Decode and Merge Cooperative MAC Protocol for intra WBAN Communication

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***Abstract*—Wireless Body Area Network (WBAN) consists of a set of sensor nodes deployed on or implanted in the body and these nodes send sensed physiological data to the personal assistant. Some of these sensor nodes can be located far from the personal assistant or due to body posture the link between the node and the personal assistant is obstructed and so require an intermediate node to help relay their data. As defined in the IEEE 802.15.6 standard, a node can initiate the two-hop extension cooperative communication to relay other nodes data. However, it is impossible to accept relaying for more than one node at the same time. In addition, when a relay node has data to send too, it has to choose either to leave the relaying mode or to maintain it. In this paper we propose a Decode and Merge technique that maintains the relaying mode by merging frames from relayed and relaying nodes. By doing so, a MAC format resizing is required. Apart from maintaining cooperative communication, this technique increases the general throughput without increasing the energy consumption, management and control flows. Furthermore, it increases the ability to resist against interference.**

***Index Terms*—IEEE 802.15.6, WBAN, MAC, Cooperation, Relay, Decode, Merge**

I. Introduction

In a WBAN, the sensor nodes location can be far from the hub or node-hub link blocked up due to different body postures and so, be out of reach or the link quality can be worse. In that situation a helper node is required to relay data between the hub and the node. It is the case when a ”WBANed” subject is making household chores. Although a simple one-hop topology is widely adopted for WBAN, it is unsufficient to achieve WBAN reliability requirements since the shadow effect occured due to body tissues and body motion is strong what can lead to signal attenuation. Besides, it is shown that a WBAN having set a single-hop star topology communication is likely to promote large path losses [1] and the interference in closest WBANs and nodes goes increasingly. Hence, the IEEE 802.15.6 standard [2] defines an optional two-hop cooperative WBAN communication to overcome that issue. In addition, many efforts have been made to face up important WBAN challenges such as reliability, energy efficiency, interference mitigation and supporting multi rates throughput [3]. As a sensor node is composed of two main parts, one for sensing and an other for transmission, it is also necessary to optimize the use of the latter to reduce energy consumption. However, in the purpose of offering and assuring Quality of Service (QoS) to WBAN communication, it is needed to review those parameters when two-hop topology is applied and there is no specification in the standard on the way the network is initialized when operating in two-hop topology to ensure the coverage of all nodes.
It is in the specific scope of intra WBAN communication that we propose a cooperative relaying mechanism based on MAC protocol, that merges data at the relaying node to increase data exchange without overloading the whole network flow with control packets. In addition, we propose an algorithm for the initialization phase when a two hop topology is set.

The rest of this paper is organized as follows: Section II presents researches conducted on the cooperation and relaying communication for the WBAN, two-hop topology and energy optimization. Our approach, Decode and Merge technique is described in Section IV with a proposition of initialization phase when a two-hop topology is adopted. In Section V, performance evaluation is done and the results are presented and discussed. Section VI concludes this paper and outlines the future work.

II. Related Works

The coexistence of many WBANs is still a major challenge due to interference that occurs while exchanging information. In [4] authors investigated the possible coexistence of multiple mobile WBANs where one WBAN sets cooperative communication with two relays and it was shown that this two-hop topology improves better co-channel interference mitigation than the single-hop topology. Moreover, the same authors extended their study and found that the opportunistic relaying reduces significantly interference [5]. Importance in setting this topology has been also explored by considering

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whether the WBAN PHY is narrow-band [6] - [7] or UWB [8] and in all these studies significant performance benefits have been achieved. However, no works on the two-hop topology for intra WBAN communication, have so far taken into consideration transmissions flow optimization.

Despite of talking about interference mitigation and performance improvement in WBAN, the energy optimization has to be taken into account to assure the reasonable network lifetime. In fact, many efforts have been made in developing protocols that minimize energy consumption and the MAC layer protocol is likely to provide the best tools to achieve this goal. Thus, many energy efficient MAC protocols for WBAN and requirements of a good WBAN MAC protocol have been identified and various approaches of WBAN MAC protocols are comparatively analyzed. Therefore [9] proposes a unified hybrid and cooperative MAC to satisfy WBANs requirements such as guaranteed QoS, multiple physical layer support and adaptability to traffic variations. In [10] a survey on WBAN MAC protocols for energy efficiency has been elaborated and cross layer architecture is presented as a good way to achieve important energy gain. Furthermore, some authors propose to act on the data transmission to increase network lifetime. It is the case of Joint Aggregation MAC [11] that is designed to work for data collection tree.

Apart from interference occured in the coexistence of WBANs or nodes and energy optimization, cooperation and relaying are also interesting aspects especially in WBAN communication. Cooperation can be relaying and vice versa according to the mechanisms set to exchange information within the network. Cooperative relaying was studied in [12] to evaluate energy efficiency performance and it was found that multi-hop cooperation is more energy efficient that single-hop communication. Contrary to [12], in [13] authors evaluated the performance difference between static relaying and dynamic cooperative relaying for short-range high path loss sensor networks and the conclusion remains that multi-hop is more efficient than one-hop. However, few authors if any studied the possibility to enhance data flow or evaluate transmission performance of WBAN cooperation while keeping energy optimization, what this paper focuses on. In addition, due to different body postures and movements, the direct links between sensors are frequently blocked resulting in a higher packet error rate (PER). Paper [14] proposes a cooperative relaying scheme for lowering the PER in a WBAN. For each node on a human body, the proposed scheme smartly and autonomously assigns a node as a cooperator out of other nodes and the cooperator relays packets from the node for a BAN coordinator to overcome the problem of blocking of direct link between them.

III. IEEE 802.15.6 MAC Overview

In this section, we briefly describe the MAC protocol of the IEEE 802.15.6 standard, focusing on the way the nodes access to medium, the network topology and the MAC frame formatting. In fact, a WBAN is composed of one and only one hub as a coordinator and up to 64 nodes deployed in one-hop star topology or in two-hop extended topology. Exchanged frames over the network are classified into three categories: Management, Control and Data frames. Management type frames include beacon, Security association and Disassociation, Connection Request and Assignment, Pairwise and Group Temporal Key, Disconnection and Command. Control type frames are all kind of acknowledgement and polling message and wakeup command. Finally, Data type frames are sensed data or emergency.
The medium access is controlled according to user priorities defined as follows: Background (UP0), Best effort (UP1), Excellent effort (UP2), Controlled load (UP3), Video (UP4), Voice (UP5), Media data or network control (UP6) and Emergency or medical event report (UP7).
The standard supports three communication modes. The first is beacon mode with superframe boundaries where the hub and nodes have to set a time reference base whose time axis is divided by the hub into beacon periods (superframes). A superframe is equally divided into allocation slots numbered from 0 up to 255 and includes Exclusive Access Phases (EAP1 and EAP2), Random Access Phases (RAP1 and RAP2), type-I/II, Access Phases and Contention Access Phase (CAP) as illustrated in Fig. 1. Allocation slots may only be contended allocations in EAP1, EAP2, RAP1, RAP2 and CAP and obtaining the contended allocation access methods CSMA/CA and Slotted Aloha are used. User priorities and access methods for contended allocations are mapped following the minimum and maximum contention windows, (CWmin, CWmax): (16,64), (16,32), (8,32), (8,16), (4,16), (4,8), (2,8), and (1,4), respectively for CSMA/CA and maximum and minimum contention probability (CPmax, CPmin): (1/8,1/16), (1/8,3/32), (1/4,3/32), (1/4,1/8), (3/8,1/8), (3/8,3/16), (1/2,3/16), (1,1/4) respectively. The second is non-beacon mode with superframe boundaries where the hub uses superframe with managed access phase (MAP) and does not send beacon to let nodes upload their data . The last is non-beacon mode without boundaries where the hub provides bilink allocations and nodes can use EAP1 or RAP1 with CSMA/CA as access mode.

The EAPs are only accessed for transmitting the emergency frames (UP7) and the RAPs are used by other frames (UP0-UP6) to access the medium.

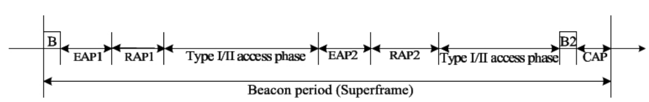

Fig. 1. Layout of access phases in a beacon period (superframe) for beacon mode

Regarding the MAC Frame, its format consists of fixed-length MAC header and Frame Check Sequence (FCS) and a variable-length MAC frame body as it is illustrated by Fig. 2.

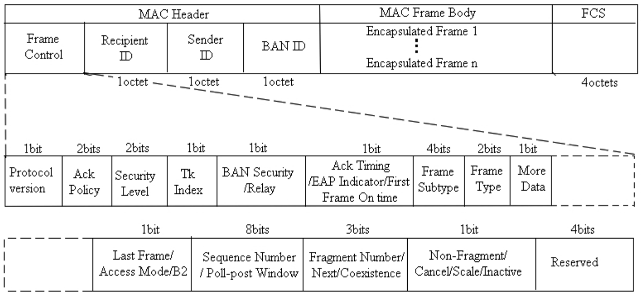

Fig. 2. IEEE 802.15.6 MAC Frame format

In the two-hop extension topology, it is stipulated that a relayed MAC Frame has to be encapsulated in a relaying MAC Frame as formatted in Fig. 3. This way of encapsulation reduces the space of payload given the redundance of some header fields of the encapsulated frame in the resultant frame. In this paper we propose a new mechanism of encapsulation at the relay node.

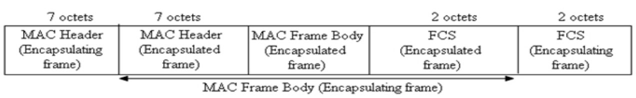

Fig. 3. General IEEE 802.15.6 frame encapsulation format

IV. Proposed approach

Our proposed approach is based on two main ideas: combining frames from relayed nodes into one at relay node and resizing MAC frame format to gain space to increase data flow.

A. Motivation and Definition

Regarding the wireless sensor network (WSN) in general and particularly WBAN, it is mandatory to develop protocols and algorithms that minimize energy consumption to achieve a long life of nodes battery especially for implants. IEEE 802.15.6 standard seems to offer opportunities to increase data flow while optimizing energy consumption. Our proposed solution falls in cooperation and relaying by resizing MAC frame format defined by the standard, merging packets to reduce transmission flow and therefore increase data transmission rate while optimizing energy consumption.

B. MAC Frame reformatting

As observations from the MAC formatting described in Section III, there is redundancy of information in some fields such as BAN ID, Receipt ID, Sender ID, Reserved, etc. Furthermore, a frame of 255 octets of frame body and 9 octets of frame header is too long for physiological data like temperature, glycemic level, heartbeat, etc. except the case of multimedia data. Therefore we propose to merge bit per bit frames from the relayed nodes into a single frame at a relaying node before getting to the hub. This merging operation is like interleaving operation with uniform interleaver and benefits for instance from burst error correcting advantages. Thus, when a node set as relay receives a packet to relay, it checks its integrity using the FCS field and removes some unnecessary fields. If it is not in the transmission schedule, it pushes it into the buffer stack. But, if it is possible to send, it checks whether the packet is urgent or the buffer is empty. If so, it encapsulates and sends it straightway. If not, it merges it with buffer packets and sets MEN (Merged Frames Number) field of the resultant frame with the number of merged frames before it sends it. Accordingly, the merging process is done as follows:

Given *m* MAC frames $R_1, \ldots, R_i \ldots, R_m$ of length *n* each, and whose bits are ordered as $R_i = b_{i1}, \ldots, b_{in}$, the coded relayed MAC frame body after merging is set as follows:

$R = B_1, \ldots, B_j, \ldots, B_n$ where $B_j = b_{1j}, \ldots, b_{ij}, \ldots, b_{mj}$

Example: $m = 2, n = 8$

$$R_1 : \underbrace{0}_{b_{11}}1001100 \quad and \quad R_2 : \underbrace{1}_{b_{21}}0101010$$

$$R : \underbrace{01}_{B_1 = b_{11} b_{21}} \quad 10010011100100$$

This process follows some principles and assumptions:

1) The Frames to be merged must be from the closest traffic type or have the same user priority (UP) if this latter is above 4. Furthermore, they must not exceed 255 octets long if merged. For our simulations we considered all frames as being from the same traffic type and same UP.

2) For data packets, the relaying is only ascending, i.e. from nodes to the hub and for INIT packet, the relaying is only descending, i.e. from the hub to nodes.

C. Frame transmission scheme

The algorithm 2 assumes that each node can reach a hub and vice versa, in at most two hops. In [15], a same idea of algorithm has been developed but that algorithm is for routing at network layer, therefore we chose a technique that works at MAC layer. In fact, by using the IEEE 802.15.6 MAC frame format, a Hub broadcasts an initialization beacon to discover the nodes by setting Relay field to 0. To define this initialization beacon we used a reserved field in MAC Frame Control as a management subtype with Frame Subtype value of **0111** and **INIT** as Frame subtype name.

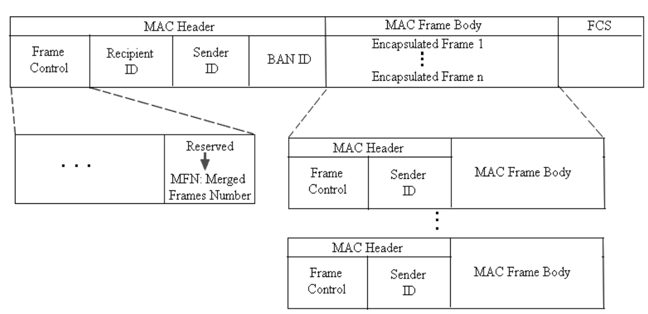

Fig. 4. General merged frame encapsulation format

Algorithm 1 Decode and Merge

if a node receives a packet **then**
Check packet integrity with FCS and Decode
Drop useless fields: Recipient ID, BAN ID, FCS
if Received Packet is not Emergency AND Buffer is not empty **then**
Merge packets (received packet with buffer packets)
Encapsulate
else
Encapsulate
end if
Send packet
end if

Algorithm 2 Initialization phase

The Hub broadcasts an INIT beacon with $Relay \leftarrow 0$
if a node receives an INIT beacon **then**
if $Relay == 0$ and is the first **then**
Use it
Relay it with $Relay \leftarrow 1$ *and* $SenderAddress \leftarrow NodeID$
else
if Is the first **then**
Use it
else
if the previous has $Relay == 0$ **then**
Discard it
else
Compare its LQI with the LQI of the previous
Choose the best link, i.e. the Relay Node
Use the choosen
end if
end if
end if
end if

And when a node receives an INIT beacon with Relay set to 0 it understands that it is at one hop from the hub therefore it uses it and forwards it after setting SenderAddress to its ID and Relay field to 1. When a node receives an INIT beacon with Relay set 1 it understands that it is at two hops from the hub and discards it. If it has previously received an INIT beacon, it keeps the best link to the source for its subsequent transmissions using LQI (Link Quality Indicator).
If a node finds it is capable of relaying, it sets Relay field to 1 and broadcasts a beacon to notify others. Thus, the relaying capability is calculated taking into account the amount of frames in the buffer, the energy and the quality link according to the formula expressed by Eq. 1 and Eq. 2.
A node is capable of relaying when:

$$FE > 0 \quad AND \quad LQI > TV \tag{1}$$

$$where \quad FE = RE - 8 \times Pn \times Fs \times Eb - TE \tag{2}$$

with:
FE: Functional Energy that allows a node to relay, *RE*: Residual Energy, energy left in the battery; *TE*: Threshold Energy, minimum energy that allows to send SOS message; *Pn*: Packet number, the number of packets in the buffer; *Fs*: Frame size (octets), length in octets of the MAC frame; *Eb*: Energy per bit, energy consumed by a bit sent what is on average 10pJ [16]; *TV*: Threshold Value, value between 0 and 255 [17]: In [18], it was shown that a LQI of 105 or beyond corresponds to maximum of link delivery ratio in IEEE 802.15.4. And then, when a node receives a beacon with Relay field set to 1 from an other node with a better link than the one it is connected to, it sets it as its new relay by sending a connection request. Finally, when a node is a relay it uses algorithm 1 to send data to the hub. Algorithm 3 summarizes all this idea. However, due to the constraints of simulation, we chose relay nodes before the simulation start.

Algorithm 3 Cooperation and Relaying

if a node is capable of relaying **then**
$Relay \leftarrow 1$
Broadcast a beacon
end if
if a node receives a beacon with $Relay == 1$ from best link **then**
Connection Request
Transmit data to Relay
end if
if a node is Relay AND Receives Connection Request **then**
Connection Assignment
Algorithm 1
end if

V. Performance evaluation and results discussion

Considering the top part the WBAN depicted by Fig. 5.a, if the two hop topology is set as defined in the standard, the relay node R will have to transmit 3 frames as illustrated by Fig. 5.b if it has data to transmit too. However, as shown by Fig. 5.c, if Decode and Merge Cooperation is applied, only one transmission will be required.

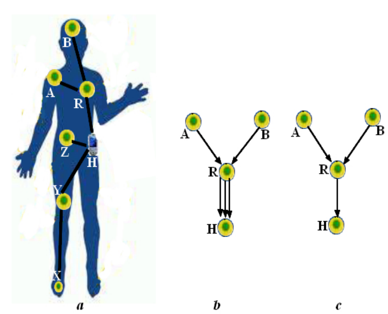

Fig. 5. WBAN two hop topology transmission models

In other words, let us take N the number of relayed nodes and r the number of relays. If all the nodes (relayed and relay nodes) have packets to transmit, $N + r$ packets will be delivered to the hub in $2N + r$ transmissions for normal WBAN defined in the standard while the same amount of packets will take only $N+r$ transmissions when using Decode and Merge. Therefore, if $N + r$ packets require $2N + r$ transmissions and T time for the WBAN model defined by the standard, $N + r + N - r = 2N$ packets will be delivered when using Decode and Merge in the same time T, that to say a gain of $N-r$. By generalizing previous results, we have:

-$Packets = PR * T * \sum_{i=1}^{N+r} Node_i$ without Decode and Merge;
-$Packets = PR * T * \sum_{i=1}^{2N} Node_i$ with Decode and Merge;
-$Gain = \frac{\sum_{i=1}^{N-r} Node_i}{\sum_{i=1}^{N+r} Node_i}$ what gives about 20% in our case.
Where PR is packet rate.

As simulation tool, we used Castalia [19], a network simulator based on omnet++ [20] and dedicated to low range sensor networks. Herein, some performance evaluation criteria are considered: general throughput (exchanged packets), energy consumption and transmission quality as interference variation. By exchanged packets we mean the amount of both transmitted and received packets including control, management and data packets. In addition, transmission quality refers to either success or failure of packets transmission due to collision, low sensitivity or interference. Simulation parameters set in table I include sensor data rate, sensor initial energy and simulation duration values which are simulator default parameters, as we found that their replacement has no influence on expected results and the results depend on the merging and the number of merged frames.

TABLE I
SIMULATION PARAMETERS

Node	Type	Energy	simulation time	PR
Node 0	Hub	18720 J	51 s	5 kbps
Node 1	relay node			
Node 2	node			
Node 3	relay node			
Node 4	node			
Node 5	node			

Results depicted by Fig. 6 show how our solution outperforms the standard model if we consider the amount of transmitted data packets. In fact, in Fig. 6 and Fig. 7, the node 0 which is set as a hub has indeed a big amount of packets because it is a one receiver. The difference noted at that node 0 in the two cases (Fig. 6 and Fig. 7) is almost the same what means that only data transmissions have increased. In this simulation case, the overall gain calculated from exchanged packets is about 23 % against 20 % expected. The node 1 and node 3 which are set as relays have increased their data flows as they relay data from nodes 2, 4 and 5 and their own data. The frames combination at those relayed nodes makes the increase less important in data flow than the general flow. However this does not have a bad impact on the general quality of transmission considering results in Fig. 8 and Fig. 9.

Ultimately, during a same simulation duration (51 s), the amount of exchanged packets (Fig. 6) and data packets (Fig. 7) is higher for our proposition than the standard model. Hereby, our proposal improves data transmission.

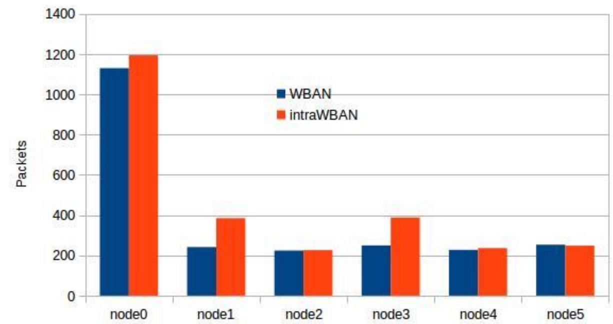

Fig. 6. Exchanged packets

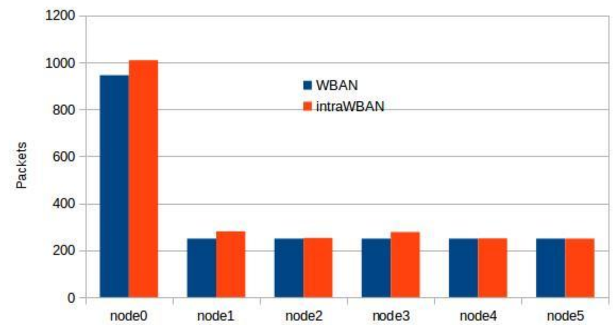

Fig. 7. Exchanged data packets

Fig. 8 illustrates failure and success transmissions. Failure is due to either below sensitivity, or interference or collision. Comparing our proposition with the standard model, success transmissions are higher and failure transmissions little in our proposal than in the standard model. In addition, relay nodes seem to promote the success of other nodes' transmissions. It is an observation from Fig. 9 that depicts the transmission success despite of interference: the gain is important for other nodes as they are helped by the relay nodes but a slight regression is observed at the relay nodes. This can be explained by the fact that they have to manage packet flows from and to the hub as well as from and to the sensor nodes. Hence, we get to the same conclusion as previous work that two-hop topology in more efficient than one-hop in terms of interference mitigation.

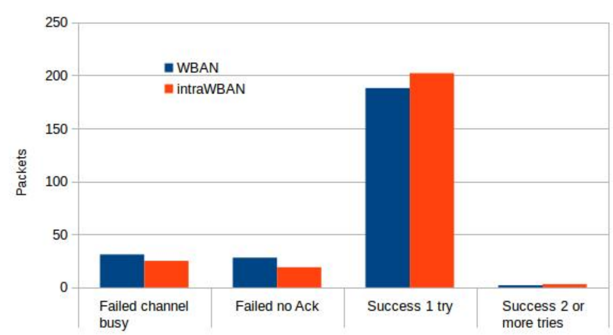

Fig. 8. Failure and success transmissions

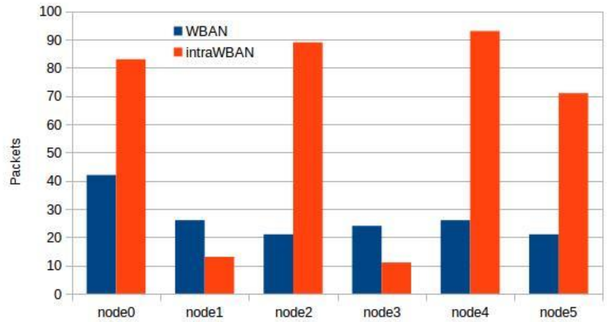

Fig. 9. Packets delivered despite interference

Regarding energy consumption, results depicted by Fig. 10 show that our proposition maintained the energy consumption level and some micro joules have decreased. This results in the fact that some nodes such as relays send few data packets than others but these packets are resultant from other packets combination.

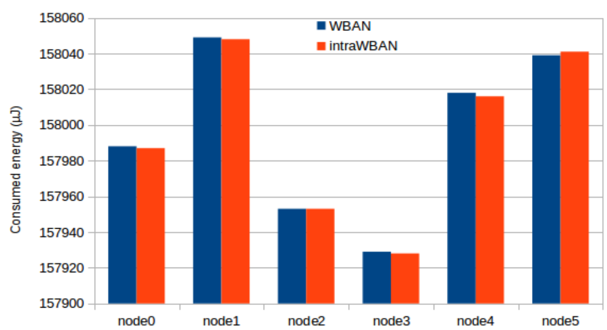

Fig. 10. Consumed energy

VI. Conclusion and Future work

In this paper we proposed a Decode and Merged technique to enhance MAC protocol for intra WBAN communication applied to two-hop topology. This technique is based on resizing frame format, frames combination and multiple input frames for single output frame. Simulation results showed that our proposition increases general throughput and specially the amount of data packets delivered to the hub. Moreover, the ability of transmission in interference conditions has increased. It was also shown that the energy consumption has been optimized what gives to our technique more energy efficient.
However, a work focusing on interference mitigation at relay nodes and effect study on relaying capability from multiple requests of relaying are required despite of the global performance achieved in this paper.

In the future, we plan to design a cooperative cross layer solution for intra WBAN communication with two-hop topology and extend the problem to the inter WBANs communication for QoS enhancement.

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