Reliable, Context-Aware and Energy-Efficient Architecture for Wireless Body Area Networks in Sports Applications

Richard Jaramillo, Alejandro Quintero, Steven Chamberland
Computer Engineering Departement
Polytechnic School of Montreal
Montréal, Canada
email: richard.jaramillo@ieee.org, alejandro.quintero@polymtl.ca, steven.chamberland@polymtl.ca

***Abstract*—Reliability, Context awareness and Energy efficiency are some of the most important requirements for Wireless Body Area Networks (WBANs). The proposed architecture for WBANs puts together a Media Access Control (MAC) protocol, a Transport Protocol and a Rate Control scheme proposed in our previous work. It proposes the use of three extra bits within each beacon period for indicating whether the hub is going to assign new slot Reallocations to the nodes, to request for lost packet Retransmissions from the nodes, to send Rate-control requests to the nodes, or any combination of them. Some experimental results are presented in order to validate the requirements and a comparison with other architectures is made using the main detected requirements for WBANs.**

Keywords–reliability; context awareness; energy efficiency; congestion control; loss recovery, WBAN architecture.

I. INTRODUCTION

Information collected from body sensors in a WBAN is sent to a hub or coordinator, which processes the information and can also perform other functions, such as managing body events, merging data from sensors, sensing other parameters, performing the functions of a user interface and bridging the WBAN to higher-level infrastructure and other stakeholders.

The IEEE Standard for Local and Metropolitan Area Networks - Part 15.6: Wireless Body Area Networks (2012) specifies short-range and wireless communications in the vicinity of, or inside a human body (although it is not limited to humans). It categorizes WBAN applications into medical and non-medical [1]. Some examples of medical applications might be: sleep staging, diabetes control and monitoring of cardiovascular diseases. Some examples of non-medical applications might be: entertainment, sports and military operations.

The design of a WBAN implies the tackle of several challenges. Among the most important challenges, we can find: (i) the energy efficiency of the whole network, which may require new MAC protocols, new routing protocols and new energy scavenging sources; (ii) the consideration of the impact of data loss, which may require additional measures in order to ensure the Quality of Service (QoS); (iii) the reliability of the network to grant accuracy and to guarantee on-time delivery of data; (iv) the context awareness for responding according to the current situation in the network.

The objective of this paper is to design an architecture for WBANs, which tries to tackle these main challenges. The architecture will be composed of three main components: (i) A context-aware and energy-efficient mechanism for providing QoS in WBANs; (ii) A reliable and energy-efficient mechanism to provide packet loss recovery and fairness in WBANs; and (iii) A context-aware rate control scheme to provide congestion control in WBANs.

Sports WBANs have a different behavior compared to other WBANs. In a Sports WBAN, most of the packets are periodic with a small portion of emergency packets that need to be delivered with low latency. A reliable, context-aware and energy-efficient architecture for WBANs used in sports applications is proposed, facing four challenges: energy efficiency, context awareness, QoS and reliability.

Several architectures for WBANs have been proposed recently in the literature. Some of them are mentioned in Section II. The requirements of the proposed architecture are summarized in Section III. Section IV presents all the protocols and schemes, the general and the node architectures, the global topology, the phases in the beacon period, and the node behavior. Some experimental results are presented in Section V for demonstrating the requirements accomplishment. A comparison of some architectures with the proposed architecture is made in the Section VI. Section VII presents the conclusion and future work.

II. RELATED WORK

Wang et al. [2] have proposed a configurable quantized compressed sensing (QCS) architecture, in which the sampling rate and quantization configuration are explored together for improving the energy efficiency. A rapid configuration algorithm has been developed to locate the optimal configuration of the sampling rate and the bit resolution, always monitoring low energy consumption, reducing the elapsed time while keeping an excellent efficiency and capacity. However, loss recovery was not mentioned.

In the following references, energy efficiency was not contemplated. Felisberto et al. [3] proposes a WBAN architecture to recognize human movement, identify human postures and to detect harmful activities in order to prevent risks. The architecture proposal comprises five basic components. (i) Sensor node – responsible for acquiring data of inertial and physiological sensors and transmitting them to the Coordinator node. (ii) Coordinator node – responsible for serving as a forwarder of data gathered by the Sensor nodes. (iii) Gateway node – it is the interface between the WBAN and the network that provides the Internet connection. (iv) Mobile node – an alternative interface used when the Gateway Node or Internet connection are not available. (v) Control center – responsible for the registration and post processing of the motion events sent by the Sensor nodes.

Almashaqbeh et al. [4] have proposed a Cloud-based real-time remote Health Monitoring System (CHMS) for tracking the health status of non-hospitalized patients while they perform their daily activities. The system tries to provide high QoS and to focus on connectivity-related issues between the patients and the global cloud. The CHMS design includes four basic components: Wireless routers, Gateways, WBANs and Medical staff.

Domingo [5] has proposed a context-aware service architecture for the integration of WBANs and social networks through the IP Multimedia Subsystem (IMS). In this architecture, multimedia services are accessed by the user from several wireless devices via an IP or cellular network based on the vital signs monitored in a WBAN. The architecture is divided into four layers: (i) Device layer – the sensors communicate with the gateway using ultra-wideband (UWB) or the IEEE 802.15.6 standard, and the gateway communicates with the monitoring station using Bluetooth or ZigBee. (ii) Access layer – responsible for the access of the monitoring stations to the radio channel. (iii) Control layer – it controls the authentication, routing and distribution of IMS traffic. (iv) Service layer - used to store data, execute applications, or provide services.

Wan et al. [6] have proposed a framework for a pervasive healthcare system with Mobile Cloud Computing (MCC) capabilities. This system is composed of four main components: (i) WBANs – which collect various vital signals, such as body temperature or heart rate information from wearable or implantable sensors. (ii) Wired/Wireless transmission. (iii) Cloud services – which possess powerful Virtual Machine resources, such as CPU, memory, and network bandwidth in order to provide all kinds of cloud services. (iv) Users – such as hospitals, clinics, researchers, and patients.

Kartsakli et al. [7] cites a remote monitoring scheme that provides ubiquitous connectivity for mobile patients. A patient-attached monitoring device collects the WBAN data, classifies them as high-priority (e.g., critical data such as blood pressure, pulse rate and heart rate) or normal priority (e.g., ECG signals) and forwards them towards the healthcare provider through a heterogeneous WiFi/WiMAX access communication network.

Kartsakli et al. [7] also cites a three-tier network architecture for the remote monitoring of elderly or chronic patients in their residence. The lower tier consists of two systems: (i) a patient-worn fabric belt, which integrates the medical sensors and is equipped with a Bluetooth transceiver; and (ii) the ambient wireless sensors that form a ZigBee network and are deployed in the patient's surroundings (e.g., in the patient's home or in a nursing house). In the middle tier, an ad hoc network of powerful mobile computing devices (e.g., laptops, PDAs, etc.) gathers the medical and ambient sensory data and forwards them to the higher tier. The middle-tier devices must have multiple network interfaces: Bluetooth and ZigBee to communicate with the lower tier and WLAN or cellular capabilities for connection with the higher layer. Finally, the higher tier is structured on the Internet and includes the application databases and servers that are accessed by the healthcare providers.

Kartsakli et al. [7] also cites a system architecture based on two independent subsystems for the monitoring and location tracking of patients within hospital environments. The healthcare monitoring subsystem consists of smart shirts with integrated medical sensors, each equipped with a wireless IEEE 802.15.4 module. The location subsystem has two components: (i) a deployment of wireless IEEE 802.15.4 nodes that are installed in known locations within the hospital infrastructure and broadcast periodic beacon frames; and (ii) IEEE 802.15.4 end devices, held by the patients, that collect signal strength information from the received beacons. Both subsystems transmit their respective data (i.e., medical sensory data and signal strength information) to a gateway through an IEEE 802.15.4-based ad hoc distribution network.

III. MAIN REQUIREMENTS

The selected architecture should offer to the hub and each node within the WBAN some specific advantages. The main requirements of the proposed architecture can be enumerated like:

- Energy Efficiency: to minimize the power consumption avoiding or mitigating collisions, idle listening, overhearing, and control packet overhead. The proposed architecture should decrease contention-based transmissions and increase the sleeping time for each node.
- Reliability: to assure the end-to-end packet delivery between the sensor nodes and the hub. The proposed architecture should allow the nodes to be able of sending all their emergency and normal packets to the hub.
- QoS: to have the ability to deliver packets with the least latency and the highest throughput. The proposed architecture should allow the trade-off between the energy efficiency and the desired reliability of the WBAN.
- Congestion Control: ability to control traffic in the WBAN in order to avoid packet collision and buffer overflow. The proposed architecture should decrease the packet loss due to the packet collision and both normal and emergency buffer overflow.
- Rate Control: ability to prevent the nodes from overwhelming the hub and the whole WBAN. The proposed architecture should allow the hub to control the packet rate of the sensor nodes in order to keep an average rate in the whole WBAN.
- Loss Detection: ability to detect the lost packets in the hub side and in each node side. The proposed architecture should provide the early detection of lost packets on both sides: the hub and the sensor nodes.

- Loss Recovery: ability to make the lost packet retransmission requests and to send the corresponding packet retransmissions. The proposed architecture should decrease the total number of lost packet through the retransmission of some of them.
- Fairness: ability to distribute the network resources equitably among all nodes of the WBAN. The proposed architecture should allow all nodes to get equal access to the network and give the corresponding priority to those nodes with emergency traffic and with high packet rate.
- Emergency Awareness: ability to respond to any emergency event in any node at any time. The proposed architecture should be able to detect early any emergency event and to give the corresponding priority to the emergency nodes.
- Context Awareness: ability to respond to any alert (high buffer, low battery, emergency) in any node at any time. The proposed architecture should be able to detect high buffer levels, low battery levels, and any emergency event into the nodes.

IV. PROPOSED ARCHITECTURE

This section explains the proposed architecture that gathers all the protocols and schemes presented in the previous work by Jaramillo et al. [8]-[10]. The section presents the proposed phases for each beacon period. Then, it summarizes all the protocols and schemes, depicts the general and the node architectures, and the global topology. Finally, the section explains the operation of the R's Indicator Bits (RIBs) scheme for each beacon period and the overall node behavior.

A. *Phases in the Beacon Period*

Figure 1 depicts the three proposed phases within the beacon period. The first phase is called Reallocation, Retransmission & Rate-control Phase (3RP). It is used by the hub for sending slot reallocations, retransmission requests and the Rate Control Factor (RCF) to all nodes. The second phase is Managed Access Phase (MAP). It is used by all nodes for sending normal and emergency traffic, always giving the highest priority to the emergency traffic. The third phase is called Special Contention Access Phase (SCAP). All nodes use SCAP for sending connection requests and additional normal and emergency traffic.

There is no contention during 3RP due to the use of the Time Division Multiple Access (TDMA) protocol. The hub uses all slots for sending slot reallocations and the RCF.

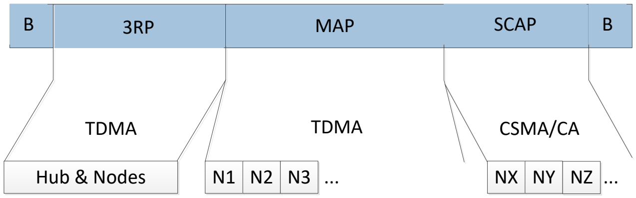

Figure 1. Phases in the Beacon Period.

The nodes only send lost packet retransmissions after they have received a lost packet retransmission request from the hub. MAP also uses the TDMA protocol for transmitting normal and emergency traffic. The use of Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) in SCAP implies contention-based transmission during this phase. At least one phase needs to offer contention to allow the unconnected nodes to connect to the WBAN.

B. *Protocols and Schemes*

The energy-efficient and emergency-aware MAC protocol for WBANs proposed by Jaramillo et al. [8] is based on the existing MAC protocol described in the IEEE 802.15.6 standard, but with some modifications in the access phases and the access methods for each beacon period in order to provide more emergency awareness while keeping energy efficiency. The proposed MAC protocol outperformed the IEEE 802.15.6 MAC protocol, the IEEE 802.15.4 MAC protocol and the Timeout-MAC (T-MAC) protocol in the percentage of emergency and normal packet loss and latency, while maintaining similar energy consumption as the IEEE 802.15.6 MAC protocol. In the MAC layer, the hub uses the Slot Reallocation Algorithm depicted in Figure 2 to create the slot reallocations for all nodes.

```
If Need Reallocations then
  Set Reallocation Indicator Bit ← 1
  For each Node in Reallocation_Buffer do
    Assign New Reallocation to Node
  End For each
  Assign Default Allocations to remaining
  nodes
  Send Slot Reallocations in the next 3RP
End If
```

Figure 2. Slot Reallocation Algorithm.

The reliable transport protocol based on loss recovery and fairness for Sports WBANs proposed by Jaramillo et al. [9] is a cross-layer design that detects out-of-sequence packets and requests retransmission of some lost packets. The hub and each node in the WBAN detect lost packets and make the requests and retransmissions during 3RP. The hub calculates the Fairness Index as the ratio between the number of lost packets and the total number of received packets. The hub uses the Fairness Index to prioritize the request creation in order to provide fairness between all the nodes in the WBAN. It outperformed the IEEE 802.15.6 Standard in the percentage of the packet loss, while maintaining similar energy consumption. The Packet Loss Detection Algorithm is used by the hub and the nodes and it is depicted in Figure 3 and Figure 4, respectively. The hub and the nodes detect lost packets in the MAC layer.

```
If sequenceNumber > lastSequenceNumber + 1 then
  Set Retransmission Indicator Bit ← 1
  Set i ← lastSequenceNumber + 1
  While i < sequenceNumber do
    Create Lost Packet Retransmission Request
    i ← i + 1
  End While
  Send Retransmissions Requests in the next 3RP
End If
```

Figure 3. Packet Loss Detection in the Hub.

```
If Transmissions + Fails = Maximum_Tries or
Current_Packet does not fit in Buffer then
  Set Retransmission Indicator Bit ← 1
  Push Current_Packet in Packet_Lost_Buffer
  Prepare to send Retransmissions in the next
  3RP
End If
```

Figure 4. Packet Loss Detection in the Node.

The rate control scheme for congestion control in Sports WBANs proposed by Jaramillo et al. [10] is context-aware and responses to emergency events in any node, reducing the normal traffic rate. When an emergency event occurs in the WBAN, the hub has to calculate RCF and communicate it to all nodes in the network in order to keep the same average rate of traffic during the entire emergency event. The proposed solution improved the performance of the IEEE 802.15.6 Standard. The Rate Control Scheme depicted in Figure 5 is used by the hub in the MAC layer to calculate the RCF for all nodes, and it is used by the nodes in the application layer for applying the RCF sent by the hub.

```
If Emergency Alert detected then
  Set Rate-Control Indicator Bit ← 1
  Push Current_Node in EmergencyBuffer
  Calculate RCF for all remaining nodes
  For each node not in EmergencyBuffer do
    Create Rate Control Request
  End For each
  Send Rate Control Requests in the next 3RP
End If
```

Figure 5. Congestion Control in the Hub.

C. General Architecture

Figure 6 depicts the proposed general architecture. The hub and the sensors are composed of five modules. (i) Sensing Module (SM) – in charge of sensing body information and detecting alerts into the packets. (ii) Memory Module (MM) – in charge of storing sensing data and lost packets for future retransmissions. (iii) Battery Module (BM) – in charge of detecting low battery levels. (iv) Processing Module (PM) – in charge of processing body information, creation of slot reallocations, detecting lost packets, sending requested lost packets, and processing the RCF for congestion control.

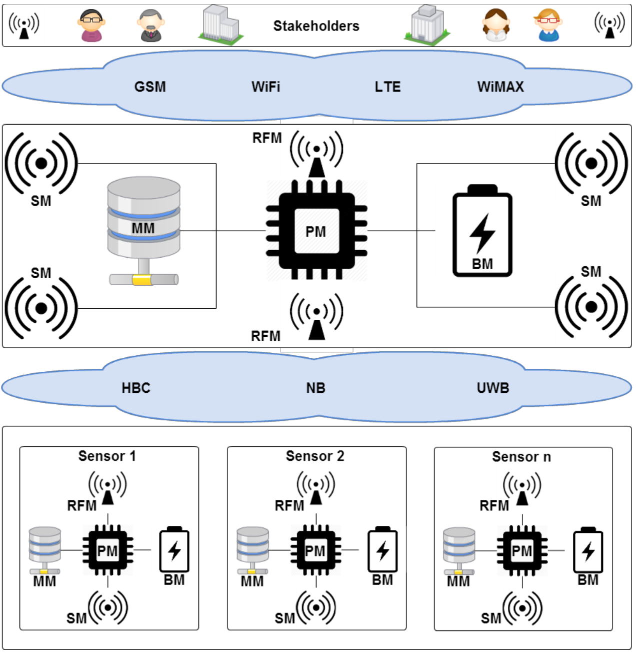

Figure 6. General Architecture.

(v) Radio-Frequency Module (RFM) – in charge of the transmission of the body information between the nodes and the hub (via either Human Body Communication - HBC, Narrow Band - NB, or Ultra-Wideband - UWB). It also manages the communication between the hub and the coach devices, data centers, and other stakeholders (via either Global System for Mobile communication - GSM, Long-Term Evolution - LTE, Wi-Fi, or Worldwide Interoperability for Microwave Access - WiMAX).

D. Node Architecture

Figure 7 depicts the node architecture with its five modules. (i) The SM supports the Slot Reallocation Algorithm with the detection of the alert type into each packet. (ii) The MM supports the Slot Reallocation Algorithm with the detection of future emergency buffer overflow, and supports the Lost Packet Retransmission Algorithm with the buffering of lost packet for future retransmissions. (iii) The BM supports the Slot Reallocation Algorithm with the detection of low battery levels. (iv) The PM supports the Slot Reallocation Algorithm, the Rate Control Scheme with the processing of the RCF, and supports both the Packet Loss Detection Algorithm and the Lost Packet Retransmission Algorithm with the creation of lost packet retransmission requests and the sending of lost packet retransmissions. (v) The RFM supports the Slot Reallocation Algorithm, the Rate Control Scheme and the Packet Loss Detection Algorithm, with the sending of slot reallocations, the RCF, and lost packet retransmissions, respectively.

E. Topologies

The proposed WBAN topology is always a star topology. In this way, the use of a special routing protocol is not needed. The hub must always be in the center.

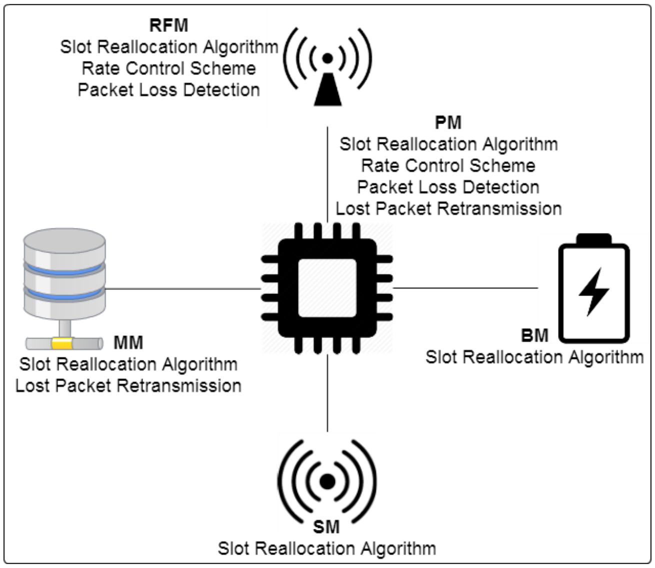

Figure 7. Node Architecture.

The sensor nodes must be around the hub. The hub is in the right hip. There are two sensor nodes over the wrists, two sensor nodes over the ankles and one last sensor node over the chest. Each sensor node has a direct wireless connection with the hub, and there are not relaying nodes for the packet routing. With this direct connection of sensor nodes to the hub, the information takes the least possible delay in transmission. Besides, the failure of a single node does not compromise the remaining nodes.

Figure 8 depicts the global topology for the proposed architecture. After gathering and processing the body information from nodes within the WBAN star topology, the hub can send this information both directly to a coach device (via Wi-Fi, GSM, LTE) or to other stakeholders (via GSM, LTE, Wi-Fi, WiMAX). The coach device can perform additional processing to help the coach to improve the training plan of the sportsman. The stakeholders can see the processed information into the data centers to improve research in training protocols of athletes, and deficiency detection.

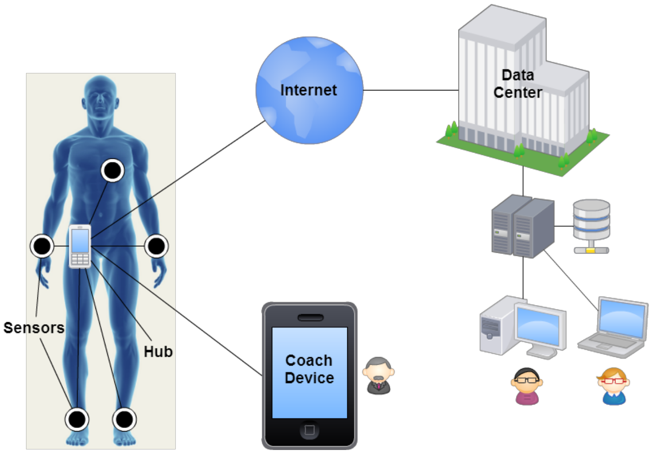

Figure 8. Global Topology.

F. RIBs in the Beacon

Table I shows the configuration of indicator bits into each beacon for the proposed architecture. Only three extra bits were used within each beacon for indicating whether the hub is going to assign slot Reallocations, to request packet Retransmissions, to send Rate-control requests, or any combination of them. When an emergency event happens in any node, the hub receives an alert from the node and it can decide whether the congestion control is necessary and use the Rate-control Indicator Bit (Third Bit). If there are many lost packets detected by the hub, it may use the Retransmission Indicator Bit (Second Bit). The Reallocation Indicator Bit (First Bit) is always used by the hub after an emergency event occurs in any node.

TABLE I. INDICATOR BITS INTO EACH BEACON

Type	3rd Bit	2nd Bit	1st Bit
None	0	0	0
Reallocation	0	0	1
Retransmission	0	1	0
Reallocation & Retransmission	0	1	1
Rate-control	1	0	0
Reallocation & Rate-control	1	0	1
Retransmission & Rate-control	1	1	0
Reallocation, Retransmission & Rate-control	1	1	1

The value of 1 (one) in the Reallocation Indicator Bit, means that the hub is going to send slot reallocations to all nodes in the current beacon period. The value 1 (one) in the Retransmission Indicator Bit means that the hub has detected lost packets and it is going to send packet retransmission requests in the current beacon period. The value 1 (one) in the Rate-control Indicator Bit means that the hub has received an emergency alert and it is going to send a RCF to control the rate inside all normal nodes in the current beacon period. This strategy allows to easily extend the number of indicator bits for new hub behaviors.

G. Nodes Behavior

Figure 9 summarizes the behavior of each node for the proposed architecture. After the beacon reception, the node has two options: it evaluates the RIBs if it is connected or it must wait until SCAP if it is unconnected. When it is unconnected, the node will always send its connection request during the next SCAP.

During 3RP phase (the yellow color zone), the node has previously evaluated the RIBs, then, the node can listen to slot reallocations sent from the hub, or listen to the RCF sent from the hub, or listen to lost packet retransmission requests sent from the hub and finally resend the lost packets requested by the hub.

During MAP phase (the blue color zone), the node sends emergency and normal packets giving the highest priority to the emergency traffic. The node uses its own assigned slots and it might use the remaining slots at the end of MAP if needed. If there were slot reallocations for this beacon period, the node will use the new slot reallocation received, otherwise, it will use the original slot relocation received when it connected to the WBAN for the first time.

ISBN: 978-1-61208-568-5

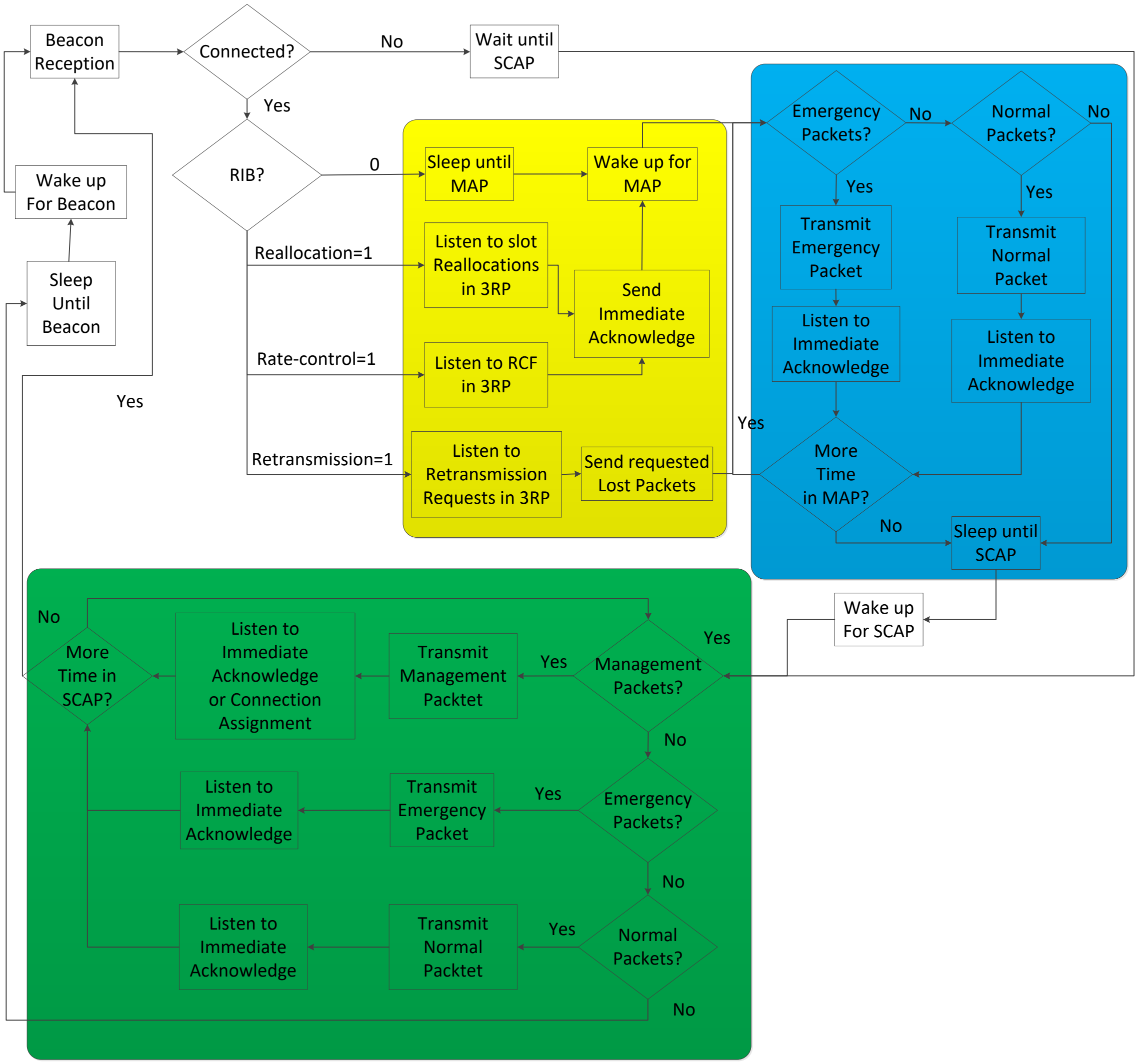

Figure 9. Overall Behavior of the Nodes.

Finally, during SCAP phase (the green color zone), the node sends management packets (e.g., connection requests) and additional emergency and normal traffic. The priority from the highest to the lowest for the traffic during SCAP is: (1) Management packets, (2) Emergency traffic, and (3) Normal traffic.

V. EXPERIMENTAL RESULTS

The MAC protocol, the Transport protocol and the Rate Control schema were compared against the IEEE 802.15.6 Standard, the IEEE 802.15.4 Standard and the T-MAC protocol. Castalia was chosen as the simulator because it offers a very good implementation for the IEEE 802.15.6 MAC protocol [11]. The performance of the architecture was evaluated using three parameters: (i) the packet loss; (ii) the Energy Waste Index (EWI), which was calculated as the ratio between the total percentage of lost packets and the average consumed energy. The lower the EWI, the better the energy effectiveness of the proposed solution; and (iii) the latency of the normal and the emergency traffic.

In some simulations, the number of emergency events was changed incrementally from one to five. Each emergency event had the duration of five seconds. The simulation time was 300s, the packet rate was 20pkt/s, and the number of nodes was 10. The percentage of emergency packet loss when the number of emergency events was changed in the WBAN is depicted in Figure 10. The proposed solution showed the lowest percentage of emergency packet loss (almost 0% no matter the total number of emergency events) because of the Slot Reallocation Algorithm and the Packet Loss Detection Algorithms. The behavior of the IEEE 802.15.4 MAC protocol and T-MAC protocol with the emergency traffic when we increased the number of emergency events in the WBAN, demonstrates why we should not use WSN MAC protocols directly on WBANs. As the emergency events were not generated at the same time, the behavior of all protocols stayed almost the same when we change the number of emergency events in the WBAN.

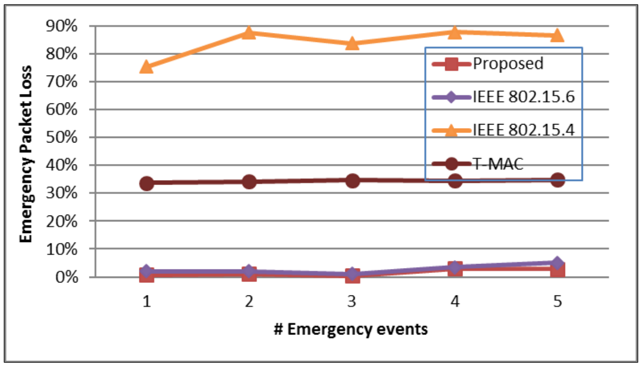

Figure 10. Emergency Packet Loss vs Number of Emergency Events.

For other simulations, the simulation time was changed incrementally from 400s to 2000s. The packet rate was 20pkt/s, and the number of nodes was ten. There were three emergency events with the duration of five seconds each. The Energy Waste Index when the simulation time was changed in the WBAN is depicted in Figure 11. The proposed solution showed the best Energy Waste Index for emergency traffic (almost 0). The IEEE 802.15.4 MAC protocol showed the worst Energy Waste Index because of its poor performance with the emergency packet loss (more than 80%). The Figure 11 shows how the IEEE 802.15.4 and T-MAC protocols improve the Energy Waste Index with the increase of the simulation time, but this is due to the increase of the average energy consumption.

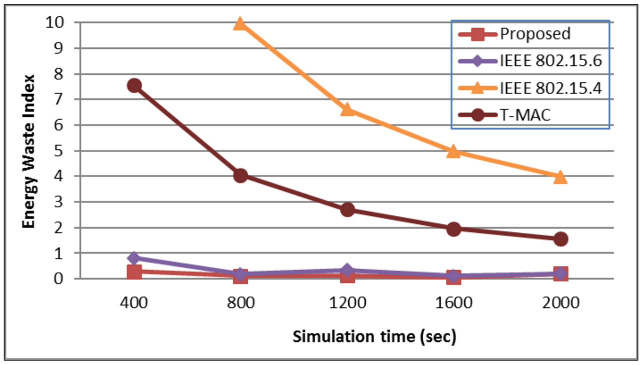

Figure 11. Energy Waste Index vs Simulation Time.

In the final simulations, the simulation time was 300s, the number of nodes was six, the packet rate was 20pkt/s and there was one emergency event at t=150s with the duration of five seconds. The latency distribution for emergency packets and normal packets is depicted in Figure 12 and Figure 13, respectively. The number of emergency packets with the lowest latency (between 0 and 100 milliseconds) in the proposed solution was much higher than the other three MAC protocols. This is due to the Slot Reallocation Algorithm, the lack of contention for emergency traffic during the MAP phase, and besides, the additional contention phase (SCAP) for emergency and normal traffic into each beacon period.

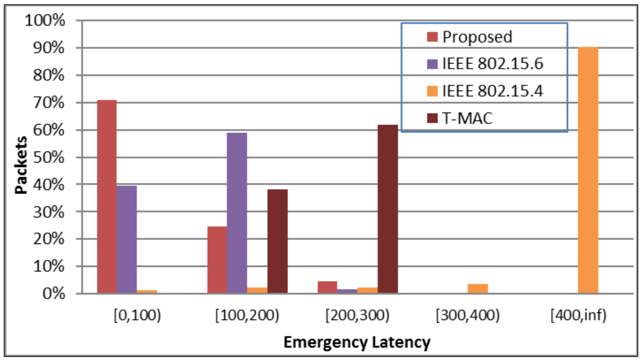

Figure 12. Latency for Emergency Traffic.

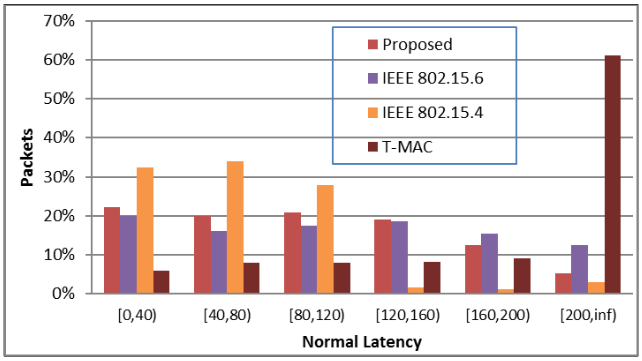

Figure 13. Latency for Normal Traffic.

The number of normal packets with low latency (between 0 and 160 milliseconds) in the proposed MAC protocol was higher than the other MAC protocols, excepting the IEEE 802.15.4 MAC protocol, because of the poor average performance of the latter with emergency traffic. With the IEEE 802.15.4 MAC protocol, almost 90% of the emergency traffic was delivered with the latency of more than 400 milliseconds, while almost 90% of the normal traffic was delivered with the latency of fewer than 120 milliseconds.

VI. ARCHITECTURES COMPARISON

The Table II presents a comparison of the proposed architecture with some architectures published recently and described in Section II. In order to make the comparison with other architectures, the main requirements of all the architectures were used. The first architecture used for the comparison was a Context-Aware Service Architecture for the Integration of WBANs and Social Networks through the IMS presented by Domingo [5]. The second architecture was an Un-Obstructive WBAN for Efficient Movement Monitoring presented by Felisberto et al. [3]. The third architecture was a Cloud-Enabled WBAN for Pervasive Healthcare presented by Wan et al. [6]. The fourth architecture was a QoS-Aware Health Monitoring System using Cloud-Based WBANs presented by Almashaqbeh et al. [4]. The final architecture was a Configurable Energy-Efficient Compressed Sensing Architecture with its application on WBANs presented by Wang et al. [2].

TABLE II. ARCHITECTURES COMPARISON

Requirement	**Proposed Architecture**	**Context-Aware Service Architecture [5]**	**Un-Obstructive Architecture - Movement Monitoring [3]**	**Cloud-Enabled Architecture - Pervasive Healthcare [6]**	**QoS-Aware Health Monitoring System [4]**	**Compressed Sensing Architecture [2]**
Energy Efficiency	Yes	No	Yes	Yes	No	Yes
Reliability	Yes	No	No	Yes	No	No
QoS	Yes	No	No	Yes	Yes	No
Congestion Control	Yes	No	No	No	Yes	No
Rate Control	Yes	No	No	No	No	Yes
Loss Detection	Yes	No	No	No	Yes	No
Loss Recovery	Yes	No	No	No	No	No
Fairness	Yes	No	No	No	No	No
Emergency Awareness	Yes	Yes	Yes	Yes	No	No
Context Awareness	Yes	Yes	No	Yes	No	No
Security	No	No	No	Yes	No	No
Coexistence	No	No	No	No	Yes	No
Interference	No	No	No	No	Yes	No
Topology changes	No	No	Yes	No	No	No
Node Placement Optimization	No	No	Yes	No	No	No
Nodes Wearability	No	No	Yes	No	No	No
Energy Harvesting	No	No	Yes	No	No	No

VII. CONCLUSION AND FUTURE WORK

The main objective was to design a reliable, context-aware and energy-efficient architecture for WBANs, ensuring QoS and fairness in sports applications. This objective was achieved through the joint of some protocols, algorithms, schemes, and the proposition of a new hub and nodes architecture. The architecture is composed of: (i) an energy-efficient, context-aware and reliable MAC protocol; (ii) a reliable transport protocol based on loss-recovery and fairness; and (iii) a context-aware rate control scheme for congestion control in WBANs.

The architecture was compared with other architectures using the main requirements of all the proposed architectures. While some architectures focused on challenges like coexistence, interference, topology changes, node placement optimization, nodes wearability, and energy harvesting, the proposed architecture is the only one focused on energy efficiency, reliability, QoS, congestion control, rate control, loss detection, loss recovery, fairness, emergency awareness, and context awareness, all at the same time.

Future work includes working in additional challenges to design WBANs like high-security mechanisms and topology changes support. Besides, the development of new energy-efficient routing protocols taking advantage of the coexistence of other WBANs in the vicinity. This work could be extended to enhance the quality of life of children, ill and elderly people.

REFERENCES

[1] IEEE Standard for Local and metropolitan area networks - Part 15.6: Wireless Body Area Networks," in IEEE Std 802.15.6-2012 , vol., no., pp.1-271, Feb. 29 2012

[2] A. Wang, F. Lin, Z. Jin, and W. Xu, "A Configurable Energy-Efficient Compressed Sensing Architecture With Its Application on Body Sensor Networks," in IEEE Transactions on Industrial Informatics, vol. 12, no. 1, pp. 15-27, Feb. 2016.

[3] F. Felisberto, N. Costa, F. Fdez-Riverola, and A. Pereira, “Unobstructive Body Area Networks (BAN) for efficient movement monitoring”. Sensors. 2012 Sep 13;12(9):12473-12488.

[4] G. Almashaqbeh, T. Hayajneh, A. V. Vasilakos, and B. J. Mohd, “QoS-aware health monitoring system using cloud-based WBANs”. Journal of medical systems. 2014 Oct 1;38(10):121.

[5] M. C. Domingo, "A context-aware service architecture for the integration of body sensor networks and social networks through the IP multimedia subsystem," in IEEE Communications Magazine, vol. 49, no. 1, pp. 102-108, January 2011.

[6] J. Wan, C. Zou, S. Ullah, C. F. Lai, M. Zhou, and X. Wang, "Cloud-enabled wireless body area networks for pervasive healthcare," in IEEE Network, vol. 27, no. 5, pp. 56-61, September-October 2013.

[7] E. Kartsakli, A. S. Lalos, A. Antonopoulos, S. Tennina, M. D. Renzo, L. Alonso, and C. Verikoukis, “A survey on M2M systems for mHealth: a wireless communications perspective”. Sensors 14, no. 10 (2014): 18009-18052.

[8] R. Jaramillo, A. Quintero, and S. Chamberland, "Energy-efficient MAC protocol for Wireless Body Area Networks," 2015 International Conference and Workshop on Computing and Communication (IEMCON), Vancouver, BC, 2015, pp. 1-5.

[9] R. Jaramillo, A. Quintero, and S. Chamberland, "Reliable Transport Protocol Based on Loss-Recovery and Fairness for Wireless Body Area Networks," 2016 IEEE First International Conference on Connected Health: Applications, Systems and Engineering Technologies (CHASE), Washington, DC, 2016, pp. 18-23.

[10] R. Jaramillo, A. Quintero, and S. Chamberland, "Rate control scheme for congestion control in wireless body area networks," 2016 IEEE 12th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), New York, NY, USA, 2016, pp. 1-6.

[11] NICTA. (2013). Castalia Wireless Sensor Network Simulator. Retrieved from http://castalia.npc.nicta.com.au/