Dynamic and Energy Efficient Wireless BAN Platform for Remote Health Monitoring

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***Abstract*—This paper presents experimental results on a fully functional body area network (BAN) platform in terms of energy consumption, delivery ratio and lifespan. The proposed BAN platform captures, processes, and wirelessly transmits six-degrees-of-freedom inertial and electrocardiogram data in a wearable, non-invasive form factor. A dynamic TDMA MAC layer has been implemented over a 802.15.4 physical layer as well as 2 lightweight protocols: a similarity-based filter to reduce the number of packets sent by the sensors and a polynomial interpolation technique to reduce the size of the packets sent by the coordinator. The system is evaluated regarding the delivery rate, the energy consumption efficiency and the lifetime while considering 3 scenarios and several human activities (sitting, walking, and running). In addition, we compare the sensors' lifespan when bluetooth or 802.15.4 is used. The experimental results show that the proposed MAC layer reduces the number of collisions and is particularly adapted to periodic data traffic from biomedical sensors. Moreover, significant improvements in energy consumption and lifetime are observed enabling health care applications and remote monitoring in harsh environments.**

I. Introduction

Wireless Body Area Networks (BAN) are formed by several low-energy wirelessly interconnected biomedical or inertial sensor devices. The sensors may capture various physiological parameters of the human body (*e.g.* temperature, heart rate, Electroencephalography (EEG), Electrocardiography (ECG), blood pressure, blood oxygen saturation levels, etc.) as well as parameters of the physical environment, such as the amount of sunlight exposure or ambient air quality. In a typical BAN architecture, sensor data are transmitted wirelessly to a coordinator (also called aggregator or gateway) where the data are forwarded to an access point and then, sent over Internet to a remote medical server for storage and analysis. Due to constraints such as energy and computation capability, nondeterministic sensor failures, radio links instability, and distrusted environments, designing and deploying a robust BAN platform is still a challenging task.

Motivation. BANs have become a leading approach for several promising applications in the medical and healthcare fields. But despite the rich availability of research works, there are only few fully functional applications that can be actually deployed in real scenarios. In particular, limited resources in energy and in radio communications make real-world deployment difficult. As a result, there is a need for both synchronized MAC protocols and low-energy communication protocols reducing collisions, traffic contention and energy consumption. In this paper, we present a BAN platform that monitor workers who are subjected to hard environmental conditions during their work. The platform implements a dynamic and synchronized MAC mechanism, a similarity filtering and polynomial interpolation techniques. The dynamic MAC protocol and the 2 lightweight mechanisms are suitable for low-power microcontroller and allow to efficiently reduce the collisions and the amount of data that must be transmitted without loss of accuracy. In addition, we show that, even with moderate compression and filtering, they still allow to significantly reduce energy consumption and increase sensors lifetime.

Due to the unavailability of public or commercial IEEE 802.15.6 chipsets, Bluetooth and the IEEE 802.15.4 technologies are currently the de facto standards to build practical and ready to use BAN applications. The IEEE 802.15.4/Zigbee standard is usually used for nodes with very low duty cycles, and transmitting occasional small amounts of data. Existing body area networks prefer to use Bluetooth because of higher data rate and synchronization. However, this paper further shows that actual Bluetooth implementation is way more energy consuming than 802.15.4 or ZigBee. In addition, number of paired devices per master node is very limited (8 with the master) and wake-up delays for Bluetooth are typically around three seconds. On the other hand, Bluetooth Low Energy (BLE) is a complete new protocol stack, using asynchronous client/server architecture and designed for low duty cycle. It is often assumed that the BLE stack is less consuming than 802.15.4/Zigbee, however few studies yet to be published have been supporting this assumption. Moreover, currently no off-the-shelf BAN devices is proposed with this technology.

In this study, the 802.15.4 standard has been chosen for its low-energy properties. Despite its limitations in terms of bandwidth, experimental results show that it exhibits a good tradeoff between throughput and energy consumption.

Contributions. This article is based on a preliminary work [1] investigating the performances of the proposed architecture in terms of accuracy and efficiency accordingly to three different thresholds. In this article, the minimal threshold is chosen to enhance quality, a new MAC layer is proposed and compared to Bluetooth, and energy consumption and lifetime are measured. To summarize, these above challenges are addressed and the contributions are made as shown in the following:

- Firstly, the architecture of the BAN platform is presented and application scenarios are described. Three types of signals are considered: electrical activity of the heart or electrocardiography (ECG), orientation measurement via a tri-axial gyroscope, and linear acceleration measurement via a tri-axial accelerometer.
- Secondly, a reservation-based TDMA is proposed to enhance the default IEEE 802.15.4 MAC protocol designed for low data rate applications. We compare this solution with Bluetooth protocol in terms of lifespan.
- Thirdly, similarity filtering and polynomial regression are proposed to provide large compression while maintaining high accuracy.
- Finally, the paper presents 3 scenarios allowing to experimentally evaluate the performance of the proposed architecture in terms of accuracy, efficiency, delivery ratio, energy saving and life time.

Novelty. WBANs have recently been the subject of intense research by many researchers worldwide and many good results are available in all such topics especially in efficient physical layer and networking protocols. However, there are only few proposed studies related to the development of practical, efficient and low-energy WBANs system. In this paper, we experimentally evaluate the practicability of a reservation-based TDMA MAC protocol and the efficiency of two lightweight mechanisms allowing energy saving while staying accurate.

The rest of this paper is organized as follows. Section II provides an overview of previous work emphasizing on information relevant to the context of this paper: previous experimental BAN architectures and existing standards are presented. In Section III, an overview of the BAN architecture is proposed: application scenarios and communication architecture are detailed. Section IV provides an insight on the hardware and methodology used. In Section V, the experimental results on the platform and performance are presented and discussed. Finally, Section VI concludes the contributions of this paper and discusses potential further work directions.

II. Related Work and Scope

Recent developments in electronics and ultra low power radio communications have enabled the design of tiny and smart wearable sensors which can be worn on, or implanted into, the human body. The resulting Wireless Body Area Network (WBAN) is currently considered as one of the key technologies of the future that will enable the emergence of a wide range of applications, such as Indoor Localization [2], patient's insomnia monitoring [3], soldier's activity monitoring [4], emotion detection [4], assets protection [5], worker's safety monitoring [6], etc.

In order to address the specific requirements and challenges of WBANs, the IEEE 802.15.6 standard [7] has been recently released. In this context, three main physical have been proposed (i.e. narrowband, ultra wideband and human body communications), and both contention-based (e.g. CSMA/CA, Slotted-Aloha) and time division-based (e.g. TDMA) Medium Access Control (MAC) protocols have been designed. However, to the best of our knowledge there are still no commercial or publicly available IEEE 802.15.6 standard compliant radio transceivers. So, Internet of Things related standards [8] remain the preferred solution to build short-term and ready-to-use WBAN solutions [9]. In this context, several WBANs monitoring platforms [10] have been designed and evaluated, especially in the context of patient's health monitoring, using a combination of existing communication technologies, such as Bluetooth Low Energy, IEEE 802.15.4 (Zigbee), IEEE 802.11 a/b/g/n (WiFi), and 3G/LTE (cellular).

Despite the increased interest in the WBANs areas, there have been few studies related to the development of practical, efficient and low-energy WBANs system enabling the real-time and remote monitoring of physiological parameters. Moreover, to the best of our knowledge, the WBANs network lifetime, energy consumption and quality of service have not been evaluated in a comprehensive manner.

III. Overview of the Proposed BAN Platform

This section describes the wearable BAN platform which was designed, implemented and evaluated to enable the remote monitoring of workers in harsh environments. The target application scenario is first described below, followed by an overview of the hardware, software and communication components.

A. Application scenario

In this study, we focus on the remote monitoring of workers in harsh environment. With the expansion and emergence of large mega construction projects, the safety and health of workers is becoming a serious concern worldwide. For instance, the number of deaths due to work-related accidents or diseases, remains unacceptably high at around 2.3 million per year [11].

In this context, it is expected that WBAN technology will enhance the safety and health of workers, for example, by enabling the remote monitoring of workers in unhealthy environments [12]–[15]. As a result, there is a need to monitor physiological signs (*e.g.* body temperature, pulse rate, respiration rate, blood pressure, etc.). With wearable sensors and BANs, workers can be monitored remotely and quick assistance can be given if anomalies on the vital signs are detected. To be practical in such context, a BAN should be able to send data continuously to a remote server for storage and analysis, while being energy efficient and accurate. In that purpose, low-power technologies, compression techniques and filtering are targeted. Moreover, the monitoring of the body

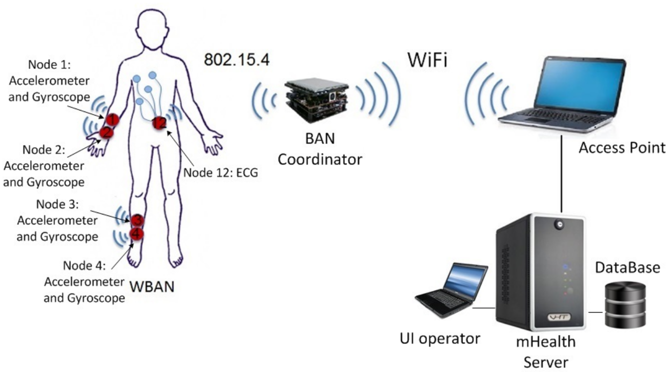

Fig. 1: Overview of the BAN Architecture

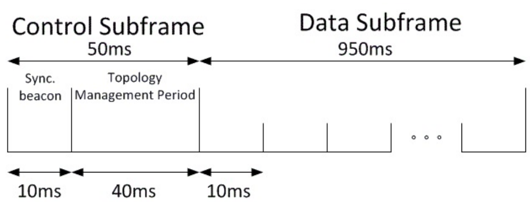

Fig. 2: A dynamic TDMA Frame

movements (e.g. acceleration, orientation, etc.) can be useful to implement safety related algorithms, such as fall detection or activity recognition, and thus to ensure the safety of the workers.

B. Communication Architecture

In this paper, wearable sensors use the IEEE 802.15.4 standard, which is defining the PHY and the MAC layers. Due to its good performance in terms of energy consumption, this standard makes a good candidate for constrained devices such as battery-powered wearable sensors and it is the basis for numerous specifications such as ZigBee [16], WirelessHART [17], or ISA100.11a [18]. In the proposed platform, a BAN coordinator aggregates the traffic from the sensor nodes and forwards it to an access point. IEEE 802.15.4 is used for the on-body communications between the sensors and the BAN coordinator and IEEE 802.11 / WiFi for the communication between the BAN coordinator and external access points, as shown in Figure 1. In IEEE 802.15.4, the CSMA/CA MAC protocol is generally used by sensors to send data and they can theoretically transmit up to 250 kbs at 2.4 GHz which is a sufficient data rate for typical wireless sensor applications. However, this MAC layer implements a collision avoidance mechanism based on random backoff which is not efficient for periodic and real-time traffic and creates latency and collisions. As a result, we propose a new MAC layer described in detail in the following section.

1) Dynamic TDMA MAC Layer: To replace the CSMA MAC layer, we propose a TDMA slot assignment protocol to improve the channel utilization and reduce collisions. The proposed protocol assigns slots to a node which joins the network accordingly to its sampling rate. To avoid sending large packets including a global schedule, each node computes its own common slots assignment. The TDMA format is illustrated in Figure 2. The control subframe is 50 ms long and divided in two timeslots. The first slot is used for the synchronization. During this slot, the coordinator sends a synchonization beacon including its local time, the id and the sampling rate of the nodes in the network. Each node receiving this beacon is able to be synchronized. Based on the sampling rate of the other nodes and their id, each node computes locally the same slot assignment. To that purpose, the following algorithm is applied. First, the algorithm checks if the assignment is possible according to the slots available and the requested sending rate. If not, the last request is rejected. Then, the priority is given to the node with the higher sampling rate. In the event of a tie, the node with the lower id is prioritized. An example of a slot assignment is given Figure 3. Considering that the first 50 ms are dedicated to the control subframe, the first slots of the data subframe are used to catch up with the sending schedule and avoid delay. This explains why, in the given example, nodes 1 and 6 use the first four timeslots. Note that, in our application, nodes send only periodic data: the sending rate (*i.e.* the number of packets sent per minute) of each node is strictly related to sampling rate (*i.e.* the number of samples per minute). This makes a synchronized MAC layer (i.e. TDMA) much more relevant than a contention-based MAC layer (i.e. CSMA). The second timeslot of control subframe is the topology management period (TPM). The TPM is dedicated for new nodes or nodes requesting new assignments. During this slot, a ”ping” packet is first sent by the coordinator and new nodes reply in a contention-based way (first probe the channel and then transmit after a random backoff). This allows new nodes to request slot assignment. No data packets are transmitted in the control subframe. The data subframe is 950 ms long and divided into 95 timeslots of 10 ms each. During the data subframe, the coordinator monitors the activity of the nodes and is able to remove an inactive node after a given backoff (fixed to 5 seconds in this study).

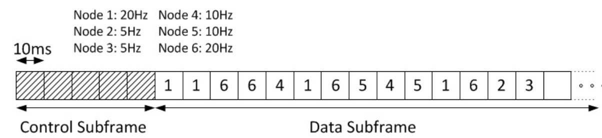

Fig. 3: Example of a slot assignment with 6 nodes

C. Algorithms and Applications Layers

In order to enable efficient on-body communications in terms of latency, delivery ratio and energy consumption, we designed and implemented two specific algorithms: a filtering algorithm at the WBAN sensor device level, and a data compression algorithm at the coordinator level.

1) Filtering algorithm: As illustrated in Figure 1, sensor nodes gather sensory information and communicate with the

BAN coordinator. With respect to their constraints in computational power, a lightweight filtering algorithm is implemented. It is defined to limit the amount of data sent by the sensor nodes. To form a packet, each sensor aggregates 10 values of each signal (e.g. acceleration and angular velocity for 6-axis sensors, lead I and lead II for the ECG sensor). Then, it sends the packet to the coordinator. The filtering algorithm compares the previously sent packet and the current packet to defines their similarity by comparing the mean of each signal and by computing the quadratic distance between them. Let two vectors v and w in R^n be as follow: $v = (v_1, v_2, ..., v_n)$, $w = (w_1, w_2, ..., w_n)$. The quadratic distance dq is: $dq = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(v_i - w_i)^2}$. If the difference of mean or the quadratic distance between the two packets is higher than a given threshold, the current packet is sent. In a previous paper [1], 3 thresholds have been defined. In this study the lowest threshold (2%), corresponding to the highest accuracy, is chosen. Otherwise, a tiny 4-octet packet is sent instead to inform the BAN coordinator of the similarity of the packet with the previously transmitted packet.

2) Data Compression Algorithm using Least-Squares Polynomial Fitting: As shown in Figure 1, the coordinator is responsible for the real-time collection of data from the different wearable sensor devices. Each sensor is responsible for the monitoring of specific physiological parameters (e.g. ECG, EEG, etc.), at a predefined sampling rate, and to send the corresponding timeseries to the coordinator. This later aggregates all the received data and transmits them via Internet to a remote back-end server for further data processing and to enable timely decision making.

In order to enable efficient and low energy communications between the deployed coordinator and remote back-end server, we designed and developed a data compression algorithm using *Least-Squares Polynomial Fitting* (LSPF). The proposed algorithm works as follows. For each received timeseries, $Y^i = \{Y_t; t \in T\}$ from a wearable sensor, i, the WBAN coordinator computes the coefficients of a polynomial $P_t^i(x) = a_n x^n + a_{n-1}x^{n-1} + ... + a_0$ of degree $n \leq N$ which better fits Y^i such that the corresponding *Root Mean Squared Error* (RMSE) is lower than a given threshold E_{max}. In this study, E_{max} is fixed to 1% corresponding to the lowest threshold found in [1].

This process is done recursively where the algorithm starts with a polynomial order $n = 1$, and keeps increasing it until the obtained RMSE is lower than the defined error threshold, E_{max}. In case the algorithm is not able to find a good polynomial fit for the received timeseries, it divides it into two sub timeseries and apply the same logic on each part of the timeseries. Finally, once the polynomial coefficients,$\{a_n, a_{n-1}, ..., a_0; n \leq N\}$, are properly identified, the BAN coordinator transmit them to the remote back-end server, along with the sampling rate, initial and last timestamps of Y^i, instead of the original timeseries. Based on the received information, the remote server is thus able to reconstruct the original timeseries with an error lower than E_{max}. The flowchart of the 2 processes is illustrated by Figure 4. The lowest threshold is chosen based on a previous study [1].

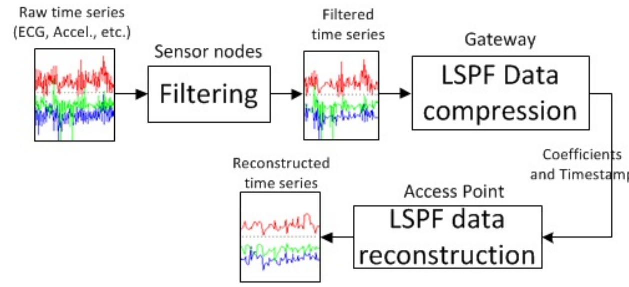

Fig. 4: Flowchart of the BAN architecture

IV. Experimental Testbed

A. Methodology and materials

The system used for the experimentation consists of three main devices:

Sensor Nodes consists of five Shimmer nodes [19] as shown in Figure 5 a). The Shimmer node is a small sensor platform well suited for wearable applications. It has low-power communication capabilities enabling long-term data acquisition and real-time monitoring. In this work, four nodes integrate 3-axis accelerometer and 3-axis gyroscope and one node is dedicated to heart monitoring and integrate a 3-lead ECG. Each node is run with TinyOS [20]. The characteristics of Shimmer nodes are summarized in I.

Coordinator Node as shown in Figure 5.b, consists of: (i) a Beagleboard XM [21], (ii) a BeagleTouch Screen (iii) an 802.11 module for Wi-Fi connection and (iv) an 802.15.4 module for Zigbee connection. The Ubuntu 11.10 OS is used to run the coordinator. A lightweight server is implemented on the platform to perform the forwarding and the polynomial data compression (LSPF). The coordinator characteristics are summarized in Table I.

Access Point which carries the proper storage, database and application softwares. It is intended to be highly available (*i.e.* 24/7) and scalable to enable the monitoring of a large number of patients. The server runs real-time analysis of sensor's data, provides user access to the database at various levels (e.g. patients, relatives, physicians, etc.) and generates alarm in case of emergencies.

The signal is first captured, amplified and digitized on Shimmer Node. It is then quantized at the selected sampling frequency from $1Hz$ to $1kHz$. Next, the shimmer node transmits the data (i.e. 7 samples per packet) to the coordinator which in turn relays the packet to the access point. The 802.15.4 and 802.11.g radios are tuned to not using the same canal and avoid interferences.

B. Scenarios Overview

Scenario 1. Five sensors are used: Sensors 1 and 2 are attached to the right arm of the subject ; sensors 3 and 4 are attached to his right leg. Finally, the ECG sensor 12 is carried

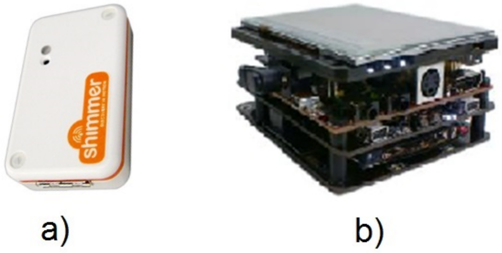

Fig. 5: a) Shimmer node, b) Coordinator

Device Manufactor	Shimmer Node	Beagleboard-Xm
Microcontroller	MSP430	AM37x 1GHz ARM Cortex-A8
Radio	TI CC2420 (802.15.4) [22] and RN Bluetooth module	TI CC2420 (802.15.4) and Ralink RT2571WT (802.11.b/g)
TX Power	0dBm	802.15.4: 0dBm, Wifi: 13dBm
Radio sensitivity	-95dBm	802.15.4: -95dBm, Wifi: -70dBm
TX/RX consumption	17.4mA/18.8mA	802.15.4: 17.4mA/18.8mA, Wifi: 390mA/270mA
Battery	280mAh, 3.7v	8400mAh, 5V
Sensing capabilities	3-axis Accelerometer, 3-axis Gyroscope, ECG	None
OS	TinyOS	Ubuntu 11.10
MAC protocol	CSMA/CA and Dynamic TDMA	CSMA/CA (WiFi and 802.15.4) and Dynamic TDMA (802.15.4)
Protocol thresholds	Quadratic distance threshold 2%	RMSE Threshold: 1%, Maximum polynom order: 10

TABLE I: Summary of the platform characteristics.

on the belt and its four leads are placed on the subject chest. Our proposed dynamic synchronized MAC protocol is used by the sensor nodes. Three phases of 10 minutes have been defined. In phase 1, the monitored subject is standing or is sitting at a workstation. Normally, his movements and his heart rate are slow. In phase 2, the subject is walking on a treadmill at 4 km per second. His movements are bit faster and heart rate is moderate. In this phase, periodicity in acceleration and orientation measurements can be noticed. During phase 3, the subject is running in a treadmill at 10 km per second. His legs and arms move much faster and heart rate is high. Again, the periodicity in acceleration and orientation measurements can be observed.

Scenario 2. the second scenario is similar to the first one except that the sensors use CSMA instead of our proposed synchronized MAC layer. Timing of the 3 phases, the sending and sampling rates are kept unchanged. The 3 phases of the scenarios 1 and 2 are illustrated in Figure 6.

Scenario 3. Three sensors are fixed on the ankle of a human subject. The 3 sensors monitor 6-axis movement with a 250 Hz sampling rate and aggregate 10 samples per packet. As a result, the sending rate is fixed at 25 Hz. The first sensor sends data to the coordinator using bluetooth standard, while the others two use IEEE 802.15.4. Unlike the second sensor, the third sensor implements the similarity filter using quadratic distance to evaluate the similarity between two consecutive

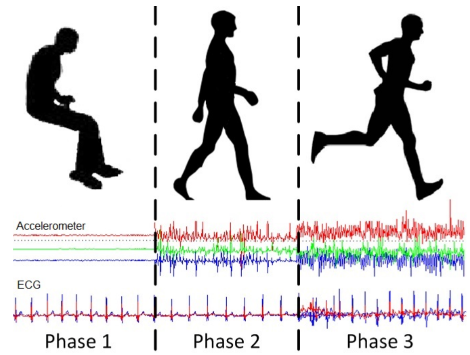

Fig. 6: Overview of the 3 phases (P1: standing, P2: walking at 4 km per hour, and P3: running at 10 km per hour)

packets. Each sensor sends their battery level during the experiment.

C. Performance Metrics

To gain insight concerning the BAN platform performance, the following metrics are measured:

Filtering rate: It is defined as the ratio between the size of the data received at the BAN coordinator after filtering and the size of the data generated by the biomedical sensors. This metric measures the efficiency of the similarity filtering.

Data compression ratio of the polynomial approximation: It is defined as the ratio between the size of the data received at the access point and the size of the data received at the coordinator. This metric measures the efficiency of the polynomial approximation.

Root Mean Square Error (RMSE): It represents the sample standard deviation of the differences between raw signal generated by the biomedical sensors and the signal received at the access point after filtering and polynomial approximation. This metric measures the accuracy of the platform.

Life span: It is the time before a node depletes its energy.

Battery level (%): In order to estimate the level of the battery, first, the voltage is measured by converting the row ADC values from analog channel and then estimated accordingly to the battery datasheet. Due to some fluctuations in the voltage measured, the battery level can only be estimated roughly. As a result, some inconsistencies may appear (for instance, the battery level may appear increasing temporarily).

Data Packet Delivery Ratio (%): It represents the ratio between the total number of packets successfully received by the BAN coordinator and the number of packets sent by the sources. This is an important metric to evaluate the efficiency of the MAC protocol.

V. Experimental Results

A. Delivery Ratio and MAC Layer Performance

The scenarios 1 and 2 allow to compare the performance in terms of delivery ratio according to the MAC layer: CSMA

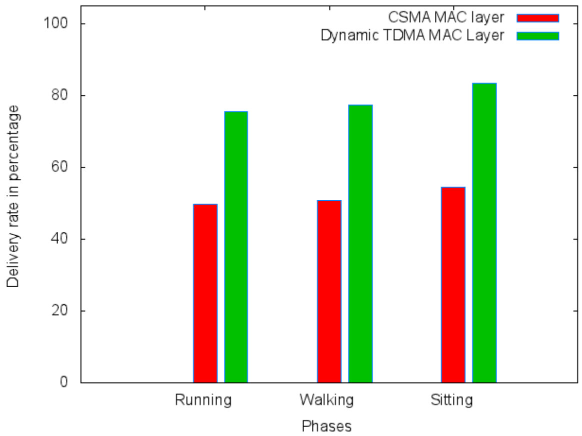

Fig. 7: Scenarios 1 and 2: Average delivery ratio during the 3 phases

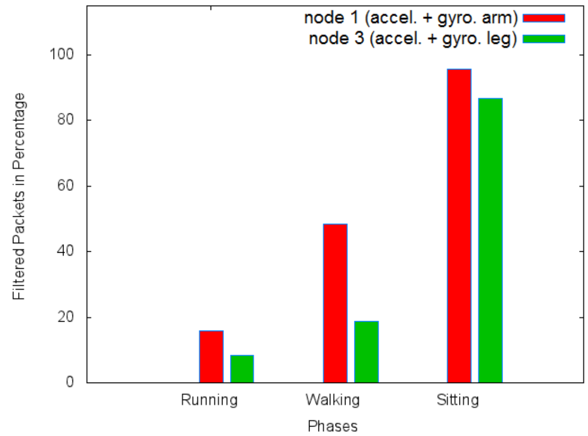

Fig. 9: Scenario 1: Efficiency of the filtering according to the activity of the subject

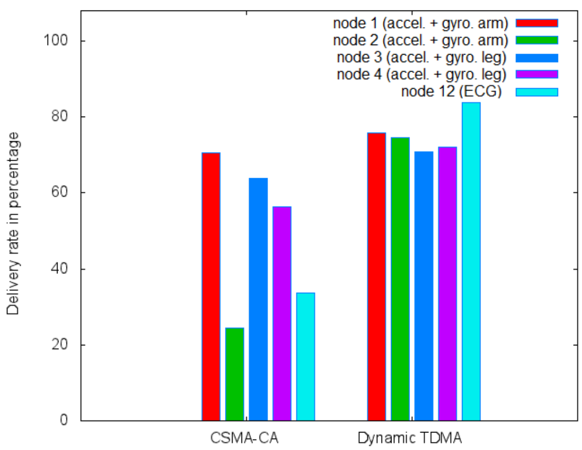

Fig. 8: Scenario 1 and 2: delivery ratio of each node during the running phase

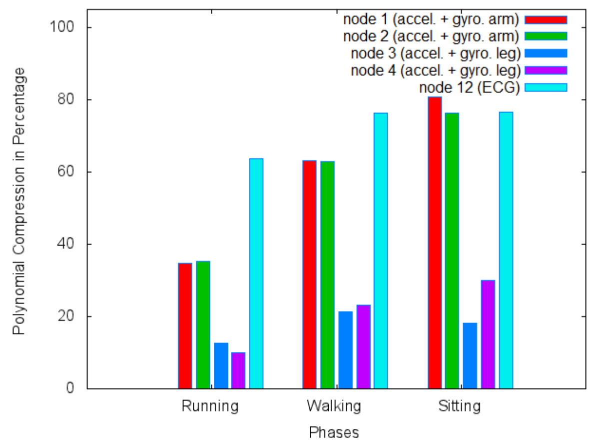

Fig. 10: Scenario 1: Efficiency of the polynomial compression according to the activity of the subject

and our proposed TDMA MAC layer. Figure 7 illustrates the average delivery ratio during the 3 phases. The performance variation during the 3 phases is not significant for both MAC protocols. However, our proposed TDMA outperforms the CSMA MAC protocol in terms of delivery ratio. Note that contrary to what is expected in simulation with none realistic radio propagation model, *i.e.* a 100% delivery rate, a percentage of packets are lost during the transmission due to pathloss or shadowing. When the conditions are optimal (when the sensors are not moving and in direct line-of-sight with the BAN coordinator, for example), a delivery ratio close to 100% is observed.

To refine over the information provided by the average delivery ratio, we also measured the delivery ratio per node. This measure allows to determine the distribution of transmission success in the node population. Synchronized MAC protocol guaranties equity between the nodes in terms of delivery ratio, whereas the CSMA leads to discriminating some nodes. These phenomenon is illustrated in Figure 8 where nodes 2 and 12 show low delivery ratio compared to the other nodes in the network.

B. Algorithm Performance

To quantify the potential of energy saving, the filtering and LSPF rates have been computed during the 3 phases and illustrated on Figures 9 and 10. Similar average compression rate are obtained than previous experimentations [1] (about 50% is obtained with the lowest threshold). However, significant differences can be observed between both nodes and phases. In particular, Figure 10 shows high disparities among sensors: the compression rate on ECG sensor (node 12) stays high and stable (between 68% and 77%) during the 3 phases while the LSPF compression rate for movement sensors 1 and 2 increases from 34% up to 80%. Meanwhile, LSPF compression rate for movement sensors 3 and 4 increases from 10% up

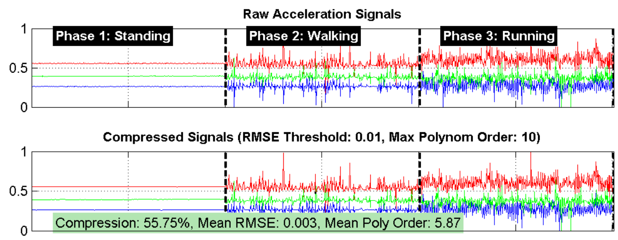

Fig. 11: Acceleration measures during the 3 phases.

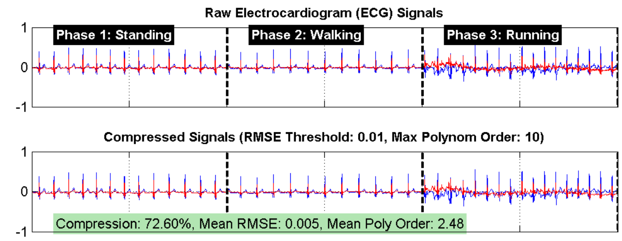

Fig. 12: ECG measures during the 3 phases.

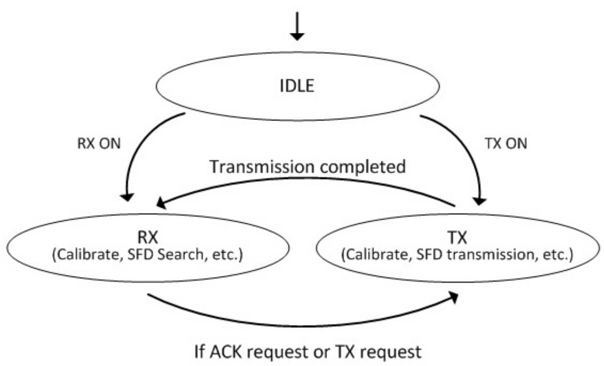

Fig. 13: Simplified CC2420 Radio control states

to 30%. These disparities are mainly due to the dynamics of the signal that the algorithm has to fit. Sensors 1 and 2 are attached to the right arm of the subject when sensors 3 and 4 are attached to his right leg. During the phase 3 (*i.e.* running) and the phase 2 (*i.e.* walking) the sensors attached to the leg experience higher dynamics than those attached to the arms, making the compression by the LSPF algorithm more difficult.

Regarding the quality of the signal compressed, the mean RMSE between raw signal and the compressed signal has been measured and is illustrated on Figures 11 and 12. The graphical representation visualizes the signal difference between the raw and compressed signals. Note that the signal is normalized to ensure the comparison between the signals. Figure 11 shows comparison between raw acceleration signals and the compressed signals during phases 1, 2 and 3. The mean RMSE is equal to 0.003. In Figure 12, the LSPF provides good results, whereas the filtering is inoperative. Given the periodicity of the ECG signal, the LSPF provides a low RMSE and a good compression rate (from 72% to 75%).

C. Energy Evaluation

In a previous study [1], energy of the system has been evaluated by indirect modeling. In indirect energy consumption modeling, global assumptions like ”sending a message to the sink costs k units of energy” have to be made. In practice, this meant counting sent and received messages and their size. However, this model is too high level and not accurate because the idle listening periods (when a node listens to an idle channel to receive potential traffic) are not considered, although it contributes to the overall energy consumption in a significant manner. In particular, on the CC2420 chipset, by default, the radio goes automatically from TX state (transmission) to RX state (reception) as illustrated in Figure 13 regarding the simplified CC2420 Radio control states. To effectively save energy, the radio has to be put explicitly on idle state when no message is expected or sent.

Scenario 3 allows to evaluate the sensor lifespan according to the radio technology used (Bluetooth or IEEE 802.15.4) and when the filtering process is active or not. Results are illustrated in Figure 14. As expected, the node using Bluetooth is the first to deplete its energy after less than 16 hours. In its normal life condition, the node with the filtering process is able to increase its lifespan of 7%.

Figure 15 shows energy of the sensors in monitor during the 3 phases as defined by the scenario 1. Due to a lack of granularity of the battery level metric, it is hard to compare the energy consumption between the different phases. As seen previously, the voltage measures used to extrapolate battery level, which experiences significant fluctuations, thereby making it hard to compare its battery levels on such short time. However, after 90 minutes, at the end of the experiments, the sensors without filtering algorithm (*i.e.* sensors 2 and 4), have reduced their battery level to 40% and 44% respectively. Meanwhile, nodes with filtering algorithm (*i.e.* sensors 1 and 3) have reduced their battery level to 23% and 20% respectively. These outcomes confirm the result found in the previous study [1].

VI. Conclusion and Future Work

In this paper, a study was conducted on proposed BAN platforms with 5 sensor nodes, a BAN coordinator and an access point. By implementing lightweight but powerful filtering and LSPF data compression, both the radio channel contention and the energy consumption were reduced, while maintaining accuracy especially with low RMSE. In addition, the implementation of a dynamic synchronized MAC protocol using IEEE 802.15.4 instead of classical CSMA MAC protocol improves delivery ratio significantly while saving energy as compared to the use of Bluetooth stack.

Future works. The current study does not investigate the case where several BANs coexist in the same radio environment (*i.e.* using the same access point). It certainly would be challenging to proposed a collision-free MAC protocol dealing

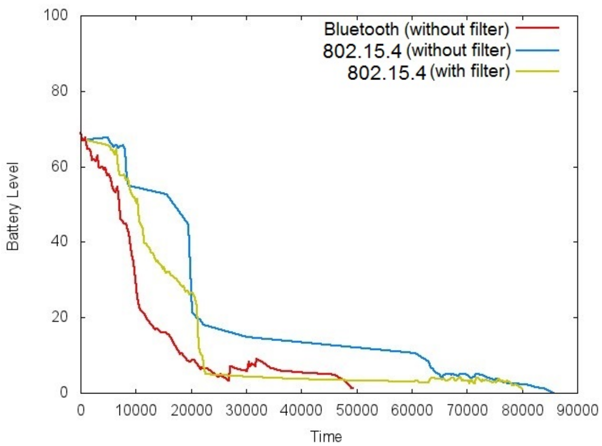

Fig. 14: Scenario 3: Lifetime and energy consumption

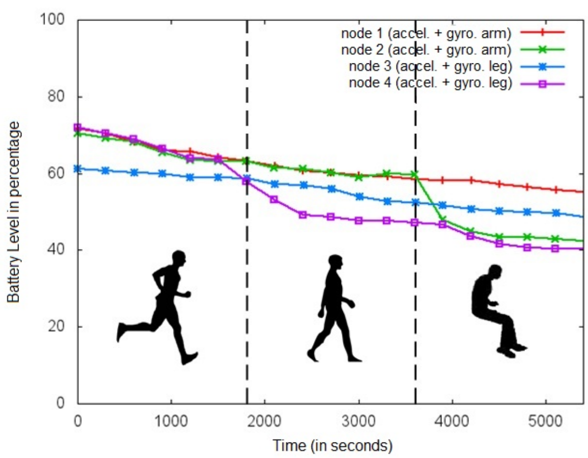

Fig. 15: Scenario 1: Energy consumption during the 3 phases

with such problematic. In addition, the similarity filtering and LSPF thresholds are chosen statically. A dynamic adaptation according to the signal would be an interesting improvement.

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