IEEE 802.15.6 standard. LLQ system is composed of one priority queue and many low priority queues. Packets in low priority queues are scheduled only when there are no packets in the priority queue. To show the benefits of our proposed queuing strategy, we will evaluate the standard throw thee queuing strategies; a) single FIFO head of line queue for all packets with length equal to 30 packets. b) LLQ with two FIFO queues, one for emergency packets (UP=7) with length equal to 10 packets and the second for the rest of packets (UP=0...6) with length equal to 20 packets. c) LLQ with one high priority FIFO queue for emergency packets with length equal to 9 packets and three waited FIFO queues using class-based weighted fair queuing (CBWFQ) for the rest of the packets with lengths equal to 7 packets for each of them[18].

The detail of our proposed LLQ with weighted low priority queues is described in Fig.2.

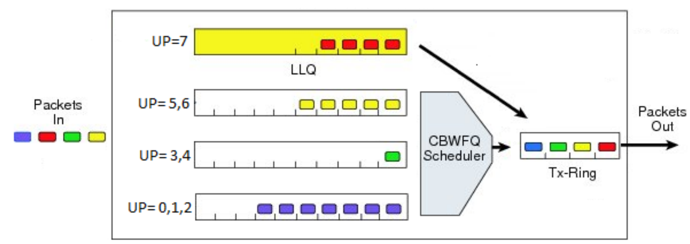

Fig.2.Low Latency Queueing in IEEE 802.15.6

IV. SIMULATION PARAMETERS

In this paper we will evaluate the QoS of the standard IEEE802.15.6 over a realistic requirements and constraints of home monitoring of an individual cardiac patient. The goal of this evaluation is to show the effectiveness of our queuing strategy to fulfill the requirements of this standard.

To perform simulations, we chose the Castalia open source simulator [19] designed for networks of low-power embedded devices, that offers a node behavior simulation in realistic wireless channels and radio models. All simulations described in this paper are realized with Castalia 3.2.

To perform simulations we consider a WBAN of home monitoring of an individual cardiac patient as it is defined in the ISO/IEEE 11073 Draft for Point-of-Care (PoC) medical devices [20]. The considered WBAN incorporates five (5) sensor nodes and one BNC. To ensure the 3-lead ECG supervision, three (3) electrodes are deployed on the rib cage of the patient. The two others sensors are placed on the left and right arms to measure the SpO2 and blood pressure respectively. All these sensors communicate wirelessly with the BNC. In our evaluations, we used a radio parameters which meets with the IEEE 802.15.6 radio proposal [5]. In all simulations, it is supposed that if the radio unit is not transmitting, it is either receiving or listening. TABLE 2 gives the various radio and the whole simulations parameters.

TABLE 2. SIMULATION PARAMETERS

Parameters IEEE 802.15.6 radio proposal	
Data rate (kbps)	1024
Modulation Type	DIFFQPSK
Bits Per Symbol	2
Bandwidth (MHz)	20
Noise Bandwidth (MHz)	1000
Noise Floor (dBm)	-104
Sensitivity (dBm)	-87
Power Consumed on reception mode (mW)	3.1
transmission power (dBm)	-15
Power Consumed on transmission mode (mW)	2.93
Power consumed on transition (transmission, reception) (mW)	3
Time of transition (transmission, reception)	0.02
Simulation parameters	
Simulation time (second)	(50 repetition)
Slot allocation length (ms)	10
Retransmission packets tries	2
Phy Layer overhead (Bytes)	6
Mac frame overhead (Bytes)	7
Packet header overhead (Bytes)	05
Data payload (Bytes)	100
EAP= 128 Slots, RAP= 127 Slots	

V. PERFORMANCE EVALUATION

The performance metrics considered in our work are: packet delivery rate (PDR), consumed energy and average packet latency. The PDR is defined as the number of successfully received packets from a node divided by the number of transmitted packets by this node, while the average packet latency refers to the interval between the packet arrival at the local MAC layer and the successful data reception by the BNC. In all simulations, we supposed that the network works under Saturation Conditions (at any time there is at least one packet in the queues) while the arrival packets follow a Poisson Process with lambda equal to 50. The whole queues size equal to thirty packets. We fixed weights for the LLQ with three low priority queues as fellow: weight=3 for packets with UP=5, 6.weight=2 for packets with UP=3, 4. weight=1 for packets with UP=0, 1, 2. we carried out many simulations while varying the percentage of emergency packets (UP=7).

a. Packet delivery rate

The PDR histogram presented in Fig.3 shows the average packet delivery rate for each of the three queuing strategies. We notice that the rate of successfully received packets by the BNC while using LLQ with two queues or LLQ with four queues is clearly higher than while using one queue. This is explained by the number of packets dropped due to the buffer overflow mainly while only one queue is used; during the EAP phase, sending packets will be blocked if there is a non emergency packet in the head of the queue. In this case, all newly arrival packets will be deleted after reaching the limit size of the queue. The second point that we noticed from the Fig.3 is that the number of delivered packets decrease while decreasing the percentage of high emergency packets. This is explained by the high sending rate and the low buffering time of high emergency packets. In fact, the time of sending a packet depends on the Backoff delay and the transmission time and as we know the Backoff time of emergency packets is less than Backoff time of low priority once. The third remark concluded concerns the reception rate of non-emergency packets; while using LLQ with two queues, all non-emergency packets have the same reception rate whereas in the LLQ with weighted queues we have a clear amelioration of the reception rate of packets with user priority equal to six and five to the detriment of low priority packets (UP=0, 1 and 2). This is due mainly to the weights fixed in our simulations which promote high priority packets. The last remark illustrated in the histograms of the two versions of LLQ is that the high emergency packets failure is almost null comparing to non-emergency packets. This is due to the high priority queue reserved for the emergency packets in LLQ strategies.

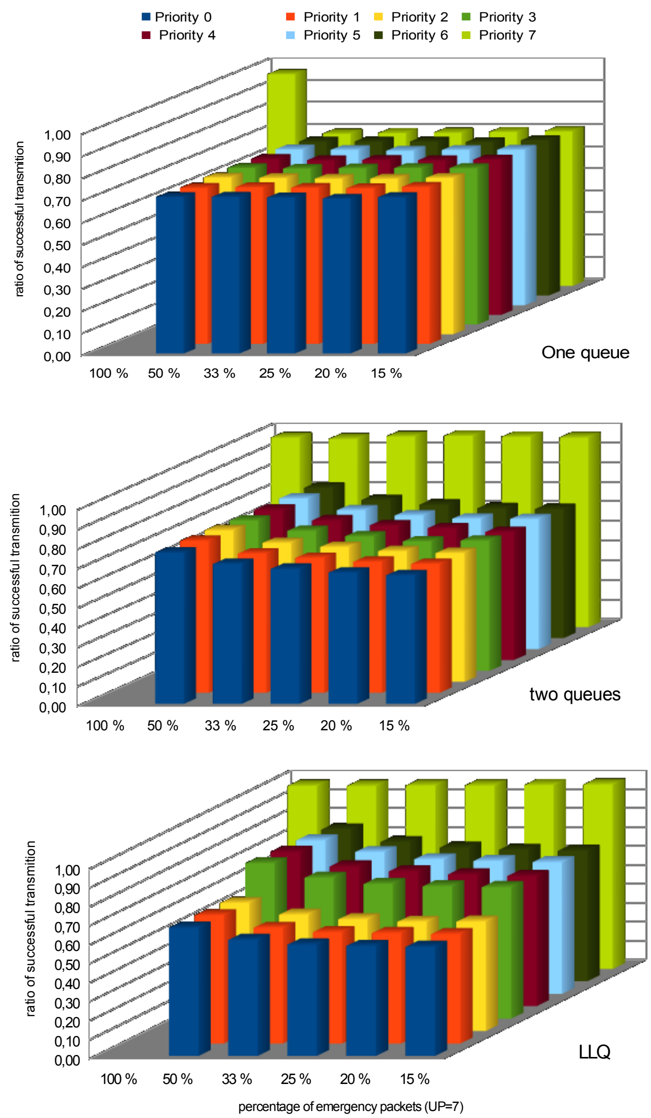

Fig.3. packet delivery rate of IEEE 802.15.6for one and LLQ staregies

To explain the differences in packets delivery rate, we will give details of packets failure and their causes in Fig.4 corresponding to one queue, LLQ with two queues and LLQ with four weighted queues respectively. We recorded the packet breakdown at the MAC layer of the senders. We have classified packets into five categories: a) Failed, buffer overflow (i.e., the packet was deleted because the MAC buffer was full). b) Failed, no Ack (i.e. at least one packet was transmitted to the radio without receiving the Ack), c) Failed, channel busy (i.e., packet failed because the CSMA mechanism never found the channel free, in all transmission attempts), d) Success, first try (i.e., an Ack was received on the first transmission attempt), e) Success, 2 or more tries (i.e., an Ack was received after more than one transmission attempt).

Results in Fig.4 are shown in number of packets. The first important characteristic that we noticed from this figure is that the main cause of no transmitting packets is due to the buffer overflow, which is related to the queuing and the scheduling strategies. In fact, all arrival packets buffered in queues waiting their turn to be sent and when a queue reaches its maximum size, all the new arrival packets will be deleted. Secondly, from the histograms which illustrate the results of one queue strategy packets breakdown, we remark a high number of packets failure of all packets including the high emergency one. As we explained above, the one queue strategy causes a high dropping of all types of packets by the buffer overflow because the arrival packets rate is more than the sending rate blocked by low priority packets.

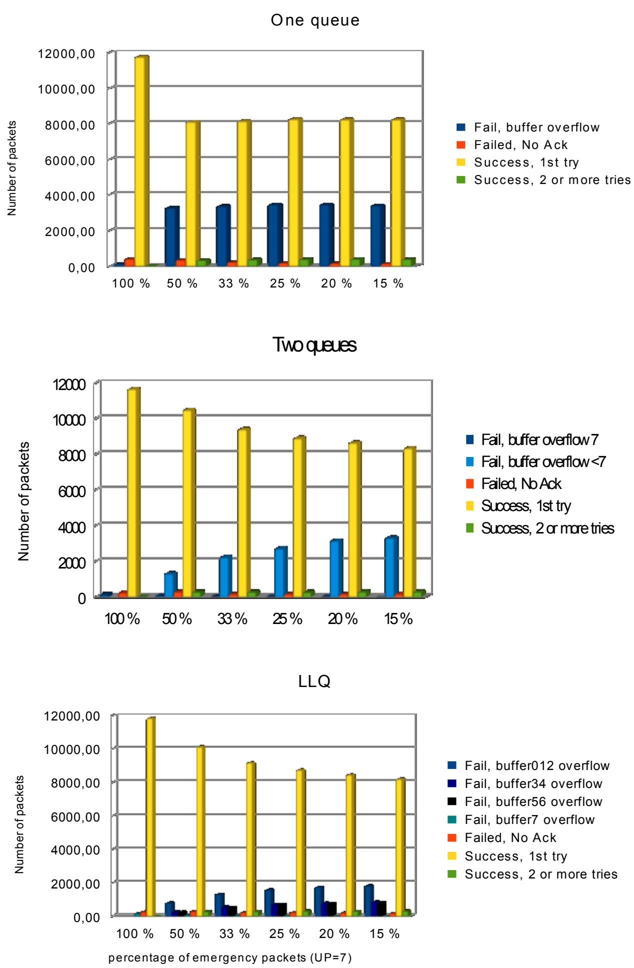

Fig.4. Data packets breakdown at the MAC for one queue and LLQ staregies

b. Latency:

The Fig.5 shows the average latency of all packets received by the BNC for each of the three queuing strategies. We noticed that the LLQ strategies offer the low average latency and the one queue strategy the high average latency. This is explained by the user priorities of transmitted packets, as we mentioned above the Backoff time decrease while increasing the user priority. LLQ with weighted queues strategy gives an exclusive priority for high emergency packets and it decreases the probability of serving of low priority packets according to the queues weights. While in the LLQ with tow queues strategy; emergency packets are served in first time, after that the rest of packets are served according to their arrival times. In the one queue strategy all packets are served according to their arrival times without giving any advantage for emergency packets. In addition, in one queue strategy non-emergency packets block sending during the EAP phase which result a high buffering time and therefore a high latency.

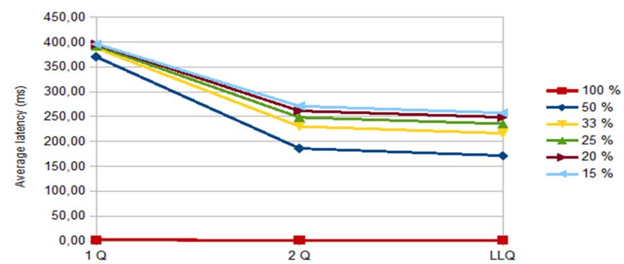

Fig.5.The average latency for one, two and LLQ queuing staregies

c. Energy consumption

The consumed energy histogram presented in Fig.6 shows the average consumed energy per all nodes in the WBAN for each of the three queuing strategies.

As shown in fig.6, we notice two remarks. First, the consumed energy in the IEEE 802.15.6 standard while using one queue is more than while using LLQ strategies. The second point to notice is that the amount of the consumed energy rises while increasing the percentage of emergency packets. This observation is mainly due to the queuing strategy and the type of radio receiver used by the standard. As known the time taken for transmitting reduces the reception / listening time which consume more energy as shown in TABLE 2. So increasing the percentage of emergency packets will increase the whole number of transmitted packets. As a result, the amount of consumed energy will decrease. And while we use only one queue, the phenomena of head of line blocking which occurs in the EAP phase will block the sent off packets and as a result the amount of the consumed energy increases because the high reception / listening time.

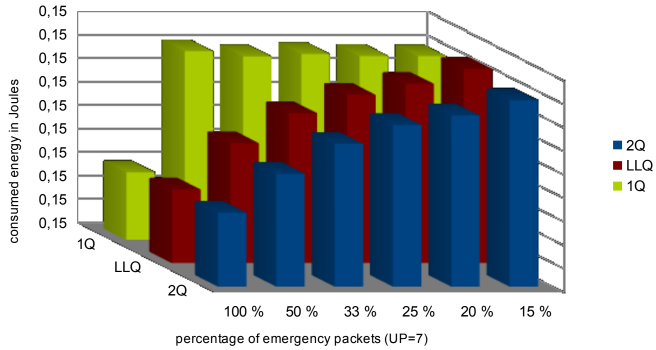

Fig.. Consumed energy per queuingstaregiesin joules

VI. CONCLUSION

WBANs can provide real-time and reliable health monitoring. In this paper, we have evaluated the performances of the IEEE 802.15.6 in terms of energy consumption, latency, packets delivery rate and packets breakdown at the MAC layer while using different queuing strategies. We demonstrated that the queuing mechanism over the IEEE 802.15.6 has a big influence on the network's performances. In addition to the energy efficiency, and latency we have showed that the use of one queue degrade the hall networks performances. We have shown the effectiveness of the LLQ queuing strategy in performing the performance of the IEEE 802.15.6 in home monitoring of an individual cardiac patient. From the obtained results, we can conclude that the use of the IEEE 802.15.6 with LLQ guarantee timely services for emergency packets. As future works, we intend to validate these results by a mathematical model. And evaluate the behavior of the standard with others queuing techniques.

REFERENCES

[1] B. Latré, B. Braem, I. Moerman, C. Blondia, and P. Demeester, "A survey on wireless body area networks," *Wirel. Networks*, vol. 17, no. 1, pp. 1–18, Jan. 2011.

[2] IEEE, "IEEE Standard for Information Technology-Telecommunications and Information Exchange Between Systems-Local and Metropolitan Area Networks-Specific Requirements-Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," *IEEE Std 802.11-1997*, p. i-445, 1997.

[3] P. Committee, "IEEE Standard for Telecommunications and Information Exchange Between Systems - LAN/MAN - Specific Requirements - Part 15: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Wireless Personal Area Networks (WPANs)," *IEEE Std 802.15.1-2002*, no. June. IEEE, pp. 1–473, 2002.

[4] L. a N. Man and S. Committee, *IEEE Standard for Information technology- Telecommunications and information exchange between systems- Local and metropolitan area networks- Specific requirements--Part 15.4: Wireless MAC and PHY Specifications for Low-Rate WPANs*, vol. 2006, no. September. IEEE, 2006.

[5] IEEE Standards Association, *IEEE Standard for Local and metropolitan area networks - Part 15.6: Wireless Body Area Networks*, no. February. 2012.

[6] R. Huang, Z. Nie, C. Duan, Y. Liu, L. Jia, and L. Wang, "Analysis and Comparison of the IEEE 802.15.4 and 802.15.6 Wireless Standards Based on MAC Layer," in *Health Information Science*, vol. 9085, Springer International Publishing, 2015, pp. 7–16.

[7] A. Salam, A. Nadeem, K. Ahsan, M. Sarim, and K. Rizwan, "A class based QoS model for Wireless Body Area Sensor Networks," *Res. J. Recent Sci.*, vol. 3, no. 7, pp. 69–78, 2014.

[8] M. Iftikhar and I. Ahmad, "A Novel Analytical Model for Provisioning QoS in Body Area Sensor Networks," *Procedia Comput. Sci.*, vol. 32, pp. 900–907, 2014.

[9] C. Kateretse, G.-W. Lee, and E.-N. Huh, "A Practical Traffic Scheduling Scheme for Differentiated Services of Healthcare Systems on Wireless Sensor Networks," *Wirel. Pers. Commun.*, vol. 71, no. 2, pp. 909–927, Jul. 2013.

[10] K. G. Dangi, "Performance Analysis of Patient Monitoring Wireless Body Area Networks using Queueing Models," *Int. J. Appl. Eng. Res. ISSN*, vol. 11, no. 9, pp. 973–4562, 2016.

[11] S. Rashwand and J. Misic, "Two-tier WBAN/WLAN healthcare networks; Priority considerations," in *GLOBECOM - IEEE Global Telecommunications Conference*, 2012, pp. 5398–5403.

[12] S. Rashwand and J. Mišić, "Effects of access phases lengths on performance of IEEE 802.15.6 CSMA/CA," *Comput. Networks*, vol. 56, no. 12, pp. 2832–2846, 2012.

[13] S. Rashwand, J. Misic, and V. B. Misic, "Analysis of CSMA/CA Mechanism of IEEE 802.15.6 under Non-Saturation Regime," *IEEE Trans. Parallel Distrib. Syst.*, vol. 27, no. 5, pp. 1279–1288, 2016.

[14] C. Li, X. Geng, J. Yuan, and T. Sun, "Performance analysis of IEEE 802.15.6 MAC protocol in beacon mode with superframes," *KSII Trans. Internet Inf. Syst.*, vol. 7, no. 5, pp. 1108–1130, 2013.

[15] M. Fatehy and R. Kohno, "A novel contention probability dynamism for IEEE 802.15.6 standard," *EURASIP J. Wirel. Commun. Netw.*, vol. 2014, no. 1, p. 92, 2014.

[16] A. Muthulakshmi and K. Shyamala, "Queuing Based Emergency Handling in," vol. 7, no. 6, pp. 2231–2239, 2016.

[17] V. Marbukh, M. Barbi, K. Sayrafian, and M. Alasti, "A queue-size & channel quality based adaptation of the energy detection threshold in IEEE802.15.6 CSMA/CA," in *2016 IEEE 18th International Conference on e-Health Networking, Applications and Services (Healthcom)*, 2016, pp. 1–6.

[18] P. Denise M. Bevilacqua Masi, P. Martin J. Fischer, and David A. Garbin, "MODELING THE PERFORMANCE OF LOW LATENCY QUEUEING FOR EMERGENCY TELECOMMUNICATIONS."

[19] NICTA, "Castalia Simulator," 2011. [Online]. Available: https://castalia.forge.nicta.com.au/index.php/en/. [Accessed: 21-Nov-2015].

[20] Health informatics — point-of-care medical device communication — technical report — guidelines for the use of RF wireless technology. IEEE Draft P11073-00101/D03, 2007.