Remote Monitoring of Electrocardiogram Signals Transmitted in a ZigBee Network

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***Abstract*— This work proposes a remote monitoring system of ECG signals. The ECG signal is generated with an algorithm called ecgsyn, and it is transmitted in a real ZigBee network. The signal received by the sink node is stored in a file, and is sent to a web server in the Internet. Thus, after an electrocardiogram test, doctors can view the biometric data in the web browser of its mobile device. Experiments were done, transmitting 2500 samples of a ECG signal, and we observed a high packet delivery ratio, even when transmitter and receiver are placed in different rooms, leading to a small reconstruction error.**

***Keywords*— ECG, ZigBee, reconstruction.**

I. Introduction

Wireless Sensor Networks (WSNs) are a special kind of ad hoc networks that use nodes with low cost and low energy consumption. These nodes are equipped with a sensor unit, and can be used to monitor physical processes, as temperature, humidity, and pressure [1]. The application that is the focus of this work is the Body Sensor Network (BSN) [2].

With a BSN, nodes sense biometric data from patients, like electrocardiogram (ECG) signals. Nodes can be arranged in the body of the patients, measuring data. They communicate with a wireless network until reach a sink node (base station), a node that receives all traffic from the network. Thus, problems with infrastructure, like wired connections for each procedure may be suppressed, making some tests less intrusive.

In this work, we consider the transmission of ECG signals in a ZigBee network (IEEE 802.15.4). This wireless network standard emerged from the union of the 802.15.4 IEEE group, and a group of companies called ZigBee Alliance [3]. The IEEE 802.15.4 developed the physical layer and the medium access sublayer (MAC), and the ZigBee alliance was responsible for the network and the above layers. This union developed a standard for low bit rate, and low energy consumption Wireless Personal Area Networks (WPANs), called ZigBee.

The ECG procedure registers the electrical activity of the heart in two phases: The systole, which is the contraction of the cardiac muscles; and the diastole, which is its relaxation. By the analysis of the components of the electrical activity of the heart (the P wave, the QRS complex, and the T wave), it is possible to evaluate the cardiac conditions of a person [4].

- **P wave**: it is the first wave of each heartbeat. It represents the electrical activity level generated by the activation of the muscles located in the atrium;
- **QRS complex**: it shows the behavior of the ventricular systole, which causes the pumping blood for the body;
- **T wave**: it represents the muscle recovery, the repolarization of the ventricles. It is also the preparation for a new cardiac cycle.

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II. Remote Monitoring System

The ECG signals used in the experiments were artificially generated in MatLab, with the ecgsyn algorithm [4]. We use two XBEE modules, from Digi manufacter, as ZigBee nodes, one used as a transmitter, and the other as a sink node, receiving data. The both XBEE nodes operate in the band centered at 2.4 GHz. The nodes were connected to desktops with RS232 interfaces.

The remote monitoring system is presented in Figure 1. The XBEE transmitter node gets the ECG signal, generated in MatLab, from RS232 interface. The signal is transmitted by ZigBee network to the sink node. After the sink receives the data from transmitter node, it is recorded in the second desktop, using the RS232 interface. The file containing the biometric data is sent to a Internet web server, in order to maintain a patient history, that can be used to evaluate the evolution of patient.

The doctor can view the ECG data in the web browser of its mobile device. An application in Processing language was developed in this work, in order to read the file with the data received by sink node, and to display the ECG signal in the doctor's web browser.

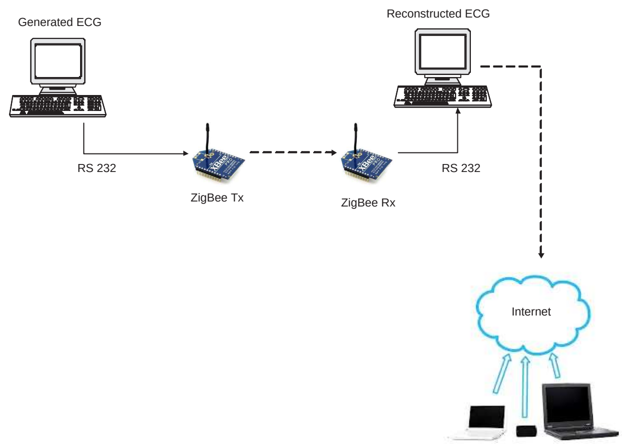

Fig. 1. The remote monitoring system

III. Performance Evaluation and Results

For the experimental tests, the transmission power of 1 mW (0 dBm) was used in the transmitter, and the receiver sensivity of -92 dBm was considered. The metrics used to evaluate the network are: The packet delivery ratio, in order to evaluate the network connectivity, defined as the ratio between the amount of received packets and the amount of transmitted packets; and the reconstruction error of the monitored ECG signal, defined as the absolute value of the difference between the original signal, $f(t)$, and the reconstructed signal, $\hat{f}(t)$, for each instant of time (eq. (1)).

$$RE(t) = |f(t) - \hat{f}(t)|. \tag{1}$$

To obtain the results, the experiment was done five times, in which 2500 samples of the ECG signal was transmitted. A confidence interval of 95% was considered for the mean, presented by the vertical bars in points: 6m and 10m of the Figures 2 and 3. For the tests, the distance between the transmitter and the sink nodes was varied between 1m, 6m, and 10m. For the distance of 10m, the nodes were disposed in different rooms, and in different floors, the first and the second floors of the Petropolis campus of CEFET/RJ.

In Figure 2 it can be observed that the increase of the distance leads to a decrease in the connectivity of the network, causing some packet loss. This situation is worst in the case that nodes are placed in different rooms, because there are structures like walls between them. This packet loss impacts the reconstruction of the process, because one uses less samples to reconstruct the signal. Thus, it can be observed an increase in the reconstruction error with the increment of the distance between nodes, in Figure 3. Figure 4 shows the original and reconstructed ECG signal, for distinct distances between nodes. We can see that the shape of the signal is sustained, even for the larger distance.

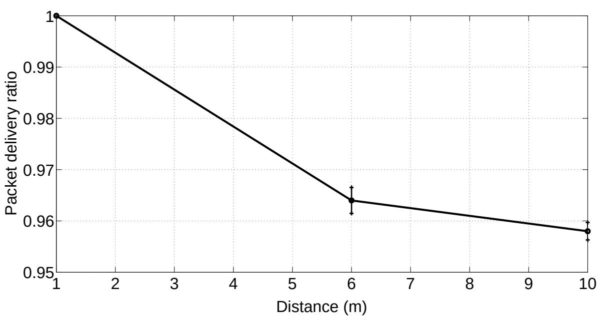

Fig. 2. Packet delivery ratio × distance (m)

IV. Conclusions

Tests were done in a real ZigBee network with XBEE nodes transmitting (and receiving) ECG signal generated by the ecgsyn algorithm. The results show a packet delivery ratio near than 96%, with nodes disposed in distinct rooms. The packet loss impacts the reconstruction of the signal, increasing the reconstruction error.

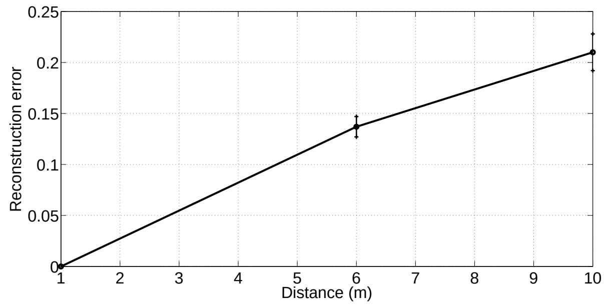

Fig. 3. Reconstruction error × distance (m)

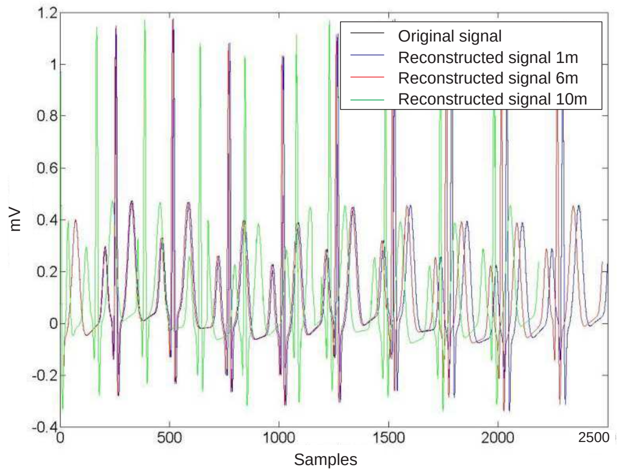

Fig. 4. Reconstructed signals for 1m, 6m and 10m between transmitter and sink nodes

For future works, we intent to use more transmitter nodes, and evaluate the impact in the reconstruction of the process. Moreover, we intent to use some energy conservation algorithms, in order to save energy of the sensor nodes [5]. Finally, we will consider other metric to evaluate the reconstruction error, like the Mean Square Error (MSE).

Acknowledgements

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References

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci, "Wireless Sensor Networks: A Survey", *Computer Networks*, vol. 38, pp. 393–422, 2002.

[2] G. Yang, "Body Sensor Networks", *Springer*, London, 2008.

[3] P. Baronti, P. Pillai, V. Chook, S. Chessa, A. Gotta and Y. F. Hu, "Wireless Sensor Networks: a Survey on the State of Art and the 802.15.4 and ZigBee Standards", *Computer Communications*, vol. 38, num. 7, pp. 1655–1695, 2007.

[4] P. E. McSharry, G. D. Clifford, L. Tarassenko and L. A. Smith, "A dynamical model for generating synthetic electrocardiogram signals", *IEEE Transactions on Biomedical Engineering*, vol. 50, num. 3, pp. 289–294, 2003.

[5] F. R. Henriques, L. Lovisolo and M. G. Rubinstein, "Algorithms for Energy Efficient Reconstruction of a Process with a Multihop Wireless Sensor Network", *Proc. of the 4th IEEE Latin American Symposium on Circuits and Systems*, Peru, 2013.