MODELLING AND SIMULATION OF A WIRELESS BODY AREA NETWORK PROTOTYPE FOR HEALTH MONITORING

Y. Callero[(a)], R. M. Aguilar[(b)]

[(a)(b)] Department of Systems Engineering and Automation, and Computer Architecture.
University of La Laguna. Spain

[(a)]ycallero@isaatc.ull.es, [(b)]raguilar@ull.es

ABSTRACT

Recent advances in technology, integrated circuits, and wireless communication have allowed the realization of Wireless Body Area Networks (WBANs). Such networks feature smart sensors that capture physiological parameters from people and can offer an easy way for data collection. WBANs also need suitable interfaces for data processing, presentation, and storage for latter retrieval. They are widely used for ubiquitous healthcare, entertainment, and military applications.

Power limitations are one of the weaknesses of the systems that use WBANs. In that sense, this paper proposes a WBAN prototype that uses the ultra-low energy communication protocol ANT to reduce de WBAN power consumption. The simulation of this architecture for health monitoring is presented to validate the availability of the architecture.

Keywords: wireless body area networks, health monitoring, ANT.

1. INTRODUCTION

The most remarkable life-changer in the past decade has been the introduction and the rapid mass adoption of wireless mobile digital devices. The ways in which we listen to and acquire music, e-mail and communicate via phone, access the Internet, and read books and periodicals electronically have all been radically transformed. In stark contrast, the ways in which diseases are monitored and treated have remained relatively static. But, in spite of this, one of the mayor area where the lack of plasticity of the medical profession and health care system in the face of new technology and information is about to be challenged, is the wireless technologies area (Topol, 2010).

One of the reasons of the growth in the adoption of wireless technologies in the health care is the evolution of the body sensors. Body sensors are small devices that are able to measure and control human body parameters. Some recent projects take advantages of these small sensors in overall body monitoring. In this context, emerged a new network approach known as body area networks (BANs). This new infrastructure is comprised of several sensor nodes placed throughout a human body. Each sensor measures specific physiological or biological parameters. Evolutions on microelectronics construction enabled endow these sensor nodes with the ability to communicate outside world using a wireless module component.

Table 1. Top ten targets for wireless medicine

Disease	Number affected (millions) in USA	Metrics potentially measured
Alzheimer	5	Vital signs, patients' location, activity, balance
Asthma	23	RR, FEV1, blood oxygen level, air quality, pollen count
Breast cancer	3	Presence of suspicious mass, as detected by ultrasounds self –exam
COPD	10	RR, FEV1, blood oxygen level, air quality
Depression	21	Medication compliance, activity, communication
Diabetes	24	Blood glucose level, calories ingested
Heart failure	5	Cardiac pressures, body weight, BP, fluid status
Hypertension	74	Continuous BP, medication compliance
Obesity	80	Weight, blood glucose levels, calorie intake and output, activity
Sleep disorders	40	Sleep phases, sleep quality, RR, apnea, vital signs, blood oxygen level, heart rhythm

Remote monitoring of human body is now possible, using WBANs to access data collected by the sensors. Sensors are implanted or placed in human body to monitor some behaviors or pathologies, and help patients maintain their health through biofeedback phenomena such as temperature analysis, blood pressure detection, Electrocardiography (ECG), Electromyography (EMG), among others (Pereira, Caldeira, & Rodrigues, 2010). (Topol, 2010) exposed top ten targets of chronic diseases that can be monitored via wireless sensors. These targets are showed in Table 1.

One of the biggest problems regarding sensor networks is power consumption, which is greatly affected by the communication between nodes (Sarpeshkar, 2006)(Adloo, Deghat, & Karimaghaee, 2009). One solution to this issue is the introduction of aggregation points to the network. The aggregation points reduce the messages exchanged between nodes and saves energy. Usually, they are regular nodes that receive data from neighboring nodes, perform some processing, and then forward the data to the next node. Another way for energy saving is setting the nodes into sleep mode if they are not needed and wake them up when required. Energy saving is one of the most challenge that engineers face when they create wireless body area networks (WBANs).

In this sense, the University of La Laguna Simulation group (SIMULL) proposes the use of an ultra-low energy communication protocol to reduce the WBAN power consumption. This paper presents a study of the availability the low power consumption WBAN trying to model and simulate its behavior. First of all, the paper presents a smart revision of the state of the art of remote health monitoring. After that, a wireless communication protocols review is presented. In next sections, the WBAN prototype modeling and simulation is presented. Finally, conclusions and future work are shown.

2. STATE OF ART

With the growing needs in ubiquitous communications and recent advances in very-low-power wireless technologies, there has been considerable interest in the development and application of wireless networks around humans. A wireless body area network (WBAN) is a radio frequency (RF)-based wireless networking technology that interconnects tiny nodes with sensor or actuator capabilities in, on, or around a human body. Typically, the transmissions of these nodes cover a short range of about 2 m. Complementing wireless personal area networks (WPANs), in which radio coverage is usually about 10 m, WBANs target diverse applications including healthcare, athletic training, workplace safety, consumer electronics, secure authentication, and safeguarding of uniformed personnel. A WBAN can also be connected to local and wide area networks by various wired and wireless communication technologies (Cao, Leung, Chow, & Chan, 2009).

WBAN applications can be categorized based on the type of sensors/actuators, radio systems, network topologies, and use cases. We enumerate here several pioneer healthcare WBAN research projects, as well as platforms for human-computer interaction (HCI) applications.

2.1. WBANs for healthcare

WBANs extend conventional bedside monitoring to ambulatory monitoring, providing a point of care to patients, the elderly, and infants in both hospital-based and home-based scenarios. Monitoring, autonomous diagnostic, alarm, and emergency services, as well as management of electronic patient record databases can all be integrated into one system to better serve people.

The CodeBlue project at Harvard University (Shnayder, Chen, Lorincz, Fulford-Jones, & Welsh, 2005) considers a hospital environment where multiple router nodes can be deployed on the wall. All nodes use the same ZigBee radio. Patients/caregivers can publish/subscribe to the mesh network by multicasting; there is no centralized or distributed server or database for control and storage. Localization functionality is provided by MoteTrack with an accuracy of 1m, based on the same radio. As a result of mobility and multihop transmissions, the system experiences considerable packet loss and is limited to 40 kb/s aggregate bandwidth per receiver.

Based on the CodeBlue architecture, the Advanced Health and Disaster Aid Network (AID-N) is being developed at Johns Hopkins University (Gao et al., 2007) for mass casualty incidents where electronic triage tags can be deployed on victims. Additional wireless capabilities (e.g., Wi-Fi and cellular networks) are introduced to facilitate communications between personal servers and the central server where data are stored. Furthermore, a web portal is provided to multiple types of users, including emergency department personnel, incident commanders, and medical specialists. A Global Positioning System (GPS) module is employed for outdoor localization, while a MoteTrack system is designed for tracking indoors. However, patients have mobility constraints due to the lack of routers in the network, and a very limited number of sensor nodes can be put on each patient because of the limited bandwidth.

The Wearable Health Monitoring Systems (WHMS) is being developed at the University of Alabama (Milenkovic, Otto, & Jovanov, 2006) and targets a larger-scale telemedicine system for ambulatory health status monitoring. Unlike CodeBlue and AID-N, WHMS has a star-topology network for each patient, which is connected via Wi-Fi or a cellular network to a healthcare provider. The personal server, implemented on a personal digital assistant (PDA), cell phone, or personal computer (PC), coordinates the data collection from sensor nodes using a time-division multiple access (TDMA) mechanism, provides an interface to users, and transfers data to a remote central server. Physicians can access data via the Internet, and alerts can be created by an agent running on the server. However, the power consumption and cost associated with long-term data uploading can hamper system realization.

2.2. WBANs for HCI

Traditional computer interfaces, like keyboards, mice, joysticks, and touch screens, are all replaceable by potential WBAN devices capable of automatically recognizing human motions, gestures, and activities. Disabled people can benefit from novel WBAN platforms based on a series of miniature sensors. The intra-body communications (IBC) applications proposed in (Ruiz & Shimamoto, 2006) can be used to assist handicapped people. For example, an IBC enabled sensor embedded inside the shoes of a blind person can be used to send voice information such as the current location to him/her by an IBC enabled facility, such as a doorway or crosswalk. IBC enabled eyeglasses that can display texts, working with IBC enabled speakers, can help deaf people comprehend audio broadcast announcements.

Early research efforts at MIT Media Lab have produced MITHril (Pentland, 2004), a wearable computing platform that includes electrocardiography (ECG), skin temperature, and galvanic skin response sensors for wearable sensing and context-aware interaction. MITHril is not a real WBAN in that multiple sensors are wired to a single processor. A later version of this platform, MITHril 2003, extends MITHril to a multi-user wireless distributed wearable computing platform by utilizing Wi-Fi function available on PDAs (i.e., a PDA acts as a personal server and relays data of each person to a central station).

The Microsystems Platform for Mobile Services and Applications (MIMOSA) (Jantunen, 2008) is a research project involving 15 partners from eight different European countries to create ambient intelligence. MIMOSA's approach is similar to WHMS while it exclusively employs a mobile phone as the user-carried interface device. Wibree, later renamed Bluetooth Low Energy technology, and radio frequency identification (RFID) tags are used for connecting local sensor nodes. NanoIP and Simple Sensor Interface (SSI) protocols are integrated into MIMOSA to provide an application programming interface (API) for local connectivity and facilitate sensor readings.

The Wireless Sensor Node for a Motion Capture System with Accelerometers (WiMoCA) (Farella, Pieracci, Benini, Rocchi, & Acquaviva, 2008) project at several Italian universities is concerned with the design and implementation of a distributed gesture recognition system. The system has a star topology with all sensing nodes sending data to a non-sensing coordinator node using a TDMA-like approach, and the coordinator in turn relays the data to an external processing unit using Bluetooth. The sensing modules, each made up of a tri-axial accelerometer, can be put on multiple parts of the body for motion detection. The radio modules of all nodes work in the 868 MHz European license-exempt band, with up to 100 kb/s data rate. A Java-based graphical user interface (GUI) at the processing unit side interprets the data stream for posture recognition.

3. WIRELESS CONECTIVITY TECHNOLOGIES IN HEALTH CARE

Standards are an important part of health care systems. One of today's healthcare industries goals is to drive patient related information to be exchanged freely between the various systems in the continuum care.

One area of these systems is the health monitoring information, in which various types of sensors gather and send patient data. In today's health monitoring market, devices and software platforms are manufactured and developed by many different entities. In order for a health monitoring system to be able to support a wide range of vital signs, it is necessary to use a wide variety of measurement devices such as blood pressure monitors, glucose meters, heart rate monitors, weighing scales, ECG sensors and fall detection accelerometers. For each type of device there are a number of companies manufacturing them, but no company makes all of these devices. Therefore, it is necessary to work with many different suppliers in order to provide a complete range of measurement devices to its customers. Unfortunately, unlike other market areas such as the financial industry, healthcare industry is still in its primordial phases when it comes to defining interoperability standards. Particularly when it comes to wireless health monitoring sensor networks, there is yet to appear a definitive standard that is adopted by the majority of the industry. Different device suppliers use different communication technologies (Wi-Fi, Bluetooth, ZigBee, etc.) and even if they all used the same technology for communication they would still use different ways of structuring the messages transmitted over the transport technology. Without standards that define how to structure messages in order to share information and what technologies to use for communication, it will never be possible to truly achieve system interoperability. Fortunately, there are various attempts at defining what technologies and communication standards are to be used between the various products in the health care industry: industry players gather to develop and agree upon guidelines or profiles that define which standards to use on a given situation and how to combine them in order to achieve interoperability. Collaboration between these entities and the use of global standards is essential for the future of health monitoring systems. Nowadays, the communications standardization in health care is guided by two important coalitions: the Continua Health Alliance and the ANT+ Alliance, and their respective sensor wireless technologies of choice: ZigBee, Bluetooth and ANT.

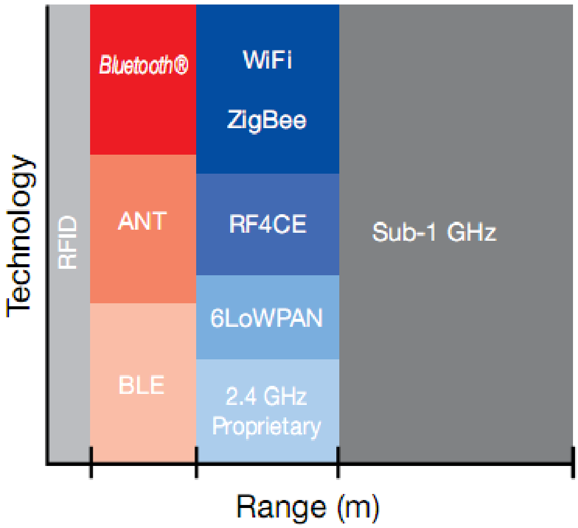

Figure 1 Wireless communication protocols classified by transmission range (Texas Instrument, 2011).

ZigBee is a standards-based technology for remote monitoring, control and sensor network applications. The ZigBee standard was created to address the need for a cost-effective, standards-based wireless networking solution that supports low data-rates, low-power consumption, security, and reliability. ZigBee can be used in any monitoring and control application that requires a wireless link:

- Home, building and industrial automation
- Energy harvesting
- Home control/security
- Medical/patient monitoring
- Logistics and asset tracking
- Sensor networks and active RFID
- Advanced metering/smart energy
- Commercial building automation

Bluetooth wireless technology is one of the most prominent short-range communications technologies with an installed base of more than three billion units. Bluetooth is intended to replace the cables connecting portable and/or fixed devices while maintaining high levels of security, low power and low cost. Bluetooth low energy technology (BLE) offers ultra-low power, state-of-the-art communication capabilities for consumer medical, mobile accessories, sports and wellness applications. Compared to classic Bluetooth capabilities, Bluetooth low energy is a connectionless protocol, which significantly reduces the amount of time the radio must be on. Requiring only a fraction of the power consumption of traditional Bluetooth technology, Bluetooth low energy can enable target applications to operate on a coin cell for more than a year. Application areas can be:

- Mobile accessories
- Consumer health/medical
- Sports/Fitness
- Remote controls
- Wireless sensor systems

ANT provides a simple, low-cost and ultra-low power solution for short-range wireless communication in point-to-point and more complex network topologies. Suitable for various applications, ANT is today a proven and established technology for collection, automatic transfer and tracking of sensor data within sports, wellness management and home health monitoring applications. The functionality of ANT enables mobile handheld device manufacturers to deliver ANT+ interoperable sports, fitness and consumer health monitoring products. Application areas can be:

- Sports/Fitness
- Consumer health/medical
- Mobile accessories

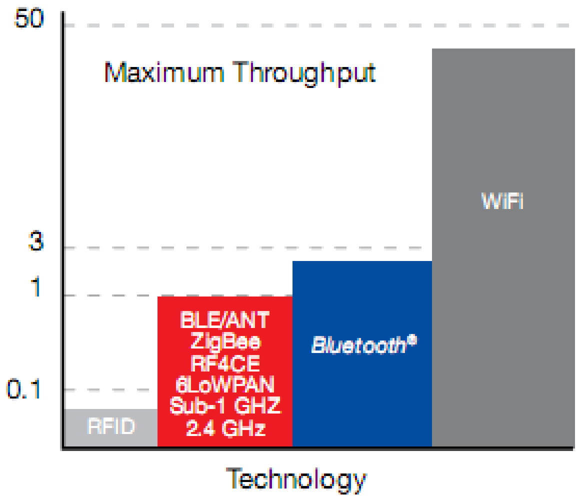

Figure 2 Wireless communication protocols classified by maximum throughput (Texas Instrument, 2011).

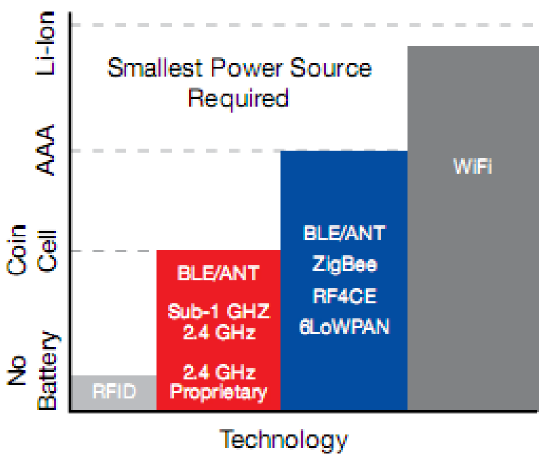

Figure 3 Wireless communication protocols classified by smallest power source requirements (Texas Instrument, 2011).

Figure 4. Monitoring system schema

- Wireless sensor systems

Figure 1, Figure 2 and Figure 3 compare these communication protocols in different technical properties such as transmission range or power consumption. As seen in this figures, ANT protocol has one of the smallest power requirements which is optimal for non-invasive sensors. About transmission range, ANT covers the needs of a WBAN and its maximum throughput covers the functionality of a health monitoring system which sensors emits small pieces of information frequently during long periods of time. In conclusion, ANT is an applicable communication protocol for a WBAN prototype centered in health monitoring.

4. MONITORING EXPERIMENT MODELING

4.1. Experiment modeling

The experiment proposed in this paper is centered in the simulation of a system which monitors several physiological parameters of a group of a group of patients in real time simultaneously.

Our case study in centered in the simulation of an elderly care center where patients have several sensors which monitor some physiological parameters and send the data to a mobile phone which store it. An example of the validity of this case study can be observed in (Love, 2011) where a similar system was developed.

Figure 5. ANT development kit (ANT, 2011)

Sensor used in the experiment is a heart rate sensor. This sensor can monitor the heart rate of patients in real time. Using this information it is possible to define an alert system, in the mobile phone, which alerts to the center nurses if the heart rate of the patient reaches dangerous values.

4.1. ANT development kit

ANT development kit Figure 5 offers a comprehensive set of hardware and software to help users to evaluate, design and prototype using ANT technology. ANTAP2DK1 and ANTDKT3 are the two ANT development kits containing the same hardware, with the exception that ANTAP2DK1 features the latest AP2 modules in replacement for AP1 modules in ANTDKT3.

This kit allows us to interface directly to an ANT module, giving you the ability to test and analyze all parameters of the ANT protocol. This includes setting channel parameters (channel type, RF frequency, message rate, pairing bit etc) to set up and monitor different types of ANT channels.

The table below shows the hardware content of the two development kits.

Table 2. ANT Development kit components

Component	ANTAP2DK1	ANTDKT3
ANTAP281M5IB module	2	0
ANT11TS33M5IB module	2	2
ANTAP1M5IB module	0	2
ANT battery board	2	2
ANT I/O interface board	2	2
USB interface board	2	2
CR2032 battery	2	2

4.2. Mobile framework

A software framework, in computer programming, is an abstraction of a collection of classes, applications and libraries helping the different components to work

Figure 7. The proposed framework

together. Frameworks can be seen as software libraries where they are reusable abstractions of code wrapped in a well-defined API. They contain the following three key distinguishing features that separate them from standard libraries: inversion of control; extensibility; and non-modifiable code. Inversion of control dictates that the overall program flows of control is dictated by the framework and not by the caller. The extensibility characteristic allows user to extend it usually by selective overriding or specialized by user code providing specific functionality. The third characteristic concerns with the code itself. In other words, the framework code is not allowed to be modified, although, users can extend the framework and implement new characteristics.

There are numerous mobile devices with different characteristics and operating systems. The proposed mobile framework is centered in the Android OS. ANT+ published and ANT+ API library for Android devices at the beginning of 2011. This library allows us to communicate with the ANT protocol chipset incorporated in mobile devices and threat data given by the ANT+ sensors.

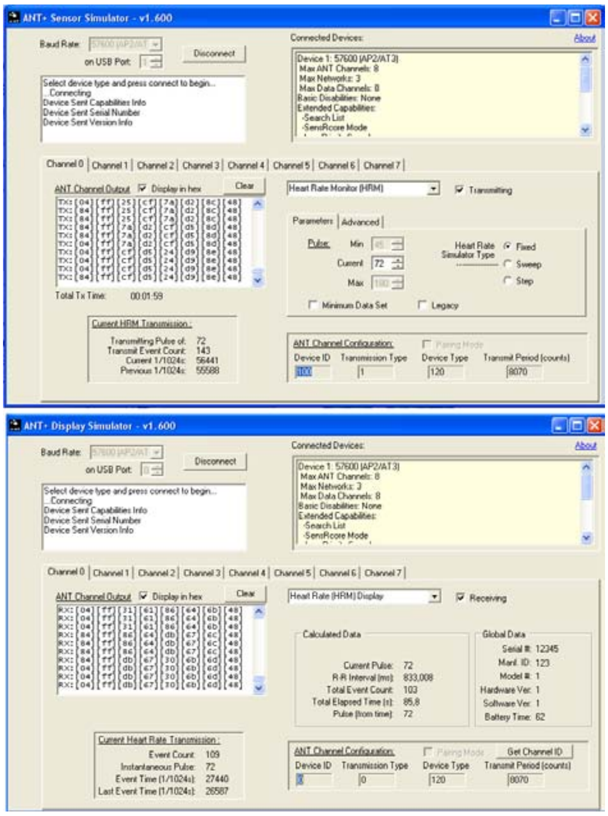

Figure 8 ANT sensor and display simulator capture

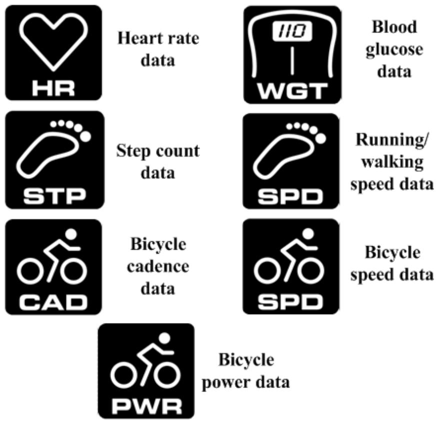

Figure 6. ANT+ simulator available sensors

The experiment mobile device target is a smartphone. Nowadays the only mobile phone vendor which incorporates the capabilities needed to recognize ANT+ communication protocol is Sony Ericsson. The Sony Ericsson Xperia mobile phones family is the first one which can manage ANT+ sensors and its commercialization starts in the second half of 2010.

The mobile phone framework proposed is showed in the Figure 7. Firstly, the sensors data will send to the ANT+ API library. Secondly, an Android application will store this data into mobile phone for its use. Finally, an Android display will manage the stored data and show it in the mobile phone display. In the development of the Android application and display and open source ANT+ demo is used as a base.

5. MONITORING SYSTEM SIMULATION

One of the key tools in ANT+ application development is the ANT+ Simulator (Figure 8). This software tool allows developers to create applications compatible with ANT+ sensors without the need of a physical sensor to generate ANT+ data during development.

The ANT+ Simulator consists of two applications: the ANT+ Sensor Simulator and the ANT+ Display Simulator. The ANT+ Sensor Simulator is used to simulate a variety of ANT+ sensors, generating and broadcasting data according to their respective ANT+ device profiles. The profiles whose can be simulated by the actual version of the simulator (v1.600) are showed in the Figure 6. The ANT+ Display Simulator receives and decodes messages transmitted from a variety of broadcast ANT+ sensors.

Using the ANT+ Sensor Simulator it is possible to emulate a heart rate sensor behavior and its communication with a mobile phone. For the experiment, the Sensor Simulator was configured as a heart rate sensor which transmits data in a broadcast mode. A Sony Ericsson Xperia Arc was used to monitor the results. As seen in Figure 9, the mobile phone is capable to receive and decode the ANT+ sensor transmission so the ANT+ communication via mobile with one sensor is successfully tested. But a WBAN is

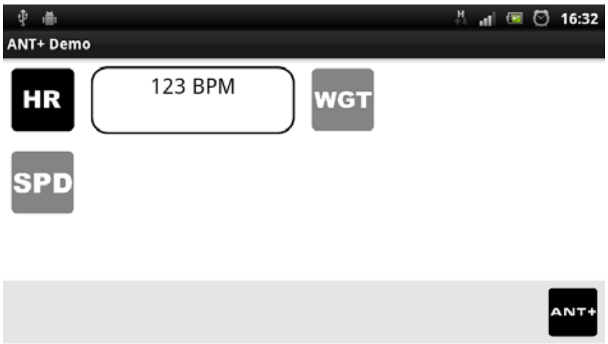

Figure 9 Single sensor simulation result

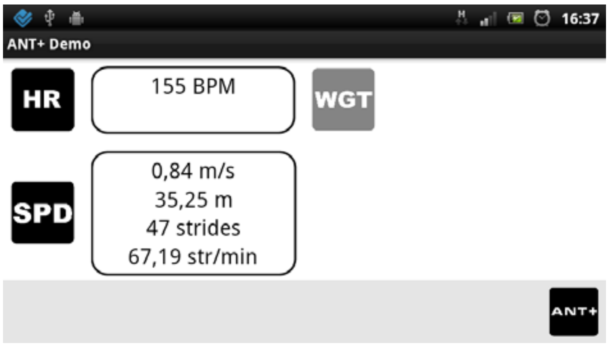

Figure 10 Multi-sensor simulation result

composed by more than one sensor usually so it is mandatory to probe the correct system behavior using more than one sensor. For this new experiment, the Sensor Simulator was configured with a heart rate sensor and a speed and distance sensor transmitting simultaneously using different communication channels. As seen in Figure 10, Sony Ericsson's device is capable to manage several sensor signals transmitting simultaneously so the multi-sensor ANT+ communication via mobile phone is successfully tested.

Once this basic experiment probes the mobile phones capabilities to work with a WBAN using ANT+ as a communication protocols, it is needed a deeper development work to reach an operational prototype of a health monitoring system. For example, it is necessary to design a more detailed user interface, and define and develop a functional alarm system. This task is planned and will be available in future works but, in this case, is beyond the scope of this paper.

6. CONCLUSIONS

The growth in the adoption of wireless technologies in the health care is a fact nowadays. There are several examples of BANs and WBANs, collecting physiological patients' data, in the scientific literature.

The next step in this continuous advance is the use of ultra-low power communication protocols in the health care monitoring. This kind of protocols allows the reduction in the sensors' size and the rise of the patients' mobility.

In addition, the mobile phone's market starts to incorporate this kind of protocols in its newer products. This fact makes available the possibility of a wireless patients' monitoring all day, not matter if they stay at home, at work…

In this work, a test of a development with ANT+ in this field is presented. An experiment was designed and the basic capabilities of the system are tested to consolidate the technical assumptions of the development. The tested capabilities are the possibility of communicate one or several ANT+ sensors with a commercial mobile phone. This test will be the start point of a health care system monitoring development.

ACKNOWLEDGMENTS

Yeray Callero is being supported by a postgraduate grant from CajaCanarias Canary Island bank.

REFERENCES

Adloo, H., Deghat, M., & Karimaghaee, P. (2009). Iterative state feedback control and its application to robot control. *2009 IEEE International Conference on Mechatronics*, *00*(April), 1-6. IEEE. doi: 10.1109/ICMECH.2009.4957228.

ANT. (2011). Homepage. Retrieved 2011, from www.thisisant.com.

Cao, H., Leung, V., Chow, C., & Chan, H. (2009). Enabling technologies for wireless body area networks: a survey and outlook. *Communications Magazine, IEEE*, *47*(12), 84–93. IEEE. doi: 10.1109/MCOM.2009.5350373.

Farella, E., Pieracci, A., Benini, L., Rocchi, L., & Acquaviva, A. (2008). Interfacing human and computer with wireless body area sensor networks: the WiMoCA solution. *Multimedia Tools and Applications*, *38*(3), 337-363. doi: 10.1007/s11042-007-0189-5.

Gao, T., Massey, T., Selavo, L., Crawford, D., Chen, B.-rong, Lorincz, K., et al. (2007). The advanced health and disaster aid network: A light-weight wireless medical system for triage. *Biomedical Circuits and Systems, IEEE Transactions on*, *1*(3), 203–216. IEEE. doi: 10.1109/TBCAS.2007.910901.

Jantunen, I. (2008). Smart sensor architecture for mobile-terminal-centric ambient intelligence. *Sensors and Actuators A: Physical*, *142*(1), 352-360. doi: 10.1016/j.sna.2007.04.014.

Love, J. (2011). *Ultra-Low Power Wireless Quarter*.

Milenkovic, a, Otto, C., & Jovanov, E. (2006). Wireless sensor networks for personal health monitoring: Issues and an implementation. *Computer*

Communications, *29*(13-14), 2521-2533. doi: 10.1016/j.comcom.2006.02.011.

Pentland, A. S. (2004). Healthwear: medical technology becomes wearable. *Computer*, *37*(5), 42–49. Published by the IEEE Computer Society. doi: 10.1109/MC.2004.1297238.

Pereira, O., Caldeira, J. M. L. P., & Rodrigues, J. J. P. C. (2010). Body Sensor Network Mobile Solutions for Biofeedback Monitoring. *Mobile Networks and Applications*. doi: 10.1007/s11036-010-0278-y.

Ruiz, J. a, & Shimamoto, S. (2006). Novel communication services based on human body and environment interaction: applications inside trains and applications for handicapped people. *IEEE Wireless Communications and Networking Conference, 2006. WCNC 2006.* (Vol. 4, p. 2240–2245). Ieee. doi: 10.1109/WCNC.2006.1696644.

Sarpeshkar, R. (2006). Invited Talk: Ultra Low Power Electronics for Medicine. *International Workshop on Wearable and Implantable Body Sensor Networks (BSN06)*, 37-37. IEEE. doi: 10.1109/BSN.2006.38.

Shnayder, V., Chen, B.-rong, Lorincz, K., Fulford-Jones, T. R. F., & Welsh, M. (2005). Sensor networks for medical care. *SenSys' 05: Proceedings of the 3rd international conference on Embedded networked sensor systems* (p. 314–314). New York, New York, USA: Citeseer. doi: 10.1145/1098918.1098979.

Texas Instrument. (2011). Wireless Connectivity Guide. *Technology*.

Topol, E. (2010). Transforming Medicine via Digital Innovation. *Science Translational Medicine*.

AUTHORS BIOGRAPHY

YERAY CALLERO was born in Haría, Lanzarote and attended the University of La Laguna, where he studied Engineering Computer Science and obtained his degree in 2008. He is currently working on his PhD with the Department of Systems Engineering and Automation at the same university. His research interests include simulation and health monitoring.

ROSA M. AGUILAR received her MS degree in Computer Science in 1993 from the University of Las Palmas de Gran Canaria and her PhD degree in Computer Science in 1998 from the University of La Laguna. She is an associate professor in the Department of Systems Engineering and Automation at the University of La Laguna. Her current research interests are decision making based on discrete event simulation systems and knowledge-based systems, intelligent agents, and intelligent tutorial systems.