Journal of Theoretical and Applied Information Technology
30th June 2023. Vol.101. No 12

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

ENERGY CONSUMPTION MANAGEMENT IN WIRELESS SENSOR NETWORKS FOR ECG MONITORING SYSTEM

Majda LAKHAL[1], Mohamed BENSLIMANE[2], Mehdi TMIMI[3], Abdelali IBRIZ[4]

[1]Sidi Mohamed Ben Abdellah University, Higher School of Technology, Morocco

[2]Sidi Mohamed Ben Abdellah University, Higher School of Technology, Morocco

[3]Sidi Mohamed Ben Abdellah University, Higher School of Technology, Morocco

[4]Sidi Mohamed Ben Abdellah University, Higher School of Technology, Morocco

E-mail: [1]majda1lakhal@gmail.com, [2]Mohamed.benslimane@usmba.ac.ma, [3]mehdi.tmimi@usmba.ac.ma, [4]abdelali.ibriz@usmba.ac.ma

ABSTRACT

Wireless sensor networks are applicable in almost every field of human activity. One of the promising application areas of Wireless Sensor Networks is medicine where WSN technology offers an important support, which allows remote consultations of patients regardless of their geographical location. The network consists of several small sensor nodes that are deployed in the zone to detect. The nodes have the ability to process, communicate and detect, allowing them to perform their functions in coordination. In recent years, this technology has made significant progress, but energy management has not developed to the same extent while the battery is the main source of energy. In addition, the network environment may prevent charging or replacement of the battery after deployment. The classic solution to this energy efficiency problem is to manage the activation period. This involves alternating the active and inactive states of a node periodically or not [15]. In this paper, we focus on the ECG monitoring system which plays a key role as a diagnostic device for cardiac abnormalities, to monitor the cardiac health of patients remotely while minimizing energy consumption.

Keywords: *WSN, WBAN, ECG, Electrodes, Energy.*

1. INTRODUCTION

A wireless sensor network (WSN) is a collection of nodes with integrated capabilities to acquire, process and communicate data. Once deployed, the nodes cooperate with each other autonomously for collecting and transmitting data to a base station for monitoring and/or controlling a particular phenomenon. This type of network is used in several fields including medicine [1]. Energy consumption is a critical element in WSNs, and the battery remains the most viable source. This is mainly due to its technological maturity and reasonable size. But any battery will eventually discharge completely and the node will become useless if the battery cannot be recharged or replaced. This requires careful and efficient management of the network. The 12-lead electrocardiogram is the tool that is widely used for the early diagnosis of cardiac disease. In the current method of acquiring an ECG, We need 10 electrodes which are placed at different points on the body[14]. There are four electrodes that are placed on each of the four limbs, three of them are used to measure blood pressure; the 4th electrode, which is attached to the right leg, is used to reduce noise. The blood pressure measurement of these electrodes is used to generate electrical signals known as limb leads ([18], [11]). Another six electrodes are attached to the chest, resulting in six other leads called thoracic leads. Over time, electrocardiography has taken many forms, with different numbers of electrodes, positions of electrodes, and systems of leads. The 12- lead electrocardiogram and the 3-lead vector electrocardiogram have become particularly popular. There are other configurations where only 3 or 5 electrodes are connected.

This paper describes the design and implementation of a prototype of a WSN platform for ECG monitoring system with minimal power consumption. Sensors deployed on the patient's body are able to monitor the patient's health status by collecting physiological information from the heart, and then communicate it to a remote medical team. The medical team will have access to the medical record of the patient and analyze the ECG trace at any time through a web monitoring application. And according to their analysis, they will be able to make the decision either to keep the 10 electrodes activated, to basically measure all the cardiac activity and to diagnose rhythmic and ischemic abnormalities on the anterior wall of the heart, or to keep only 5 or 3 electrodes to record the 24 hours data ([5],[2]) and to deactivate the other electrodes to reduce the power consumption, with taking into consideration the patient's health status.

2. ELECTROCARDIOGRAM (ECG)

An electrocardiogram is a measurement of the heart's electrical activity. It is completely painless and can be performed quickly [17]. The heart's electricity is detected by electrodes attached to the skin. The results of these measurements are called leads. Various lead systems have been developed and improved over the last century. These include the Einthoven, Goldberger and Wilson systems [4].

3. ECG LEADS

On the electrocardiogram (ECG), cardiac leads are the recording of the difference in electrical potential between two points, either between two electrodes (bipolar lead) or between a virtual point and an electrode (unipolar lead).

It is important to know that the cardiac leads should not be recorded separately but with the whole electrocardiogram because each lead is a different view of the same electrical stimulus. The ECG can record several Potential Difference, depending on the position and number of electrodes distributed on the chest and limbs. Each measurement of these potentials corresponds to a lead. A lead system consists of a set of leads, each lead is defined by the arrangement of the electrodes on the patient's body [7].

3.1 The 3-lead ECG

The 3-lead ECG (Figure-1) is most commonly used to record 24-hour data. The 24-hour record is a common tool for diagnosing cardiac problems [2].

R (Red) is positioned in the 2nd intercostal space, around the right midclavicular line. Y (Yellow) is positioned in the 2nd intercostal space, around the left midclavicular line. G (Green) is positioned in the left side, under the pectoral muscles, at the lower edge of the left rib cage.

Using these three bipolar leads, you can see the ECG trace from lead positions I, II and III. Most 3-lead ECG systems default to showing the lead II tracing. While a 3-lead system is great for monitoring rhythm changes, heart rate, and the presence of life-threatening arrhythmias.

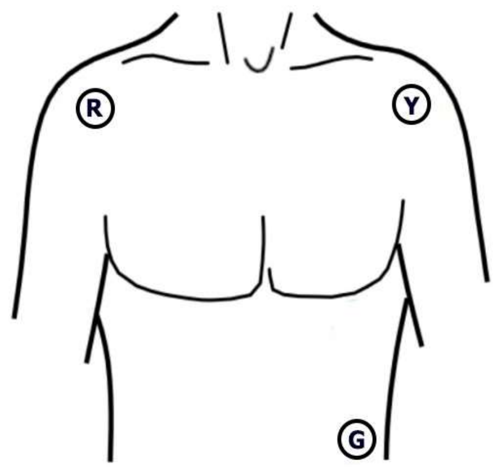

Figure 1: 3-electrode lead system

3.2 The 5-lead ECG

In this configuration (Figure-2), the R, Y, and G are positioned in the same manner as in the 3-lead configuration, to be equidistant from the heart. V is positioned in the 4th intercostal space, just to the right of the sternal border (in a 12-lead configuration, this is the V1 position). B (Black) is positioned in the right side in mirror position to G. Using 5-lead monitoring, you will be able to see the tracing of positions I, II, III and V1. You can also move the V lead to one of the positions (V1-6) and view that position (see 12-Lead Placement for V1-6 placement guidelines). Like 3-lead ECG systems, a 5-lead system will display the lead II trace as the default setting [13]. While a 5-lead system is great for monitoring rhythm changes, heart rate, and the presence of fatal arrhythmias.

Journal of Theoretical and Applied Information Technology
30th June 2023. Vol.101. No 12

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

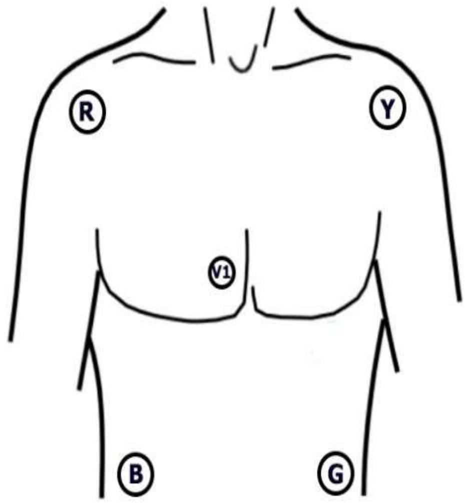

Figure 2: 5-electrode lead system

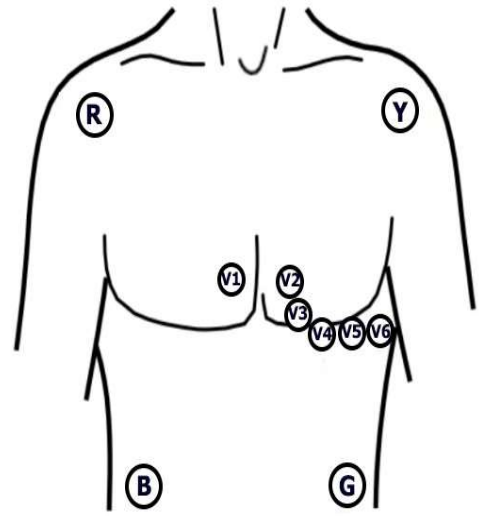

Figure 3: 12-electrode lead system

3.3 The 12-lead ECG

A 12-lead ECG (Figure-3) combines the Einthoven, Goldberger and Wilson lead systems, providing information on both vertical and horizontal axes. . For the standard ECG we will need 10 electrodes: six on the precordium and one electrode on each wrist and ankle. We have two types of leads recorded : Bipolar leads are used to determine the potential difference of the negative and positive electrodes. The unipolar leads are used to determine the potential variation of one electrode compared to a constant potential reference obtained from the average of the potentials of the left ankle, left wrist and right wrist. This gives: I, II and III are the three bipolar leads and aVR, aVL, aVF and V1 to V6 are the nine unipolar leads [8].

The 12-lead ECG basically measures all cardiac activity and diagnoses rhythmic and ischemic abnormalities in the anterior heart wall [6].

Figure 4 is a graphic representation of the electrical activation of the heart using an electrocardiograph, for each lead an ECG trace is recorded, 12 leads are classically recorded on the ECG trace and can be extended to 18 leads under certain circumstances.

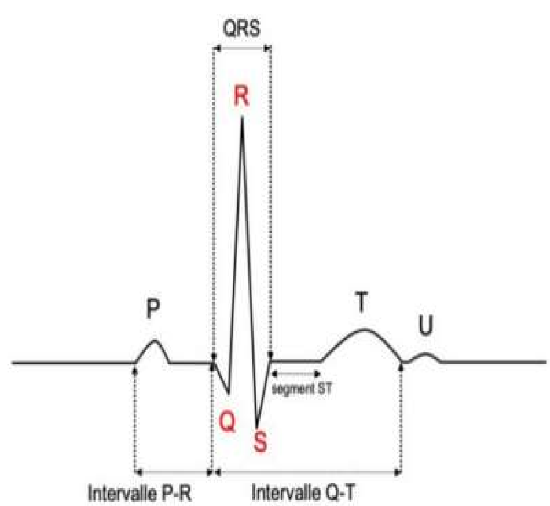

Figure 4: ECG signal [9]

This activity is collected on a patient lying down, at rest, by electrodes that record electrical signals placed on the surface of the skin. In order for an ECG to be normal, several points must be present, among which are [9]:

- In adults, the normal heart rate (coming from the sinus node in the right atrium) is a regular rhythm with a sinus rate between 60-100/min. Below 50/minute it is called bradycardia and above 100 it is tachycardia.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

- Each sinus P wave precedes each QRS to detect conduction disorders between the atria and ventricles.
- The space between two QRSs must always be the same, which indicates that the heart rhythm is regular.
- The morphology of the atrial P wave and the ventricular QRS complex should be normal.
- The P-R (or P-Q) interval has a constant duration (0.12 to 0.20 s).
- QRS have a frontal axis between -30 to 90°.
- The ST segment is isoelectric to the PQ segment.
- The T wave is asymmetric and positive and its maximum amplitude < 2/3 of QRS and minimum > 10% of R.

4. PROPOSED ARCHITECTURE OF THE ECG SYSTEM

The following figure (Figure-5) represents our proposed architecture, applied on cardiac patients. This WBAN can be split into 3 sections. The 1st section is the intra-WBAN communication, that is a connection between personal server and sensor node. The receiver node will store the physiological data collected by the sensors positioned on the patient's body, and send it through a wireless network to the personal server. The 2nd section, which is the nonBAN communication, represents the Inter-BAN communication, which is done between the personal server and the access point. The 3rd section is communication that takes place between the access point and medical staff via the Internet. To measure the heart's electrical activity, we will need sensors, their location will be similar to that of the ECG electrodes to get the accurate data. The red electrode is placed in the frame of the rib cage, just under the clavicle, the yellow electrode is positioned under the left clavicle, at exactly the same level as that of the red electrode, while the green electrode is positioned on the left side, at the lower edge of the left rib cage, and the black electrode is positioned on the right side, at the lower edge of the right rib cage. Precordial electrodes complement the peripheral electrodes and are arranged in a horizontal plane, with each electrode placed at a specific location. Taking into consideration the patient's health condition, doctors can choose the configuration of the ECG system, they have three choices: the first choice is to activate the 10 electrodes to have the result of a 12-lead ECG, the second choice is to keep 5 electrodes activated to have the graphs of a 5-lead ECG and the third choice is to leave only 3 electrodes activated to have the result of a 3-lead ECG.

The information collected from the heart sensors will be stored and sent to the server of the hospital, then the physician can analyze the medical record via web application. This application is dedicated mainly to health professionals, patients and the administrator who manages access and maintenance of the application.

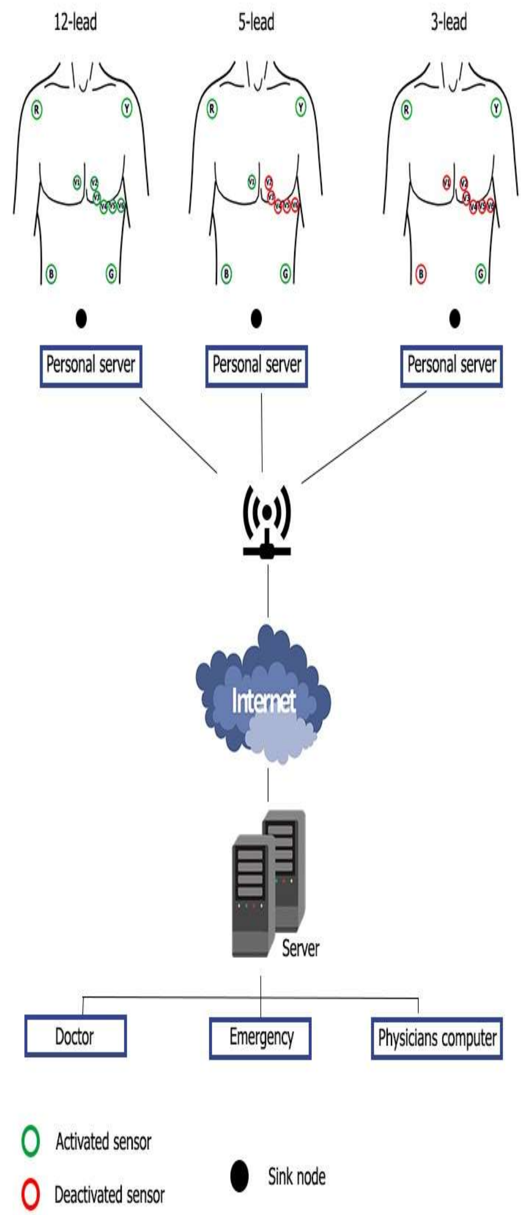

Figure 5: ECG system architecture

5. THE TOPOLOGY USED IN THE SYSTEM

In order to ensure efficient data routing, we propose a star topology in which all nodes are connected through a central node, our choice is based on the strong energy constraint in WSN. These nodes can only send or receive a message to or from the single central node [15]. They are not allowed to exchange messages directly with each other. The central node acts as a relay between the different nodes. To date, this topology is the most proposed and used for WBANs. This topology has advantages that can be summarized as simplicity, low energy consumption of the nodes and lower communication latency between the central node and the nodes [12].

6. THE COMMUNICATION TECHNOLOGIES USED

6.1 ZigBee technology

The proposed ECG system is equipped with sensors that are attached to the body of the patient for diagnosis and patient monitoring. Those sensors are connected via a communication protocol to form a wireless network. We have chosen ZigBee technology that is mainly used for health monitoring. ZigBee technology is supported by the IEEE802.15.4 standard, that standardizes the basic PHY and MAC layers of the network[9]. And it's can achieve machine-to-machine transmission with the extremely lowest cost, lowest data rate, and lowest energy consumption [18]. The following table gives summary of the difference between the most used communication protocols, such as WiFi, Bluetooth and Zigbee.

Table 1: Difference between the most used communication protocols [10].

Protocol	ZigBee	Bluetooth	Wifi
IEEE	802.15.4	802.15.1	802.11 a/b/g
Memory requirements	4-32 KB	250 Kb+	1M+
Autonomy	Years	Days	Hours
Nodes's number	65 000+	7	32
Transfer rate	250 Kb/s	1 Mb/s	11-54_108 Mb/s
Range	300 m	10-100 m	300 m

The protocols used in ZigBee use recent work on optimal path finding algorithms for communications, in particular the Adhoc On-demand Distance Vector (AODV) algorithm. It is a reactive routing algorithm, which means that it establishes a route to a destination only on request. If no device has information to send or receive, the network is silent.

This explains why equipment connected to a ZigBee network consumes very little energy (equipment is dormant up to 97% of the time). If a device wants to establish a communication, it sends a request and the network is then activated. At that time, all the devices that received the request relay the message, thus creating a set of possible routes. The AODV algorithm is responsible for defining the optimal route.

If this route does not work correctly, the process of finding another route is triggered again. This algorithm was designed to limit the number of messages to be transmitted to ensure that the network operates correctly. For example, if a route defined by the algorithm proves faulty, several transmission attempts will be made before triggering the search process for a new route. The beauty of the AODV algorithm is that once a route has been defined, it does not require any additional traffic other than that required for data transmission. But there is a drawback: to establish a connection, it takes longer than with other radio link standards.

Thus we can note that a sensor that uses ZigBee can have years of autonomy compared to the energy of its battery, unlike Bluetooth which lasts for days and wifi only for hours.

We can also see the number of nodes that ZigBee can connect (more than 65,000), is very high compared to Bluetooth (7) and wifi (32). In our solution we will only need a maximum of 12 sensors. On the other hand, the weak point of ZigBee compared to the others, lies in the level of the scope of each one. But this is not a problem in our case. ZigBee's range is 300 m, and we only need a maximum of one meter between 2 sensors in our network.

6.2 TinyOS system

We have chosen the TinyOS system to manage the communication between the sensors and it is the most used system in the applications based on sensors. The goal is to check the health status of the patient, and manage the configuration of the ECG system. The advantage of the tinyos system is that it is simple and powerful to program. It is entirely designed in NesC, which is a component-oriented language, similar in syntax to C language [10]. TinyOS was designed to meet the requirements and characteristics of sensor networks, which include small memory size, low power consumption, robust operations, intensive support operations, and power consumption optimization ([7], [16]).

7. SIMULATION

7.1 TinyViz

The TinyViz tool is a graphical application that allows us to have an overview of our network without having to deploy the sensors in the wild. Effort saving and material preservation are possible thanks to this tool, the application allows a step-by-step analysis by activating the different available modes. As we notice in Figure 6, the sensors are arranged in (in red) the software window, they are placed in space according to our topology. The top part (in blue) gathers all the commands allowing to intervene on the simulation.

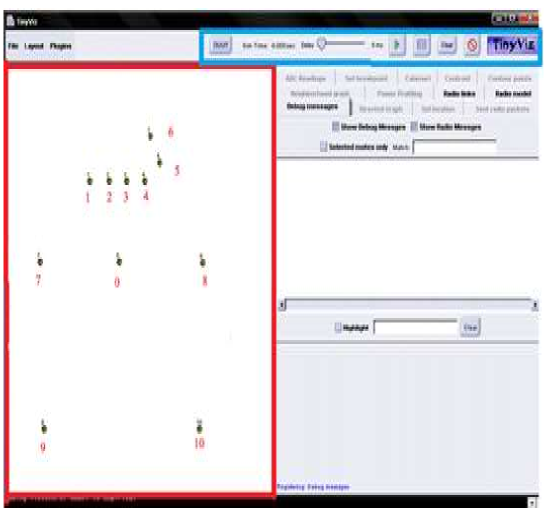

Figure 6: The TinyViz software window with spatial distribution

- On the pectorals of our patient will place 6 sensors, these are the sensors from 1 to 6 in Figure 6.
- On the right hand there is sensor 7, on the left hand there is sensor 8, on the right foot there is sensor 9 and on the left foot there is sensor 10.
- Finally in the middle, there is the Sink sensor which has the number 0.

7.2 Solution files

Our application called ECG is made up of the following components:

- a module, called "ECGM.nc".
- a configuration, called "ECG.nc".
- the header file, called "MessageECG.h".
- the configuration file "sensors.mps".

The configuration file bearing the name of the application itself with a particular extension (in our case ECG.nc) allows the NesC compiler to generate an executable file. ECG.nc is used to wire the module to other components that the ECG application requires.

7.3 The execution steps of our solution

In Figure 7 we find the sending of messages from node 6 until arriving at node 1.

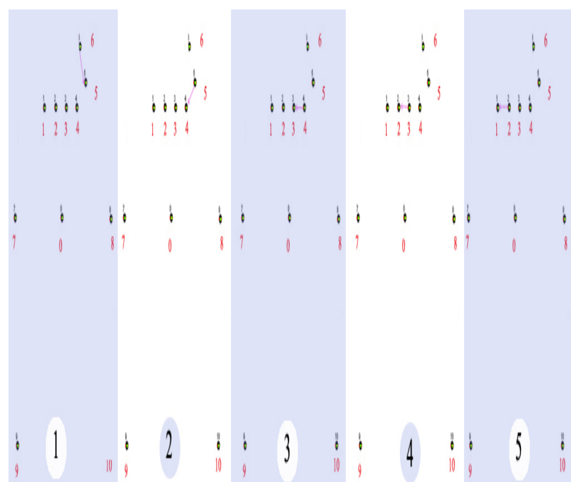

Figure 7: Sending messages from sensor 6 to sensor 1

The V6 sensor will send the value captured to the V5 sensor which in turn will send the value received from the V6 and the value captured by itself, and so on until arriving at the V1 sensor which will have the values captured by the 6 sensors.

In Figure 8 we find the sending of messages from node 1, 7, 8, 9, 10 to Sink sensor.

Journal of Theoretical and Applied Information Technology
30th June 2023. Vol.101. No 12

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

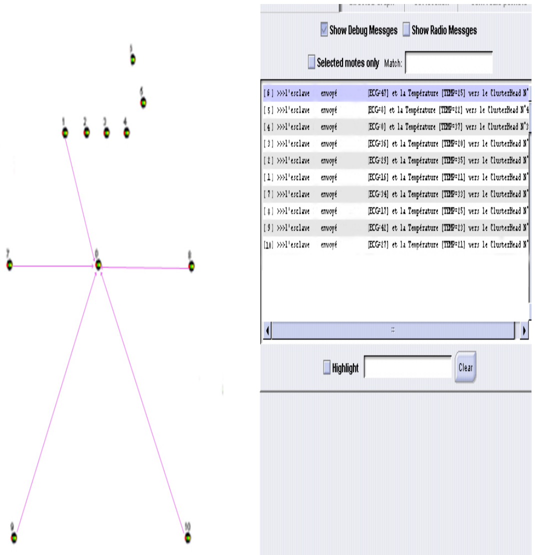

Figure 8: Sending messages to the Sink

The sensors 1, 8, 7, 10, 9 will send the captured values to the central sensor Sink (0) which will send all results at the workstation to generate the ECG signal.

8. CONCLUSION

In many applications, once the battery is depleted, the node becomes useless. This leaves us with the operation of the network as the average variable to extend the life of the battery and thus the network. The battery is still the primary source of power, although new ways to power the system have evolved. Batteries are a good fit, not only because they are the same size as the nodes, but battery-powered nodes are easier to deploy.

Therefore, the proposed ECG system architecture to remotely monitor patients, will reduce power consumption, based on the under the classical solution to this energy efficiency problem which is the management of the sensor activation period and by using the star topology in which all nodes are connected through a central node. These sensors are connected to each other through the zigbee communication protocol and they are managed by the TinyOS that also contribute in reducing energy consumption. Healthcare workers will be able to assess the patient's condition by the physiological information retrieved from the wireless sensor network.

We have proposed a WSN architecture for monitoring cardiac patients remotely, based on ZigBee and TinyOS to minimize the energy consumption of the sensors' batteries during communication. In the next works, we will implement the simulation on a real network to analyse the results and compare them with those present in the literature, while studying the problems of noise, security, etc.

REFERENCES:

[1] B. Mohamed, A. Ibriz, H. Mostafa: COOPERATIVE COMMUNICATION AND COOPERATION TECHNIQUES IN SENSOR NETWORKS, Journal of Theoretical and Applied Information Technology, Vol. 57(1), 2013, pp. 95-103.

[2] B. Gray, A. Kirby, P. Kabunga, S.B. Freedman, L. Yeates, A. Kanthan, C. Medi, A. Keech, C. Semsarian, R.W. Sy, Twelve - lead ambulatory electrocardiographic monitoring in Brugada syndrome: Potential diagnostic and prognostic implications, Heart Rhythm, 14(6) , 2017, pp. 866-874.

[3] B.J. Drew, R.M. Califf, M. Funk, E.S. Kaufman, M.W. Krucoff, M.M. Laks, P.W. Macfarlane, C. Sommargren, S. Swiryn, G.F. Van Hare, Practice standards for electrocardiographic monitoring in hospital settings: An American Heart Association scientific statement from the councils on cardiovascular nursing, clinical cardiology, and cardiovascular disease in the young, Circulation, 110(17) , 2004.

[4] C.M. Fort, A.M. Ciupe, S. Vlad, An ECG front-end device based on ADS1298 converter, IFMBE Proceedings, 59, 2016, pp. 99–102.

[5] D. Chung, J. Choi, J.H. Jang, T.Y. Kim, J. Byun, H. Park, H.S. Lim, R.W. Park, D. Yoon, Construction of an electrocardiogram database including 12 lead waveforms, Healthcare Informatics Research, 24(3), 2018.

[6] J.C.L. Himmelreich, E.P.M. Karregat, W.A.M. Lucassen, H.C.P.M. van Weert, J.R. de Groot, M. Louis Handoko, R. Nijveldt, R.E. Harskamp, Diagnostic accuracy of a smartphone-operated, single-lead electrocardiography device for detection of rhythm and conduction abnormalities in primary care, Annals of Family Medicine, 17(5), 2019, pp. 403–411.

[7] H.Y. Hsieh, C.H. Luo, C.C. Tai, Wireless potential difference electrocardiogram constituted by two electrode-pairs wearing comfort, Journal of Instrumentation, 15(8), 2020.

[8] K. Yoneyama, M. Naka, T. Harada, Y. Akashi, Creating 12-lead electrocardiogram waveforms using a three-lead bedside monitor to ensure appropriate monitoring, Journal of Arrhythmia, 36(6), 2020, pp. 1107–1108.

[9] M. Lakhal, M. Benslimane, M. Tmimi, A. Ibriz, Architecture of Real-Time Patient Health Monitoring Based on 5G Technologies, Advances in Science, Technology and Engineering Systems Journal, 6(2), 2021, pp. 351–358.

[10] M. Benslimane, A. Bouayad, A. Ibriz, H. Mostafa: Architecture of a telemedicine system for monitoring sick heart remotely, Journal of Theoretical and Applied Information Technology, Vol. 10(1), 2013, pp. 142-149.

[11] M. Simjanoska, M. Gjoreski, M. Gams, A.M. Bogdanova, Non-invasive blood pressure estimation from ECG using machine learning techniques, Sensors (Switzerland), 18(4), 1–20, 2018.

[12] N. Qaqos, S. R. M. Zeebaree, B. Hussan, Opnet Based Performance Analysis and Comparison Among Different Physical Network Topologies, Academic Journal of Nawroz University, 7(3), 2018, pp. 48–54.

[13] P. Kaewfoongrungsi, D. Hormdee, The comparison between linear regression derivings of 12-lead ECG signals from 5-lead system and EASI-lead system, 17th International Symposium on Communications and Information Technologies, ISCIT, 2017.

[14] S. Mcstay, Recording a 12-lead electrocardiogram (ECG), 2018, pp. 756–759.

[15] S. Obenofunde, S. Obenofunde, G. De, Gestion de la topologie dans les reseaux de capteurs sans fil, HAL Id: tel- 03114995 PhD IN Computer Science, 2021.

[15] S. Pramono, A.O. Putri, E. Warsito, B.S. Basuki, Comparative analysis of star topology and multihop topology outdoor propagation based on quality of service (QoS) of wireless sensor network (WSN), 2017 IEEE International Conference on Communication, Networks and Satellite, COMNETSAT 2017 - Proceedings, 2018, pp. 152–157.

[16] TinyOS Home Page, http://www.tinyos.net/, last accessed 24/03/2023.

[17] U.B. Baloglu, M. Talo, O. Yildirim, R.S. Tan, U.R. Acharya, Classification of myocardial infarction with multi-lead ECG signals and deep CNN, Pattern Recognition Letters, 122, pp 2019, 23–30.

[18] Z.K. Hussein, H.J. Hadi, M.R. Abdul-Mutaleb, Y.S. Mezaal, Low cost smart weather station using Arduino and ZigBee, Telkomnika (Telecommunication Computing Electronics and Control), 18(1), 2020, pp. 282–288.