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WBAN data scheduling and aggregation under WBAN/WLAN healthcare network

Nourchène Bradai *, Lamia Chaari Fourati, Lotfi Kamoun

Laboratory of Electronics and Information Technologies, National School of Engineering, University of SFAX, B.P.W, 3038 Sfax, Tunisia

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A B S T R A C T

Nowadays, wireless body area networks (WBANs) become an emerging technology which has grown considerably. An increase in the deployment of devices on patients promotes researchers and application developers to focus on issues related to WBAN networks. Therefore, several studies have been done in this field by researchers. The IEEE 802.15.6 standard was proposed to satisfy all the requirements for WBANs communication. As sensed data in such type of networks, it should be transmitted in a reliable and QoS based way. A public-BAN is defined as a network of several personal-BANs. The centralized public-BAN consists of a static coordinator and several personal-BANs. The static coordinator is able to command a portable coordinator in order to control a personal-BAN and runs as an Internet Gateway. In this paper, we considered bridging communications between the IEEE 802.15.6-based WBANs and the IEEE 802.11e-based centralized public-BAN (WLAN). Especially, we proposed two new scheduling algorithms to satisfy QoS requirements in WBAN networks and to overcome the starvation mode of the packets without the highest priority. In order to perform this aim, we introduced the critical delay (CD) as a parameter to serve packets taking into account their priorities and classify them into an aggregated frame. The performance of our proposed schedulers is compared with Priority Queue scheduler (PQ) and Priority Queue Aggregation scheduler (PQA). Conducted simulations illustrate that our proposed schedulers performance overcomes the other schedulers in term of latency, throughput and dropped packets for emergency, general monitoring and controlled load traffics.

1. Introduction

The recent advances of communication technology, micro-electronics, circuit's integration, system-on-chip designs and low power intelligent sensors allowed the realization of wireless networks managing the human body functionalities which is called wireless body area network. A WBAN is a collection of miniaturized wireless sensor nodes, which supervise the human body functions and their environment. Many challenges and requirements [1,2] should be considered in WBAN systems and architectures [3]. These include the restricted energy consumption, the wide variability of data rates, quality of service, ease-of-use by medical professionals, interoperability, interference, and security. The Institute of Electrical and Electronic Engineers (IEEE) approved the formation of a working group for IEEE 802.15.6, intended to endow a future generation of short-range electronics both in body and on or around it. The IEEE 802.15.6 task group [4] is developing a communication standard optimized for low power devices. It defines a medium access control (MAC) layer that supports three physical layers namely Narrowband (NB), Ultra Wideband (UWB), and Human Body Communications (HBC) layers [5]. In this article, we highlighted two

* Corresponding author.
E-mail addresses: Norchene.bradai@gmail.com (N. Bradai), lamia.chaari@tunet.tn (L. Chaari Fourati), lotfikamoun2@gmail.com (L. Kamoun).

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main communication modes for WBANs: intra-body communication and extra-body communication. The first one refers to the information exchanged around the human body. It can be sub-categorized as communication between biosensors, and communication between biosensors and the personal server (PS) as a PDA or smart phone. However, the second refers to the exchanging data between the PS and the external environment (hospital, doctor ...). In this work, we consider that the PS employs a WLAN to reach an internet access point (e.g., a home gateway). Similarly, this access point uses internet to communicate with the final destination. Fig. 1 illustrates the network architecture of a healthcare system including the WBANs, PSs, and the WLAN access point. MAC parameters of the IEEE 802.15.6 and the IEEE 802.11e standards have a strong impact on the network performance, therefore bridging WBANs and WLAN is a big challenge that requires a deep study. IEEE 802.15.6-based WBAN performance has been evaluated through analytical models and simulations only in [6,7]. Other works in the literature that develop systems and devices for healthcare applications are presented in [8–10]. The only study that addresses bridging between the IEEE 802.15.6 and the IEEE 802.11e standards is explained in [11] and this is the first work that investigates the impact of bridged WBAN/WLAN priority differentiation on the overall healthcare network performance. However, this approach does not contain a priority scheduler module in order to satisfy QoS requirements in WBANWLAN bridging system. In this paper, we studied the communications under WBAN/WLAN healthcare system in which we consider only three WBAN user priorities (UPs). The medical data streams are assigned to different UPs according to their priorities and disseminated to PS by considering a star topology. The PS bridges the WBANs traffic to WLAN networks and aggregates different WBAN frames into WLAN frame.

The contribution of this paper encompasses the following main tasks: data packets classification, WBAN/WLAN bridging system with integration of mapping module and two scheduling mechanisms. In fact, in this paper, we proposed a PFA (Priority Frame Aggregation) scheduler that performs a scheduling algorithm, mapping between WBAN and WLAN, and finally aggregate them into WLAN frame and a PF (Priority Frame) scheduler that perform the scheduling algorithm and mapping between WBAN and WLAN. We investigate the performance of WBAN/WLAN healthcare networks under varying priority differentiation of the WBAN networks (here we consider only three UPs). The remainder of this paper is organized as follows. Section 2, addresses the related work in the literature. Section 3, presents the WBAN system architecture. Section 4, briefly introduces the IEEE 802.15.6 standard and the IEEE 802.11e. In Section 5, we give details about the QoS mechanisms namely, classification and scheduling mechanisms. In Section 6, we present and explain our proposed algorithm for scheduling and aggregating different WBAN frames into WLAN frames. In Section 7, we discuss the performance of WBAN/WLAN healthcare networks, under varying priority differentiation in WBAN. Furthermore, a comparison of our proposed scheduling mechanism to Priority Queue scheduler (PQ) and Priority Queue Aggregation scheduler (PQA) mechanisms is depicted. Finally, Section 8 concludes the paper and highlights some future works.

2. Related work

There aren't enough works speaking about the WBAN/WLAN bridging. However, there are many researches separately focalized on the IEEE 802.15.6 [12–14] and IEEE 802.11e MAC protocols [15–18].

In [19], a Seamless Interworking Architecture (SIA) for WBAN in heterogeneous wireless networks and a cost-based vertical handoff decision algorithm based on a cost function for WiMAX/WLAN integrated networks are proposed. It is based on a cost function that includes data throughput and power consumption costs. The authors also present a coexistence study of WBAN with Wireless Local Area Networks (WLAN) and Wireless Wide Area Networks

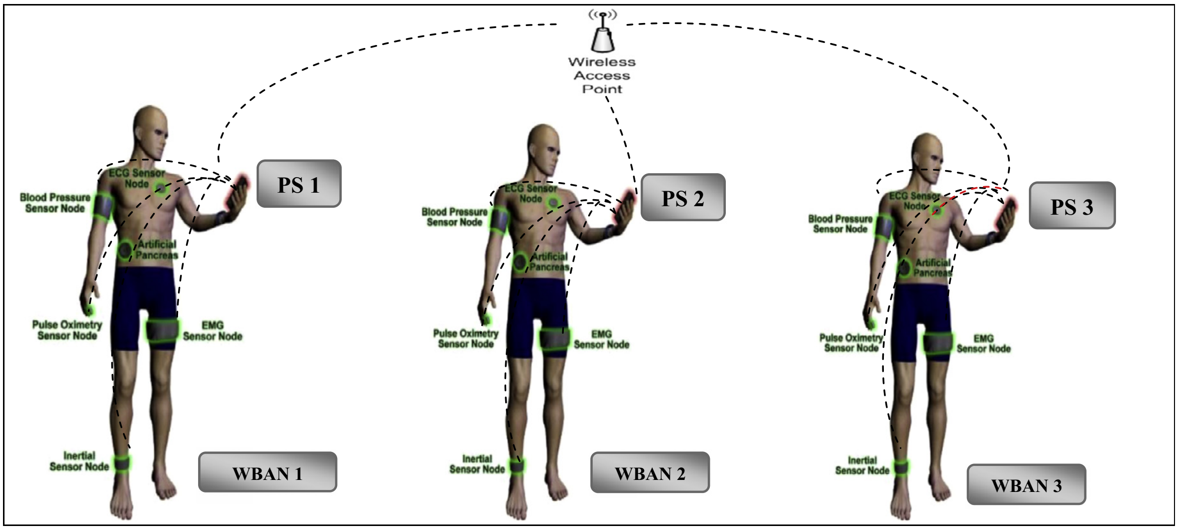

Fig. 1. Network architecture for WBAN/WLAN healthcare system.

(WWANs). The simulation results show that the proposed scheme outperforms classic approaches in packet loss rate, delay and throughput. In [20], authors study the coexistence of WBAN and WLAN in medical environments (hospital room) in order to evaluate the impact of IEEE 802.11g interference on the performance of a point-to-point IEEE 802.15.4 link. Experimental interference tests are used for this evaluation; the parameters that the authors conducted are channel modeling, and power spectrum measurements. The main factors that affect badly the system and recommendations for high performance operation are afforded. In [21] a context-aware handover architecture healthcare service in WLAN is introduced taking into account power efficiency. Authors offer a model of the power-efficient handover and propose an algorithm for the realization of context-aware mobility management which can support high mobility in WBAN and WLAN networks. The proposed model and algorithms were evaluated with simulation and results show that the system can be used in several types of healthcare application services. In [22], the design alternatives of the wireless portion of a healthcare system are discussed. Especially the topology and the choice of wireless communication technology for tiers taking into consideration the bridging between tiers and well defined function. Results show that multitier wireless networks, using Zigbee (802.15.4) and 802.11b, are a very good solution for online healthcare monitoring system. In [23], the interconnection between IEEE 802.15.4 body area network (BAN) which consists of electroencephalography (EEG), electrocardiography (EKG), blood pressure and pulse oximeter and IEEE 802.11b was presented. The design issues of CSMA/CA bridge between the BAN implemented, using beacon enabled 802.15.4 network, and 802.11b wireless LAN was discussed. In [24], a two-tier WBAN/WLAN wireless healthcare network is developed. Authors use eight WBAN UPs based IEEE802.15.6 and four WLAN based IEEE802.11e EDCA Access Categories (ACs). They also discussed the performance of the network by varying differentiation and nodes levels in the WLAN. Results indicate that differentiation by AIFS is more affected to preserve relative order of frame response times in WBAN. Therefore, in our knowledge there is no proposed Priority Frame Aggregation scheduler for WBAN/WLAN bridging module.

3. WBAN system architecture

WBAN is made up of nodes implanted in human bodies (implantable nodes) [25] or put on-body (wearable nodes) [26] that continuously monitor patient information for diagnosis and prescription. The system has three-level hierarchies, which are sensor nodes, a personal server and a medical central server as it is illustrated in Fig. 2.

3.1. First tier: WBAN sensor nodes

A sensor node [27] is a device that converts a non-electrical physical or chemical quantity into an electrical signal which can be read by an observer or by an instrument. Its function is to process and communicate vital signs [28]. Among sensors used for sensing human body signs we cited: electrocardiogram (ECG), (EEG), electromyography or EMG, blood sugar, blood pressure, pulse oximeter, humidity and temperature.

- ECG is a sensor used for monitoring heart activity. The electrocardiogram records the electrical stimulation to the heart muscle by the conduction system and traces the movement of those impulses. In order to obtain an ECG signal, several electrodes are attached at specific sites on the skin (e.g., arms, and chest), and the potential differences between these electrodes are measured.
- The EEG is a test function, used for monitoring brain electrical activity by attaching small electrodes to the human's scalp at multiple locations. The information of the brain's electrical activities sensed by the electrodes forwarded to an amplifier for producing a pattern of tracings. Synchronous electrical activities in different brain regions generally assumed to imply functional relationships between these regions.
- The EMG involves recording the spontaneous electrical activity of a muscle or nerve during contractions or at rest. The electrodes used are very thin and inserted under the skin on the path of a nerve. An electrode is used as transmitter and receiver (when it comes to measuring the nerve conduction velocity and the velocity of nerve impulses in a nerve).
- Blood sugar monitoring is a way of testing the concentration of glucose in the blood (glycemia). A blood sugar is also called blood glucose.
- The blood pressure sensor is designed to measure systolic and diastolic human blood pressure.
- Pulse oximeter is used for cardio-respiratory monitoring. It measures oxygen saturation.
- Humidity and temperature sensors are used for measuring the temperature of the human body and/or the humidity of the immediate environment around a person.

3.2. Second tier: personal server

The sensor nodes process and communicate vital signs. Before their memory fills, they keep information and issue them to the personal server [28] that can be implemented on a PDA or a cell phone or can run on a home personal computer.

To communicate received data to the central server, the personal server can employ mobile telephone networks (2G, GPRS, and 3G) or WLANs to reach an Internet access point. In our case, the personal server employs a WLAN to reach an internet access point (e.g., a home gateway) in order to communicate with the central server. The PS should, in general, be responsible for the following tasks: data collection, data processing, data aggregation and data communication. A flowchart illustrating the PS functionalities is shown in Fig. 3.

- *Data collection:* The PS communicates and collects data from the WBAN sensor nodes. Sensor nodes encapsulate their data into WBAN messages (or frames) and forward them to PS.

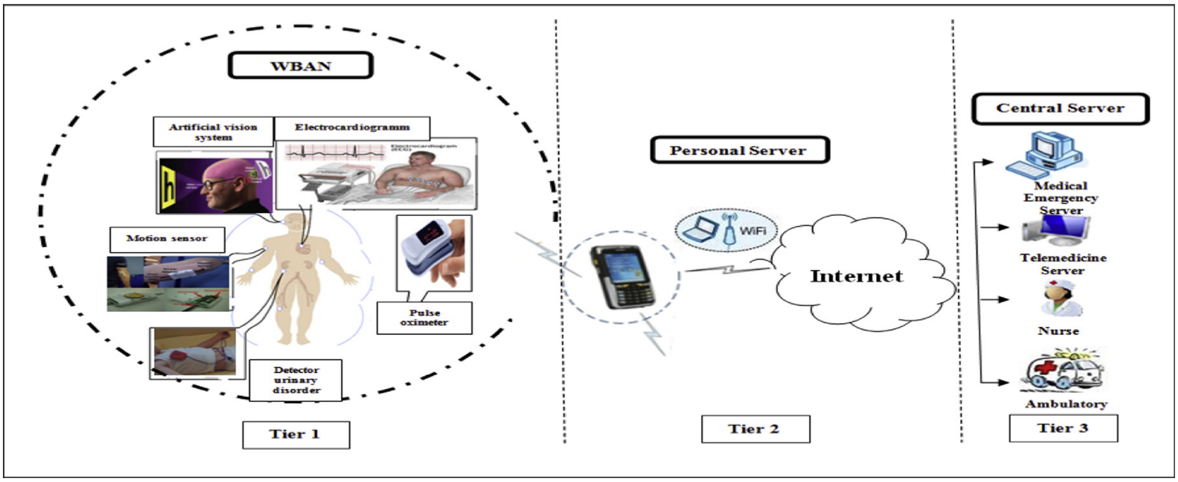

Fig. 2. A general architecture of the WBAN in e-healthcare application.

- *Data processing:* The PS has to process the data which has been collected in the data collection phase. It performs three tasks: decode, filter and convert data. In fact, the message transmitted from WBAN nodes should be filtered and collected only those with interesting information.
- *Data aggregation:* The body sensors in wireless body area networks provide data to the PS (body aggregator) which is responsible for managing events from sensors. The PS aggregates data received from different sensors into one frame. This process corresponds to data fusion.
- *Data communication:* The PS transmits the processed and aggregated data wirelessly (via WLAN).

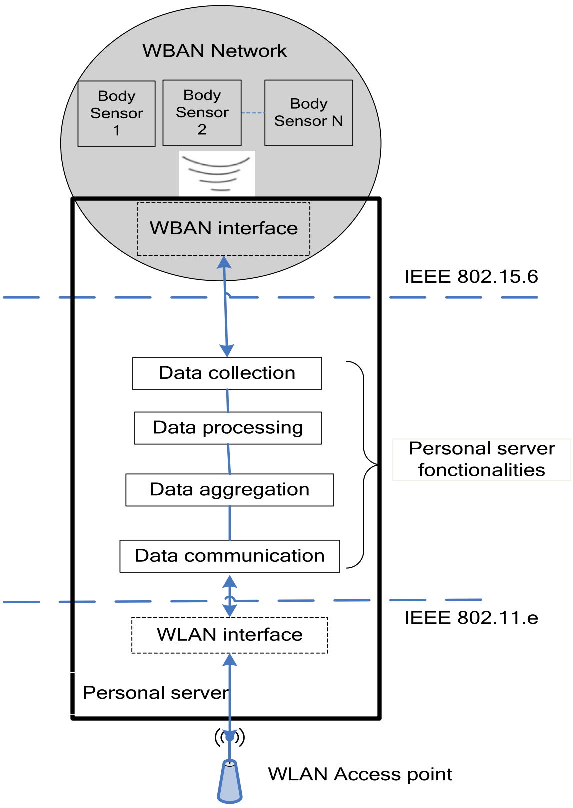

Fig. 3. A flowchart of the personal server functionalities.

4. MAC access mechanisms: background

4.1. IEEE 802.15.6 MAC protocol

4.1.1. Description of the standard

The IEEE 802.15.6 [4] operates in and around the human body (but not limited to humans). It appears to focus on functioning at relatively low frequencies, less than one megahertz, short-range use, low cost, reliable wireless communication, QoS, and especially an ultra low power. According to the IEEE 802.15.6 specification, every BAN has one hub and a range of nodes between 1 and 64. In our study, the hub corresponds to the personal server. In this section, we try to present the medium access control protocol as described in the standard. In this work, we consider that the PS operates in the beacon mode with beacon period super frame boundaries [12]. In this case, the PS transmits a beacon frame in each beacon period, except in inactive super-frame, it has sensed to provide time referenced allocation and should divide the beacon access mode in access phases supported in beacon mode as it is shown in Fig. 4. The super-frame structure of IEEE 802.15.6 is constructed of nine access phases, which are beacon, Exclusive Access Phase 1 (EAP1), Random Access Phase 1 (RAP1), Managed Access phase (MAP), Exclusive Access Phase 2 (EAP 2), Random Access Phase 2 (RAP 2), Another Managed Access phase (MAP), Beacon 2 and a Contention Access Phase (CAP).

- *Beacon:* Beacons initialize a super frame, they are sent in the first slot of each super frame. Their functions are: identifying the coordinator, facilitating network and powering management, and clock and devices synchronization.

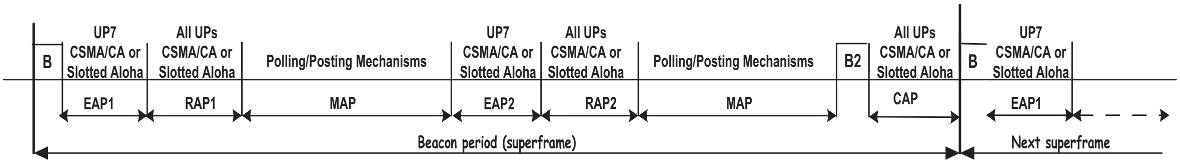

Fig. 4. Access phases of a super frame in beacon mode.

- *EAP1 and EAP2:* These access phases are used for emergency traffics where failure of delivery in a certain delay, may affect the health of a person and his life so that, they present the highest priority.
- *RAP1, RAP2 and CAP:* These kinds of access are dedicated for normal traffic where the data traffic is in their normal conditions without the critical time and events upon request.
- *Managed Access Phases (MAP):* This access phase is used to arrange scheduled uplink, downlink, and bilink allocation intervals. It can provide unscheduled bilink allocation intervals, improvise type-I, but not type-II, immediate polled allocation intervals as well as posted allocation intervals starting in this MAP.
- *Beacon 2:* Beacon two frame is dedicated for indicating the beginning of the CAP phase, grouping acknowledgment, coexistence information and fast reservation or adaptation.

4.1.2. Access mechanisms

The allocations in EAPs, RAPs and CAP may only be contended, so the access methods for obtaining the contended allocations in these access phases are: CSMA/CA and slotted aloha access.

- *CSMA/CA:* Uses a backoff counter and a contention window in order to obtain a new contended allocation. Here, we explain the CSMA/CA procedure in the IEEE 802.15.6 standard. A node shall initialize its counter to a random integer value between one and CW where CW belongs to CWmin and CWmax, depending on the user priority. Then, the counter decremented when an idle CSMA slot is equal to "pCSMASlotLength" and data is transmitted when the counter is equal to zero. The node locks its backoff when the channel is busy and the CW is doubled in this case until it reaches CWmax.
- *Slotted aloha access:* Uses a contention probability and a node will maintain this probability in order to guess if it obtains a new contended allocation in an aloha slot. A node also can start, use, modify, abort and end a contended allocation.

4.2. WiFi – IEEE 802.11

WiFi is a high-power, high-speed WLAN radio technology governed by Wi-Fi Alliance [29]. WiFi covers most of the IEEE 802.11 standards including 802.11a, 802.11b, 802.11e and 802.11n. However, here we will only describe the specifications of IEEE 802.11e based WiFi, since it defines priority levels which we can map with priority levels in WBANs; we will explain the mapping procedure further.

4.3. IEEE 802.11e EDCA

The IEEE 802.11e [30] enhances the MAC layer of the legacy 802.11 in order to support real-time applications and to fulfill their QoS requirements. IEEE 802.11e EDCA function allows traffic differentiation into four ACs which are Voice (VO), Video (VI), Best Effort (BE), and Background (BK) from the highest priority. The EDCA medium access mechanism presented in Fig. 5 is analogous to 802.11 DCF in the way that each AC contends to the channel based on CSMA/CA scheme. Frames arriving at the MAC layer are firstly classified according to their priorities. Traffic differentiation is accomplished through medium access parameters which presume different values for each AC. The EDCA parameters associated to the different access categories are illustrated in Table 1. These parameters are: the Arbitration Inter-Frame Space Number (AIFSN), the Minimum and Maximum Contention Window (CWmin and CWmax) and the Transmission Opportunity Limit (TXOPLimit). They manipulate the medium access in the subsequent manner. For each ith AC, $AIFS_i$ determines how

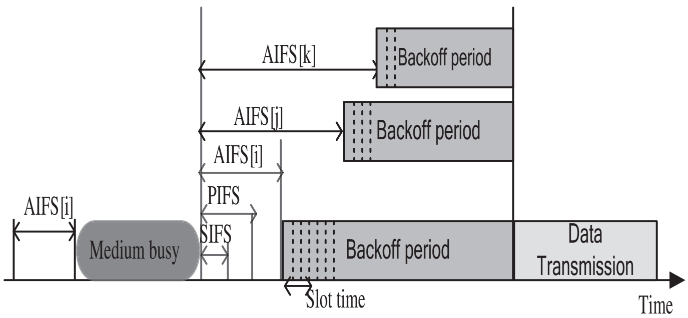

Fig. 5. 802.11e EDCA mechanism.

Table 1
EDCA parameters.

	AIFSN	CWmin	CWmax	TXOPLimit
AC3	2	7	15	1504 µs
AC2	2	15	31	3008 µs
AC1	3	31	1023	0
AC0	7	31	1023	0

Table 3
Mapping WBAN UPs into WLAN ACs.

WBAN		WLAN	
UPs	**Traffic Designation**	**ACs**	**Traffic Designation**
7	Emergency	**AC3**	Highest Priority
6	Medical data	**AC2**	↓
3	Controlled load	**AC1**	↓
0	Non-Medical Data	**AC0**	Lowest Priority

long the medium has to be idle before a transmission or backoff countdown can begin. It is calculated as (1):

$$AIFS_i = SIFS + AIFSN_i \cdot Time_{slot} \quad (1)$$

5. Data packets classification and scheduling

To provide QoS satisfaction, network designers must integrate QoS mechanisms to allow differentiation between all traffic types that have strict requirements in terms of delay, throughput, and loss. Basically, in this work, we take into consideration the classification and scheduling mechanisms.

5.1. WBAN/WLAN classification scheme

The classification mechanism aims to distinguish packets belonging to different user priorities in order to identify and separate different traffic into flows or groups of flows. This mechanism is adopted since different applications especially medical monitoring applications have different requirements in terms of QoS. WBAN traffic is categorized into on demand (OD), emergency (EM), and normal (NR) traffics. The coordinator or doctor, launch traffic on demand to acquire information, mostly used for diagnostic recommendations, this is further divided into continuous (in case of surgical events) and discontinuous (when timely disclosure is required). The nodes initiate the emergency traffic when they exceed a predefined threshold. This kind of traffic that is produced on a regular basis is very unpredictable. Normal traffic is the data traffic in normal condition without the critical time and events upon request. This includes health monitoring of a patient and treatment of several diseases such as gastro-intestinal, neurological disorders, cancer detection, rehabilitation of disability, and heart diseases. The normal data is collected and processed by the coordinator. Table 2 gives an idea about the three user priorities used in our proposed approach with their traffic designation, packet subtype and description. After classification, the PS is responsible for mapping between the categories of access presented above in Table 2 and the access categories of WLAN protocol. The UPs/ACs mappings are shown in Table 3. In this work, we map the WBAN UPs into WLAN ACs based on the priorities of the WBAN data frames and traffic rates of all UPs, as shown in Fig. 6. The main purpose of the mapping module is to map the three WBAN UPs (UP7, UP6 and UP3) into WLAN ACs. The data frames arriving to the personal server (bridge) from the WBAN nodes which belong to one of the three UPs, can be transferred to the WLAN access point either by transmitting every received WBAN data frame or by using the aggregation mechanism. In case of using the aggregation, WBAN data frames are compressed into a single WLAN data frame so the UP of the data frames, the number of aggregated frames, and the size of the aggregated WLAN data frames must be considered. In this work, we assume that data frames with specific UPs are aggregated into a single WLAN data frame where the maximum degree of aggregation (DoA) is the max payload size of the IEEE 802.11e. By this manner, a WBAN/WLAN bridge collects and aggregates data frames from WBAN nodes in order to transfer them further to the medical server.

Table 2
Data packets type classification.

Category specification		Description
User priority	7	Dedicated for the most critical data packets such as packets reporting data values that exceed normal thresholds (alerts). Flows belonging to this categories should be forwarded in a brief time and reliable way.
Traffic designation	Emergency	
Packet subtype	Emergency (EM)	
User priority	6	Normal packets must be delivered in stringent deadlines. However, a reasonable packet loss is tolerated. Flows belonging to this categories correspond to multimedia packets e.g. video streaming of elderly monitoring and motion control.
Traffic designation	Medical data	
Packet subtype	Normal traffic (NR)	
User priority	3	The lowest priority is given to OD packets. They correspond to regular measurements of patient physiological parameters that typically indicate normal values.
Traffic designation	Controlled load	
Packet subtype	On-demand (OD)	

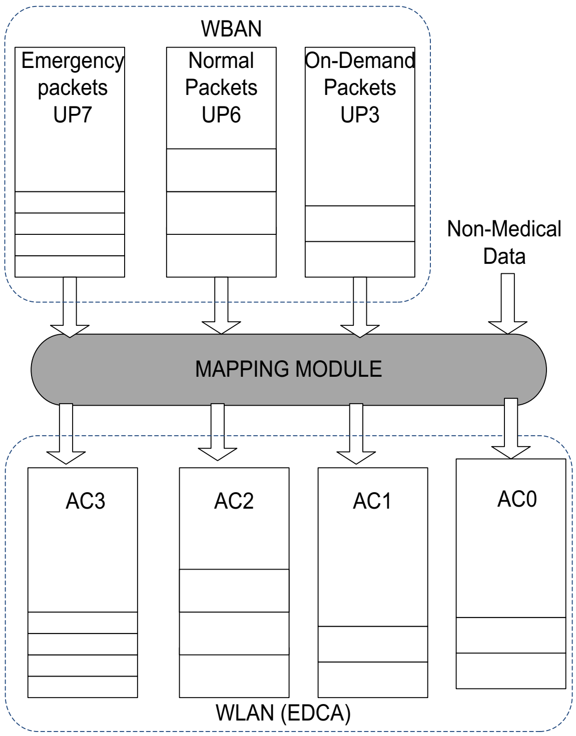

Fig. 6. Mapping scheme.

5.2. Scheduling deployment in WBAN/WLAN networks

Packet scheduling mechanism aims to select a packet from packets waiting in the transmission queue for transmission. It chooses which packet from which queue and node will be scheduled for transmission in a certain period of time. A good scheduling system schedules different flows according to the QoS requirements of each one, and all flows having the same QoS requirements must be treated in a similar way. In our WBAN/WLAN bridging system, we can integrate two different scheduling schemes. The first one is for intra-WBAN traffic scheduling which is located in the personal server and the second deployed in the WLAN access priorities for inter-WBAN traffic scheduling. In this work, our contribution is to conceive the intra-WBAN scheduler. Fig. 7 illustrates the interaction of the scheduling modules with the whole WBAN/WLAN system.

6. New Priority Frame Aggregation scheduler

6.1. Priority Frame Aggregation scheduler design

In our contribution, we consider two proposed schedulers: one with aggregation and it's called Priority Frame Aggregation scheduler (PFA). The operation of this scheduler can be divided into three parts, generating, selecting and aggregating packets with priorities mapping. The second one is called Priority Frame scheduler (PF). The difference between the PFA and PF scheduler is using or not the aggregation mechanism. In the following, we will explain the PFA scheduler functionalities.

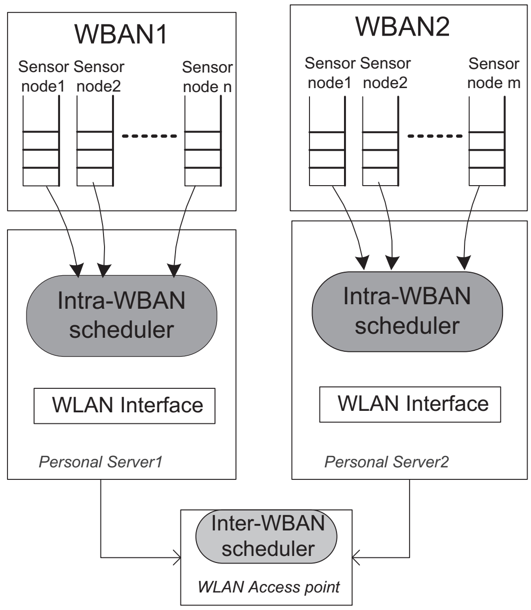

Fig. 7. Possible scheduler types.

We consider in our design that there are three types of data traffic which generate packets along the simulation duration: emergency, medical data and controlled load traffic. All packets belonging to same UPs will be placed in the same queue. After packet generation, each frame will be mapped into UPs and will be stored into one of the three priorities. We consider in our proposed design that packets are generated in a random distribution. After generating packets, there is a selection of packets to be sent so the data traffic generated will converge at the network layer before being forwarded to the next destination. Apparently, packets are queued at the MAC layer if the total input rate exceeds the packet forwarding rate at this layer. Even, using the Priority Frame Aggregation scheduling technique ensures QoS traffic differentiation and it leads to the starvation problem. In fact, high priority packets contend resources more aggressively than those of lower priority. Therefore, in this case, on-demand packets may be indefinitely blocked by normal and emergency packets. To cope with this problem, at each time "t" the PFA scheduler calculates the critical delay (CD) of each packet generated. CD refers to the time spent for serving a packet and it's equal to:

$$\mathrm{CD}(t) = \mathrm{TLD}(t) - \mathrm{WD}(t) \tag{2}$$

where TLD is the tolerated latency delay and it refers to the time when a node wants to send a packet and the time when this packet should reach its destination. In other words, it is the maximum delay that packet can support it before its delivery. WD is the waiting delay in our scheduler; it means that it is the time between "t" and the arrival time T_a of packet in the scheduler. If the waiting delay exceeds the TLD value, the packet will be automatically dropped. WD is expressed as follows:

$$\mathrm{WD}(t) = t - T_a \tag{3}$$

After calculating CD, the scheduler selects packets whose CD is the lowest i.e. packets with lowest CD are served first.

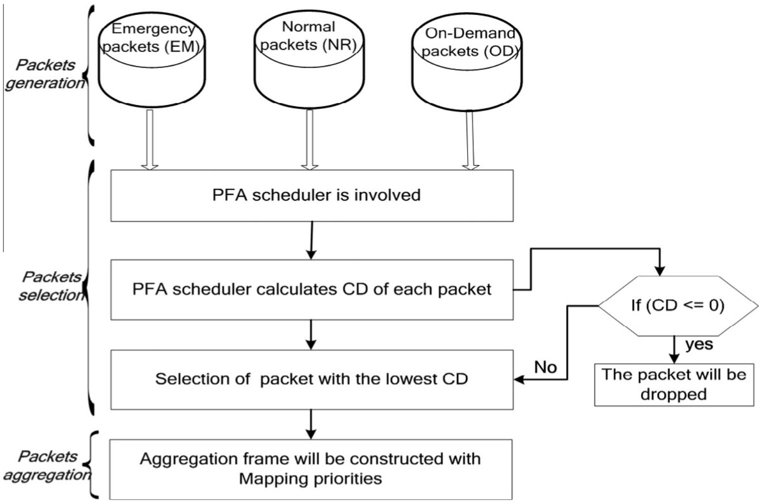

Fig. 8. PFA scheduler algorithm description.

Hence, the proposed PFA scheduler gives priority to packets according to their CD. We have now packets which are selected to be served. The next step is to collect and aggregate packets coming from sensors where the aggregated data have a fixed degree of aggregation. When a particular degree is indicated, packets are not forwarded to the central server until the construction of the aggregated data with maximum length. In our work, we consider the maximum degree of aggregation (DoA) is the max payload size of the IEEE 802.11e. Especially, in this part, the PS is responsible for encapsulating WBANs packets, aggregating many WBANs packets into one WLAN frame with priorities mapping. If the aggregated frame contains at least one EM packet, then we attribute it to the highest priority (AC3). Also, if the aggregated frame contains at least one NR packet, then we attribute it to access category AC2 and if the aggregated frame contains at least one OD packet, then we attribute it to access category AC1.

6.2. PFA scheduling algorithm

We present in this section the PFA scheduler algorithm whose functional bloc diagram is shown in Fig. 8. We note that our proposed traffic classification considers only the three types of traffic listed previously (on-demand (OD), emergency (EM), and normal (NR) traffic). Nodes having one of the three priorities generate packets in a random way among the time. After that, the scheduler is involved at $t = T_s$, where T_s is the time of scheduling, to calculate CD of all non scheduled packets using Eq. (2) and selecting packets having the lowest CD. Packets having negative CD will be dropped. After scheduling, an aggregation phase is started in order to construct the aggregated frame with priorities mapping.

7. Performance analysis

We evaluate the performance of our proposed schedulers in comparison with two schedulers: the PQ scheduler, in which packets are scheduled based on their TLD, and then they are forwarded to the network without aggregation.

The second is PQA scheduler where packets are scheduled based on their TLD, and then the aggregated frame size is fixed as it is defined in IEEE 802.11e.

In this section, we present the performance evaluation obtained through simulations. We analyzed the efficiency of our proposed schedulers (PFA scheduler and PF scheduler) in comparison with PQ scheduler and PQA scheduler. Firstly, we describe the simulation settings as well as the model of traffic generation. After that, we discuss the performance of our proposed schedulers in terms of delay, data rate, and percentage of dropped packets. The considered emergency, normal, and on-demand parameters are listed in Table 4 and the main MAC parameters are listed in Table 5.

7.1. Delay and throughput evaluation

In this section, we aim to investigate the performance of our proposed schedulers in terms of delay and throughput

Table 4
Traffic parameters.

	Emergency	Normal	On-demand
Payload size/packet (B) [23]	50	150	300
TLD (ms) [3]	50	150	250

Table 5
Simulation parameters.

SIFS	16 μs
DIFS	34 μs
MAC header	36 bytes
MPDU delimiter	4 bytes
FCS	4 bytes
Slot duration	9 μs
Basic rate	6 Mbps
PHY rate	54 Mbps

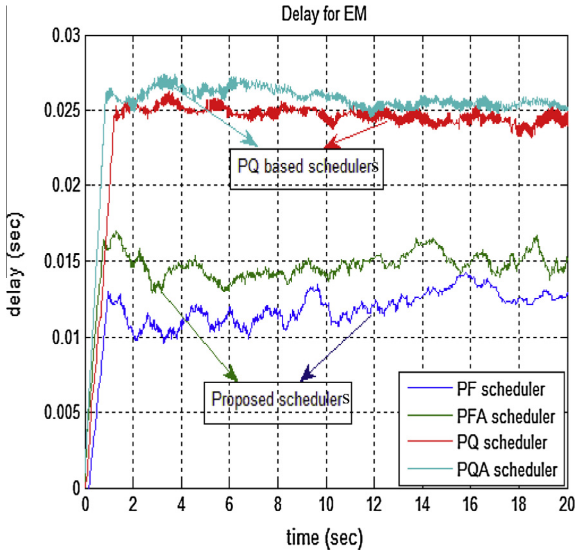

Fig. 9. Delay variation for emergency packets.

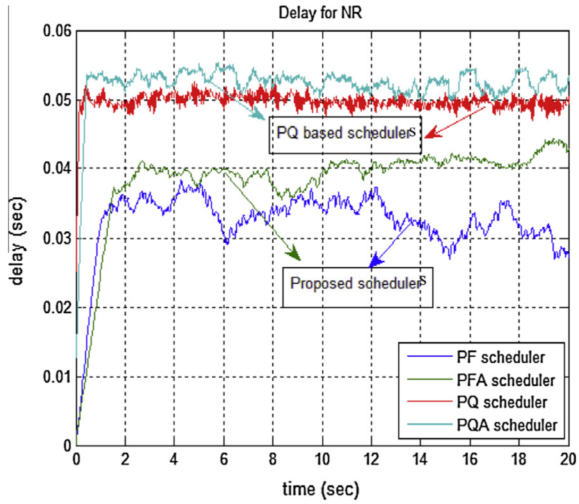

Fig. 10. Delay variation for normal packets.

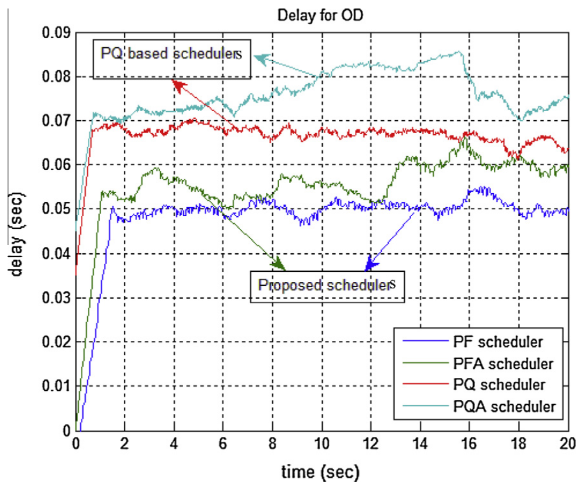

Fig. 11. Delay variation for on-demand packets.

behavior. The measured delay is considered as the elapsed time between the instant of packet generation until its serving instant. Figs. 9–11, plot the delay variation among the time for emergency, normal, and on-demand packets respectively. On the other part, we consider the throughput (also called traffic rate) as:

$$\text{Throughput} = \frac{\text{Payload\_packet}}{\text{Transmission\_delay}} \tag{4}$$

where Payload_ packet refers to the frame payload size, and transmission_delay corresponds to the required delay to transmit this packet.

$$\text{Transmission\_delay} = \text{DIFS} + T_{backoff} + \text{WD} + T_{phy\_hdr + T_{agg}} + 2\text{SIFS} + T_{Ack} \tag{5}$$

This delay includes the inter-frame spacing delays such as DIFS and SIFS, the backoff delay, the waiting delay WD, the transmission delay of the aggregated frame in which this packet is encapsulated T_{agg}, and the required delay to transmit an acknowledgment.

Figs. 12–14 draw the average throughput variation along the simulation duration for emergency, normal and on-demand packets respectively. For all traffic types, we observe first that: when the proposed schedulers are enabled, the serving delay is highly decreased and the throughput is greatly increased. Second, scheduling packets based on PQ scheduler badly affect delay and throughput. In fact, it causes the highest delay with the lowest rate. Finally, we can see that all delays values satisfy the required QoS delay since packets that go above this constraints are systematically dropped.

We will firstly examine the performance of our proposed schedulers based on CD parameter (PFA and PF schedulers) versus the other schedulers based on TLD parameter (such as PQ and PQA schedulers). From delay and throughput curves, we note that scheduling packets based on their CD is better than scheduling packets based on their TLD parameter, since higher delay with lower rates are obtained with the last one. As a result, PFA and PF schedulers provide better delay and throughput performances compared to PQ and PQA schedulers.

Such performance is obtained by considering the waiting delay of each packet. In fact, serving packets based on TLD, the instant from which the entered packets are waiting in the priority queue is not considered. So, packets that are not selected must wait to be scheduled. In that case, they will be scheduled lately or they will be dropped if their waiting delay goes above the tolerated delay to serve a packet. Knowing that the serving delay is the difference between the instant "t", at which the packet is selected, and the instant of arriving at the priority queue, hence, the serving delay is increased with PQ and PQA schedulers. On the contrary, based on CD parameter, PFA and PF schedulers consider the waiting delay when scheduling packets. In that case, the oldest packets will be the first scheduled and so the serving delays of these packets will be reduced.

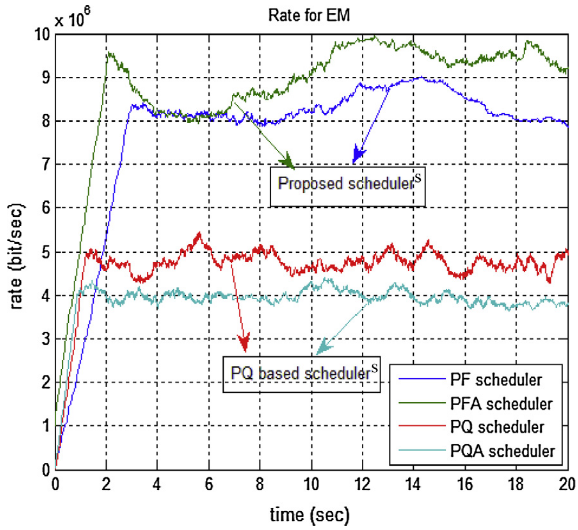

Fig. 12. Throughput variation for emergency packets.

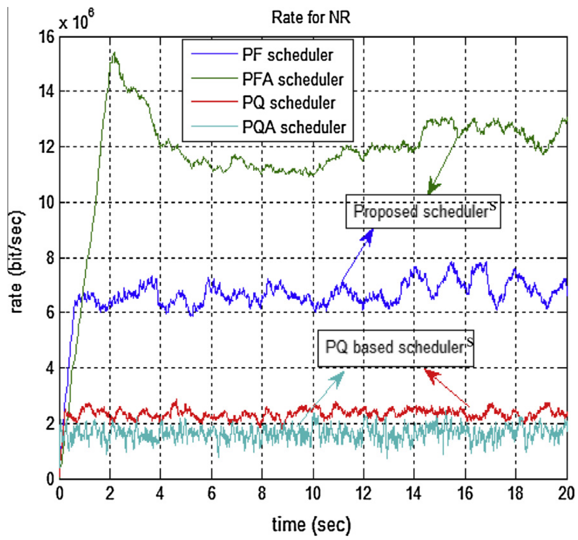

Fig. 13. Throughput variation for normal packets.

For the above reasons, and knowing that rate is inversely proportional to delay, PFA and PF schedulers provide lower delays with better rates compared to PQ and PQA schedulers. We can also see in all types of traffic that the PF scheduler is the best for delay requirements and the PFA is the best for throughput and that's explained by using the aggregation mechanism which we know that it affects badly the delay as it's clear in Figs. 12–14. So, we can conclude finally that, when we focus on minimizing the delay, we use PF scheduler and when we have applications that demand high throughputs, we use the PFA scheduler.

7.2. Bit error rate evaluation

We intend by this section to analyze the effect of our proposed schedulers, in terms of dropped packets, in comparison with other schedulers. Figs. 15–17, draw the

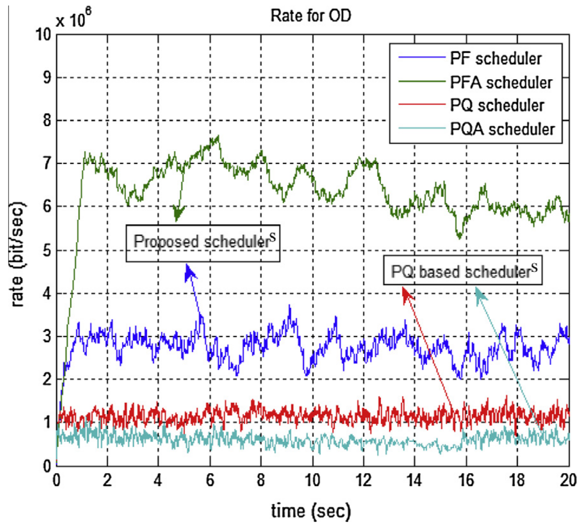

Fig. 14. Throughput variation for on-demand packets.

percentage of dropped packets of each scheduler for emergency, normal, and on-demand traffic respectively.

Firstly, we mention that, for all traffic types, our proposed schedulers guarantee the lowest values of dropped packets compared to other schedulers. Therefore, the PFA and PF schedulers improve the number of scheduled packets in the network. Furthermore, it is obvious that the highest number of dropped packets is achieved with PQA scheduler. More packets are scheduled with PFA and PF schedulers are explained by considering the waiting delay of each packet. By this factor, the scheduler respects the QoS delay of each packet. In fact, it reduces the number of accumulated packets that will be rejected once the tolerated serving delay is exceeded. Contrarily to PQA scheduler that drops more and more packets due to not considering the priority to serve the oldest packets. From the above curves, we firstly mention that PQA scheduler rejects most of the on-demand packets, up to 53% normal packets, and 5% of emergency packets. When scheduling packets based on TLD, emergency packets will be the most scheduled particularly under saturated network condition. Indeed, emergency packets have the lowest LTD compared to normal and on-demand packets. Hence, normal and on-demand packets are accumulated until some will be rejected. Based on our proposed PFA scheduler, around 35% on-demand packets, 22% normal packets, and only 1.6% emergency packets are dropped. Based on our proposed PF scheduler, around 41% on-demand packets, 32% normal packets, and only 2% emergency packets are dropped Therefore, our proposed schedulers have a positive impact on serving normal and on-demand packets and it overcomes the inefficiency of PQ scheduler. It also overcomes the starvation mode of the packets without the highest priority. Indeed, considering the waiting delay and aggregation has a positive impact on the number of scheduled packets. By this task, there is more chance to select packets which are coming first, so serving them with a reduced delay. From this analysis, we conclude that a maximum number of scheduled packets is granted when packets are scheduled based on our proposed schedulers.

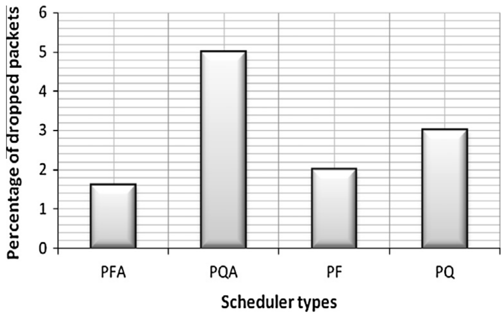

Fig. 15. Emergency dropped packets.

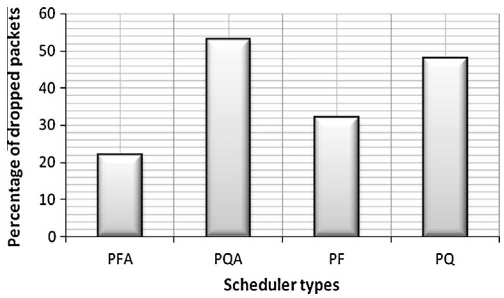

Fig. 16. Normal dropped packets.

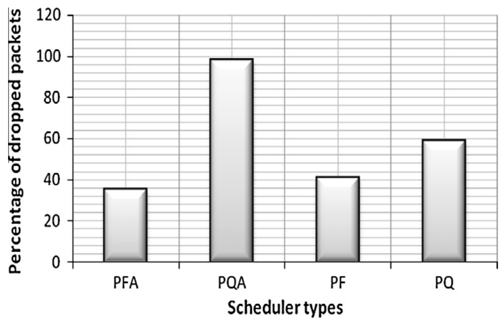

Fig. 17. On-demand dropped packets.

Table 6
QoS gain of PF scheduler vs. PQ and PQA.

QoS	Schedulers	EM (%)	NR (%)	OD (%)
Delay	PQ	52	30	27
	PQA	53	34	33
Throughput	PQ	60	140	200
	PQA	100	200	320
Dropped packets	PQ	1	16	18
	PQA	3	21	54

We summarize the overall performance of our proposed schedulers in terms of delay, throughput, and dropping packets for each traffic type. All the above results prove that better QoS performances are obtained with PFA and PF schedulers. We mention that PFA and PF schedulers provide both better QoS in terms of throughput performance, and they improve the number of scheduled packets in the network as well. Such performances are explained by scheduling packets based on their CD, as well as using the aggregation. In fact, using CD avoids storing high number of packets in the priority queue as well as increasing the waiting delays of the earliest entering packets mainly for normal and on-demand. Tables 6 and 7 show the gain in terms of delay throughput and dropped packets in our proposed schedulers vs. PQ and PQ schedulers.

Table 7
QoS gain of PFA scheduler vs. PQ and PQA.

QoS	Schedulers	EM (%)	NR (%)	OD (%)
Delay	PQ	40	20	16
	PQA	42	24	22
Throughput	PQ	90	380	550
	PQA	137	500	800
Dropped packets	PQ	1.4	26	24
	PQA	3.4	31	60

8. Conclusion

In this paper, we have proposed two schedulers for integration in the WBAN/WLAN healthcare system: PFA and PF schedulers. From our previous study, we have evaluated the IEEE 802.15.6 analytically and we concluded that there is a starvation mode of the packets without the highest priority.

To overcome these drawbacks, we have proposed these schedulers which define new parameters to serve packets. By these schedulers, packets are served according to their critical delay, and then the aggregated frame will be constructed in case of PFA scheduler. Therefore, waiting delays are reduced and throughputs are upgraded. Simulation results prove that our proposed schedulers are able to guarantee delay and throughput requirement for real time flows particularly of emergency, normal and on-Demand traffics. Indeed, serving packets based on their critical delay is a key to maintain required QoS and overcome the problem of starvation. Our future work consists of proposing an inter-WBAN traffic scheduling which is deployed in the WLAN access point.

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Nourchene Bradai was born in Sfax, Tunisia, in 1985.She received her degree in Electrical Engineering and her Masters in Electronic Engineering from Sfax National School of Engineering (ENIS), Tunisia, in 2009 and 2010, respectively. In 2014, she joined the Mahdia High Institute of Applied Science and Technology, Tunisia, as an assistant. She is a member of Sfax Laboratory of Electronics and Information Technology (LETI). Her current research interests are communications, networking and are specially related to wireless and body area networks.

Lamia Chaari was born in Sfax, Tunisia, in 1972. She received the engineering and PhD degrees in electrical and electronic engineering from Sfax national engineering school (ENIS) in TU NISIA. Actually she is an assistant professor in multimedia and informatics higher institute in SFAX She is also a researcher in electronic and technology information laboratory (LETI). Her scope of research are communications, networking and signal processing which are specially related to wireless and new generation networks.

Lotfi Kamoun was born in Sfax Tunisia, 25 January. 1957. He received the electrical engineering degree from the Sciences and Techniques Faculty in Tunisia. Actually he is a Professor in Sfax national engineering school (ENIS) in TUNISIA, Director of SFAX Higher Institute of Electronics and Communications in Tunisia and director of electronic and technology information laboratory (LETI). His scope of research are communications, networking, and Software radio and signal processing which are specially related to wireless and new generation networks.