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Procedia Computer Science 14 (2012) 181 – 188

Procedia Computer Science

Proceedings of the 4th International Conference on Software Development for Enhancing Accessibility and Fighting Info-exclusion (DSAI 2012)

A Bluetooth approach to diabetes sensing on Ambient Assisted Living systems.

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Abstract

The metabolic disorder which entails the absent or reduced control of blood glucose in the body by means of insulin dependence (Type1) or intolerance (Type 2) affects more than 366 million people in 2011. This represents an increase of 28% new cases in one year. Diabetes Mellitus has become the most common chronic diseases in nearly all countries, and continues to increase in numbers and significance, as economic development and urbanization lead to changing lifestyles characterized by reduced physical activity, and increased obesity.
Ambient Assisted Living (AAL), is based on a set of technologies which aims to provide an enhanced support to people's daily life, namely the offer of new solutions for healthcare to improve the quality of life of the population and reduce costs associated with healthcare.
This paper presents a Bluetooth prototype low power battery-less wireless sensor communication system capable transmitting the information to a mobile phone or wrist wireless phone. The purpose of the system is to gather routine information from the glucose monitoring system proposed by Leal, et al and interact with systems like Ambient Assisted Living from Martins, et al.

Keywords: Bluetooth Low Energy; Wireless Sensor; Battery-less Sensor; Diabetes; Ambient Assisted Living

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 doi:10.1016/j.procs.2012.10.021

1. Introduction

Wireless Sensor Networks (WSNs) is the term that is used for wireless sensor and control networks that use batteries or energy harvesting techniques to power the device. With the availability of low cost integrated circuits to perform the sensing, signal processing, communication, and data collection functions, coupled with the versatility that wireless networks afford, we can move away from fixed, hard-wired network installations in both new construction as well as retrofits of existing installations [1].

Recent advances in wireless sensor networking technology, have led to the development of low cost, low power, multifunctional sensor nodes. Sensor nodes enable environment sensing together with data processing. Instrumented with a variety of sensors, such as temperature, humidity and volatile compound detection, allows different environments monitoring. They are able to network with other sensor systems and exchange data with external users [2].

On daily life diabetes patients should, in order to reduced complications originated by the disease, follow a tight metabolic control [3], to achieved this patients currently puncture their fingers several times during the day using glucose meters [4] based on the enzyme sensor technology developed by Clark and Lyons [5] in 1962. Patients should also perform once every 2 to 3 months a test to the percentage of glycated hemoglobin, or HbA1c, in the blood in order to control the average blood glucose.

The system proposed by Martins, et al [6] not only helps patients to follow this tight control by emitting alarms at the control times but, when link together with the monitor glucose sensor like the one proposed by Leal, et al [7] can automatically take into account measurements and inform the patients about any actions to be undertaken.

In fact the European Association for the Study of Diabetes and the International Diabetes Federation) [8] decided that the A1c assay should be considered as the primary method for the diagnosis of diabetes [9].

HbA1c is a stable glycated hemoglobin derivative formed by the non-enzymatic reaction of glucose with the N-terminal valine of the β-chain of normal adult Hb (HbA). Since it reflects the average blood glucose level over the preceding 2-3 months and is not affected by the daily fluctuation of the glucose level, the HbA1c level provides a more accurate index for diagnosis and long term control of the disease. Traditionally, clinical laboratory assays for HbA1c have been obtained by ion-exchange chromatography, immunochemical methods, electrophoresis and boronate affinity chromatography. All these methods share a common disadvantage, they need expensive equipments and trained personnel thus making the best control and diagnosis method unsuitable for point-of-care.

Therefore an AAL system with a glucose monitor device can indeed create a database where, not only immediate measurements are store, but an average of the blood glucose level can be perform allowing patients and doctors to better diagnose and control the disease.

2. Battery-less wireless system

The block diagram of Figure 1 illustrates the battery-less wireless system. The implementation is based on the TMS37157 (PaLFI) low-frequency device a CC2540 microcontroller plus Bluetooth on chip solution and the Balun-Low Pass Filter integrated passive component 2450BM15A0002 to enable easy antenna matching. Finally the TPS62730 is use to power supply the sensor and microcontroller.

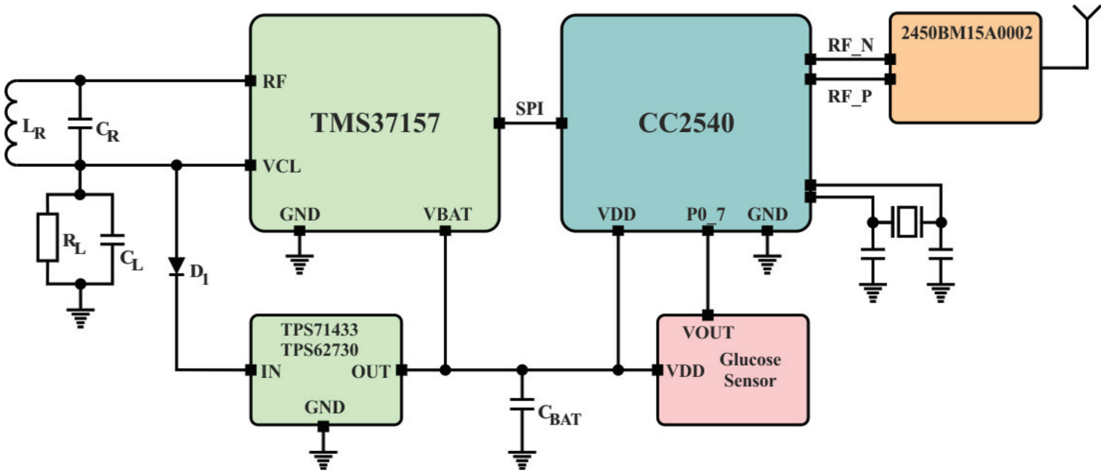

Figure 1 - Principle Schematic of the non-battery Wireless Sensor

The input of the DC/DC converter TPS71433 or TPS62730 is connected to VC_L trough diode D_1. D_1 prevents the resonance circuit (consisting of L_R and C_R) from any disturbances coming from the dc/dc converter. Capacitor C_{BAT} stores the energy derived from the RF field [10].

Using an external dc/dc converter instead of the internal of the TMS37157 overcomes the issue of higher currents because the external dc/dc converter can provide higher output currents in comparison to the internal regulator (80 mA compared to 5 mA).

The Glucose Sensor Output signal will enter the CC2540 on P0 7 as seen on Figure 1. This input will be compared with an internal reference voltage and sent to the Sigma Delta modulator. As stated by Leal, et al [7] the V_{out} signal from the Glucose sensor should be presented to at least 10 bits Analogical to Digital Converter (ADC). The selected chip CC2540 uses a 12 bits ADC to convert the Glucose output signal.

This modulated signal will then be sent to the decimation filter where a sampling frequency of 4 MHz is used to convert the signal into a 12 bit binary word in 2's complement form. Timing for the ADC is required to be provided by the 32 MHz crystal oscillator provided by pins XOSC Q1 and XOSC Q2. The selected ADC uses a default sampling frequency of 4 MHz generated by fixed internal division.

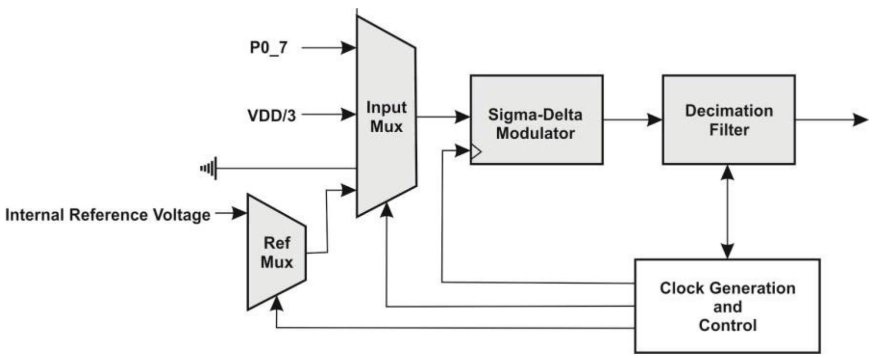

Figure 2 - Adapted ADC Block diagram [10]

This binary data is then sent to the radio registers shown in Figure 2 via the Direct Memory Access (DMA) controller.

The DMA controller operation is programmed using the M Code control signal.

One of the most important features of a wireless system is his robustness in term of harsh environments. The proposed system ensures that by the use of the Low Frequency Band and also by adding redundancy to the transmission data (data is send to LF Reader and to BLE master receiver), later the protocol compares and validates the readings obtained.

During LF transmissions, a FSK signal is transmitted. The resonance frequency of the trimmed antenna circuit (f_L) represents a low bit and high bits, are represented by a lower frequency (f_H), which is achieved by switching in a Modulation Capacitor in parallel with the antenna resonance circuit [10].

Figure 3 shows the global system where the glucose sensor receives power from the LF reader, undertakes measurements and emits Bluetooth LE signal that can be received by the wrist watch, the BLE phone or the main Ambient Assisted Living program running on the PC.

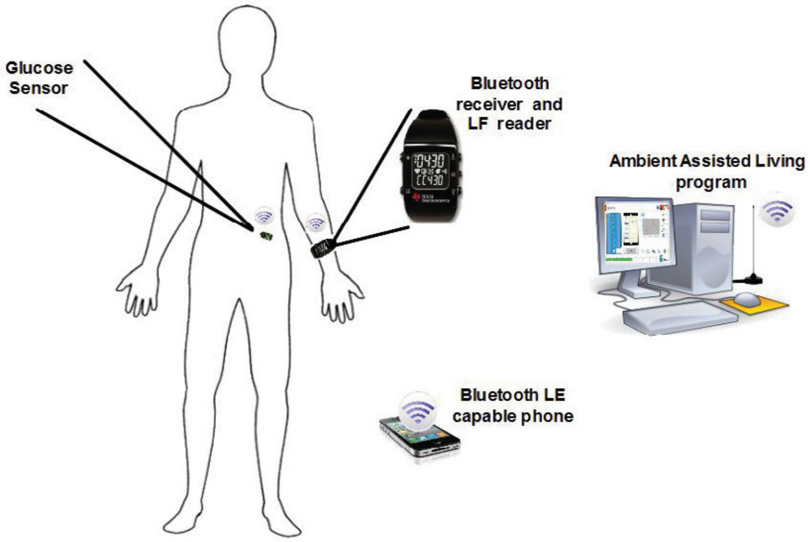

Figure 3 - Global Ambient Assisted Living system

3. Power Sources- RF Energy Harvesting

For an implanted system the selected power can determine the life time cycle of the system. The purpose of our model is to be auto-sufficient so in order to achieve this goal we choose a RF energy harvesting as main supply for the system. The TMS37157 from Texas Instruments is the heart of our harvesting system, capable of directly supplying up to 4 mA to an external Microcontroller and sensor. Nevertheless we add to the circuit the TPS71433 in order to ensure an higher current supply (up to 80 mA [11]). The total current consumption of our circuit can be estimated from the modules datasheet and its equal to 25 mA plus Glucose Sensor therefore our Glucose sensor can consume up to 55 mA.

4. Bluetooth Low Energy Protocol

The Bluetooth Low Energy (BLE) protocol stack architecture is illustrated on Figure 4. The protocol stack consists of two sections: the controller and the host. This separation of control and host goes back to standard Bluetooth BR/EDR devices, in which the two sections were often implemented separately. The profile and application that are being used sit on top of the GAP and GATT layers of the stack.

The PHY layer is a 1Mbps adaptive frequency-hopping Gaussian Frequency-Shift Keying (GFSK) radio operating in the unlicensed 2.4 GHz ISM (Industrial, Scientific, and Medical) band.

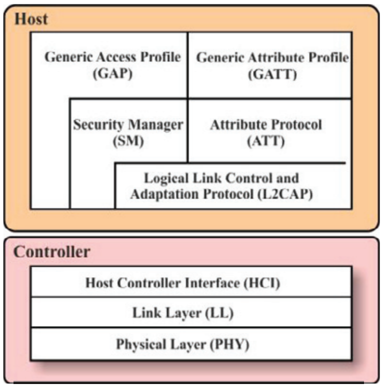

Figure 4 - BLE Protocol Stack

The PHY layer essentially controls the RF state of the device, being in one of five possible states: standby, advertising, scanning, initiating, or connected. Advertisers transmit data without being in a connection, while scanners listen for advertisers. An initiator is a device that is responding to an advertiser with a connection request. If the advertiser accepts, both the advertiser and initiator will enter a connected state. When a device is in a connection, it will be connected in one of two roles: master or slave. The device that initiated the connection becomes the master, and the other device that accepted the request becomes the slave, as showed in Figure 5.

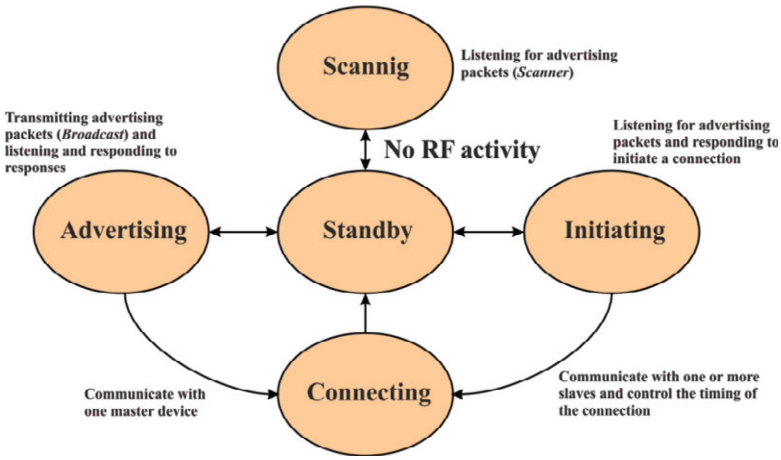

Figure 5 - Device states [10]

The HCI layer provides a means of communication between the host and controller via a standardized interface.

The L2CAP layer provides data encapsulation services to the upper layers, allowing for logical end-to-end communication of data.

The SM layer defines the methods for pairing and key distribution, and provides functions for the other layers of the stack to securely connect and exchange data with another device.

The GAP layer directly interfaces with the application and/or profiles, and handles device discovery and connection related services for the device. In addition, GAP handles the initiation of security features.

The ATT protocol allows a device to expose certain pieces of data, known as “attributes”, to another device. In the context of ATT, the device exposing attributes is referred to as the “server”, and the peer device is referred to as the “client”. The LL state (master or slave) of the device is independent of the ATT role of the device. For example, a master device may either be an ATT server or an ATT client, and a slave device may also be either an ATT server or an ATT client. It is also possible for a device to be both an ATT server and an ATT client simultaneously.

The GATT layer is a service framework that defines the sub procedures for using ATT. GATT specifies the structure of profiles. In BLE, all pieces of data that are being used by a profile or service are called “characteristics”. All data communications that occur between two devices in a BLE connection are handled through GATT sub-procedures.

Therefore, the application and/or profiles will directly use GATT.

The Bluetooth receiver displayed on Figure 6 allows the Ambient Assisted Living application from Martins, et al [6] to process the data collected in order to detect anomalies and issue an alert.

Figure 6 - CC2540 Receiver [6]

The AAL application is connect not only to the Glucose sensor but with other complement sensors namely ECG, Body temperature, SpO2m, body weight and pressure sensors. The java application has three layers structure. The first layer is responsible for the signals acquisition and acts directly with the Bluetooth receiver. The second layer analyses and converts all the received data from the sensors. Finally the third layer is responsible for the graphic representation of the data shown Figure 7.

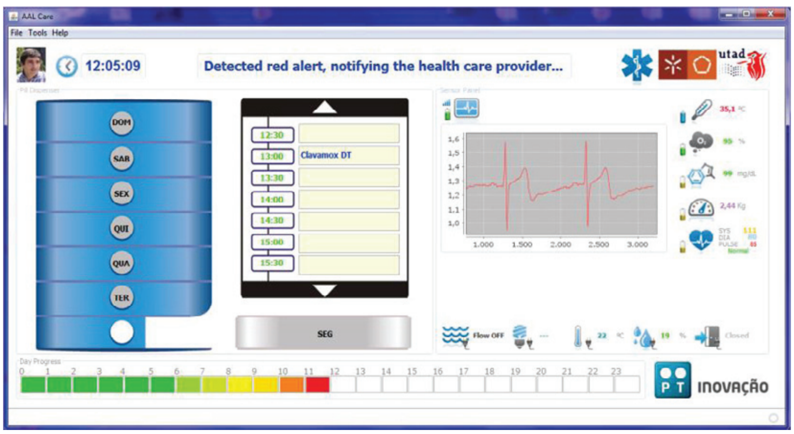

Figure 7 - Graphics from Martins, et al application [6]

5. Results

The sensor used for tests was the glucose used by Leal, et al [7] on their work and showed on Figure 8.

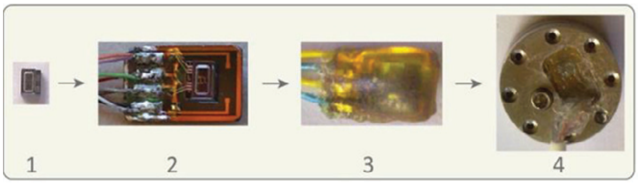

Figure 8 - Osmotic glucose sensor. 1) MEMS pressure; 2) after wire bonding; 3) Sealing with epoxy glue; 4) sensor inside a container with a laser

The experimental assays were performed using albumin (albumin from bovine serum, EC No. 232-9362, M W = 67 kDa, Fluka, USA) in concentrations of 0, 0.5 and 1 mM in order to simulate low, medium and high solute concentration, respectively. The obtained behavior of the developed monitoring system to the performed experiments is illustrated in Figure 9.

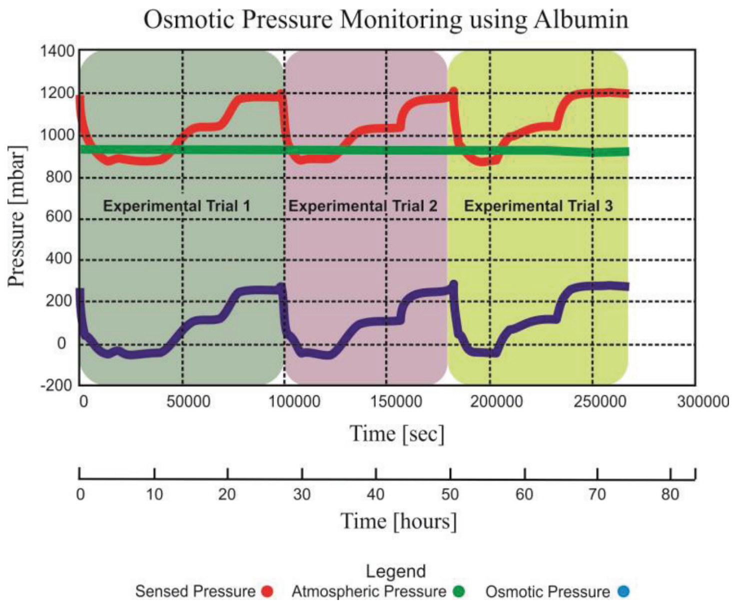

Figure 9 - Osmotic pressure changes during three experimental trials performed on albumin solutions with concentration of 1 (label 1), 0.5 (label 2)

From the analysis of this behavior, we can conclude that the system showed a positive response to the different albumin concentrations in means of osmotic pressure variations. The data obtained was send transmitted by the system with Bluetooth protocol.

6. Conclusions

This work presents a Bluetooth prototype low power battery-less wireless sensor communication system capable transmitting the information to a mobile phone, wrist wireless phone or windows PC application. The use of Low Power Bluetooth in conjunction with well known establishes harvesting RF methods allows the development of new wireless battery-less sensors may work for years without battery replacement. An energy aware microcontroller, and an optimized RF Radio link delivers the reality of long life, maintenance-free Zero Power Wireless Sensor, providing cheap sensor nodes to be use together with Ambient Assisted Living systems like the one Martins, et al implemented. With population aging, health monitoring systems need to adapt to new situations, giving patients and doctors freedom of move along with knowledge of patients habits necessary to determine correct therapy application on different environs and making life of chronicle diseased patients, like diabetics, easer and reducing the number of disease complications. The pursuit must continuous in order to prove the application of BLE in Ambient Assisted scenarios and assures doctors of QoS (Quality of Service). Future work includes testing the implemented prototype robustness and performs measurements in real time scenarios.

Acknowledgements

The authors would like to thank Erik A. Johannessen at the Vestfold University College (VUC) in Norway. This work was partially supported by Portugal Telecom Inovação in the context of Project AAL care solutions (2009-2011).

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