Republic of Iraq
Ministry of Higher Education
and Scientific Research
University of Babylon
College of Engineering

Healthcare Monitoring System Based on Wireless Sensor Networks (WSN)

A Thesis

Submitted to the College of Engineering
of the University of Babylon in Partial Fulfillment
of the Requirements for the Degree of Master in Science
in Electronics and Communications Engineering

by

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Oct. 2013 ***1434***

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

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صَدَقَ اللَّهُ الْعَلِيّ الْعَظِيم

يوسف (76)

To my beloved family

To the memory of my father

Supervisor Certification

I certify that this thesis entitled "**Healthcare Monitoring System Based on Wireless Sensor Networks (WSN)**" was prepared by **Akram Jaddoa Khalaf** under my supervision at the Department of Electrical Engineering, College of Engineering, University of Babylon, as a partial fulfillment of the requirements for the degree of Master of Science in Electronics and Communications Engineering.

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Acknowledgments

In the name of Allah, Most Gracious, Most Merciful

First and above all, I praise ALLAH, the almighty for providing me this opportunity and granting me the capability to proceed this thesis.

I submit my highest appreciation to my thesis advisors, Dr. Mahmoud Shaker Nasr and Dr. Samir Jasim Mohammed, for their constant help, encouragement, guidance, patience and support through this research.

I would like to thank my friends and colleagues for their assistance, collaboration and friendship. I also thank the faculty and staff of the Department of Electrical Engineering for their kind support.

I am expressing my deepest gratitude to all those who gave me helpful hand through this study. I also acknowledge Merjan Hospital staff for all the facilities made available for me.

Finally, I would like to express my deepest gratitude and gratefulness to my family. The sacrifice they made throughout my years here are simply ineffable and whose endless love and encouragement enabled me to complete this work.

Abstract

Development of healthcare monitoring systems based on wireless sensor network (WSN) has seen a great increase extensively in previous years and so far. These systems are more prevalent because of the importance of human life and the provision of appropriate techniques to be applied. So they should be suitable for healthcare requirements.

In the present thesis, the researcher designed a real-time healthcare monitoring system based on WSN. The system senses and displays ECG, Heart Rate (HR), and temperature of a patient. The ECG is the main sensor in this system and the HR is calculated from ECG signal. The temperature of the human body is measured using thermistor. The ECG signal is displayed with high resolution graph in the graphical user interface (GUI). Also the GUI displays the HR as a value and the temperature as a value and indicator.

The system is characterized by its friendly GUI, easy to use, and very simple to manage by the doctor in charge. In addition that the system has the ability to detect and put in work any new node (patient node) automatically. Also, when any node fails in operation for any cause, the system states the problem of the system status. The system has the ability to integrate with the other systems which are based on other protocols such as the internet and also it is easy to develop with new requirements from the specialists.

We implemented the system with all steps including the selection of equipment and then operating, programming and calibrating this equipment to be able to deliver the correct information to the GUI. Also in the designed system we add the doctor node; this node is movable (doctor accompanied when he is out of Intensive Care Unit, ICU) which gives him an alarm signal for any abnormal case. Moreover, we achieved the home healthcare monitoring system using WSN and internet as important system improvement of monitoring the HR and Temp. for any patient outside the hospital.

In relation to the network which is used in this work is star topology and ZigBee wireless protocol. The software used are LabVIEW as a processing, GUI, and an auto alarm. The proposed system is designed to operate in hospital as well as in home healthcare.

The presented system is installed in Merjan Hospital – Babylon city and tested by the hospital specialist doctors for many cases; the obtained results are approved and very satisfactory.

LIST OF CONTENTS

ABBREVIATIONS

ADC	Analog to Digital Converter
APL	Application
APS	Application Support
BS	Base Station
CCA	Clear Channel Assessment
CMRR	Common Mode Rejection Ratio
CRC	Cyclic Redundancy Check
CS	Carrier Sense
CSMA	Carrier Sense Multiple Access
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
CTS	Clear-To-Send
DDS	Data Decision System
DRL	Driven Right Leg
DSP	Digital Signal Processors
ECG	Electrocardiograph, Electrocardiogram
ECG_{I}	ECG lead I
ECG_{II}	ECG lead II
ECG_{III}	ECG lead III
ED	Energy Detection
EEG	Electroencephalography
EMF	Electromotive Force
EMG	Electromyography
FCS	Frame Check Sequence
FPGA	Field Programmable Gate Arrays
GTS	Guaranteed Time Slot
GUI	Graphical User Interface
GW	Gateway
HPF	High Pass Filter
HR	Heart Rate
ICU	Intensive Care Unit
IDE	Integrated Development Environment
INA	Instrumentation amplifier
ISM	Industrial Scientific Medical

ISO	International Organization for Standardization
ITU	International Telecommunication Union
LA	Left Arm
LCD	Liquid-Crystal Display
LL	Left Leg
LPF	Low Pass Filter
LQI	Link Quality Indicator
MAC	Medium Access Control
MCU	Micro-Controller Unit
NTC	Negative Temperature Coefficient
NWK	Network
OS	Operating System
OSI	Open Systems Interconnection
PAN	Personal Area Networks
PDA	Personal Data Assistance
PHY	Physical
PTC	Positive Temperature Coefficient
RA	Right Arm
RF	Radio Frequency
RSS	Received Signal Strength
RTD	Resistance Temperature Detector
RTS	Request-To-Send
SW	Software
Temp	Body temperature sensor
UART	Universal Asynchronous Receiver/Transmitter
USB	Universal Serial Bus
WSN	Wireless Sensor Network
ZDO	ZigBee Device Objects

LIST OF TABLES

LIST OF FIGURES

Chapter One

Chapter One

Introduction

1.1 Background

The Wireless Sensor Network (WSN) is a new class of networks appeared in the last few years. The WSN dominates many applications like healthcare, environment, industrial, and military. The recent years have high attention in field of healthcare monitoring system [Fisal et al. 2009, Jin 2012, Chung et al. 2012] because WSN are considered as one of the keys that are used for improving the quality of life [Alemdar and Cem 2010].

The healthcare monitoring systems based on WSN may save humans lives using an alarm system for emergency case, storing the information in database for medical research, and decreasing the cost of medical services [Fisal et al. 2009]. The healthcare system can be classified to hospital care and home care; the hospital care can be classified to patient monitoring and environment monitoring. Owing to the development of sensors, batteries, processors, and wireless communication systems, the implementation of wearable device becomes possible. So WSNs have opportunity for realization of the wireless monitoring system.

The medical applications of wireless sensor networks aim to improve the existing healthcare and monitoring services especially for the elderly, children and chronically ill people. There are many terms for services or systems used for medicine/healthcare and information technology (IT) such as *E-health*, *Telehealth*, and *Telemedicine*. *Telemedicine* is the use of Information and Communication Technology (ICT) to deliver medical services and information from one location to another. *Telehealth* is the provision of healthcare at a distance using ICT, it is refer to clinical and non-clinical services such as medical education, administration, and research. *E-health* is the combined used of electronic communication and IT in the health sector. There are several benefits achieved with these systems. To begin with, remote monitoring capability is the main benefit of pervasive healthcare systems. With remote monitoring, the identification of emergency conditions for at risk patients will become easy and the people with different degrees of cognitive and physical disabilities will be enabled to have a more independent and easy life. The little children and babies will also be cared for in a more secure way while their parents are away. Thus, depending on the special care givers will be decreased [Alemdar and Cem 2010].

WSN consists of individual nodes that are able to interact with their environment by sensing or controlling physical parameters; these nodes have to collaborate to fulfill their tasks as, usually, a single node is incapable of doing so; and they use wireless communication to enable this collaboration. In essence, the nodes without such a network contain at least some computation, wireless communication, and sensing or control functionalities. Despite the fact that these networks also often include actuators, the term wireless sensor network has become the commonly accepted name. These WSNs are powerful in that they are amenable to support a lot of very different real-world applications; they are also a challenging research and an engineering problem because of this flexibility. Accordingly, there is no single set of requirements that clearly classifies all WSNs, and there is also not a single technical solution that includes the entire design space [Karl and Andreas 2007].

A wearable node which carries by the patient can be a big part of healthcare applications. Due to the nature of medical applications, however, it has to pass the correct physical information without any data loss, error, and end-to-end delay. Also, sensor nodes should be small, light-weighted, and low-power consuming to keep good mobility of patients and to reduce the cost of healthcare services [Jin 2012].

The sensors used in healthcare are Medical Sensors that combine transducers for detecting electrical, thermal, optical, chemical, genetic, and other signals to indicate the patient health status [Jeong et al. 2010]. The common most cause of death is the heart disease. So the electrocardiograph (ECG) can identify any case out of the ordinary activity of the heart. The most appropriate area of application for the WSN is ECG monitoring system [Kim et al. 2007]. The WSNs features are high reliability, low cost, low data rate, low power, and real-time. All these features make the WSN suitable for healthcare applications.

WSN requirements are the reason to develop global hardware and software standard such as ZigBee. ZigBee protocols are developed to allow different systems to work together [Pan and Yu-Chee 2006]. The Physical and Medium Access Control layers are defined by the 802.15.4 and ZigBee are defined the Network and Application layers [Jin 2012]. The ZigBee has many network topologies (star, tree, and mesh). Each method has its advantages that make it suitable for a particular application.

The core of WSN are the nodes which can be operated as coordinator, routers, or end devices. The coordinator is the heart of the network which connects the other nodes. Depend on the network topology the end nodes connect to router nodes or directly to coordinator. The WSN operates at the 433 MHz, 868 MHz, 915 MHz, and 2.4 GHz license-free Industrial Scientific Medical (ISM) frequency bands [Pan and Yu-Chee 2006, Dargie and Christian 2010, Kohvakka 2012].

1.2 Problem Definition

The health care system is developed for the purpose of preservation of human life. The traditional systems are complex, which leads to the difficulty to develop and deal with it at the time of the technological progress made in communication systems, networks and software. The traditional system use wires for communication between the devices (patients and central computer), and has limitations as follows:

- Restrict the movement of the patients to their association with fixed devices.

- The inability to monitor the patients except in hospitals where these devices are available.
- A fixed number of patients are covered by accommodate system.
- These systems can be updated only by reference to the companies equipped.
- Difficulty in integration with other networks.
- The system flexibility is low.

Since the WSN features, it is a promising technology for many applications; one of these applications is the healthcare to improve the quality of life. The advantages of using wireless system are:

- Patients no longer waste waiting time to meet their doctor.
- Patients free movement.
- The use of wireless healthcare systems outside the hospital helps to save the healthcare cost for care providers.
- WSN allow many patients to work while they are still under their doctor's care.
- Such systems can alert any medical emergency if specific vital signs change drastically, e.g., heart rate is beyond the norm [Jin 2012].

The following key principles should be kept in mind throughout the process for designing and implementation of the healthcare system:

- This is a healthcare problem, not a technology problem. At the center is the patient, not the technology.
- There is often more than one way to achieve a clinical or care objective, the first technology solution that appears may not be the best.
- The simpler the technology is, the better attraction solution will result.
- WSNs for healthcare are mission-critical; reliability is of paramount importance [Dishongh et al. 2009].
- Flexibility in extending the network.
- Friendly user interface.

- Emergency alert.

1.3 Literature Review

In this section some of the related works that have been developed related will be discussed.

The CodeBlue [Shnayder et al. 2005] projected from Harvard University explores WSN for a range of medical applications. It employs WSN in emergency medical care, hospitals and disaster area as an emergency message delivery system. With MICA motes, CodeBlue uses pulse oximetry and electrocardiogram (ECG) sensors to monitor and record blood oxygen and cardiac information from a large number of patients.

[Oliver and Flores 2005], Microsoft announced the HealthGear, a wearable real-time health monitoring system. It consists of several physiological sensors for monitoring and analyzing the blood oxygen level (SpO2), and heart rate [Jin 2012].

[Dagtas et al. 2007] presented a framework for a wireless health monitoring system within a smart home environment using ZigBee. They designed some basic processing platform that allows the heart rate and fatal failure detection. They are currently building a prototype of the proposed system using in-home ECG probes and ZigBee radio modules [Jin 2012].

[Kim et al. 2007] designed and implemented a ubiquitous Electrocardiogram (ECG) monitoring system using serial connection and wireless ZigBee network that can be used for remote ECG monitoring, analysis and diagnosis for homecare.

[Fisal et al. 2009] proposed a WBSN node platform with featuring a low cost ECG, a user-friendly graphical user interface (GUI) and also IEEE 802.15.4 based wireless sensor nodes.

[Almalkawi 2009] implemented a complete platform for health monitoring system using wireless sensor networks. It is developed a medical sensor (pulse oximeter) with popular Mica2 mote and have integrated the system with a host computer running a server to interpret and store the data in SQL data base.

[Jeong et al. 2010] introduced the WSN for healthcare challenges and provide examples of initial attempts to confront them.

[Alemdar and Cem 2010] evaluated the state of the art research activities and present issues that need to be addressed to enhance the quality of life for the elderly, children and chronically ill people. They provide survey of the recent research on future intelligent monitoring applications not only from a smart home perspective but rather from a more healthcare related perspective. They also discuss benefits that will be achieved and challenges that will be faced while designing the future healthcare applications.

[Chung et al. 2012] focused on the finding of optimized routing protocol for the wave-like health signals, such as ECG, EEG etc. The fast link exchange minimum cost routing protocol developed in their experiment shows very low wireless data packet and high reliable wave-like signal transmission in multi-hop communication.

[Chang et al. 2012] described the design and implementation of a WSN healthcare monitoring system for the care of elderly people living in nursing homes, using a clinical experiment to evaluate the system.

[Narendra et al. 2012] explained the important role of body sensor networks in medicine to minimize the need for caregivers and help the chronically ill and elderly people live an independent life, besides providing people with quality care. Although offered significant benefits, the field of wearable and implantable body sensor networks still faces major challenges and open research problems which are investigated and covered, along with some proposed solutions.

[Kumar 2012] designed a hardware and software with the WSN and a remote server. An onboard Data Decision System (DDS) has been designed to make a decision of the health states of the elderly according to the sensing data from sensor nodes. A low resource requires and high efficient database is designed for this system. Furthermore an Ethernet module is implemented to communicate with remote server and a GSM/GPRS module for sending emergency messages.

[Jin 2012] described the applications of wireless sensor networks in the healthcare area and discusses the related issues and challenges.

Some of the above works are theoretical and others are practical systems with some weak aspects such as not real-time, only one sign, and more complex. In relation to the presented system differ mainly by the following important features:

- Real time monitoring without delay.
- Multi sign.
- Auto detection for any new nodes.
- Portable alarm system with display.
- High resolution ECG monitoring.
- Auto detection for nodes failure and communication errors.

1.4 Aim of Thesis

The main goal of this thesis is to develop a healthcare system based on WSN which has many properties when compared to the traditional systems used in healthcare. Moreover, this system provides the advantages of being able to integrate with other modern networks in communications and networks. This system has more suitable features compared with to the previous systems, the desired features for real-time multi-patients monitoring and an alarm system with portable doctor alarm system. In addition, it has high system reliability, efficient network, and easy to use. The main objectives of this work are as follows:

- Design an effective system of healthcare that covers the required points mentioned in the problem definition.
- Hardware and software implementation of the system.
- Calibrating the results of the system.
- Testing the system actually under the supervision of the physician in charge.

We designed and implemented a real-time monitoring system for multi-patient and auto alarming system. The ECG, heart rate, and temperature for each patient are collected and sent to the computer for monitoring and alarm system. In case of any emergency for the patient the system automatically sends an alarm for remote doctor node.

1.5 Thesis Layout

The thesis is organized as follow:

- Chapter 1 "Introduction" presents a background of the thesis and its problem definition, goal and related work.
- Chapter 2 "Wireless Sensor Network (WSN) Concepts and Architecture" shows the WSN components and properties. Node architecture and protocol for WSN are also described.
- Chapter 3 "Healthcare Sensors" introduces some basic knowledge about biomedical sensors which are used for healthcare, including a definition and classification.
- Chapter 4 "System Design and Implementation". It represents the hardware, software and operation for the implemented system.
- Chapter 5 "Results and Discussion" shows the practical system results and their discussion.
- Chapter 6 " Conclusions and Future Works ". The thesis future works and its conclusions are explained in this chapter.

Chapter Two

Chapter Two

Wireless Sensor Network (WSN) Concepts and Architecture

The WSN consists of two main parts the nodes and wireless communication protocol. The main part is the node, which communicates with the other nodes using a wireless protocol. Each sensor node collects the physical measure using sensors related to node. In this chapter, the concepts of the WSN (node and protocol) and the node architecture are described.

2.1. Introduction

A wireless sensor network is a number of nodes organized into a wireless network. These nodes consist of processing capability (one or more microcontrollers, CPUs or DSP chips), may contain multiple types of memory (program, data and flash memories), have a RF transceiver (usually with a single omni-directional antenna), have a power source (e.g., batteries and solar cells), and contain various sensors and actuators. The wireless network connects all these nodes. The WSN systems may contain 1000's of nodes. Such systems can change the way we live and work [Stankovic 2008].

A simple equation can describe the concept of the WSN [Hill 2003, Sowjanya 2008, Imre 2009]: *Sensing + Processing + wireless telecommunication leads to numerous applications.*

Figure 2.1 shows the relation between the WSN parts. These parts will be explained in the next sections.

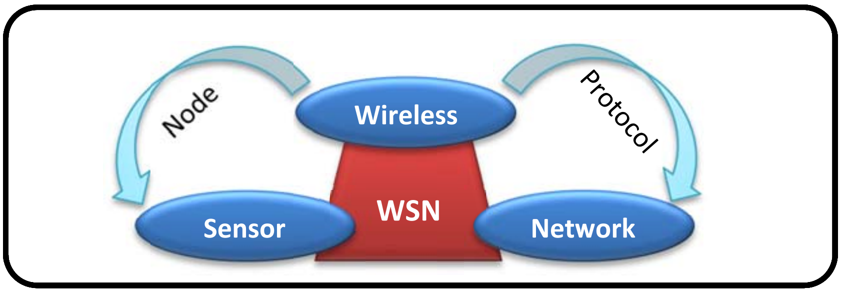


Fig. 2.1 The WSN parts

There is a wide ability of sensor nodes, simple sensor nodes may monitor a single physical phenomenon, while more complex devices may combine many different sensing techniques. Each sensor node (small in size) senses physical phenomenon, simple processes the sensing data, may stores it, and transmits these data wirelessly. The sensor node is often not only responsible for data collection, but also for in-network analysis, correlation, and integration of its own sensor data and data from other sensor nodes. Sensor nodes communicate not only with each other but also with a Base Station (BS) using their wireless radios (RF), allowing them to disseminate their sensor data to remote processing, visualization, analysis, and storage systems. Some nodes relay these data to other nodes. Where, the BS collects these data to perform system purpose like monitoring and controlling [Dargie and Christian 2010]. The basic concept of the WSN is shown in figure 2.2.

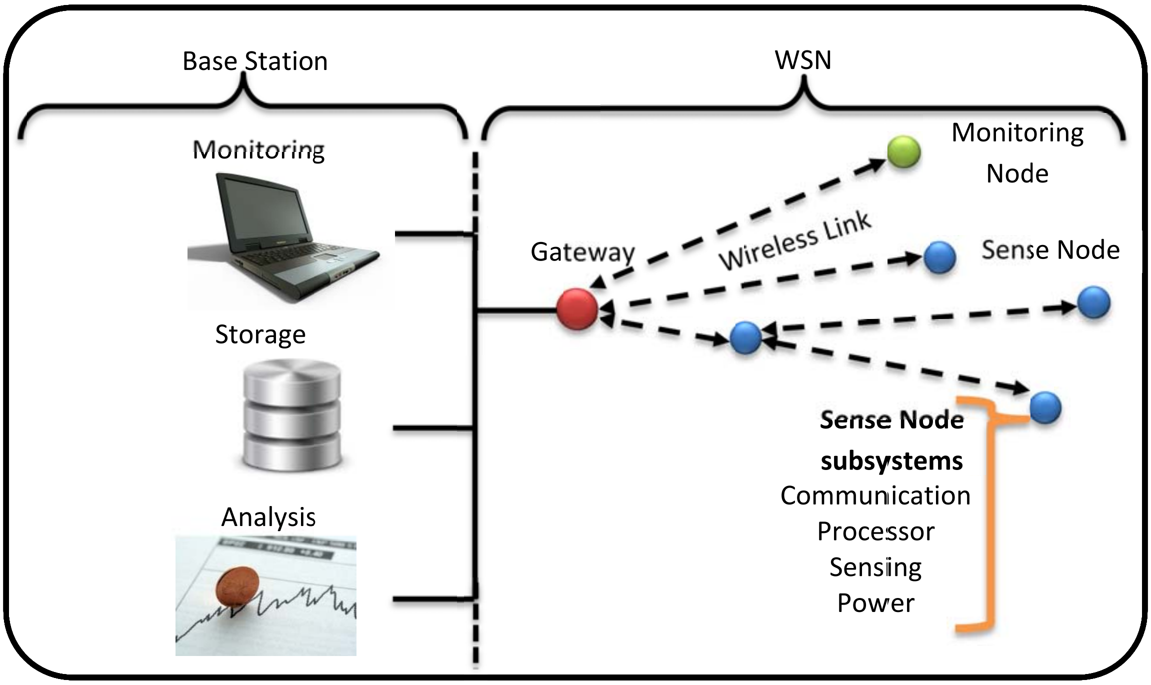


Fig. 2.2 The basic concept of the WSN

WSNs are a class of wireless networks. A wireless protocol connects the nodes, it should achieve the features of the WSN. These features are to meet the requirements of the sensing applications. Sometimes, these features can be constraints depend on the application requirements. The features of WSNs enable monitoring, object tracking, and control functionality [Kohvakka 2012].

The WSN features are:

- Low data rate and short-range broadcast communication.
- Low cost.
- Low power, memory, and computing.
- High reliability.
- Sensing application.
- Real-time.
- Self-organizing capabilities.

2.2 Node Architecture

The central element in a WSN is the wireless sensor nodes. Where the nodes are sensing, processing, communication take place, stores, and executes the communication protocols and the data-processing algorithms. The physical resources available to the node influence the quality, size, and frequency of the sensed data that can be extracted from the network. Therefore, the wireless sensor node design and implementation are a critical step [Dargie and Christian 2010, Mahmoud et al. 2013].

General sensor node platform hardware architecture is shown in figure 2.3, it can be divided into four subsystems [Kohvakka 2012]:

- ***Communication subsystem*** is enabling wireless communication.
- ***Sensing subsystem*** is connecting the wireless sensor node to the outside world.
- ***Processor subsystem*** is allowing data processing and the management of node functionality.

- ***Power subsystem*** is providing the system supply voltage.

So, the designer has a large number of options in deciding how to build and put together these subsystems into a unified, programmable node. In the following, details of each subsystem are presented.

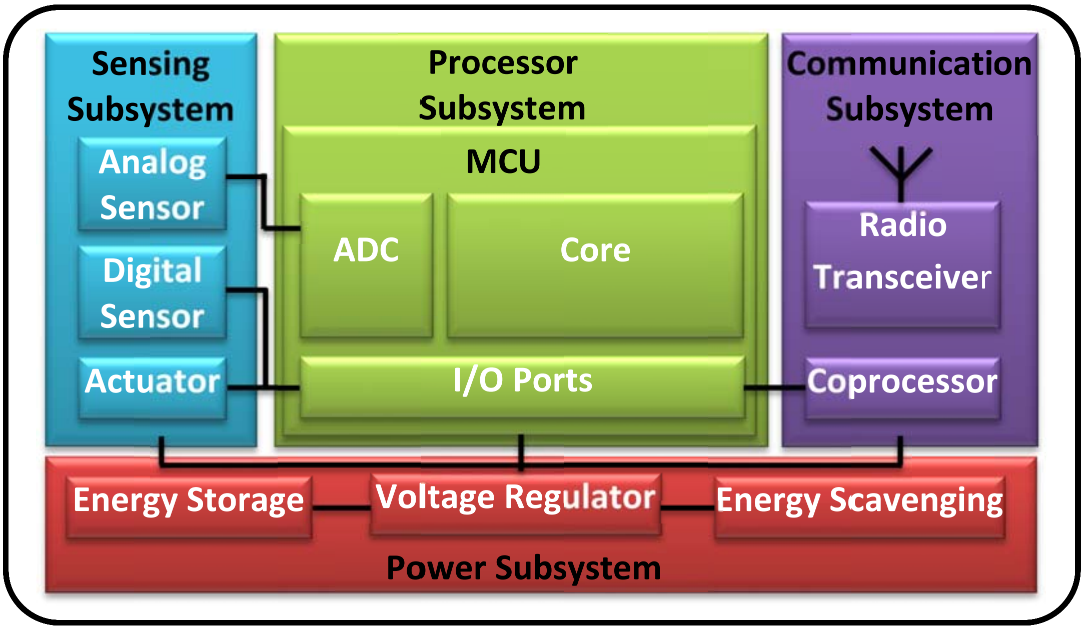


Fig. 2.3 General architecture of a wireless sensor node

2.2.1 Sensing Subsystem

One or more physical sensors are integrated the sensing subsystem and one or more analog-to-digital converters as well as the multiplexing mechanism to share them. The virtual world and the physical world are interfacing using the sensors [Dargie and Christian 2010].

A large variety of low power sensors which is suitable for WSNs exist such as air pressure, humidity, illumination, infrared, magnetic field, geographic position, and temperature. *Low power consumption*, *fast response time*, *and low cost* are important requirements for WSN's sensors to determine the energy consumption of a single sensing [Kohvakka 2012].

The sensors can be classified to Analog sensor and Digital sensor. The principle of the sensor based on the transducer which is a device that converts one form of energy into another form, typically into an electrical energy (voltage). The transducer's output is an analog signal having a continuous magnitude as a function of time. In this case, the sensing subsystem and the digital processor interface is an analog-to-digital converter (ADC). The digital sensors have built-in ADC which can be directly connected with the processor through a standard protocol. The microcontroller's analog interface is one or more internal ADC [Dargie and Christian 2010].

The ADC converts the analog input into a digital output. The conversion has two steps [Dargie and Christian 2010]:

A. The sampling frequency: In the WSN system this frequency is decided by the Nyquist rate.
B. Quantization: The analog signal converts from a continuous valued signal into a discrete valued signal; discrete both in time and magnitude. At this stage, the most important decision to determine the number of allowable discrete values which depends on two factors. The first one is the frequency and magnitude of the signal, and the second is the available processing and storage resources.

The ADC resolution is an expression of the number of bits that can be used to encode the digital output. It can be expressed in volts – since the output of most sensors is analog voltage. The ADC resolution is equal to peek-to-peek voltage divided by the number of levels [Dargie and Christian 2010].

$$Q(volt) = \frac{E_{pp}(volt)}{2^M} \quad \text{.......} \quad (2.1)$$

Where, Q is the ADC resolution (step value), E_{pp} is the peek-to-peek voltage, M is the ADC's bits, and 2^M is the quantization level.

2.2.2 Communication Subsystem

This subsystem contains of a wireless transceiver and antenna that is used to transmit and receive messages. The selection of a frequency channel and a transmit power, the modulation transmitted and demodulation of received data, symbol synchronization, and clock generation for received data are the functions of the transceivers. Some subsystems consist an embedded coprocessor to enhance the quality of received signals, cancel noise, and perform bit error corrections [Dargie and Christian 2010, Kohvakka 2012].

To reduce the processing requirements of Micro-Controller Unit (MCU), the transceiver may also include additional functions. For example, the physical layer for IEEE 802.15.4 has functions to enhance the wireless communication such as synchronization, link quality, bits error detection and correction, and network security. All these features can improve overall network energy-efficiently. On the other hand, it is increasing complexity which it raises hardware cost [Kohvakka 2012].

The communication subsystem is controlled by the processor subsystem which either turning it off or putting it in sleep mode. When it receives a packet that should be processed immediately, an interrupt signal may be raised by the communication subsystem [Dargie and Christian 2010].

The goals of designing the communication subsystem depend on the choice of a modulation technique. The relation between power consumption and spectrum efficiency are [Dargie and Christian 2010]:

- A power efficient modulator can transmit information at the lowest practical power cost.
- A spectrally efficient modulator can send as many bits of information as possible within a limited bandwidth.

These two efficients cannot be achieved at the same time for WSN.

2.2.3 Processor Subsystem

The processor unit that forms the processor subsystem is the central component of the node. The processor subsystem brings together all the other subsystems. The main purpose is to execute instructions related to sensing, communication, and self-organization. The tradeoff between flexibility and efficiency – in terms of both energy and performance depends on processor choice. The processor can be a microcontrollers (MCU), digital signal processors (DSP), or field programmable gate arrays (FPGA) [Dargie and Christian 2010, Kohvakka 2012].

The MCU is typically implemented for WSN, which consists of processor core with program and data memories, timers, configurable I/O ports, Analog-to-Digital Converter (ADC) and other peripherals. Where the program memory is flash memory, data memory are SRAM and Electrically Erasable Programmable Read-Only Memory (EEPROM) [Kohvakka 2012].

2.2.3.1 Microcontroller

A single integrated circuit is the microcontroller which consists of simple central processing unit, high-speed buses, memory unit, and external clock. Many products and embedded devices are integrated with the microcontrollers. It typically consists of the following components:

- CPU from 4-bit to 64-bit.
- RAM for data storage.
- ROM, EPROM, EEPROM, or flash memory for instruction code.
- I/O interfaces.
- Clock generator.
- Internal analog-to-digital converters.
- Serial communications interfaces.

The MCU is chosen over other types because of its programming flexibility. It is suitable for WSN because of its *small size*, *low power consumption*, and *low cost*. Assembly language and the C programming language can be used to program the most commercially available microcontrollers. However, DSPs and FPGAs are more powerful and efficient than the microcontrollers [Dargie and Christian 2010].

2.2.3.2 Operating Systems

A thin software layer that logically resides between the node's hardware and the application is the operating system (OS) in a WSN which provides basic programming abstractions to application developers. Each sensor node needs an OS that can control the hardware, provide hardware abstraction to application software, and fill in the gap between applications and the underlying hardware. The main task of the OS is to enable applications to interact with hardware resources, and to schedule tasks. Moreover, the following features include [Sohraby et al. 2007, Dargie and Christian 2010]:

- Memory management.
- Power management.
- File management.
- Networking.
- Interpreters.

The OS can be classified to single-task and multitasking. The single-task processes one task at a time while a multitasking operating system can execute multiple tasks simultaneously so multitasking operating systems require a large amount of memory. For example, in a wireless sensor node, the processor subsystem may interact with the communication subsystem while aggregating data that arrive from the sensing subsystem [Dargie and Christian 2010].

The major issues for the design of operation systems for WSNs are size (memory requirement), energy-efficient, task scheduling, and effective code [Sohraby et al. 2007].

2.2.4 Power Subsystem

All other subsystems are supplied by the power subsystem. It contains a battery, DC-DC converter, and energy scavenging. Moreover it may consist of additional components such as a voltage regulator. The DC–DC converter is used in providing the right amount of supply voltage to each individual hardware component by conversion of the main DC supply voltage into a suitable level. It can be a step-down (buck), or a step-up (boost) depending on the requirements of the individual subsystem [Dargie and Christian 2010].

An energy storage, a voltage regulator, and optionally an energy scavenging unit are the power subsystem components [Kohvakka 2012].

A. Energy Storage: It can be a non-rechargeable battery, a rechargeable battery, or a supercapacitor. Non-rechargeable batteries are cheap and have the highest energy density. Rechargeable batteries have lower energy density and are more expensive. Supercapacitors have lowest energy density and they are more expensive.
B. Voltage Regulators: It can be linear and switched-mode regulators. The first one controls the output voltage by adjusting the voltage drop across a series power transistor, which is located between the unregulated input and the regulated output voltage. So, it is simple, cheap, small, and have very low electromagnetic interferences. The second type converts and input voltage to a lower output voltage by a switching transistor that is opened and closed periodically. The output current is fed to a simple coil-capacitor (L-C) filter and a diode, which average the output voltage. It is expensive and large, and has high electromagnetic emissions. Typically, linear regulators are used for WSN.

C. Energy Scavenging: the self-powered devices are required because the energy storage has finite capacity. The scavenging is collecting the available energy from its surrounding environment to reduce the dependency on batteries [Kohvakka 2012].

2.3 Wireless Sensor Network Protocol

The International Organization for Standardization (ISO) characterizes and standardizes the internal functions of a communications system by partitioning it into abstraction layers in a conceptual model called the Open Systems Interconnection (OSI).

In recent years, many protocol standards in wireless communication of WSN are developed like ZigBee, Bluetooth, 6LoWPAN, Wireless HART, and SP100 [Marrón et al. 2011].

ZigBee is designed by the ZigBee Alliance and has a reliable, cost-effective, low-power, wirelessly networked monitoring and control product features. These features make it the most suitable for WSN. ZigBee includes IEEE 802.15.4 for the physical (PHY) and Medium Access Control (MAC) layers. In addition, the suite ZigBee protocol has network (NWK) and application (APL) layers support also. ZigBee aims to become the global control/sensor network standard by providing the following features [Cayirci and Chunming 2009]:

- low-cost, low-capacity devices;
- low power consumption;
- a simple and efficient protocol;
- scalability for high-density deployment;
- reliable short-range data transfer;
- an appropriate level of security

ZigBee is a standard for wireless Personal Area Networks (PAN) in which the contention based and contention free Medium Access Control (MAC) schemes are applied as their MAC standard [IEEE, 2006]. It is based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) [Pan and Yu-Chee 2006, Jin 2012].

ZigBee wireless networking protocol layers are shown in figure 2.4. The ZigBee protocol layers are based on the International Organization for Standardization (ISO) Open System Interconnect (OSI). The ISO/OSI model consists seven layers, but ZigBee implements only the layers that are essential for low-power, low-data rate wireless networking. The physical (PHY) and MAC layers are defined by the IEEE 802.15.4 standard and the network (NWK) and application (APL) layers are defined by the ZigBee standard [ISO 1994, IEEE 2006, Farahani 2011].

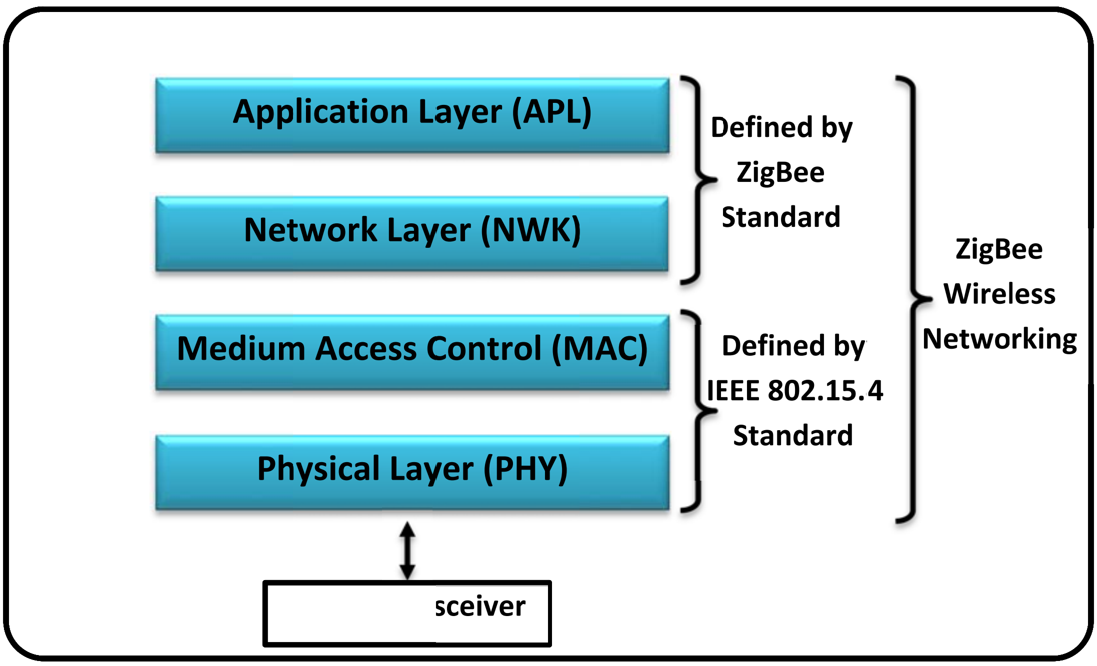
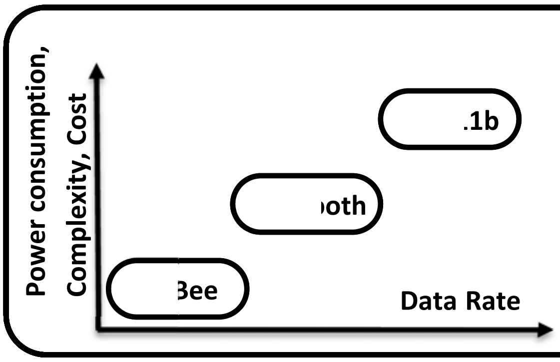


Fig. 2.4 ZigBee wireless networking protocol layers

2.4 ZigBee Protocol

The ZigBee standard is defined side by side with the IEEE 802.15.4 standard. As shown in figure 2.4, IEEE 802.15.4 standard defines specific layers of the protocol stack which are Physical (PHY) and (MAC) layers, while the ZigBee standard defines the rest layers of the protocol stack which are the network (NWK) and the application (APL) layers [Ian and Mehmet 2010, Jin 2012].

When compared with the other protocols, the Zigbee has the lowest data rate which provides the most power and the most cost-efficient solution as shown in Fig. 2.5. These advantages make ZigBee suitable for WSN requirements.



	Data Rate	Range	Examples
ZigBee	20-250 Kbps	10-100 m	WSN
Bluetooth	1-3 Mbps	2-10 m	Wireless mouse
802.11b	1-11 Mbps	30-100 m	Wireless internet

Fig. 2.5 Comparing ZigBee with Bluetooth and IEEE 802.11b

In the next subsections with more details, the (PHY and MAC) layers within IEEE 802.15.4 standard, and the (NWK and APL) layers within ZigBee standard.

2.4.1. Physical Layer

The ability of the wireless sensor nodes to communicate over a wireless link is one of the desirable aspects. So, it can support the mobile application, it is flexible deployment of nodes, the nodes can be placed in areas that are otherwise inaccessible to wired nodes [Dargie and Christian 2010].

In IEEE 802.15.4 PHY, there are three operating frequency bands with 27 radio channels. These bands are 868 MHz, 915 MHz, and 2.4 GHz. The channel arrangement is shown in figure 2.6. Channel 0 is in the frequency 868.0-868.6 MHz, which provides a data rate of 20 kbps. Channels 1 to 10 work in frequency 902.0-928.0 MHz and each channel provides a data rate of 40 kbps. Channels 11-26 are located in frequency 2.4-2.4835 GHz and each channel provides a data rate of 250 kbps [Pan and Yu-Chee 2006].

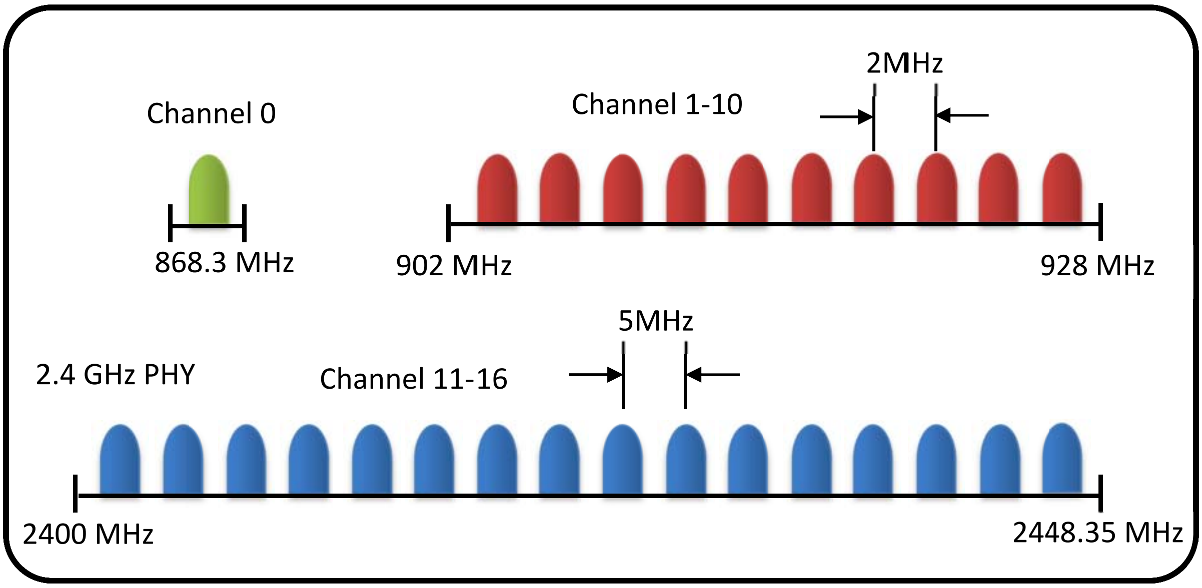


Fig. 2.6 the Channels in IEEE 802.15.4

The following definitions are important to be able to understand the functions of this layer:

i. **Channel Assignment:**

As previously explained, the PHY select the available channel. This process is called *Channel Assignments*. That means there is no other nearby devices use the same channel [Farahani 2011, Shafiullah et al. 2012].

ii. **Clear Channel Assessment (CCA)**:

Any device plans to transmit a message, the PHY performs a *clear channel assessment (CCA)* to ensure that the channel is not in use by any other device. That can be done using three modes depending on result of the *energy* *detection (ED)* and *carrier sense (CS)*. The ED detects and estimates the signal energy level in the desired channel without detection of the signal type (ED does not reveal whether this signal is an IEEE 802.15.4 standard or not). And ED procedure is not able to detect weak signals with energy levels close to the receiver sensitivity level. The CS detects the type of any possible signal that might be present in the desired channel. So the CS demodulates the received signal regardless of the signal energy level. If the signal is compliant to the IEEE 802.15.4, the CS is considered a busy channel [Farahani 2011].

IEEE 802.15.4 PHY is able to operate in any of CCA three modes, these modes are:

- Mode 1: The ED result only is taken to be considered as a busy channel.
- Mode 2: The CS result only is taken to be considered as a busy channel.
- Mode 3: An (AND/OR) combination of mode1 and mode2. So, mod3 can be ED AND CS or can be ED OR CS to be considered as a busy channel.

iii. Link Quality Indicator (LQI):

The quality of the data received by the receiver indicates by the *link quality indicator (LQI)*. The signal quality measure used is the *received signal strength (RSS)* which measures the total energy of the received signal. The LQI level uses from any other layers (MAC, NWK, and APL). For example, to decide the message path used, the NWK layer use the LQI levels of the devices in network which is the highest overall LQI [Farahani 2011].

iv. The physical Layer Tasks

The physical layer is the lowest layer of the protocol stack; it is responsible for the following [Ian and Mehmet 2010, Farahani 2011]:

- Frequency selection.
- Carrier frequency generation.

- Signal detection.
- Modulation and demodulation.
- Activating and deactivating the radio transceiver.
- Transmitting and receiving data.
- Performing ED. The ED is the task of estimating the signal energy within the frequency band of interest. This estimate is used to understand whether or not a channel is clear and can be used for transmission.
- Performing CCA.
- Generating an LQI. The LQI is an indication of the quality of the data packets received by the receiver. The signal strength can be used as an indication of signal quality.

3.4.2. Medium Access Control (MAC)

Multiple network devices must share the wireless medium; therefore to control access to the medium a mechanism is required. This responsibility is carried out by the second layer of the protocol stack which is the Medium Access Control (MAC) layer. The MAC layer full control over the medium because it operates directly on top of the physical layer. The MAC layer main function is to decide when a node accesses a shared medium and to resolve any potential conflicts between competing nodes. Additionally, it is responsible for correcting communication errors occurring at the physical layer and performing other activities such as framing, addressing, and flow control [Dargie and Christian 2010].

The following functions are important to be able to clarify the tasks of this layer:

i. CSMA-CA:

The mechanism used for channel access is *Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA)*. This mechanism performs at any transmission time to ensure that the channel is not in use by any other device. Anytime a device wants to transmit a signal, it first goes into receive mode to detect and estimate the signal energy level (ED) AND/OR carrier sense (CS) in the desired channel. If the channel is not clear, the device backs off for a random period of time and tries again [Farahani 2011].

First in CSMA, the node goes to receiving mode to listen to the medium, the node starts transmission immediately if the medium is found to be idle, or the node performs a backoff operation if the medium is busy, it waits for a certain amount of time before attempting to transmit again [Karl and Andreas 2007].

Second in CSMA/CA (CSMA with Collision Avoidance), a variation of CSMA that aims to improve the performance by avoiding collisions is called CSMA/CA. In CSMA/CA, the nodes not immediately access the channel after sense the medium and it is found idle. The node waits for a time period plus the random backoff value. If there are multiple nodes attempting to access the medium, the one with the shorter backoff period will win [Karl and Andreas 2007].

ii. Device Roles:

There are three types of devices in ZigBee standard, the coordinator, the router, and the end device. In any ZigBee network, there is *one coordinator* and number of *routers* and *end devices*. The coordinator responsibility is to start and manage the network [Farahani 2011].

iii. Beacon-Enabled vs. Nonbeacon Networking:

Beacon is a specific format packet that is used to synchronize the clocks of the nodes in the network. Beacon signals are transmitting by the coordinator to synchronize the devices attached to it. If the network uses the beacon signal, it is called beacon-enabled PAN. The beacon-enabled PAN has the disadvantage that all the devices in the network must wake up on a regular basis, listen for the beacon, synchronize their clocks, and go back to sleep. The battery life of a device in a beacon enabled network is normally less than a network with no beaconing because many devices in the network may wake up only for synchronization and not perform any other task while they are active [Farahani 2011].

iv. Contention Based and Contention Free:

There are two methods for channel access: contention based or contention free [Farahani 2011]:

- *Contention-based channel access*: For the same frequency channel, all devices that want to transmit use the CSMA-CA mechanism which the first one that finds the channel clear starts transmitting.
- *Contention-free channel access:* A specific time slot to a particular device dedicates by the coordinator. This slot is called a *guaranteed time slot* (GTS). At the GTS allocated to the device can start transmitting during that GTS without using the CSMA-CA mechanism.

In beacon, the devices use contention-based or contention-free to access the channel and called slotted. But in nonbeacon, the devices use contention-base only and are called unslotted.

v. Data Transfer:

Three data transfer models are defined by IEEE 802.15.4: 1) data transmission to a coordinator, 2) data transmission from a coordinator, and 3) data transmission between peers. The star networks use the first two models and the peer-to-peer networks use the third one. These models are introduced as follows [Pan and Yu-Chee 2006, Karl and Andreas 2007, Farahani 2011]:

- *Data transmission to a coordinator*: In a beacon-enabled network, devices that have data to send synchronizes its clock on a regular basis and transmits the data to the coordinator using the CSMA-CA method to contend for channels after receiving beacons. The coordinator may acknowledge the reception of the date. In a non-beacon-enabled network, device transmits the data as soon as the channel is clear using the unslotted CSMA/CA mechanism. The coordinator may acknowledge the reception of the date in the beacon or nonbeacon. Figure 2.7 shows the data transfer sequence in a beacon and nonbeacon network.

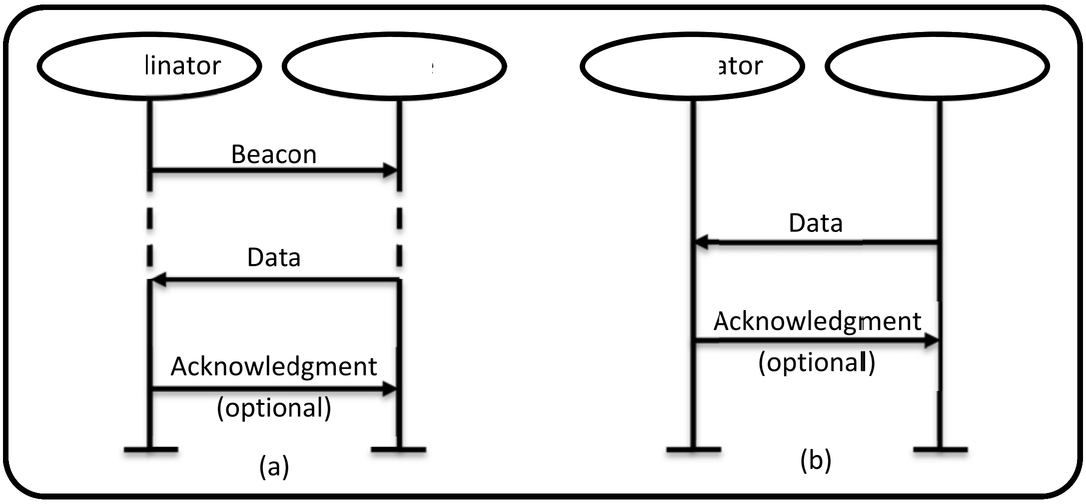


Fig. 2.7 Data transmission to a coordinator
(a) in a beacon-enabled network, (b) in a non-beacon-enable network

- *Data transmission from a coordinator*: In a beacon-enabled network, the coordinator indicates in its beacon message that a data message is pending for that device. If the device is active and ready to receive the data, it sends a data request message to the coordinator. Optionally, the coordinator acknowledges the receipt of the data request. In a non-beacon-enabled network, the device requests the data from the coordinator. If there is no data pending for that device, the coordinator sends an acknowledgment message that indicates there is no data pending for that device. Figure 2.8 shows the data transfer sequence from coordinator in a beacon and nonbeacon network.

- *Data transmission between peers*: peers cannot send data to each other directly in a beacon-enabled network. But, in a non-beacon-enabled network, peers can directly transmit data to each other.

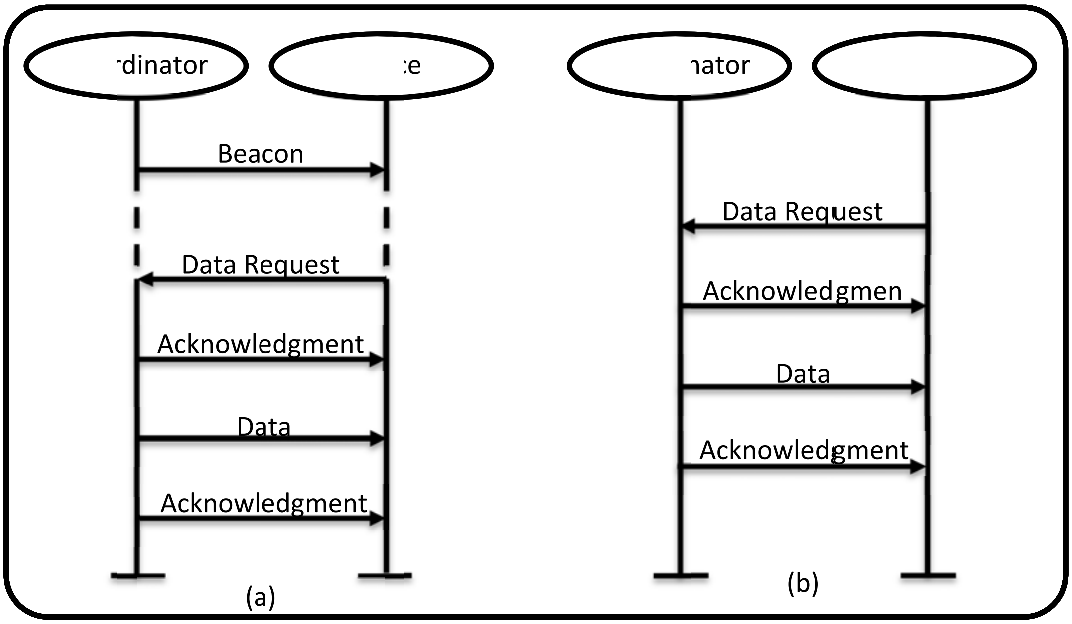


Fig. 2.8 Data transmission from a coordinator
(a) in a beacon-enabled network, (b) in a non-beacon-enable network

vi. Hidden and Exposed Node Problems:

A *hidden terminal* refers to the node within the range of the intended destination but out of range of the sender, so the hidden terminal cannot be aware of the ongoing transmission. The hidden node (terminal) problem is a weakness of the CSMA-CA. For example shown in figure 2.9a, nodes A and B are not able to receive each other's signals which these nodes A and B can communicate with node B. If node C is transmitting, the node A cannot detect this signal (is too weak), and can decide the frequency channel available. This will create a collision of packets. The way to overcome this issue is changing the location, increasing the output power of nodes, or using request-to-send/clear-to-send (RTS/CTS) handshake mechanism.

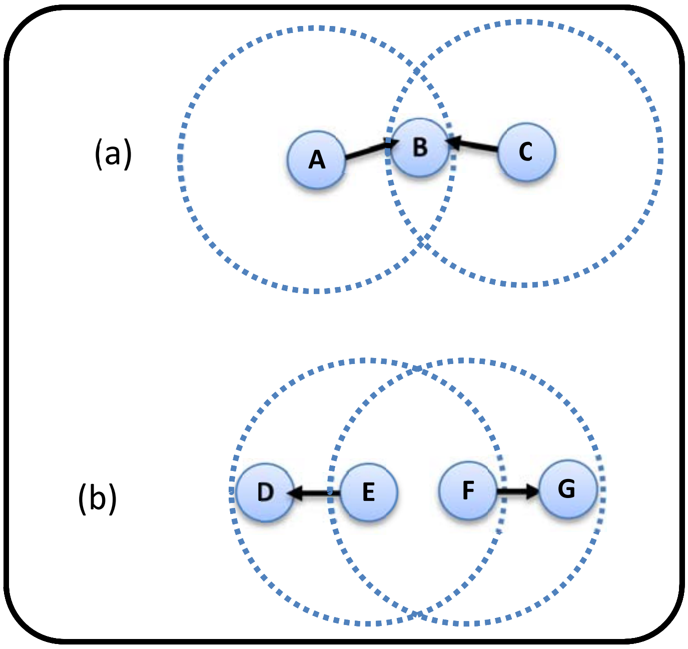


Fig. 2.9 Node problems (a) The hidden node problem and
(b) The exposed node problem

An *exposed terminal* is the node within the range of the sender but out of range of the destination, so the exposed terminal will be improperly precluded from sending in order to avoid collision. In example shown in figure 2.8b, node E intends to transmit a message to node D while node **F** is transmitting a message to node G. Node E and node F can concurrently transmit without any collision issue because Node D is outside the radio influence of node F. because, node E is in the radio influence of node F, CSMA-CA will prevent node E from transmitting. The way to overcome this issue is changing the location, decreasing the output power of nodes, or using (RTS/CTS) handshake mechanism [Ilyas and Imad 2005, Farahani 2011].

vii. Data Verification and Error Detection:

A number of bits transmitted together with a specific format is called *packet*. There is receiver mechanism to verify any of the received bits are recovered in error. A 16-bit Frame Check Sequence (FCS) based on the

International Telecommunication Union (ITU) Cyclic Redundancy Check (CRC) to detect possible errors in the data packet [Farahani 2011].

viii. Association and Disassociation:

IEEE 802.15.4 provides *Association* and *disassociation* services that can be used to allow devices to join or leave a network. For example, a device sends an association request to the coordinator to join a PAN. The device request can be accepted or rejected by the coordinator. If the device intent to leave the network, it is used the disassociation to notify the coordinator [Pan and Yu-Chee 2006, Farahani 2011]. Figure 2.10 shows this procedure.

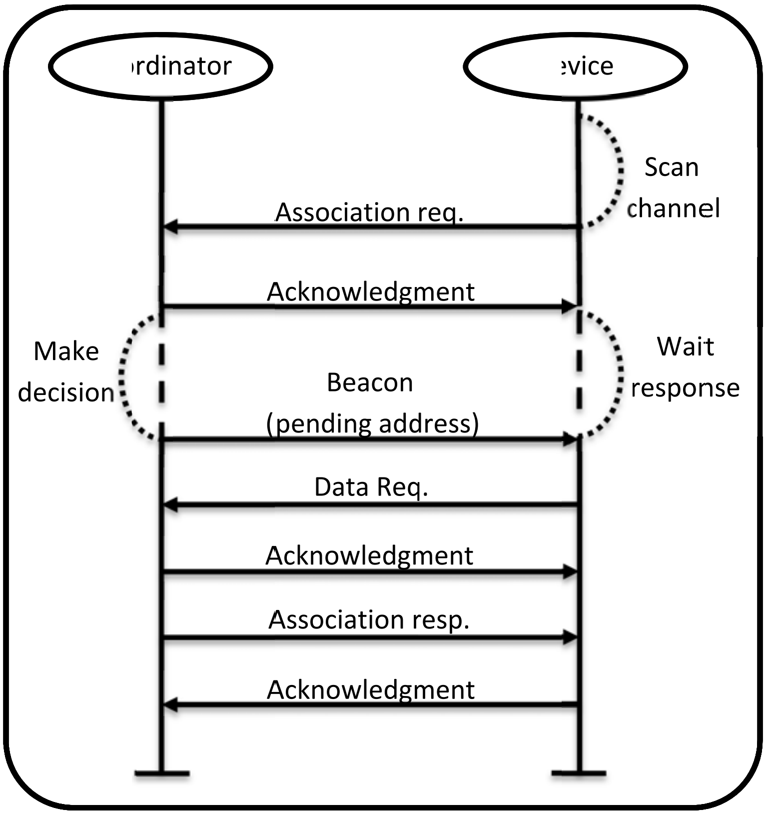


Fig. 2.10 The association procedure

ix. The MAC performs the following duties: [Farahani 2011]

- Generating beacons (if the device is a coordinator in beacon-enabled).
- Synchronizing the device.

- Employing the CSMA-CA for channel access.
- Managing GTS channel access.
- Providing a reliable link between two peer MAC entities (two different devices).
- Providing PAN association and disassociation services.
- Providing support for security; the MAC layer is responsible for its own security processing, but the upper layers determine which security level to use.

The PHY and MAC layers are specified for low-rate wireless personal area networks. Devices that are within each other’s transmission range are specification only concerns communications. For larger sensor networks, the support of network layer protocols is needed. In the next sections, we will introduce ZigBee standard, which supports protocols above the MAC [Pan and Yu-Chee 2006].

3.4.3. Network Layer (NWK)

The NWK layer which interfaces between the MAC and the APL layers is responsible for managing the network formation and routing. The process of selecting the path through which the message will be relayed to its destination device called Routing. The ZigBee devices that are the coordinator and the routers only are responsible for discovering and maintaining the routes in the network. But the ZigBee end device cannot perform routing process, where the other devices will perform route discovery on behalf of the end device. The NWK layer of a ZigBee coordinator is responsible for establishing a new network, selecting the network topology (tree, star, or mesh), and assigns the NWK addresses to the devices in its network [Farahani 2011].

The following concepts show the NWK layer responsibility:

i. Addressing:

A unique address assigns to each device in the network. There are two methods of addressing [Farahani 2011]:

- 16-bit short addressing.
- 64-bit extended addressing.

The network can use any of these addressing (16-bit or 64-bit). In a single network, the short address allows communication where the short addressing mechanism allows for a reduction in the length of the messages which saves on required memory space that is allocated for storing the addresses. For communication between independent networks, a combination of a unique PAN identifier and a short address can be used [Farahani 2011].

A 64-bit addressing can maximize the number of devices in the network which approximately $1.8*10^{19}$ addresses. So, the network has practically no limit on the number of devices that can join the network [Farahani 2011].

The NWK layer of a ZigBee coordinator responsibly is to assign the 16-bit addressing. If a new device that joins its network needs a MAC address, The ZigBee coordinator assigns the IEEE 802.15.4 MAC address which is the 64-bit addressing. The network address must be the same as the 16-bit IEEE 802.15.4 MAC short address assigned to the device [Farahani 2011].

ii. Communication Mechanism:

There are three general categories for the communication mechanism which are *broadcast*, *multicast*, and *unicast*. The broadcast mechanism is intended for any device that receives the message. The multicast mechanism is delivering the message to a specific group of devices in a network where the unicast mechanism is delivering the message to specific device. Figure 2.11 shows the communication mechanism [Farahani 2011].

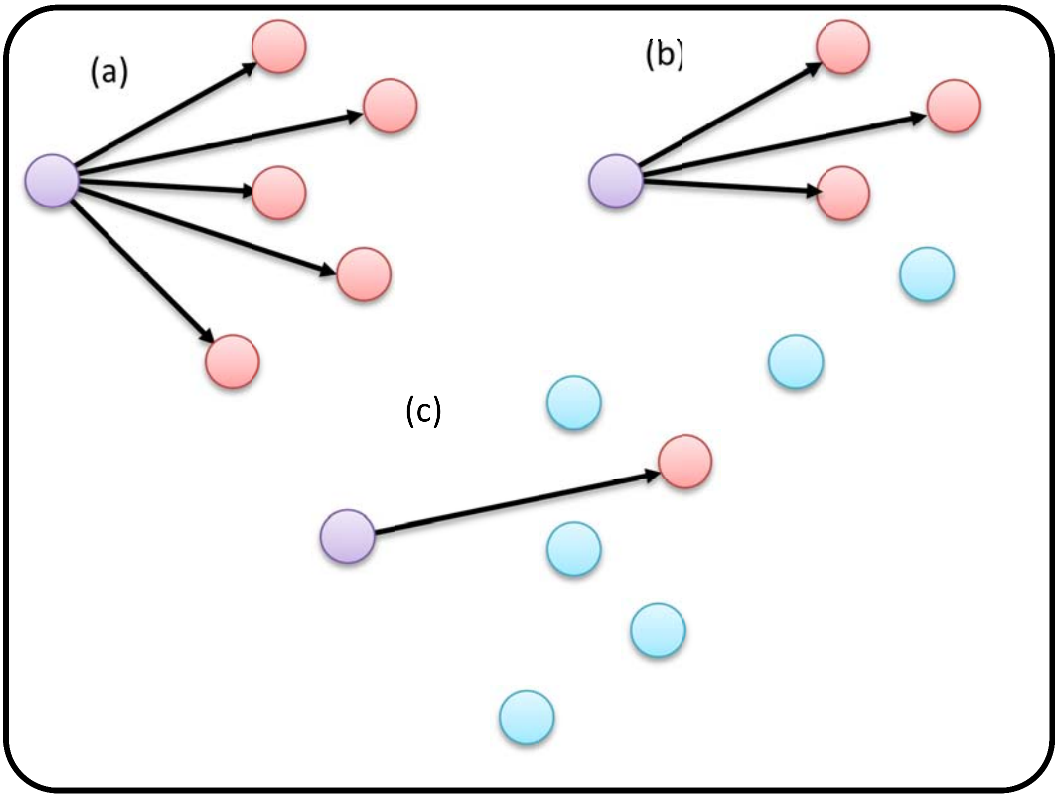


Fig. 2.11 Communication mechanisms
(a) Broadcast, (b) Multicast, and (c) Unicast

iii. Network Topologies:

The NWK layer can support three types of network: *star*, *tree*, and *mesh*. Initializing, maintaining, and controlling the network are the ZigBee coordinator responsibility. In star network, all devices are directly connecting to the coordinator. In mesh and tree networks, all devices can communicate with each other in a multihop fashion which one ZigBee coordinator and multiple ZigBee routers which are the network backbone. Beacons can use in tree network by the coordinator and the routers but in mesh network, beacons are not allowed. In a mesh network, devices can only communicate with each other by peer-to-peer transmissions. Examples of topologies are shown in Fig. 2.12 [Pan and Yu-Chee 2006].

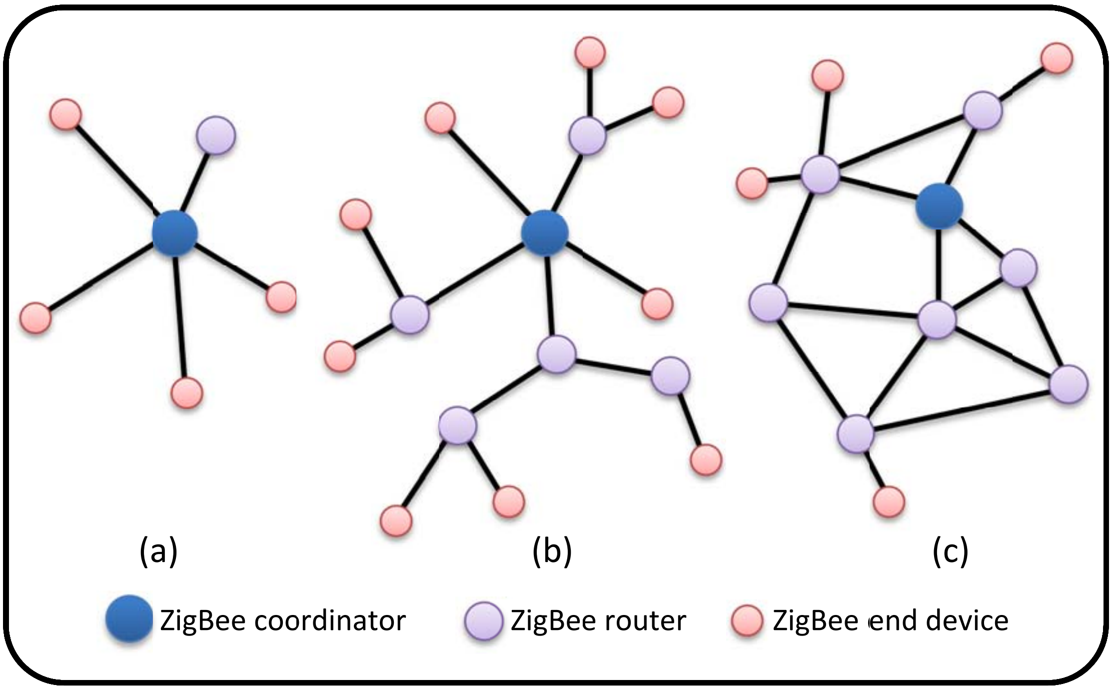


Fig. 2.12 ZigBee network topologies: (a) Star, (b) Tree, and (c) Mesh

Any device has coordinator-capability and currently not joined a network, can be a ZigBee coordinators. The ZigBee coordinator scans all channels to find a suitable one that called channel selection. After that, the ZigBee coordinator initializes a PAN by broadcasts a beacon containing a PAN identifier. The other devices that receive beacons of an existing network can join this network by performing the association procedures, as a ZigBee router or as an end device. The coordinator determines whether to accept this device or not by considering its current capacity and its permitted association duration, and sends association response if a device is successfully associated. The association response will contain a short 16-bit address for the request sender that is the network address for that device [Pan and Yu-Chee 2006].

ZigBee is designed to support low-cost network layer. It supports three kinds of network topologies, which are star, tree, and mesh networks. Network developers can choose a suitable network topology for their applications. The pros and cons of these three topologies are summarized in Table 2.1 [Pan and Yu-Chee 2006].

Table 2.1 ZigBee network topologies pros and cons.

	Pros	Cons
Star	1. Easy to synchronize. 2. Low power operation. 3. Very low delay.	1. Small scale.
Tree	1. Low routing. 2. Allow multihop communication.	1. Route reconstruction is costly. 2. High delay.
Mesh	1. Robust network. 2. Low delay.	1. Route discovery is costly. 2. High storage for routing table.

iv. The NWK layer responsibility

The NWK layer is responsible for the following operations [Farahani 2011]**:**

- Configuring a new device. Here, a new device can be configured to begin its operation as a ZigBee coordinator or try to join an existing network.
- Starting a new network.
- Joining and leaving a network.
- Applying NWK layer security.
- Relay messages.
- Discovering and maintaining routes between devices. This is the ability to discover and record paths through the network for efficient routing of the messages.
- Discovering one-hop neighbors. These are the devices that can be reached directly without using any other device relay service.
- Storing pertinent one-hop neighbor information.
- Assigning addresses to devices joining the network. Only ZigBee coordinators and routers can assign addresses.

3.4.4. Application Layer

The highest protocol layer in the ZigBee wireless network is the application (APL) layer which hosts the application objects. The application objects are developed by manufacturers to customize a device for various applications. The protocol layers in a ZigBee device are controlled and managed by the application objects. In a single device, there can be up to 240 application objects [Farahani 2011].

There are three sections of the ZigBee APL layer, shown in figure 3.13, the *application support* (APS) sublayer, *ZigBee Device Objects* (ZDO), and the *application framework.*

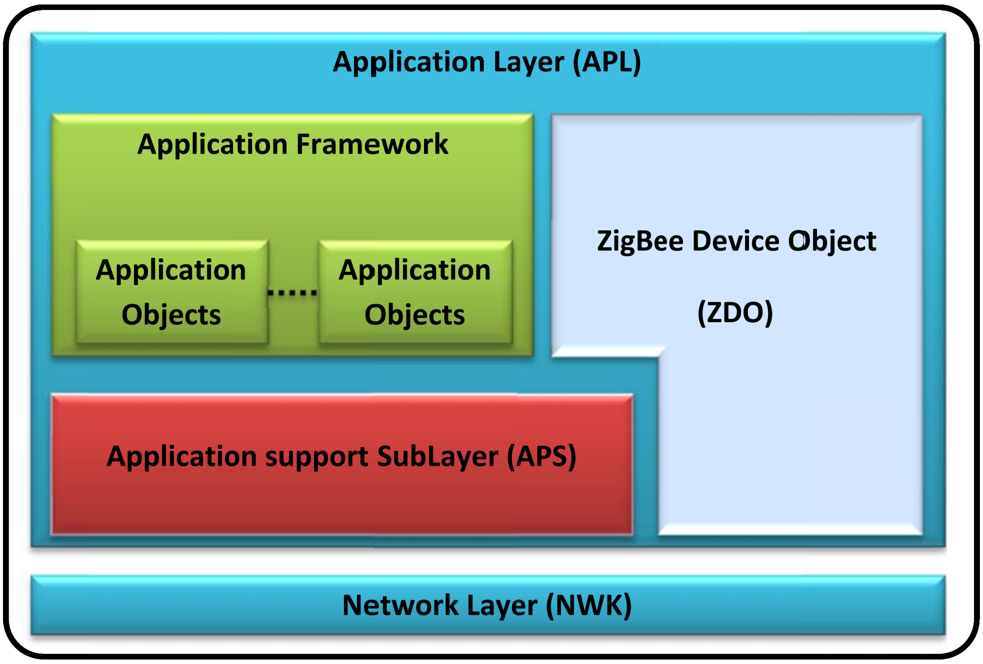


Fig. 2.13 The ZigBee APL Layer

- The *application support sublayer (APS)* is providing an interface between the network layer (NWK) and the application layer (APL).
- The *ZigBee Device Objects (ZDO)* is providing an interface between the APS sublayer and the application framework. The ZDO contains the functionalities that are common in all applications operating on a ZigBee

protocol stack. For example, the ZDO is responsible of configuring the device in one of three possible logical types of ZigBee coordinator, ZigBee router, or ZigBee end device.

- The environment in ZigBee is the *application framework* in which application objects are hosted to control and manage the protocol layers in a ZigBee device. Application objects are developed by manufacturers, and that is where a device is customized for various applications. There can be up to 240 application objects in a single device [Farahani 2011].

i. **Binding**:

Binding is the task of creating logical links between the applications that are related. For example, a ZigBee device connected to a lamp is logically related to another ZigBee device connected to the switch that controls the lamp. The information regarding these logical links is stored in a binding table. The ZigBee standard, at the application layer, provides support for creating and maintaining binding tables. Devices logically related in a binding table are called bound devices.

ii. The APL Layer Responsibilities

The APL Layer Responsibilities are:

- Application Support (APS) sublayer provides an interface between the network layer (NWK) and the application layer (APL). The following are application support sublayer responsibilities:
  - Maintain binding tables.
  - Forward messages between bound devices.
  - Manage group addresses.
  - Map 64 -bit IEEE address to 16-bit network address, and vice versa.

- ZigBee Device Objects (ZDO) use NWK and APS sublayer services to implement a device in one of three ZigBee roles: ZigBee coordinator, router, or device:
    - o Define the role of the device in the network.
    - o Discover the devices on the network and their application. Initiate or respond to binding requests.
    - o Perform security-related tasks.
- The application framework in ZigBee is the environment in which application objects are hosted.

2.5 Applications

WSN dominates the large number of applications; some of these applications can be classified as follows:

i. Military Applications:

   i. Monitoring hostile forces.
   ii. Monitoring friendly forces and equipment.
   iii. Battlefield observation.
   and more

ii. Environmental applications:

   i. Microclimates.
   ii. Forest fire detection.
   iii. Flood detection.
   and more

iii. Health applications:

   i. Medical sensing.
   ii. Tracking and monitoring doctors and patients inside a hospital.
   iii. Micro-surgery.
   and more

iv. Home applications:

i. Home automation.

ii. Home environment.

iii. Automated meter reading.

and more

v. Commercial applications:

i. Environmental control in industrial and office buildings.

ii. Inventory control.

iii. Vehicle tracking and detection.

and more

Chapter Three

Chapter Three

Healthcare Sensors

As stated previously, there are numerous applications for WSNs, where each application has certain sensors. In other words, different sensors are used for different applications. Generally ***low power***, ***fast response time***, and ***low cost*** sensors are used for WSN. The sensors used for healthcare applications are relative to the human body, these sensors are called biomedical sensors. Some of biomedical sensors are explained in this chapter.

3.1 Introduction

A sensor is a transducer that converts the measured (a quantity or a parameter) into electrical signal carrying information. The biomedical sensor is a very important kind of sensors. First we will introduce some basic knowledge about biomedical sensors including a definition and classification.

The sensors can provide information about the physical, chemical or biological state of a system. So, sensor detection technology is one that uses sensors to transform measured quantities into physical quantities which are easy for communication and processing, and then goes on with transformation, communication, displaying, recording and analyzing. The biomedical sensors are special electronic devices which can transfer various electrical or non-electrical quantities in biomedical fields into easily detectable electrical quantities. Therefore, they are incorporated into healthcare systems. Biomedical sensing technology is collecting human physiological and pathological information and is also an important branch [Wang and Quingjun 2011].

The properties of biomedical signals are usually weak, random with strong noise and interference, and allowing dynamic change. Therefore, *biomedical measurement technologies are more complex and rigid than* *common industrial detection technology*. They involve the detection of physical, chemical and biological signals. For example of these types [Harsányi 2000, Wang and Quingjun 2011]:

- **Electrical physiological** signals such as ECG, EEG, and EMG.
- **Non-electrical physiological** signals such as blood pressure, body temperature, breath, blood flow and pulse.
- **Chemical or biological** signals such as blood and urine.
- **Biological signals** such as enzymes, proteins, antibodies and antigens.

Some of the previously mentioned signals (ECG and body temperature) are explained in the next sections with more details.

The specificity of biomedical measurement is used for human signal detection and is a non-invasive, safe and reliable measurement. In recent years, it has become an important research project. Non-invasive detection is easily administered to people because there is no wound or a slight wound. It helps to keep the physiological status of objects, and long-time or real-time monitoring can take place. Therefore it is convenient for clinical examination, monitoring and recovery evaluation. Non-invasive detection has become an important part of biomedical measurement technology [Wang and Quingjun 2011].

The development of the medical sensor has basically changed the traditional mode, forming the development trend of smart, micro, multi-parameter, remote-control and noninvasive, and achieved some technical breakthroughs. The revolution of medical sensor technology helps the development of modern medicine [Wang and Quingjun 2011].

3.2 Electrocardiogram (ECG)

Firstly, it is important to understand the physiological basis of the ECG before attempting any signal processing of the electrocardiogram. The heart is composed of muscle (myocardium) where every normal heartbeat, a wave of electrical current passes through the entire heart, which triggers myocardial contraction [Clifford and Francisco 2006].

3.2.1 The Physical Basis of Electrocardiography

A method that registers the electrical activity of the cardiac muscles of the heart against time is Electrocardiography. The changes in electrical potential difference (voltage) during the activity of the myocardial fibers are recorded from the body surface itself by placing electrodes (for making electrical contacts with the skin surface) at specific locations without requiring any invasion. The contractile cardiac muscle cells are the source of the electrical potentials. The ECG waveform is either printed on paper or shown on a computer screen [Chaudhuri et al. 2009, Gacek 2012].

The electrocardiogram (ECG) is a graph of electrical signals caused due to electrical activity of the heart. For many years, it is a noninvasive tool widely used for basic cardiac monitoring in a clinical set-up. As a result of technology advancement, the ECGs components are available in a smaller form factor with some useful features [Chaudhuri et al. 2009, Gacek 2012].

A large amount of research reports for the detection of physiological quantities in the circulatory system and nervous system are developed relatively early and rapidly. Many ECGs researchers are still working on automatic extraction and discriminating arrhythmia information from ECG under strong interference. ECGs are mainly applied in diagnosing heart disease (including arrhythmias, conduction disturbances, and heart morphology) and preventing sudden cardiac death. In addition, it is also useful for assessing performance of pacemakers [Harsányi 2000, Wang and Quingjun 2011, Gacek 2012].

An adult human heart beats form 60-100 times per minute in normal health conditions. Each time, the cardiac muscles go through specifically ordered electrical activities which are distinctly identifiable from the patterns in the ECG signal during every beat [Chaudhuri et al. 2009].

The ECG signal can detect many types of cardiac disorders, in particular, those due to improper electric conduction through damaged cardiac muscles. A qualified professional can visually identify some of the abnormal patterns in the ECG signal and relate the damages in certain region of the heart. The signal acquired from a specific pair of ECG electrodes placed at predefined locations on the body call lead. Every ECG lead looks at the specific area of the heart and, different ECG leads are required in order to cover different areas of the heart. The standard 12-lead configuration are commonly used, where standard configuration has three primary limb leads called lead - I (right arm (RA) with respect to left arm (LA)), II (RA with respect to left leg (LL)) and III (LA with respect to LL), and that $ECG_{II} = ECG_{I} + ECG_{III}$ [Chaudhuri et al. 2009].

As previously described, the ECG signal is acquired from a pair of specific locations on the body and electrodes are used for making electrical contact with the skin surface. The ECG acquiring can use *two types of electrodes***:** reusable suction electrodes, and disposable foam pad electrodes. Pre-gelled foam pad electrodes are preferred due to the ease in usage for long term continuous monitoring applications [Chaudhuri et al. 2009].

The disposable foam pad electrodes are preferred in long term cardiac monitoring applications thus from reliability and patient comfort viewpoints. A disposable foam pad adhesive ECG electrode is depicted in figure 3.1. A male snap provided for connecting the lead wire is the silver colored center in front.

The rear side of the connector is pre-gelled. The adhesive on the white foam on the rear side helps the electrode to be held at a fixed position on the skin.

Fig. 3.1 The disposable foam pad electrode

A typical ECG cycle in the ECG signal as shows in figure 3.2 has the following segments called **P** wave, **QRS** complex and **T** wave occurring in a sequence which is important in depth analysis. The heart rate can be determined from the ECG cycle where this cycle is repeated continuously in the same ordered and time. The heart rate is variable due to many different physiological aspects such as respiration rate, physical stress, anxiety etc. The spectrum of the ECG signal approximately lies in the range of 0.05Hz to 130Hz [Gacek 2012].

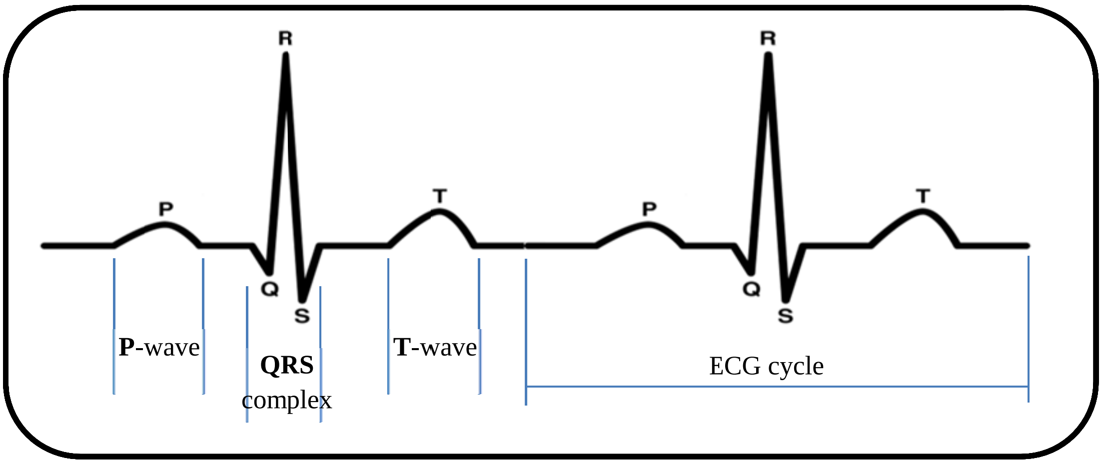


Fig. 3.2 Typical shape of ECG signal

3.2.2 Signal Conditioning

The ECG signals are the best-known biomedical signals, given their nature. They bring forward a number of challenges during their recording, processing, and analysis. Typically, the amplitudes of ECG signals have amplitude of several mV which collected on the body surface, and ECG signals are always affected by noise like muscles noise. So, a general signal conditioning block diagram is shows as figure 3.3.

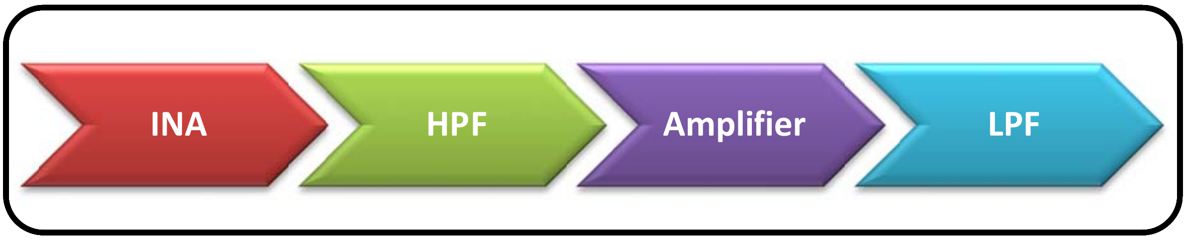


Fig. 3.3 ECG conditioning stages

The extraction and the amplification of differential signals from sensors, with maximum amplitude of a few mV, from a noisy environment is a part of signal conditioning. Instrumentation amplifiers (INAs) mainly achieved these tasks and followed by gain and filter stages. The INAs are designed to provide high input impedance, high CMRR (common mode rejection ratio), and moderate gain. Where the gain is used to amplify the low magnitude signals (ECG), the CMRR reduce the noise, and the high input impedance for low level signals [Dunn 2006, Chaudhuri et al. 2009].

A Driven Right Leg Circuit or “DRL” circuit is an electric circuit that is often added to biological signal amplifiers to reduce Common-mode interference. Biological signal amplifiers such as ECG circuits measure very small electrical signals emitted by the body. Unfortunately, the patient's body can also act as an antenna which picks up electromagnetic interference, especially 50/60 Hz noise from electrical power lines. This interference can obscure the biological signals, making them very hard to measure. Right Leg

Driver circuitry is used to eliminate interference noise by actively canceling the interference.

The output signal from the instrumentation amplifier is input to a high pass filter, to remove the DC offset. After that, the signal is again amplified, this second amplification stage further increases boosts the signal voltage to a range appropriate for sampling with an A/D converter [Clifford and Francisco 2006]. The final stage is low pass filter to remove the frequencies that exceed the ECG high frequency [Thakor 2000].

The useful bandwidth of an ECG signal, depending on the application, can range from 0.5 Hz to 50 Hz for a monitoring application in intensive care units and up to 1 kHz for late-potential measurements (pacemaker detection). A standard clinical ECG application has a bandwidth of 0.05 Hz to 100 Hz [Hartmann 2003].

3.3 Body Temperature Sensors:

Temperature is one of the most closely controlled variables of the human body. Its regulatory system is extremely efficient and capable of maintaining interior body temperature within a range of 0.5°C. The inner (core) temperature is almost independent of the exterior environment, even when exposed to extreme conditions; it is about 37°C for a healthy person. The main measurement requirement is resolution of 0.1^{o} C, over a range of a few degrees (35^{o} C to 50^{o} C) [Harsányi 2000]. During the past few decades, thermometers have been used in clinical testing. Now the time for continuous monitoring devices is rising, especially wearable instruments [Wang and Quingjun 2011].

All temperature sensors can be divided into two classes: the *absolute* sensors and the *relative* sensors. An absolute temperature sensor measures temperature which is referenced to the absolute zero or any other point on a temperature scale, such as 0◦C, 25◦C, and so forth. The examples of the absolute sensors are thermistors and resistance temperature detectors (RTDs). A relative sensor measures the temperature difference between two objects where one object is called a reference. An example of a relative sensor is a thermocouple [Frank 2005].

There are many types of temperature sensors some of these can be summarized as follows:

- Thermo-resistive Sensors
  - Resistance Temperature Detectors (RTD)
  - Thermistors
    - NTC Thermistors
    - PTC Thermistors
- Thermocouple
- Semiconductor

3.3.1 Thermo-resistive Sensors

RTDs and thermistors are types of thermo-resistive. The thermo-resistive advantages are simplicity of interface circuits, sensitivity, and long-term stability [Frank 2005].

3.3.1.1 Resistance Temperature Detectors (RTD)

RTD is usually related to the metal sensors, fabricated either in the form of a thin film or a wire. All metals and most alloys can be used for temperature sensing because the temperature dependence of resistivity [Harsányi 2000, Frank 2005]. The RTDs are fabricated of pure metals (platinum, nickel, and copper), of carbon, germanium, silicon, or other semiconductor materials [Nawrocki 2005]. The advantages of the RTD are accuracy, stability, and linearity. On the other hand, the disadvantages are slow response time and size.

3.3.1.2 Thermistor

A thermistor is made of a semiconductor material that is a temperature-dependent resistor. It is used for temperature measurement with *large resolution* in a *narrow range* of temperatures [Harsányi 2000, Nawrocki 2005].

The term thermistor is shortened from the two words *thermal* and *resistor*. It is usually applied to metal-oxide sensors. A thermistor is one of the absolute-temperature sensors; there are no needs for reference temperature. There are two types of thermistors: NTC (negative temperature coefficient) and PTC (positive temperature coefficient). Only the NTC thermistors are useful for precision temperature measurements [Harsányi 2000, Frank 2005].

The NTC is a metal-oxide thermistor, its resistance decreases with the increase in temperature. The physical dimensions and the material resistivity determine the resistance of the NTC [Harsányi 2000, Frank 2005]. The NTC advantages are high sensitivity, high accuracy, low cost, and fast time response. Where, the disadvantages are moderate nonlinearity and self-heating.

All metals may be called positive temperature coefficient (PTC) materials. One of the more frequently used metals is *Platinum* which has a temperature range of –260°C to 750°C, good linearity and stability. The PTC has disadvantages represented by the high nonlinearity response [Harsányi 2000, Ripka and Frank 2005, Alois 2007].

3.3.2Thermocouple

The Seebeck effect is: As in figure 3.4, two conductors are made of different materials A and B are connected, with one junction at temperature T1 and the other at temperature T2, a voltmeter (with infinite internal resistance) is able to read an electromotive force (EMF) E. The voltage E depends on the materials used and on the difference in temperature between T1 and T2 [Harsányi 2000, Ripka and Alois 2007].

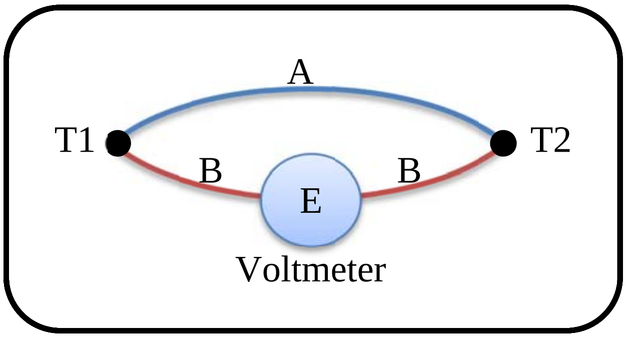


Fig. 3.4 The thermocouple

Thermocouples are used for applications which need above 300^{o}C. The thermocouples advantages are good range, self-powered, and no self-heat. The disadvantages are Cold-junction compensation, low accuracy and reference need [Nawrocki 2005].

3.3.3 Semiconductor

The dependence of voltage in the p-n junction on the temperature is the base operation of the semiconductor temperature sensors. The p-n junction is a function of voltage-biased and temperature for the diode or the transistor [Nawrocki 2005]. The semiconductor advantages are ease of use, rugged, and low cost. The disadvantages are low accuracy, limit applications, low stability, and long-time response.

3.3.4 Signal Conditioning

All temperature sensors can be placed in series or in parallel to perform average readings. The change in resistance is measured with converters available in retail. The measuring circuit of these converters can be based on the Wheatstone bridge as shown in figure 3.5. Where, equation 3.1 calculates the R_x value.

$$R_x = \frac{R_2}{R_1} \times R_3 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.1)$$

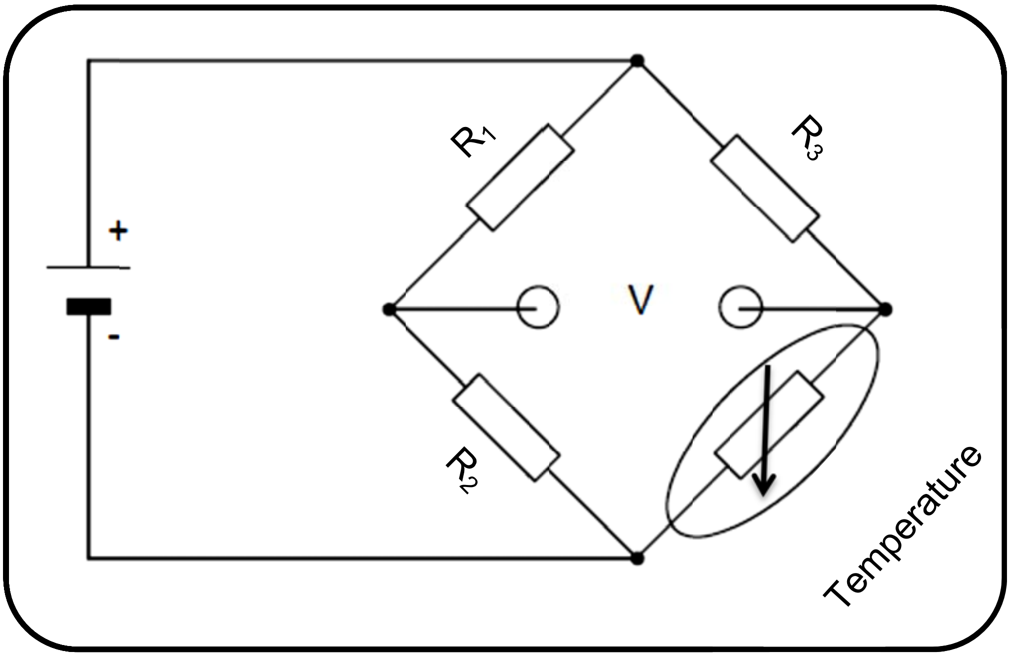


Fig. 3.5 Wheatstone bridge

From all temperature sensor types, the perfect temperature sensor should have the features:

- Precisely accurate.
- Fast response time.
- Easily conditioned.
- Low power, low cost, and Small size (the sensor and the condition circuit).

Chapter Four

Chapter Four

System Design and Implementation

The proposed system is based on WSN for hospital care and home care environments. The main system is the hospital care which has been improved to use for home care. This chapter describes the hardware, software and operation for the implemented system in this thesis.

4.1 Overall System Description

The implemented system operation is based on collecting the sensing data from the patient nodes. The system displays the sensing data to the person responsible (doctor) for patients monitoring. As previously depicted the main goal of the system present in this thesis is for the monitoring the ECG, Temp, and HR of any number of the patients wirelessly. In addition the system sends alarm signal to the doctor in remote site in case of any abnormal case. Also, the system has the ability to detect any error may occur in the network. Figure 4.1 shows the block diagram of the proposed system considered in the present work. The system consists mainly of the following parts:

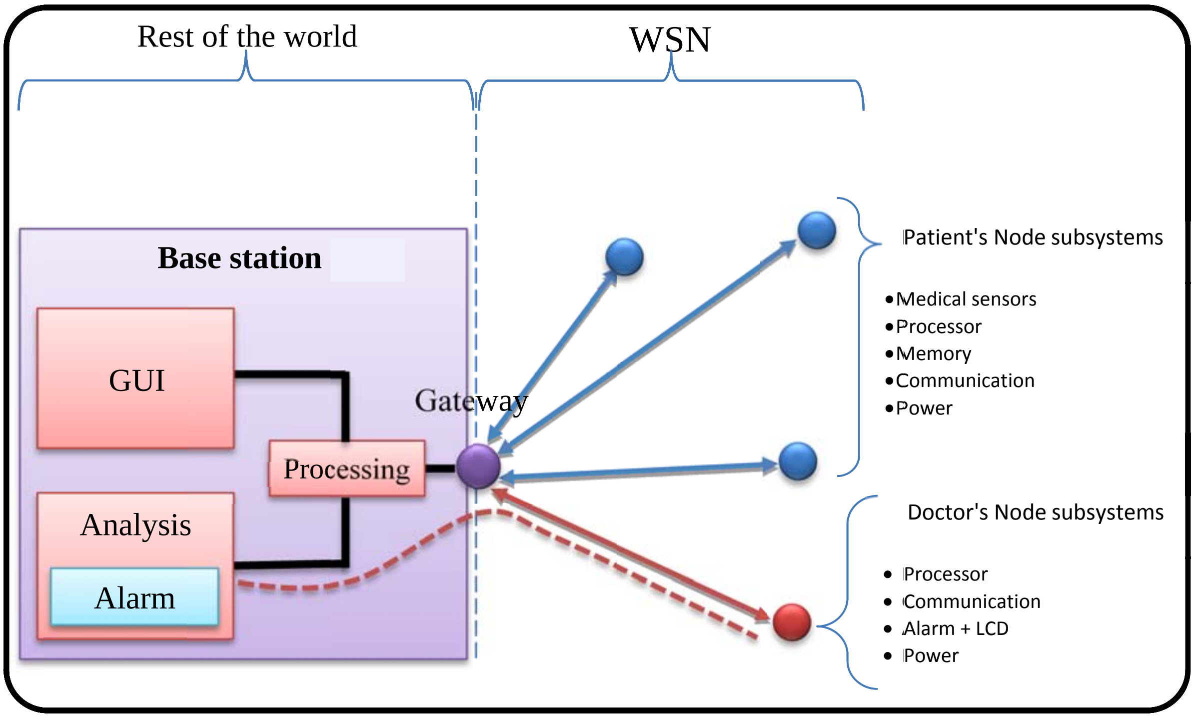


Fig. 4.1 The Proposed Healthcare system

4.2 The Patient Node

The patient node is a number of wearable sensing nodes, each patient has one node. The patient node (sensing node) consists of subsystems: Biomedical sensors, processor, memory, power, and communication. Each subsystem is presented in the following:

4.2.1 Sensors

In healthcare, the sensors are biomedical sensors that combine transducers for detecting the biomedical signals to indicate the patient health status. Each patient node has three sensors, two of them are hardware sensors which are the ECG and body temperature, the last one is the HR which is calculated from the ECG signal. These three sensors are explained as follows:

4.2.1.1 ECG (Electrocardiogram)

The ECG shows the electrical signal of the heartbeat which describes the heart health. ECG sensor used in this work is Olimex shield (ECG card) whose main circuit which refers to data sheet appendix (C.1). There are three electrodes of the ECG card which are used for making electrical contact with the body skin surface which can be reusable suction electrodes and disposable foam pad electrodes. Two of these electrodes are used as ECG lead. ECG lead can be selected as lead I, lead II, or lead III and the last one is used as a drive right leg (DRL).

The ECG card works with 5V-DC as recommended or 3.3V-DC, and it supplies 3V reference voltage. An electrodes jack is the ECG input of card which has three connections for the electrodes and the analog output of the card is 6-channels for selection, we use channel 1. Moreover it has an adjustable gain for calibration. The conditioning stages of the ECG card are shown in figure 4.2.

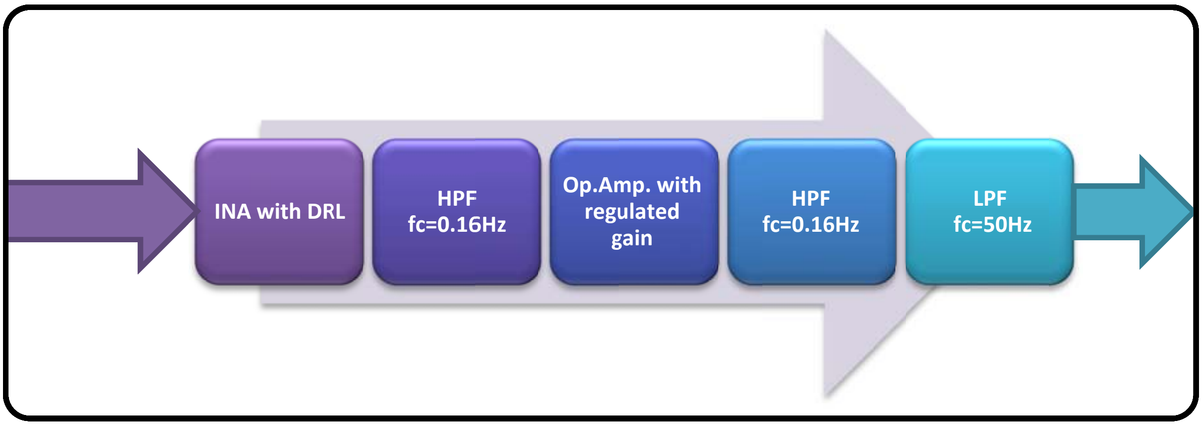


Fig. 4.2 ECG circuit stages [Olimex 2011]

When this card is powered on, the ECG input signal is amplified and filtered to appear from the selected analog output. Where the input signal is low voltage noisy signal and the output is 0-5V pure ECG signal. This level of voltage is appropriate input for analog to digital converter. The analog output signal continues with the time so the sampling and quantization steps applied to this signal by the MCU, it will be described in the processor unit. The card layout is shown in figure 4.3.

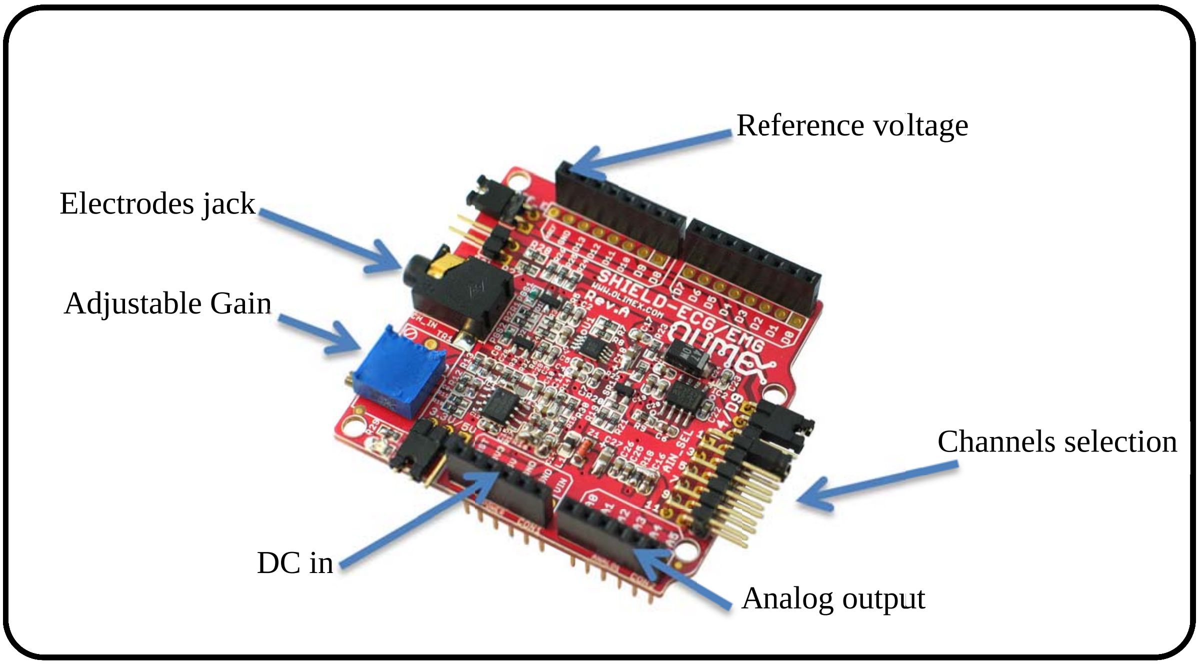


Fig. 4.3 The ECG card layout [Olimex 2011]

4.2.1.2 Heart Rate (HR)

The HR is the number of heart beats per minute of time. The normal range of HR for adult is 60-100 pulse/min and for children from 60-140 pulse/min. We have built an algorithm in the patient nodes to calculate the HR from the ECG signal according to the flowchart shown in figure 4.4. The program works as a counter to count the number of the QRS complex part of the ECG signal. It is easy to detect the QRS complex because it is higher than another waves. The program counts up each time the ECG sample exceeds the threshold value. This condition happens only when the QRS is appearing. The threshold value must exceed the P-wave and T-wave. When the program is executed for a certain time, say 5 sec, the counter counts the number of beats for 5 sec, so the HR can be calculated from equation 4.1:

$$HR\ \left(\frac{pulse}{min}\right) = \frac{counter\ value\ (pulse)}{execute\ time(Sec)} \times 60(sec/min) \ldots\ldots\ldots\ldots\ldots\ldots (4.1)$$

The algorithm for the HR calculation is described as follows:

- Reading the new ECG signal from the ECG card and setting the value of ECG_old to zero.
- If the value of the new ECG exceeds a threshold value and the ECG_old is less than the threshold value, which means the QRS appears. So the algorithm increases counter by one.
- Reading new ECG value and store the old value in the ECG_old.
- These previous points repeat for a certain period of time to calculate the number of beats per this period.

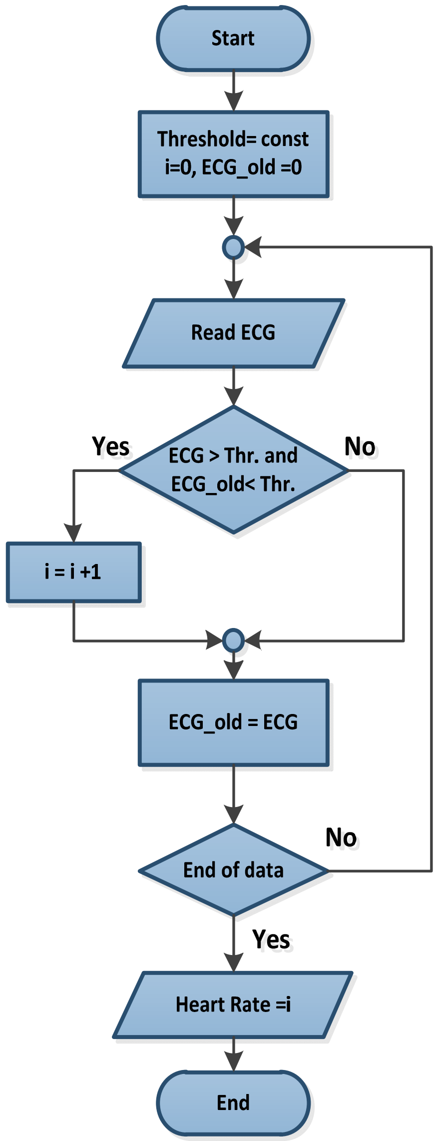


Fig. 4.4 Algorithm for the heart rate calculation

4.2.1.3 Body Temperature Sensor

The human temperature is measured using biomedical sensor which is the thermistor. The thermistor properties that should be considered for human body are tolerance and range. As the human body temperature is between 35-39 degrees Celsius so it is important to choose a sensor that works in this range with good tolerance. The response time of the thermistor which is used for WSN is an important issue for reason of power consumption. Therefore, the thermistor should have a good tolerance and fast response time within the range 35-39 ^{o}C.

We chose a temperature sensors model (NTC- MA100BF103A). Its tolerance 0.05 ^{o}C in the temperature ranges 35-39 ^{o}C as refer to appendix (C-2) and its time response 2 seconds as shown in table 4.1.

Table 4.1 NTC tolerance for (MA100BF103A) model

Temperature ^{o}C	Tolerance ^{o}C±
0-20	0.15
20-35	0.1
35-39	0.05
39-42	0.075
42-45	0.1
45-50	0.15

The signal conditioning circuit is simply voltage divider as shown in figure 4.5 because the other option like bridge consumes more energy which is very important criteria in WSN. Therefore, we chose the voltage divide with chosen resistor.

The source voltage for the conditioning circuit is 5V-DC (MCU digital output). It is necessary to connect a series resistance (R_1) with the thermistor. The following points must be taken into account for R_1 selection:

- If the resistance value is high, the resolution of ADC is low and the power consumption is low.
- If the resistance value is low, the resolution of ADC is high and the power consumption is high.
- If the resistance value is moderate the resolution and the power consumption are good at the same time.

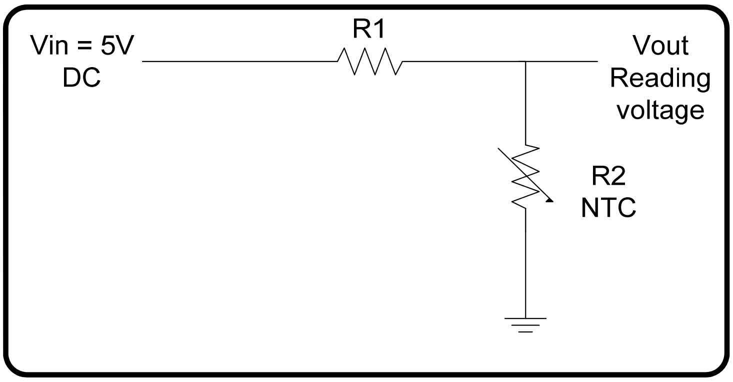


Fig. 4.5 The temperature conditioning circuit

The voltage divider equations are:

$$V_{out} = V_{in} \times \frac{R_2}{R_1 + R_2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.2)$$

$$R_2 = \frac{R_1}{\left(\frac{V_{in}}{V_{out}} - 1\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.3)$$

$$R_1 = R_2 \times \left(\frac{V_{in}}{V_{out}} - 1\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.4)$$

Since R_2 is known from the data sheet (32 KOhm) also V_{in} (5 V from digital output of the MCU) and V_{out} (3 V wanted value), so equation 4.4 can be used to calculate R_1 which is equal to (22 KOhm).

We used equation 4.3 to determine the NTC resistance (R_2) which is equivalent to the temperature. Each NTC resistance value has equivalent temperature value as shown in appendix (C.2). There are two ways to calculate the temperature value form this table: curve fitting method and lookup table. We chose the curve fitting in order to decrease the used memory.

The range of the selected sensor (NTC) is from 0 to 50 ^oC and the human body temperature range is 35-39 ^oC. There are two options for the curve fitting:

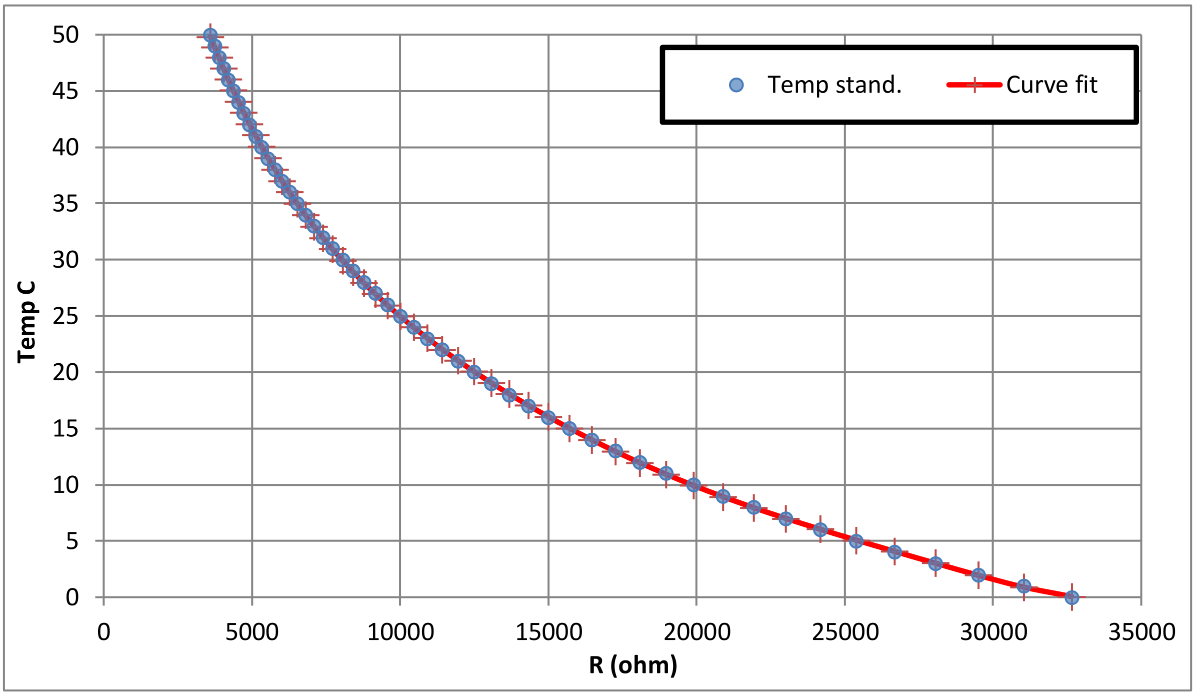
i. Taking the all NTC range (0-50) ^{o}C, so a 6-degree polynomial can fit the curve with 99% accuracy. The fitting temperature equation is illustrated in expression (4.5):

$$T = (6.26575944063483E - 25 \times R^6) - (7.69320629815188E - 20 \times R^5) + (3.84632366042777E - 15 \times R^4) - (1.01395012359292E - 10 \times R^3) + (1.54036218706876E - 06 \times R^2) - (0.0145430592803649 \times R) + 86.3735014647837 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (4.5)$$

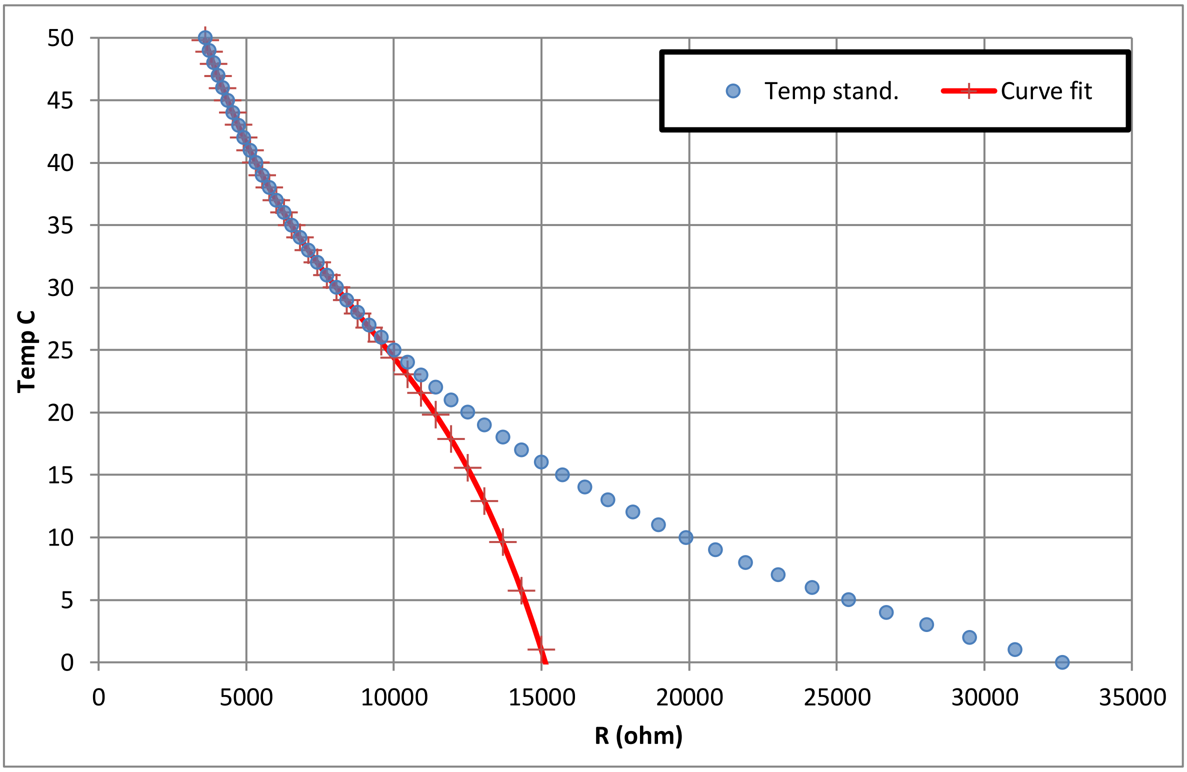
ii. Taking the range 35-39 ^{o}C, so a 3-degree polynomial can fit the curve with 99% accuracy. The temperature equation is proposed in (4.6):

$$T = -(4.42275016504466E - 11 \times R^3) + (1.20256080706569E - 06 \times R^2) - (0.0137373134589598 \times R) + 85.7427489936404 \ldots (4.6)$$

Practically, these two equations are tested by the researcher for multiple values of temperature and the NTC reading gave very satisfactory result compared with an accurate mercurial thermometer. The error of the measured value is not exceeding 0.05 ^{o}C in the first polynomial and is not exceeding 0.03 ^{o}C in the second one. Figure 4.6 shows the curve fitting for both polynomials. So equation 4.6 is considered in this thesis.



(a)



(b)

Fig. 4.6 The curve fitting of the NTC for the polynomial

(a) 6-degree and (b) 3-degree

4.2.2 Processor (MCU)

The MCU is used for processing the data, scheduling the node task, and controlling the other subsystems. The processor unit used in patient node is the Atmel MCU (ATmega328), we used the Arduino platform which contains the ATmega328 MCU as shown in figure 4.7, and this platform is open-source platform based on flexible, easy-to-use hardware and software. The MCU main specifications are (for more detail see appendix C.3):

Digital I/O	14 (of which 6 provide PWM output and 2 Rx/Tx for serial connection as *Universal Asynchronous Receiver/Transmitter* (UART)
Analog Input	6 (10-bits ADC)
DC Current per I/O	40 mA
DC Current for 3.3V	50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz

The MCU on the board is programmed using the Arduino programming language which is integrated development environment (IDE). This language based on C / C++ language. The IDE supports with a software library called "Wiring", which makes many common input/output operations easy.

We programmed the MCU to control the node tasks (refer to appendix A.1). It is sending and receiving the data from and to the XBee using the serial pins (Tx and Rx) as shown in figure 4.8. The MCU controls two patient node operations which are setup operation and sensing operation as shown in figure 4.9. The sensing operation is the main operation for the patient nodes and the rest of operations are auxiliary operation for it. In Setup operation the MCU is receiving the patient personal data form the GW through the XBee and storing it in the node.

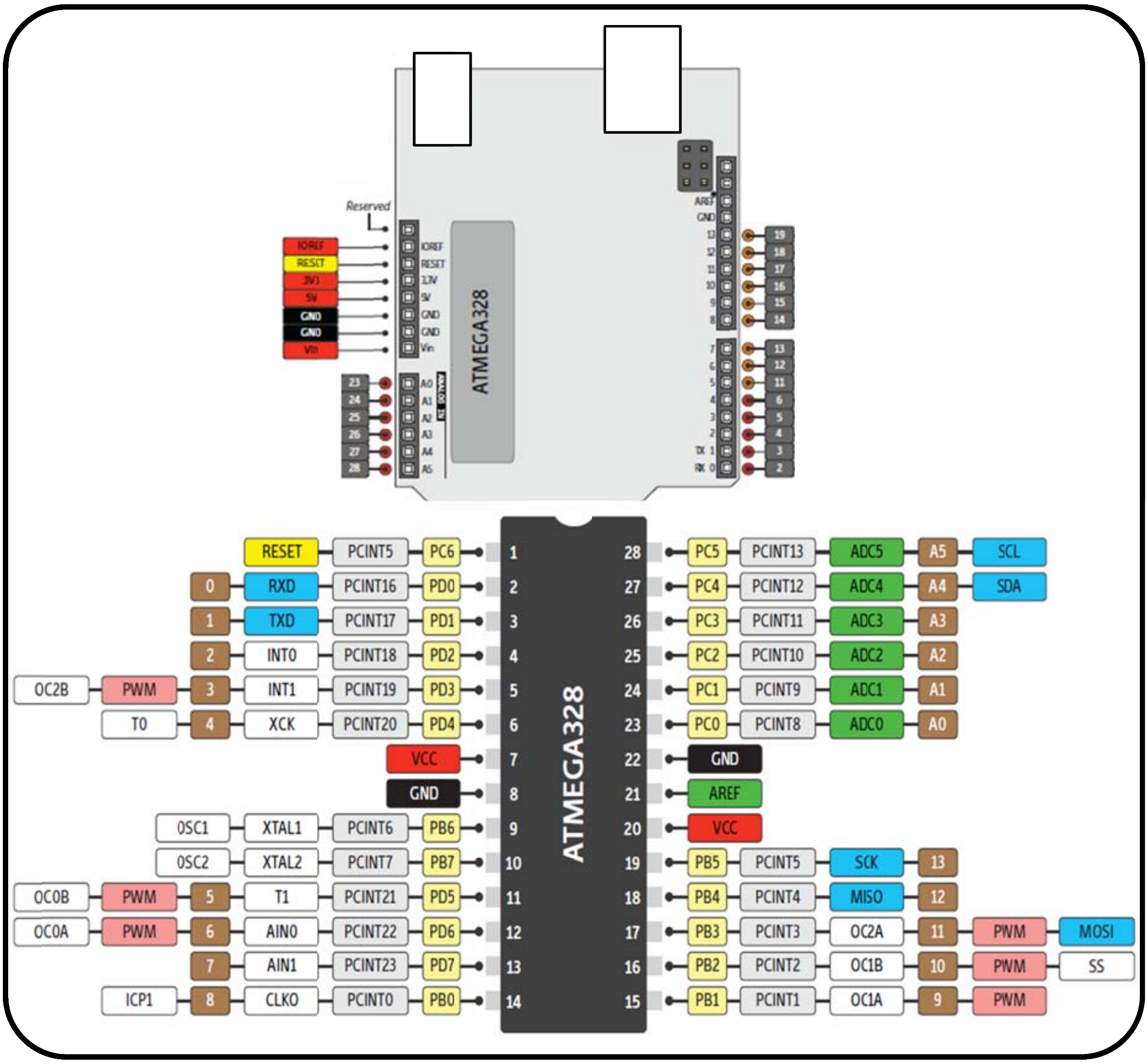


Fig. 4.7 Atmel MCU (ATmega328) and the Arduino pinout

The MCU also controls the node sensing operation, after receiving the command from the GW to start this operation. It is starting up the ECG and temperature circuits. The analog inputs (ECG and Temp) are connected to the ADC (pin A0 and A2) where the digital outputs are available on (pin D0 to D13). The MCU perform the following steps (refer to flowchart in figure 4.9):

i. It is powered on the ECG card and temperature circuit.

ii. Samples the NTC analog voltage and it is converted to 10-bit digital signal using it is A/D converter. We use the ECG reference voltage (3V-DC) to increase the ADC resolution as shown below:

- If the reference voltage is 5V, the step value is:

  $Q = \frac{E_{pp}}{2^M} = \frac{5}{2^{10}} = 4.88\ mV$ ……………………………………… (7)

- If the reference voltage is 3V, the step value is:

  $Q = \frac{E_{pp}}{2^M} = \frac{3}{2^{10}} = 2.93\ mV$ ……………………………………… (8)

Referring to figure 4.5 a voltage divider resistance (R_1) of 22KOhm is series with the NTC, this value is selected in such a way that the power consumption is low and decreasing the measured voltage in the NTC range.

The NTC resistance value starts from 32 KOhm to 3.6 KOhm (0 to 50 ^{o}C respectively), and the ADC input has a range from 0.703V to 2.985V. Therefore, 0.76% from the range of ADC is used from the 3V reference and 0.46% from the range of the ADC is used from the 5V reference.

iii. Sends the body temperature value to the GW after executing the fitting formula to calculate the temperature value and store this value in the SD-card after storing the personal data.

iv. Samples the ECG signal using 200 samples/sec and calculating the HR for these samples. As mentioned before, the bandwidth for standards ECG 0.05Hz to 100Hz. So 200Hz practical is the suitable sampling frequency for monitoring application.

v. Sends the ECG samples to the GW and stores it in the SD card.

vi. Sends HR value to the GW and stores it in the SD card.

vii. Finally, it sends a signal to stop the sensing operation (end of sensing).

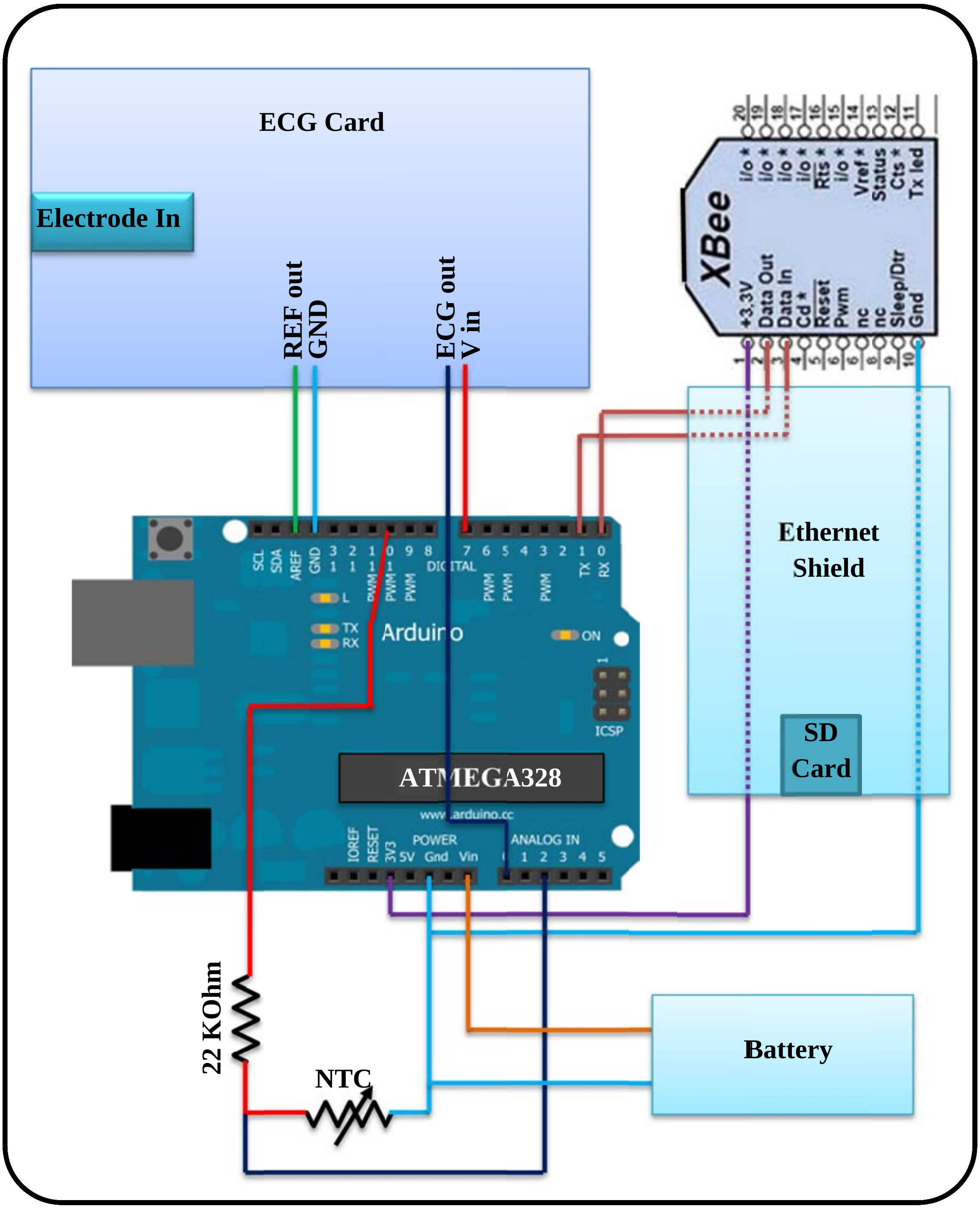


Fig. 4.8 The patient node circuit

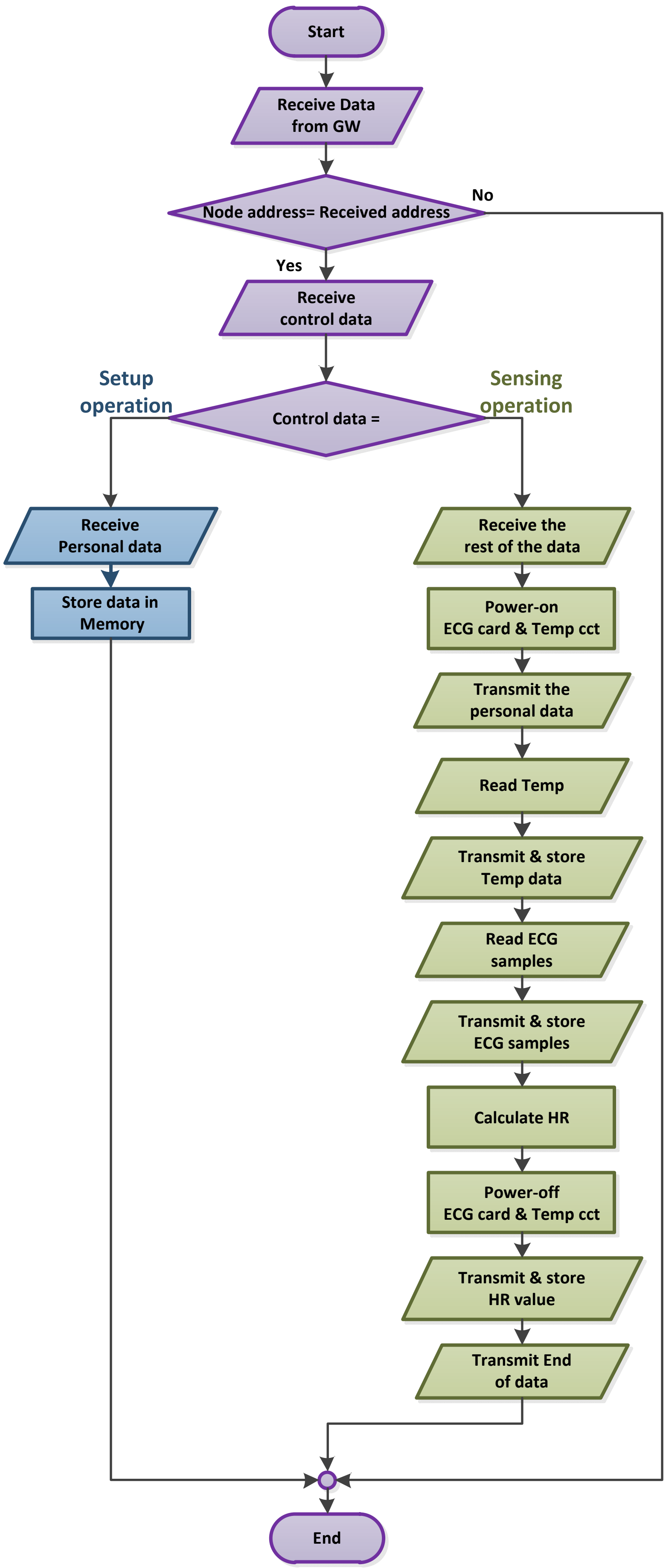


Fig. 4.9 The patient node operations at the MCU

4.2.3 Communication

It is used to connect the nodes (patients and doctor node) in the network, we select XBee module to perform the wireless communication between the nodes. Arduino and XBees can work extremely well together in wireless sensor systems. This module has the following features (for more details refer to appendix C.4):

Indoor/Urban Range	Up to 40m
Outdoor line-of-sight Range	Up to 120m
Transmit Power Output	2mW
RF Data Rate	250 kbps
Receiver Sensitivity	-95 dBm (1% packet error rate)
Supply Voltage	2.8 – 3.4 V
Number of Channels	16 Direct Sequence Channels
Operating Frequency Band	ISM 2.4 GHz

It is Supported Network Topologies Point-to-point, Point-to-multipoint, Peer-to-peer, and Mesh. XBee is configured using the X-CTU which is the official configuration program for XBee module. The firmware is a program runs in the XBee module to perform addressing, communication, security, and utility functions. It can be configured for different settings, we configure this XBee as end-device firmware. The XBee modules interface to the Arduino through the Rx and Tx serial connection (UART). It has a serial pins to connect with Arduino serial pins through the Ethernet shield as shown in figure 4.8. This shield provides the connection between the XBee and the Arduino and contains an SD card slot. The modes of operation for XBee module are:

- Idle Mode: the RF module is in Idle Mode when not receiving or transmitting data.

- Transmit Mode: When serial data is received and is ready for sending, the RF module will exit Idle Mode and attempt to transmit the data.
- Receive Mode: If a valid RF packet is received and its address matches the RF module's, the data is transferred to the serial transmit buffer.
- Command Mode: the module must first enter into Command Mode to modify or read RF Module parameters.
- Sleep Mode: Sleep modes are supported on end devices only and allow the end device to sleep for a specified period of time.

The XBee shifts into these modes to receive the personal data from GW, send the sensing data to the GW, and go to the idle and sleep for power consumption depending on the coordinator setting. We use cyclic sleep mode which synchronize all network nodes with coordinator. The sleep mode time period is 18 Sec for XBee end-device and the active mode time period is 2 Sec for receiving data from coordinator. The time period for sending data to the coordinator is 15 Sec which is the time of the sensing operation.

4.2.4 Memory

The memory is used to store the data as a file. Each patient node has SD card in the Ethernet shield slot, for store the data in a log. The size of the SD card is 2GB, and the log type used is text file. The text file which store the data contained the personal data, temp, ECG, HR, date, and time. Every time the node sends the data to the GW, it stored in the SD card. This card store data for long time and for multi patients. This text file can be displayed at any time by computer using the SD card reader.

4.2.5 Battery

The battery supplies power to the node. A rechargeable battery uses as a power supply for each node. It has 9V-DC and 350 mAh. Therefore, there is a limit time for node operation. In order to save the power consumption, the MCU power each sensor (ECG and temperature) for a certain time which is the response time for sensor. At the same time the data transmit using the XBee module. And the MCU power-off all inactive components to go to the sleep mode.

The power consumption for the nodes components can be divided into the active mode and the sleep mode. In the active mode, the nodes are sensing and sending the data to the GW. In the sleep mode, the nodes are saving the power by power-off all unused components. There are six different modes available for the MCU as follow:

- SLEEP_MODE_IDLE
- SLEEP_MODE_ADC
- SLEEP_MODE_PWR_SAVE
- SLEEP_MODE_STANDBY
- SLEEP_MODE_EXTEND_STANDBY
- SLEEP_MODE_PWR_DOWN

The SLEEP_MODE_IDLE is used and by disable the unnecessary functions (such as ADC and timers) which is active at this mode in order to almost reach the power down mode. Therefore, the power used for the active mode is greater than for the sleep mode. Table (4.2) shows the power consumption for the active and sleep modes.

Table 4.2 Active and sleep modes power consumption

Mode / Component	Active	Sleep
MCU	15 mA	0.6 mA
Temp Sensor	0.19 mA	0 mA
ECG card	8.7 mA	0 mA
XBee	40 mA	10 µA

We implement three patient nodes as shown in figure 4.10.

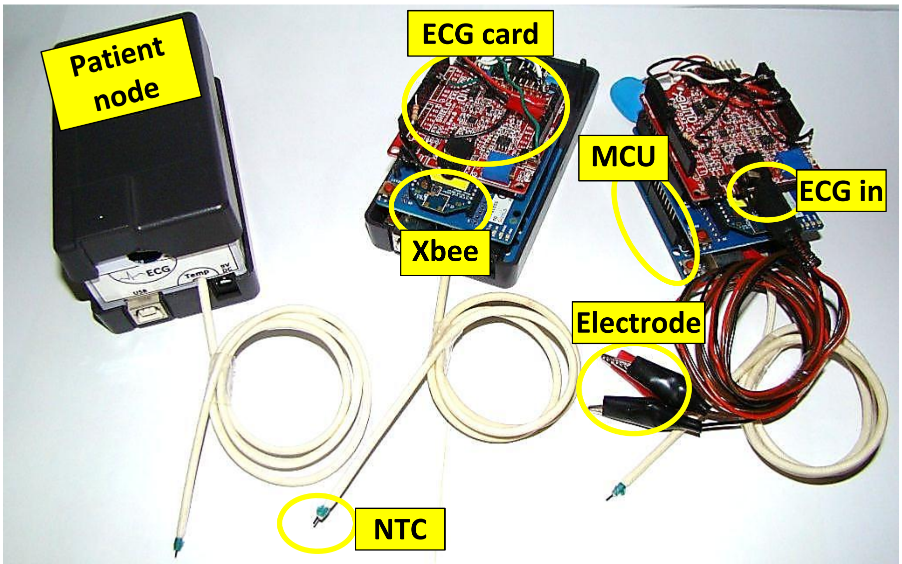


Fig. 4.10 Patient nodes components

4.3 The Doctor Node

This node is carried by the doctor and gives him alarm signal when any abnormal case is happened for any patient. The doctor node consists of the following components:

- Atmel MCU.
- XBee communication.
- 9V battery.
- LCD
- Alarm sound

The doctor node has the same patient node components but of course without sensors and it has 16*2 char LCD and alarm sound as shown in figure 4.11. The MCU performs the alarm operation, after the node receiving the data from the GW. When the doctor node receiving the alarm information (patient node address, HR status, HR as a number, temp status, and temp as a number), the MCU display this information in the LCD and it is called the voice of alarm (refer to appendix A.2). Finally the doctor node sends the success of the receipt of alarm data to the GW.

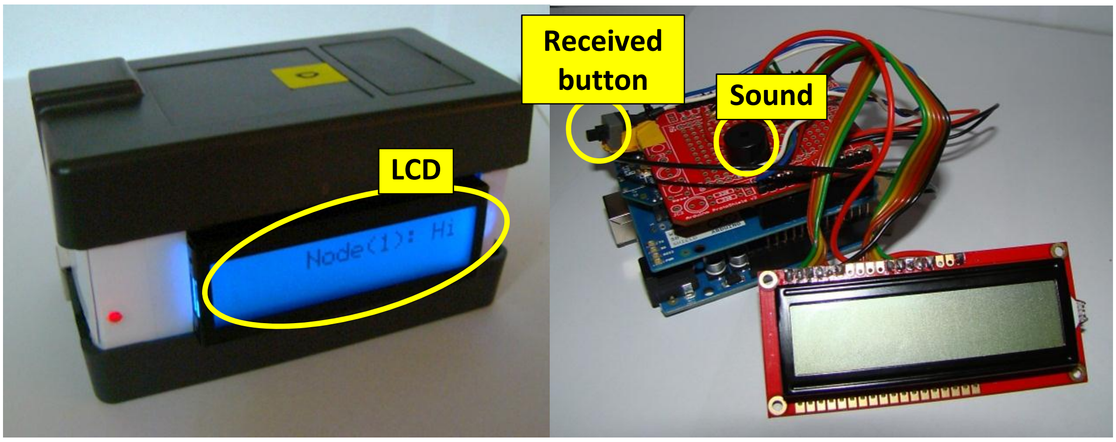


Fig. 4.11 Doctor node

The doctor node is a portable alarm with indicator. Each time when it receives the alarm data, refer to figure 4.12, the MCU executes the following operations:

- Firstly, the doctor node receives the data from the GW.
- Separates the data as patient no., HR status, HR value, Temp status, and Temp value.
- Each of these separation data process to select the suitable display text or value.
- Finally, the LCD displays the full text which indicates the alarm detail.

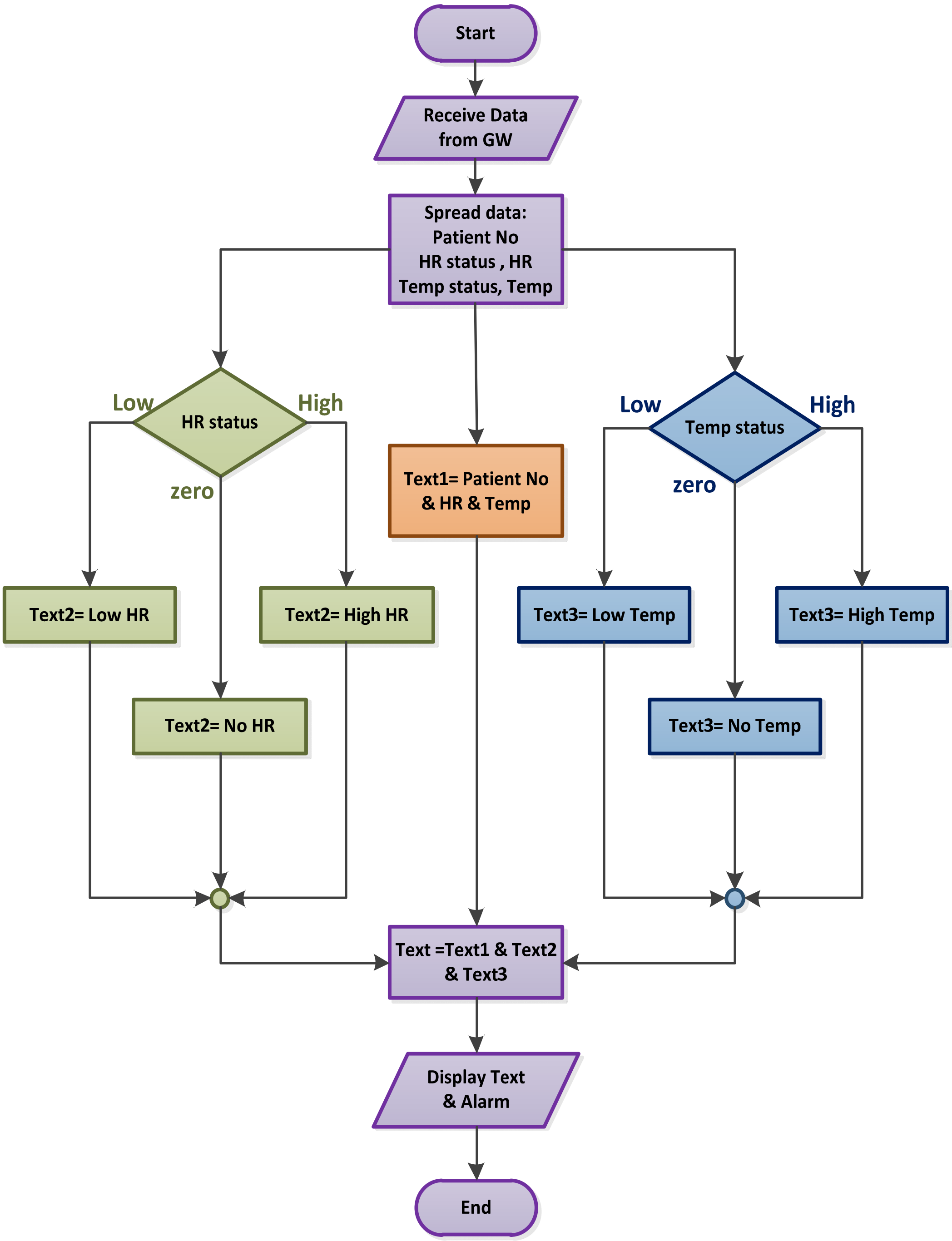


Fig 4.12 Doctor node alarm operation

The connection of the LCD with the Arduino and other components in the doctor node is shown in figure 4.13.

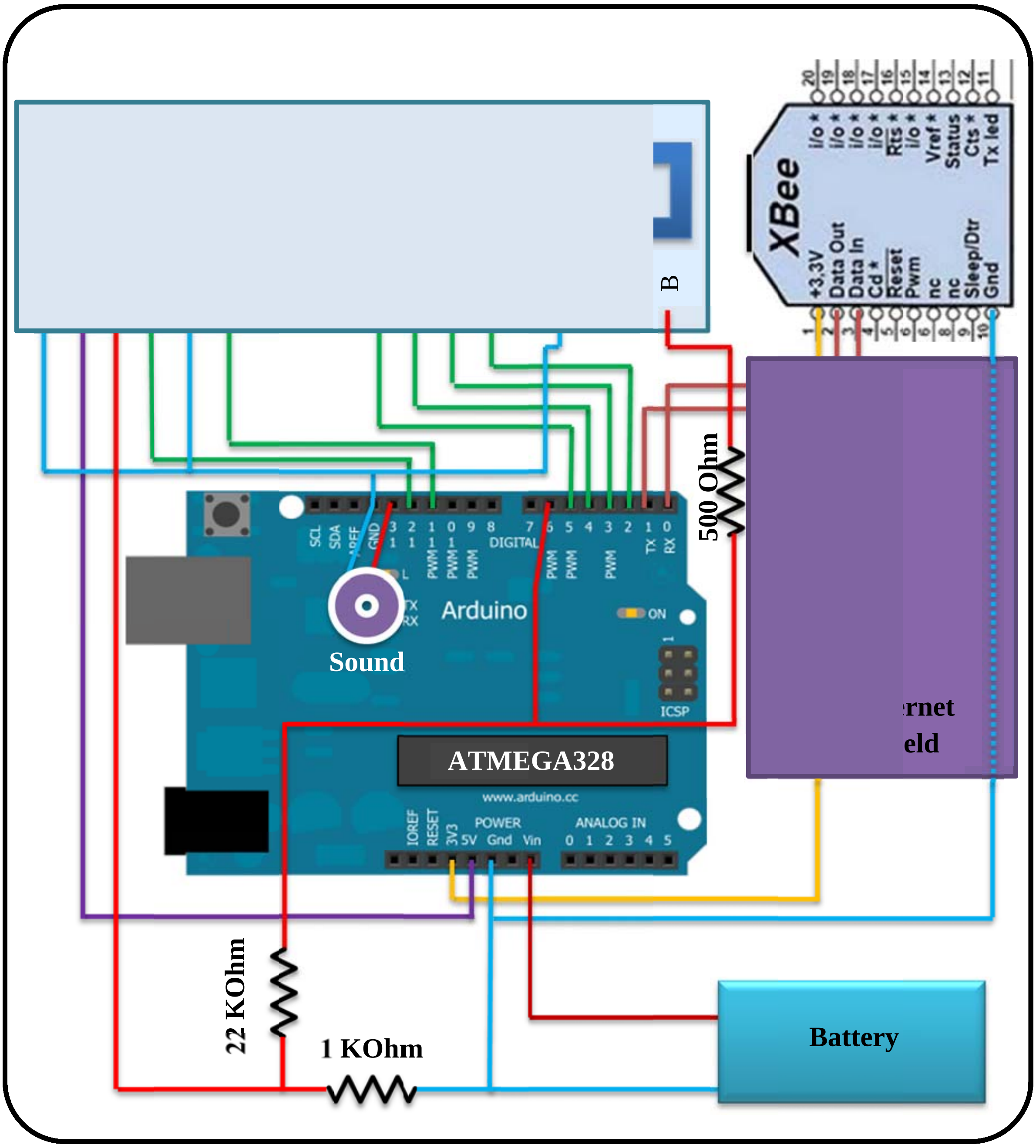


Fig 4.13 Doctor node circuit

4.4 Gateway Node (GW)

The GW is the WSN gate to the base station (BS), whose function is as bridge between the nodes and the BS. The GW node consists of two parts which are the XBee module and its USB explorer circuit as shown in figure 4.14. The USB explorer provides the voltage supply and the serial connection to the XBee module. Typically, it is used to connect the XBee to a USB port for computer to have direct access to the serial and programming pins on the XBee.

The ZigBee network must have one coordinator which connects all the nodes (has the ability to access all nodes). Therefore, the firmware of the GW is coordinator which has all coordinator features like staring network, router, store, and manage information about the network including routing tables and security keys. The coordinator in the ZigBee network should be powered by a power source because it works all the time and there is not matter for the power consumption issue. Moreover, this node is passing the data form WSN to computer and vice versa. So it works as a gateway between WSN which is based on the ZigBee protocol and the computer (BS) by using the serial connection UART protocol.

The GW also has the cyclic sleep mode which is 18 Sec. The GW is active all the time and 18 Sec is the time that the data is available in the GW for other nodes. The cyclic sleep synchronizes the XBee modules, where the XBee end-devices shift cyclic from the active modes to the sleep mode and vice versa.

The BS controls the system operations through the GW node where the BS can send any command operation for any nodes (patients nodes and doctor nodes) using this node. Therefore, the GW node manages the system by connecting the WSN to the BS.

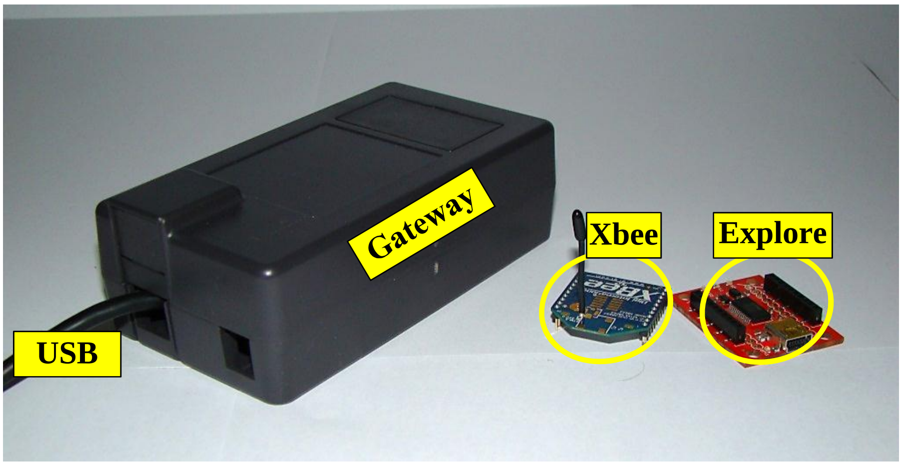


Fig 4.14 The GW node

4.5 Wireless Sensor Network (WSN)

All the nodes considered in the system are interconnected via WSN. We select ZigBee protocol for the wireless connection which can be supported by the XBee module. The healthcare monitoring system has derived significant interest from the Zigbee that is designed to support low data rate, low power consumption, and low cost wireless communications. As mentioned before, the protocol features are more suitable for healthcare applications. ZigBee protocol worked in 2.4GHz band for international standard which provide more communication channels. Its physical layer (PHY) supports 16 channels.

There are three types of networks topology can be supported by ZigBee protocol which are star, tree, and mesh. We select star topology for the healthcare network because it is easy to synchronize, low power, and very low delay. The GW is the ZigBee coordinator and the other nodes (patients and doctor nodes) are end device. Therefore, the star topology can perform the real time because there is a direct connection between the GW and the other nodes without using router nodes.

We have designed a protocol payload in order to meet the requirements of the system operations where there are three modes of system operation that are *setup*, *searching*, and *sensing* operations. Figure 4.15 shows the network frame payload which contains the control and data.

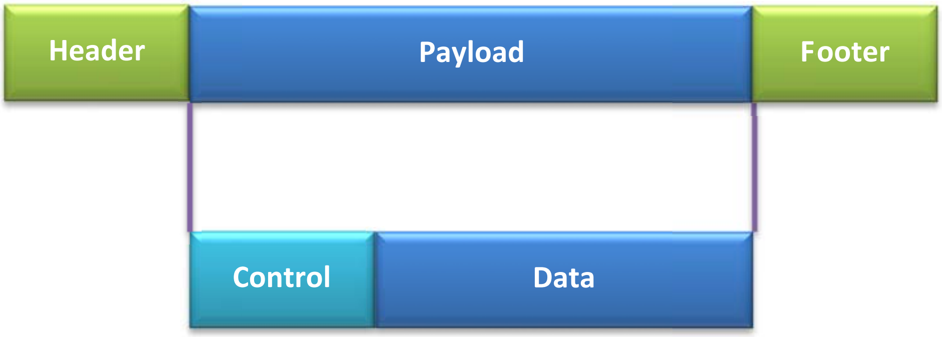
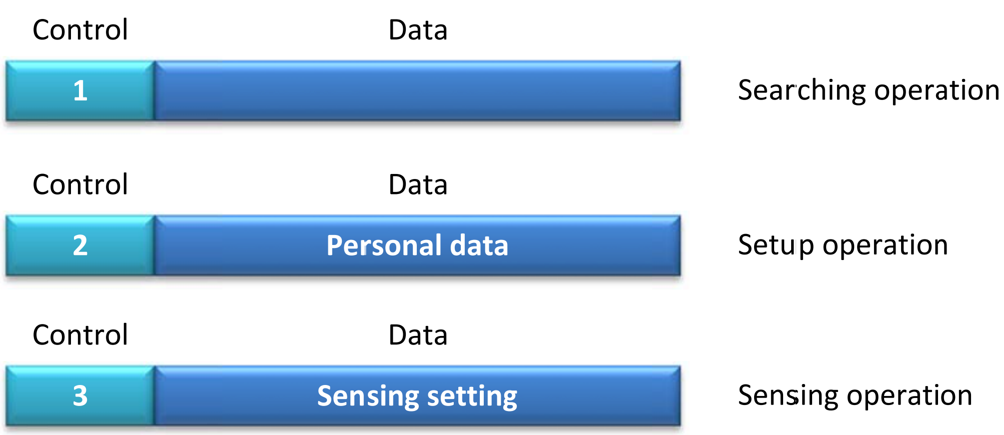


Fig. 4.15 Network frame

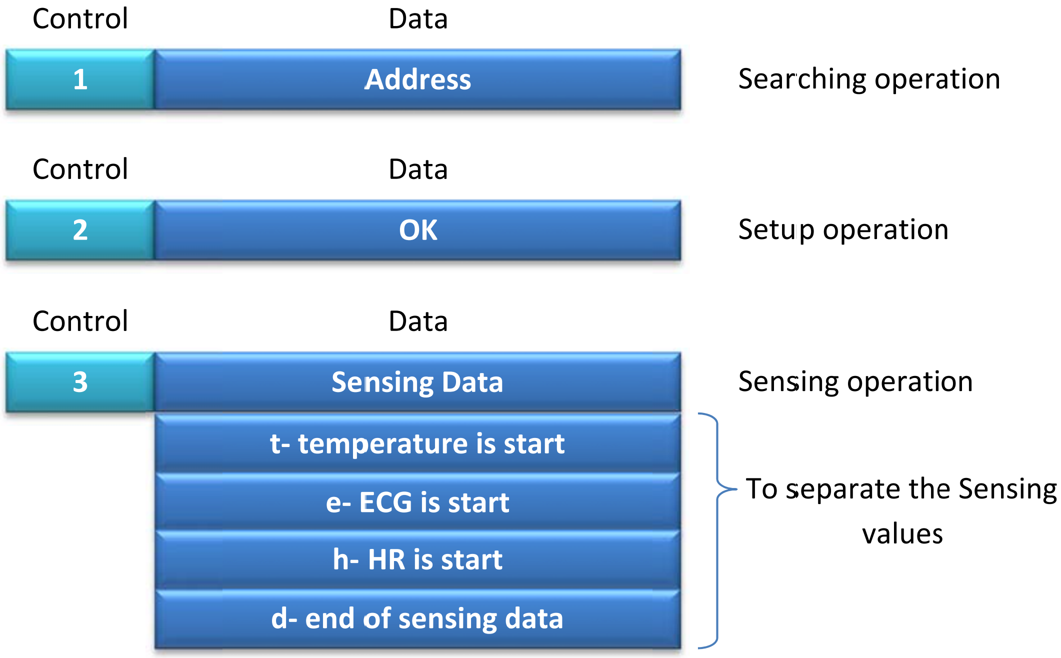
Where: Header is the ZigBee protocol header from APL, NWK, MAC and PYH layers.
Control is an operation control.
Data is the data bytes.
Footer is the protocol footer from the MAC layer.

The main data for the healthcare system is the sensing data which are ECG, Temp, or HR samples. The packet contains one sample from the sensing data to perform the real time. In other words, the sample sends without waiting for the next sample that is one sample per packet. The payload for each operation is explained as follow:

i. Payload from GW to the patient node



ii. Payload from the patient node to GW



iii. The payload from the GW to doctor node:

iv. The payload from doctor node to the GW:

4.6 Base Station (BS)

The base station can be a laptop or PC which has a good performance which represents the central operation, data collection, and display, and it uses USB for data communication and portable software (SW). The BS operating system is windows 7 -64 bits and the SW used is LabVIEW. We programmed the LabVIEW to achieve the requirements of the system (refer to appendix B). The SW use serial connection as input and output data which interface with the XBee serial connection for the GW. There are two windows (graphical user interface (GUI)) which are the setup window and the monitoring window to perform the system operations. Moreover, the SW is easy updates to keep up with the new requirements by specialists. This software performs the three main operations, referring to figure 4.16. These operations are explained with details in the next section.

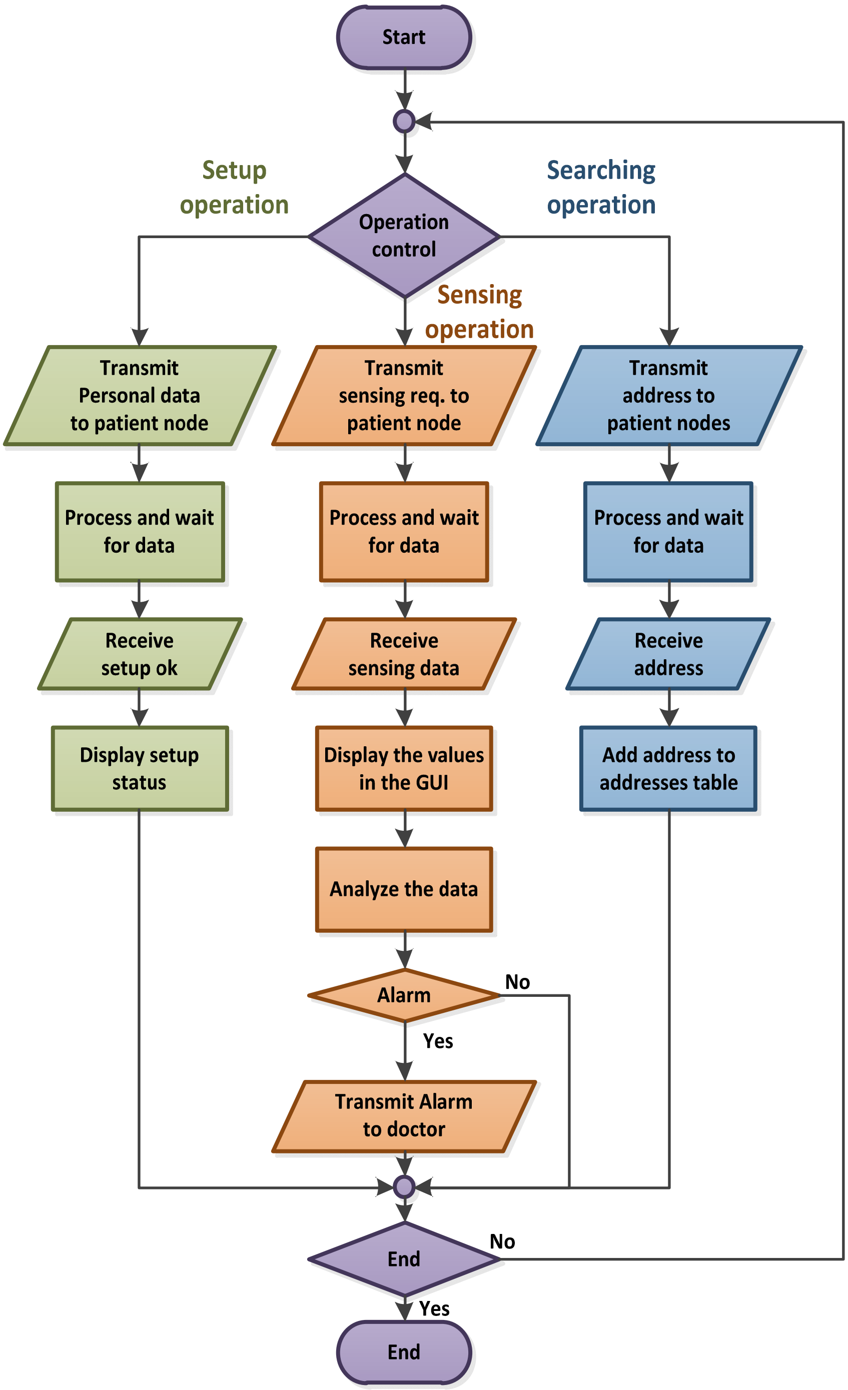


Fig. 4.16 Software (LabVIEW) operations

4.7 System Operations and Diagnostic

The base station runs the SW with two GUIs. First is setup each patient node for new patient by the setup operation. The next step is searching operation to search the existing (actual) number of nodes in the WSN. After these two operations the sensing operation which is the main operation runs to display the sensing values and signal. The main points of the system are:

- Each patient carry wearable device called the patient node, it contains an ECG, HR, and temperature sensors for the patient, the sensing value send to the BS for monitoring and alarm system and store at the SD card in the same node.
- The BS receives the data from each node at a real-time to display and analyze. In case of any unhealthy values, the BS sends an alarm to the doctor node.
- The doctor node has LCD and alarm sound to alarm the doctor about the patient case with some details.
- The SW searches all actual nodes in the network and diagnoses any system or network errors.
- The system can easily integrate with any other network including the internet.
- The system is flexible and can be develop according to the new requirements.

The monitoring GUI can use two methods of operation which are the multi-node and the single-node. The first one is displaying data form all patient sequentially. The second one selects a certain node to be monitored at a time. The monitoring GUI contains system status which describes the doctor node status and the patient node status. Moreover, it has a status bar to describe the system task at the time of operation.

4.7.1 Setup Operation

This operation for patient nodes is only to store the patient personal data at the MCU in the patient node. These data are Patient Name, Doctor Name, Age, Gender, Date, and Time. As shown in figure 4.17, it is easy way to setup any patient nodes using WSN. A success message is shown after the operation success or error message if the operation is failed.

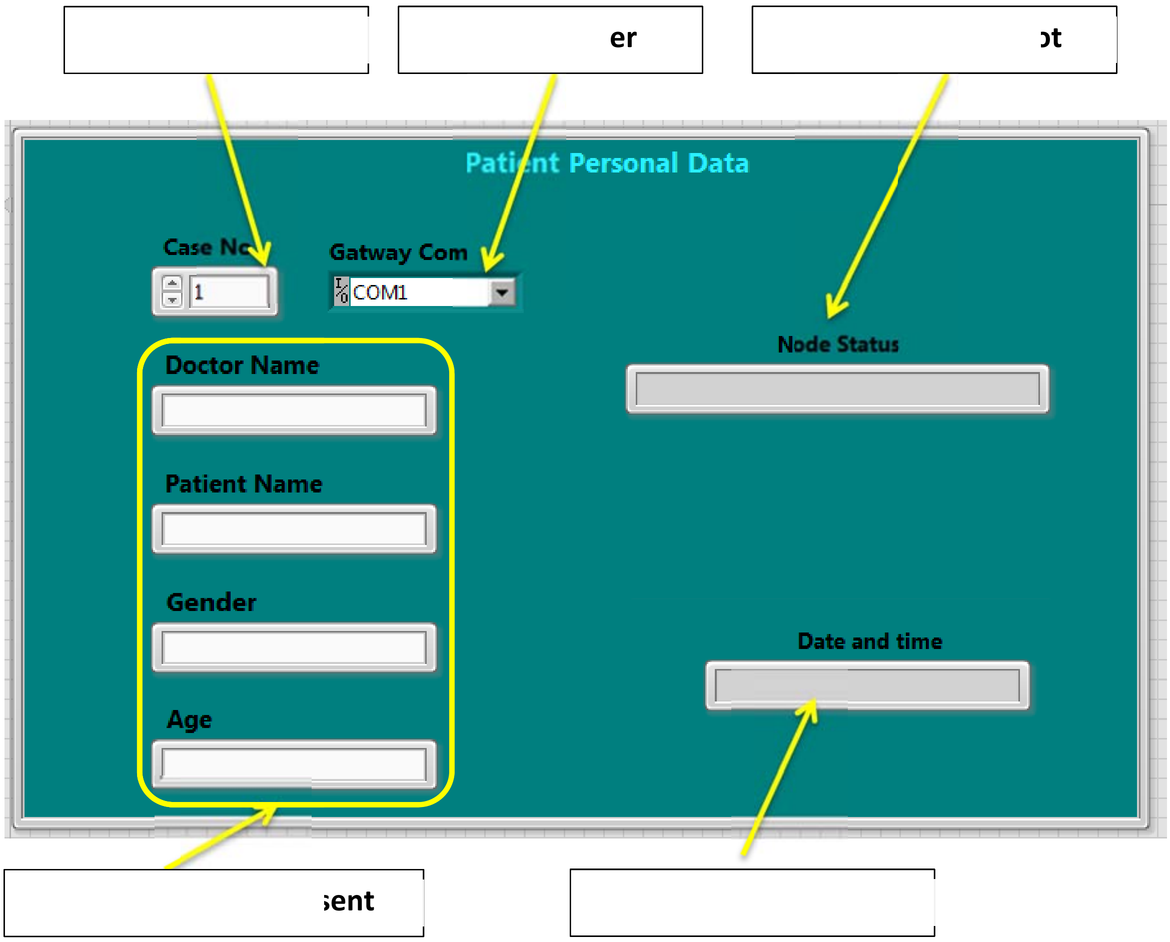


Fig. 4.17 Patient nodes setup GUI

4.7.2 Searching Operation

It performs the searching for all nodes in the network and stores it in the nodes addresses table, so the other operations can be processed using this table. The system can update these nodes at any time by starting the searching operation. The SW diagnoses any failure response for patient's node. The status bar at the monitoring windows shows that the system searching nodes so the SW in the searching operation now.

4.7.3 Sensing Operation

The setup and searching operations support the major operation which is the sensing operation. In the sensing operation, the base station sends a control packet to the patient nodes to start sensing, each node process the temp, ECG, and HR data and sends this data with the personal data back to the base station. The base station receives these data and processes it, and then displays each data (personal, temp, ECG, and HR) instantaneously in its display place in the GUI as shown in figure 4.18. At the same time, the base station scans the received data to give an alarm signal to the doctor for any emergency case. If the alarm system was ON, the doctor receives the data form the base station contained the node no, HR status (high or low according a threshold value depending on a medical standard), HR value, Temp status (high or low according a threshold value depending on a medical standard), and its value. In this operation the status bar display the system is connecting to the patient node now.

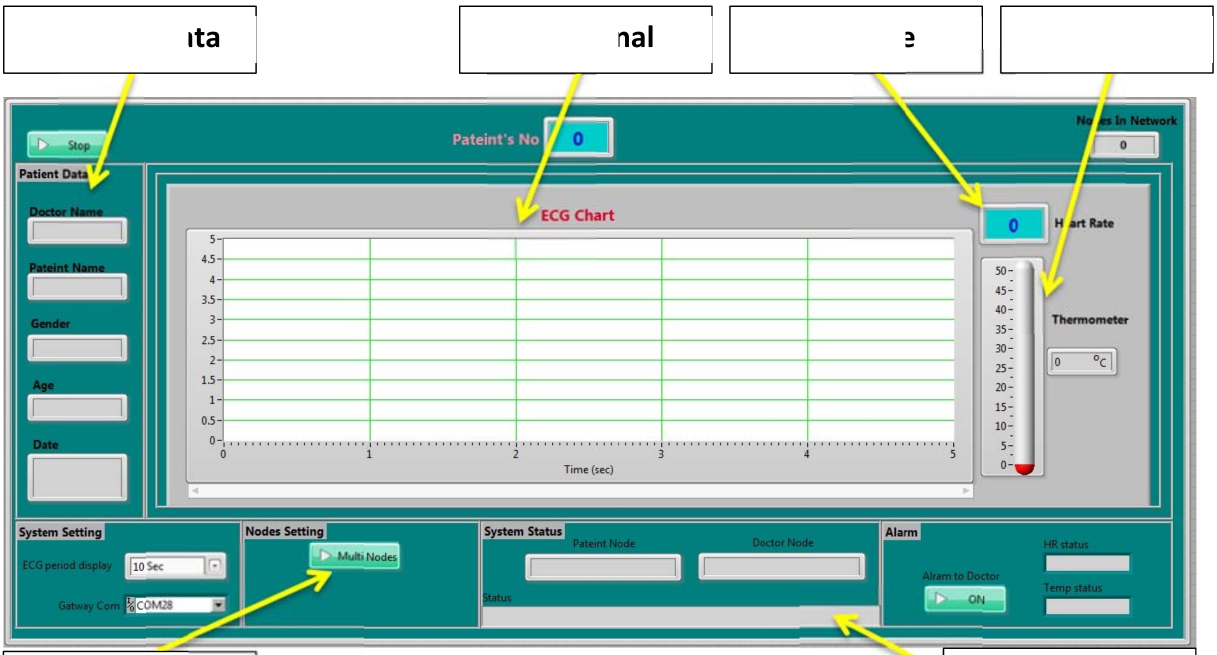


Fig. 4.18 The monitoring GUI

4.8 System Features

We developed this prototype system which is characterized by the following features:

- Real time monitoring without delay.
- Multi patients system.
- Auto detection for any new nodes.
- Portable alarm system with display.
- High resolution ECG monitoring.
- Auto detection for nodes failure and communication errors.
- Display system status for all operations
- Software can operate at any computer.
- Wireless system no more cable complexity.
- Free patient movement.
- Friendly user interface.

4.9 Home Healthcare Monitoring System

The improved system for home patients monitoring is shown in figure 4.19. The purpose of the system is to monitor the patient at home to decrease the hospital services cost and if the patient's condition does not require staying in the hospital only to monitor the situation.

The home healthcare system has two main parts:

- ***Patient node***: is the sensing node which senses the vital signal from the patient body.
- ***Gateway node***: connect the patient node to the rest of the world using the internet.

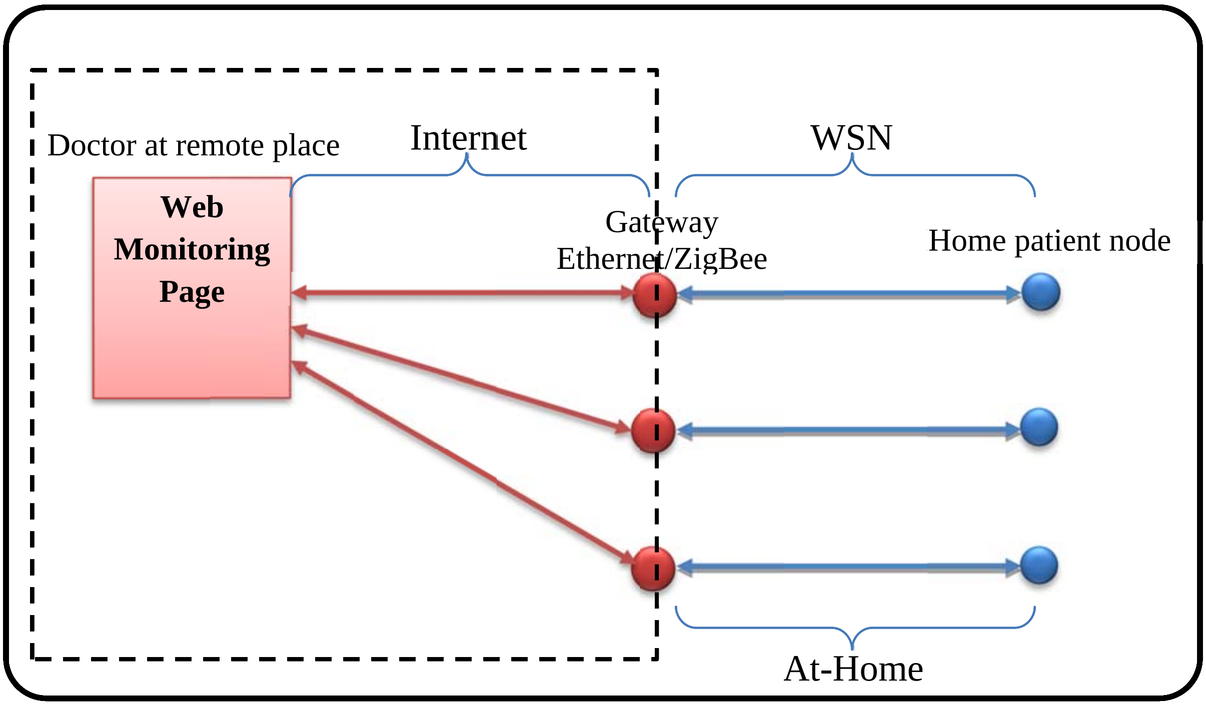


Fig. 4.19 Home healthcare monitoring system

4.9.1 Patient Node

The patient node is the same patient nodes for the previous system. Where, it is sensing the body temperature, the ECG, and the HR. The values of the Temperature and HR send to the GW node periodically. The period time can be fixed or flexible depending on the patient case.

4.9.2 Gateway Node

Refer to figure 4.20, the Gateway node consists of the following components:

- MCU.
- XBee communication.
- Power adapter.

The hardware and software details of each of the mentioned components are explained in the next subsections.

4.9.2.1 MCU

The processor unit used is the Atmel MCU (ATmega328), we used the Arduino Ethernet platform where it contains the ATmega MCU, and also has a Wiznet Ethernet interface. The platform specifications are:

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O	14 (of which 6 provide PWM output)
Analog Input	6
DC Current per I/O	40 mA
DC Current for 3.3V	50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz
Ethernet Controller	W5100 TCP/IP

This platform uses the same Arduino methods for communication and moreover uses the TCP/IP protocol. The board can connect to internet via Ethernet using wire connection by providing an IP address and a MAC address. It receives data from the serial connection (Tx and Rx) and sends the data through the Ethernet.

We program the platform using the serial connection to the computer. The GW task is receiving the data from the ZigBee network and sending the data to the Internet. The received data from the XBee sends to the internet to feed the web monitoring page by the patient case. There are many web sites which can support this operation, we use a free site. Three format types can be supported to feeding the data which are json, xml, and csv. We use json format because it feeds the site better than another format and without any errors. We accomplish all necessary work to fit this format in the MCU program because it has many details and should upload to the site with a certain format.

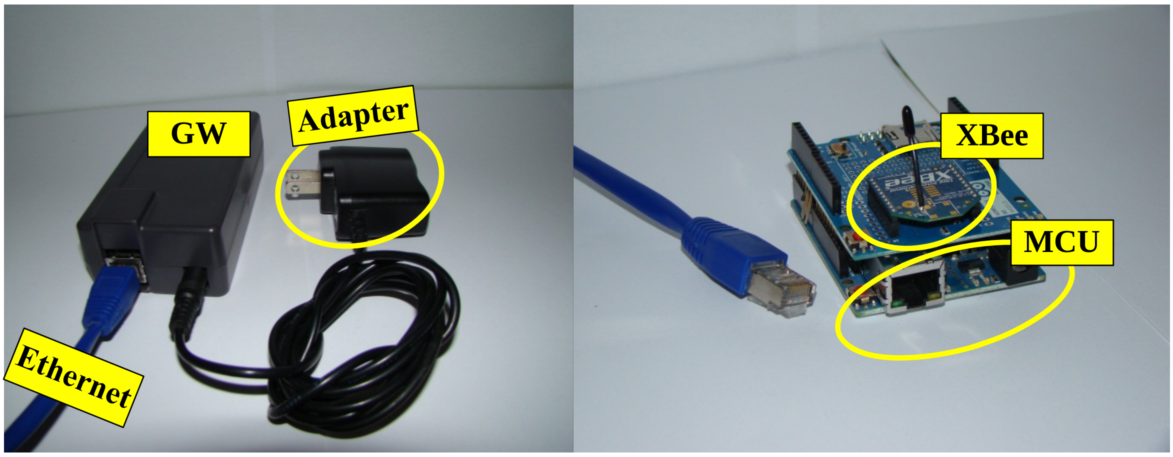


Fig. 4.20 The GW node

4.9.2.2 XBee Communication

The XBee connects to the Arduino Ethernet using the Ethernet shield and has the same specifications as shown in the previous system. We configure the XBee as a coordinator to start ZigBee network and to communicate with the patient node's XBee. The XBee modules interface to the Arduino Ethernet through the Ethernet shield. Therefore, the XBee receives the data from the patient node which is the HR and temperature and sends it to the Arduino Ethernet.

4.9.2.3 Power Adapter

The Arduino Ethernet is supplied by 9V-DC. A 220V AC/9V DC adapter which it uses to supply this platform. The GW is a fixed node because it will connect to Ethernet using wire. Therefore, the GW can be easy supplying from any nearby AC power.

4.9.3 Operation

There are many patients who can be monitored out of the hospital if the technology can provide the home healthcare system. The home healthcare system depends on the patient node measure the value and the GW to send these values (HR and Temp) to the web monitoring page using the global international network (Internet). The GW feeds the web page by these values to be available at any location using any web browser. The system performs the following operations (refer to figure 4.21):

- The patient node (in home) starts the sensing operation which measures the body temperature value and read the ECG signal to calculate the HR value. This operation is performed periodically for a certain time depends on the GW which sends the data request. Additionally, it stores these values in the SD card inside the node.
- The patient node sends these values to the GW using the XBee module which is based on ZigBee protocol. Where the patient node's XBee is configured as ZigBee end device.
- The GW receives these values from the patient node and prepares the data with the proper format. After that, the GW sends the data to feed the web monitoring page using TCP/IP protocol.
- The web monitoring page displays the received data. The web page provides a historical graph to monitoring the case for any time period such as one hour, 1day, or 1 month. It can be global page to display the data for any one or secure for an authentic person (doctor). The web page receives the data from many patients and displays the data on a per person basis.

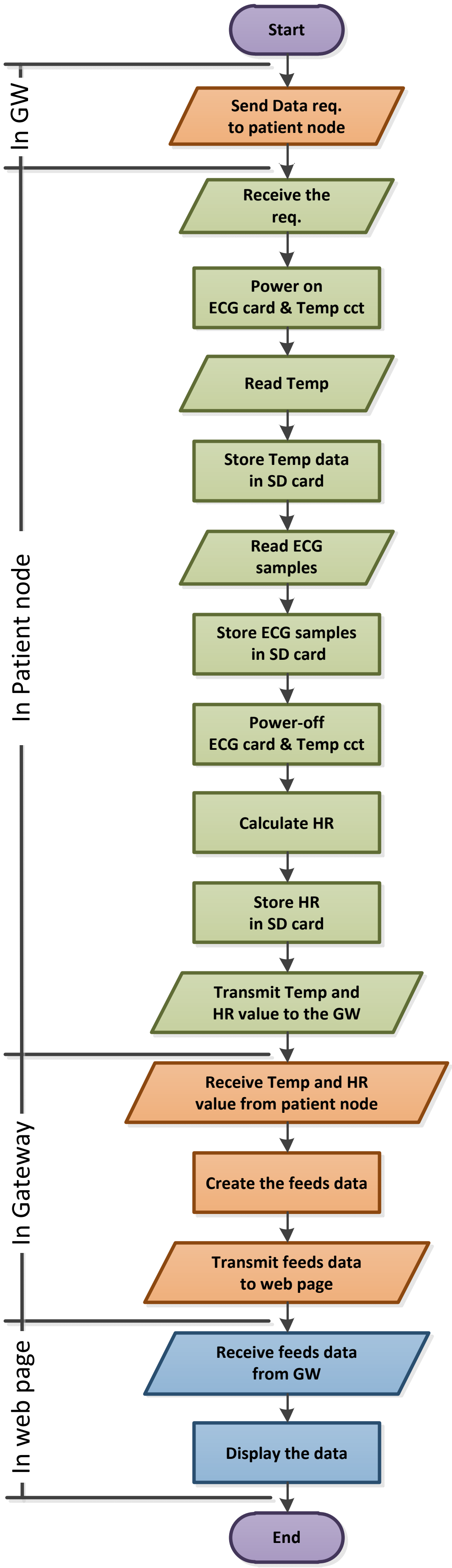


Fig 4.21 Homecare system operations

Chapter Five

Chapter Five

Results and Discussion

5.1 Results

At the beginning, we show the GUI screen descriptions which display the reading values and control of system. We divide the results into two parts, the first is the results reading from the serial connection of the MCU which is a wired connection between the MCU and the BS, and the second is the wireless results using the WSN.

5.1.1 The GUI Descriptions

GUI displays three measured values from the patient which are the ECG, HR, and Temperature as shown in figure 5.1. The GUI screen also displays the number of nodes in network (number of patients) and the system status. The following fields are displayed in the GUI:

- No. of nodes: is the total number of nodes (patients) in the network.
- Active node: the GUI displays the data of the active patient.
- Personal: is the patient personal data.
- ECG chart: is the filed for displaying the ECG signal as a graph.
- HR indicator: is the field in which the value of HR value is displayed.
- Temp indicator: is the filed for displaying the value of the temperature.
- Operation Modes: is the control for Multi-node or single-node operations.
- Status bar: displays the system messages such as which operation is running, status of node, and error messages.
- Alarm: for ON or OFF of alarm and its indicators.

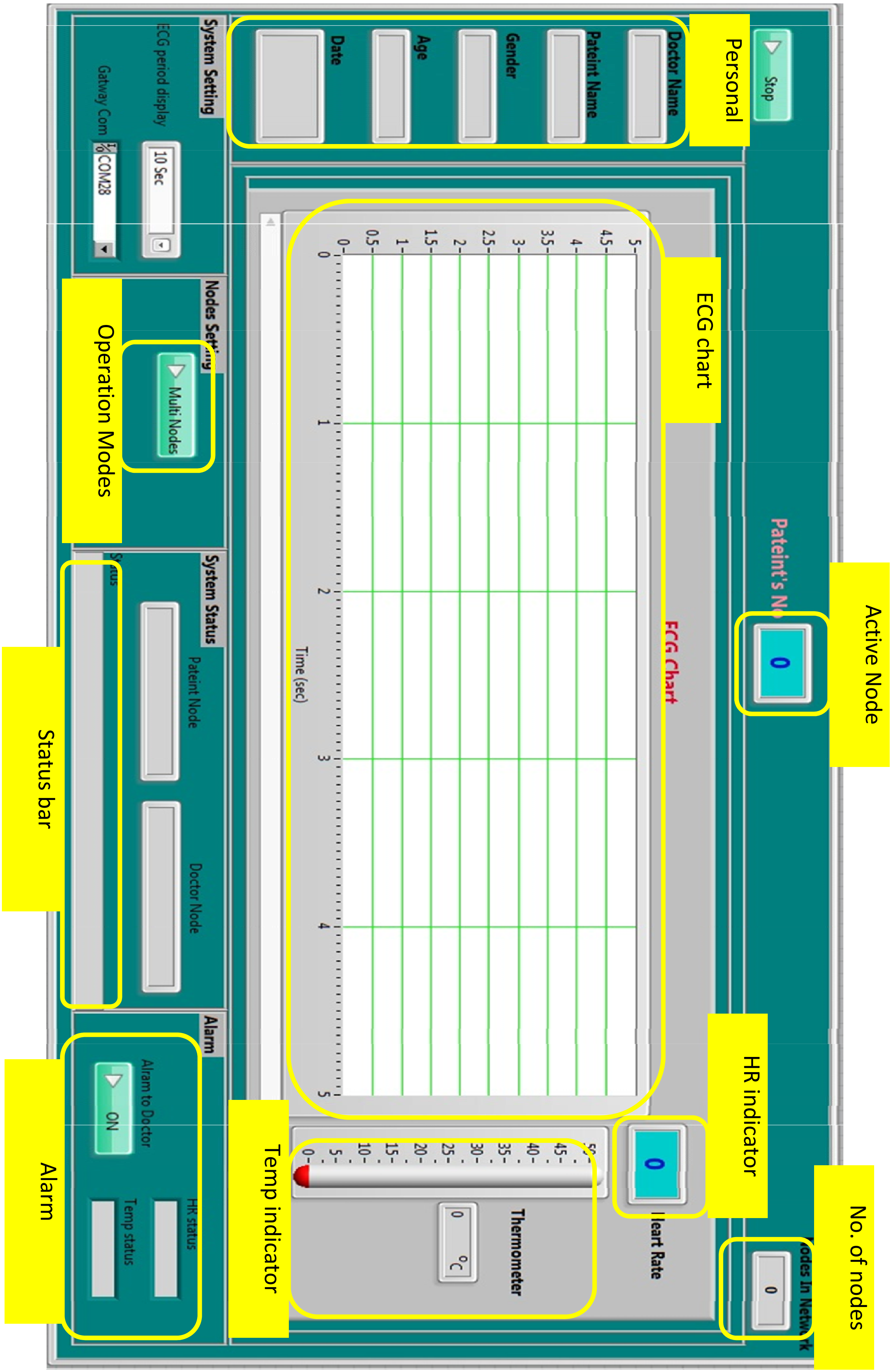


Fig. 5.1 The GUI display fields

5.1.2 The Serial Connection Results

Firstly, we tested the ECG card by drawing the received data for the MCU serial connection using the Ms. Excel program as shown in figure 5.2. The sampling rate is 1450 samples per second and using the reusable electrodes in the limbs for ECG-lead-I.

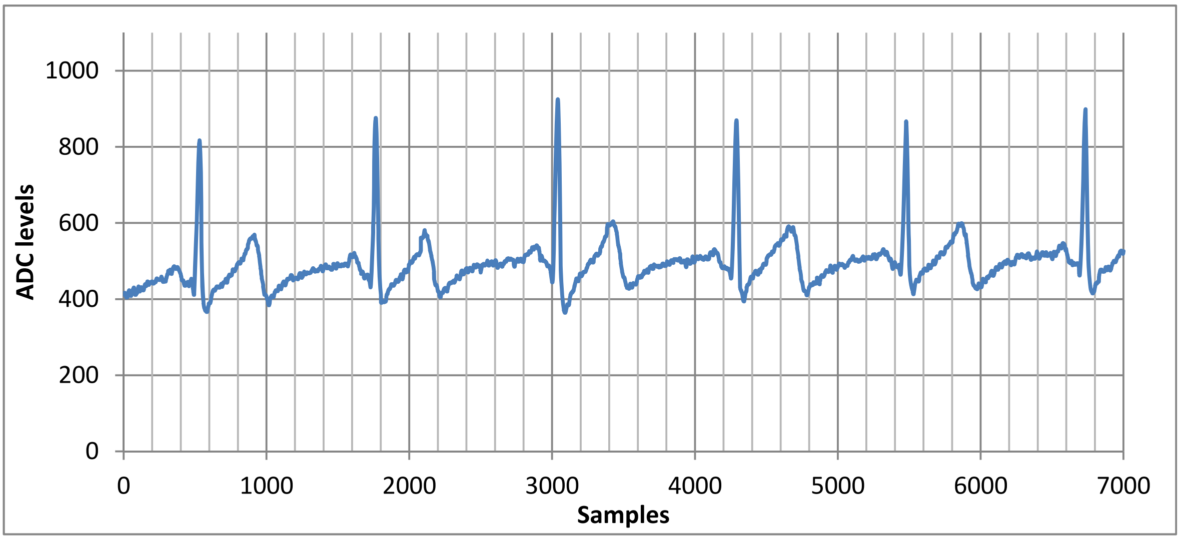


Fig. 5.2 ECG-lead-I / limbs electrodes / 1450 (samples/s)

Figure 5.3 shows the ECG-lead-I at sampling rate is 200 samples per second and using the reusable electrodes in the limbs.

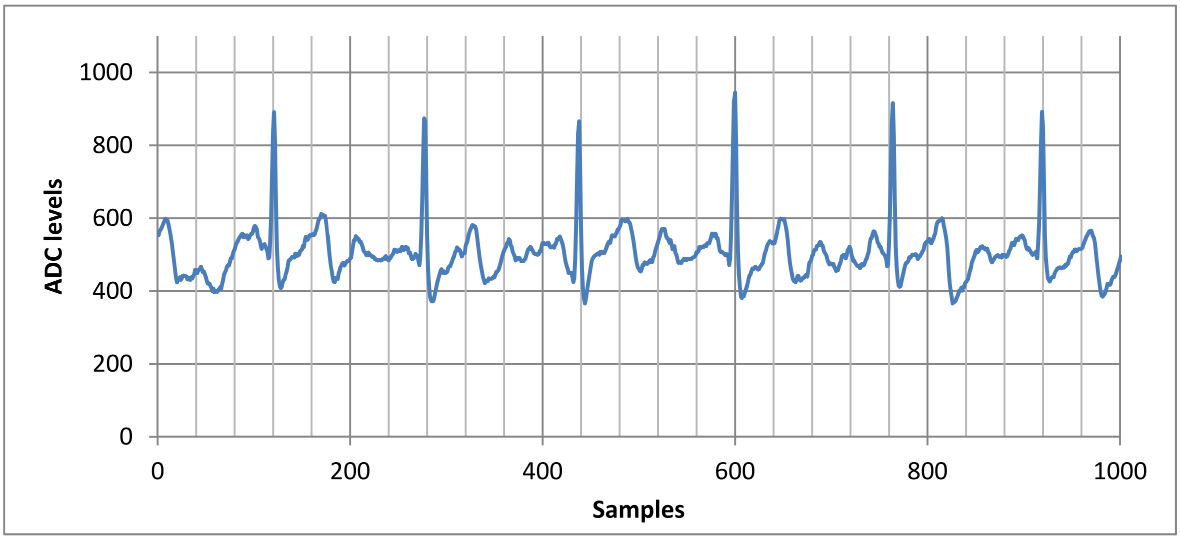


Fig. 5.3 ECG-lead-I /limbs electrodes/200 (samples/s)

At the same time, we store the ECG samples in the SD-card and it draw using the Ms. Excel as shown in figure 5.4. The sampling rate is 200 samples per second.

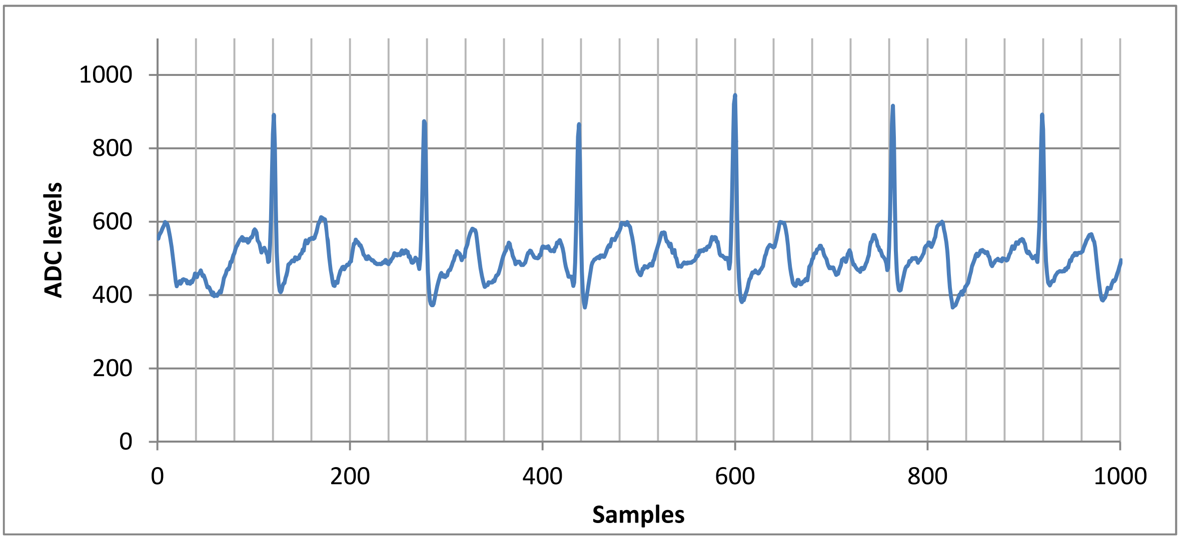


Fig. 5.4 ECG-lead-I /limbs electrodes/200 (samples/s) / SD-card

Now we wish to explain how to use our GUI for displaying the ECG signal which is based on the LabVIEW software. The sampling rate is 200 samples per second and using the chest electrodes for ECG-lead-I as shown in figure 5.5.

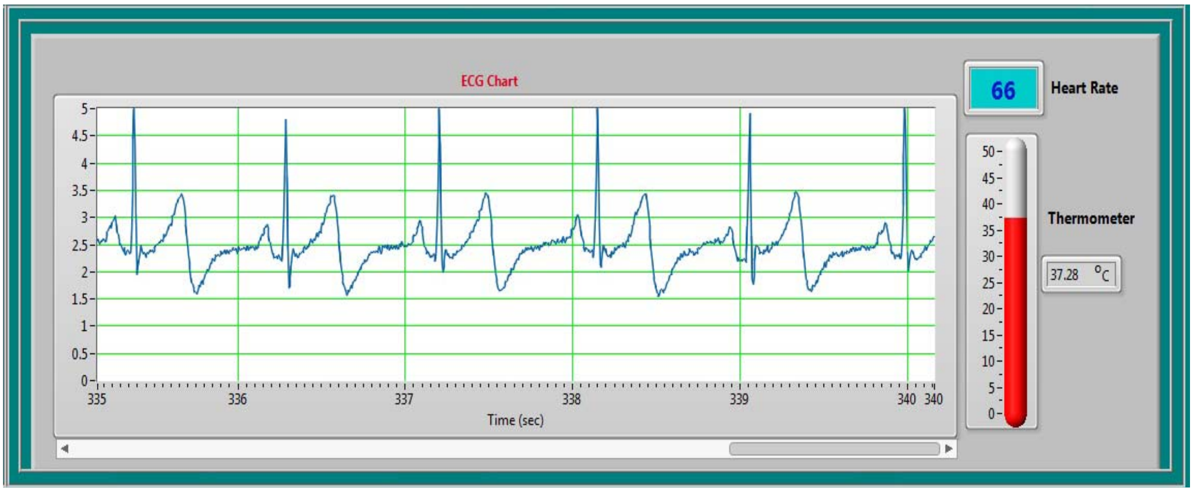


Fig. 5.5 ECG-lead-I /chest electrodes/1450 (samples/s)

At the same time, we store the ECG samples in the SD-card as shown in figure 5.6. The sampling rate is 1450 samples per second.

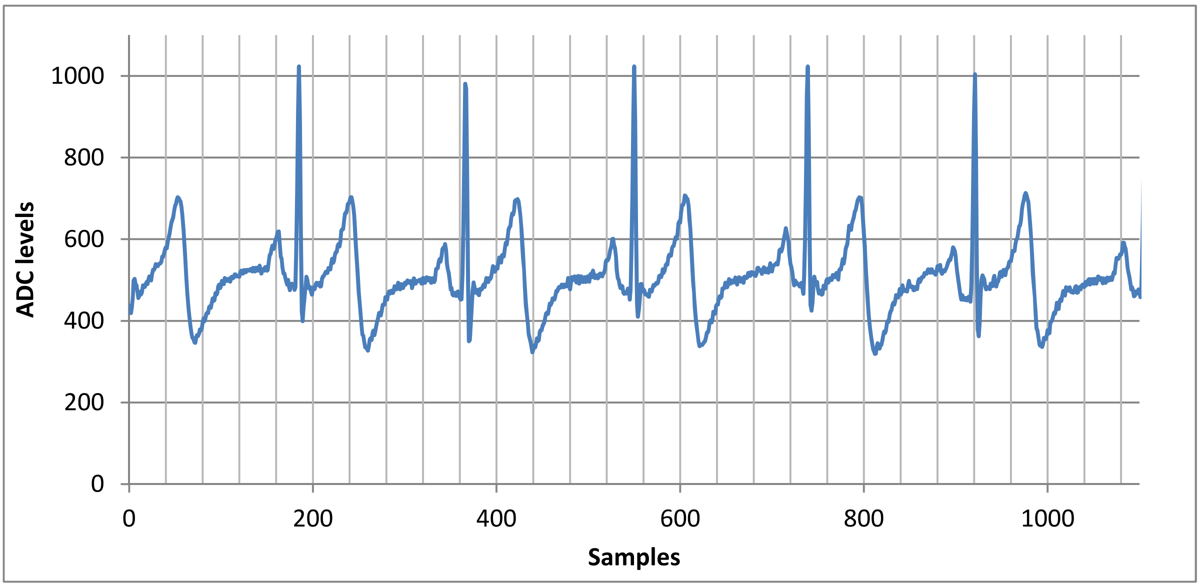


Fig. 5.6 ECG-lead-I /chest electrodes/1450 (samples/s) / SD card

The ECG-Lead-II using the chest electrodes is shown in figure 5.7. The sampling rate is 1450 samples per second.

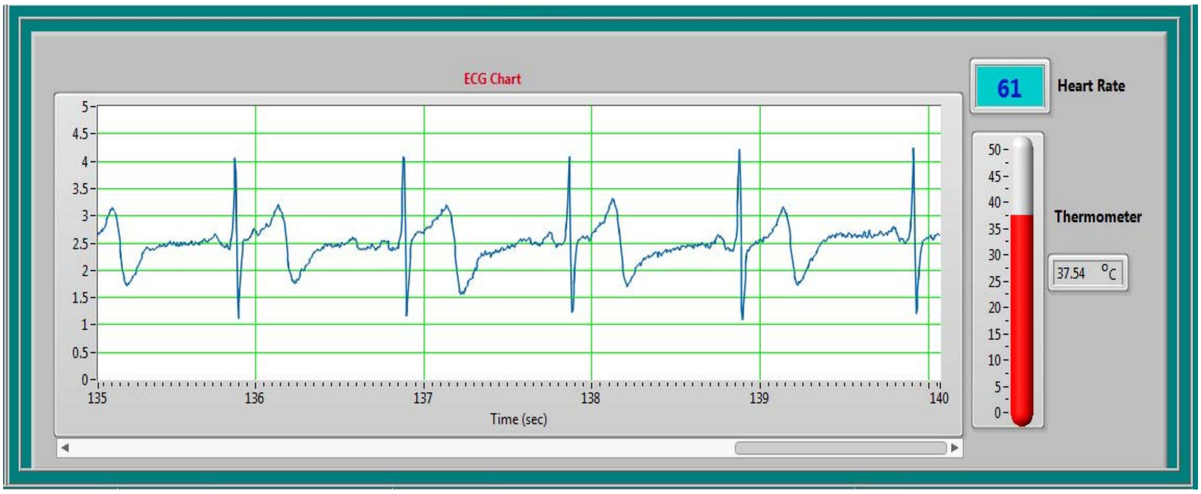


Fig. 5.7 ECG-lead-II /chest electrodes/1450 (samples/s)

5.1.3 The Wireless Results

The patient data sends from the patient node to the BS through the GW wirelessly. After that the GUI displays the data in the allocated fields. The ECG-Lead-I at 200 samples per second is shown in figure 5.8 using limbs electrodes.

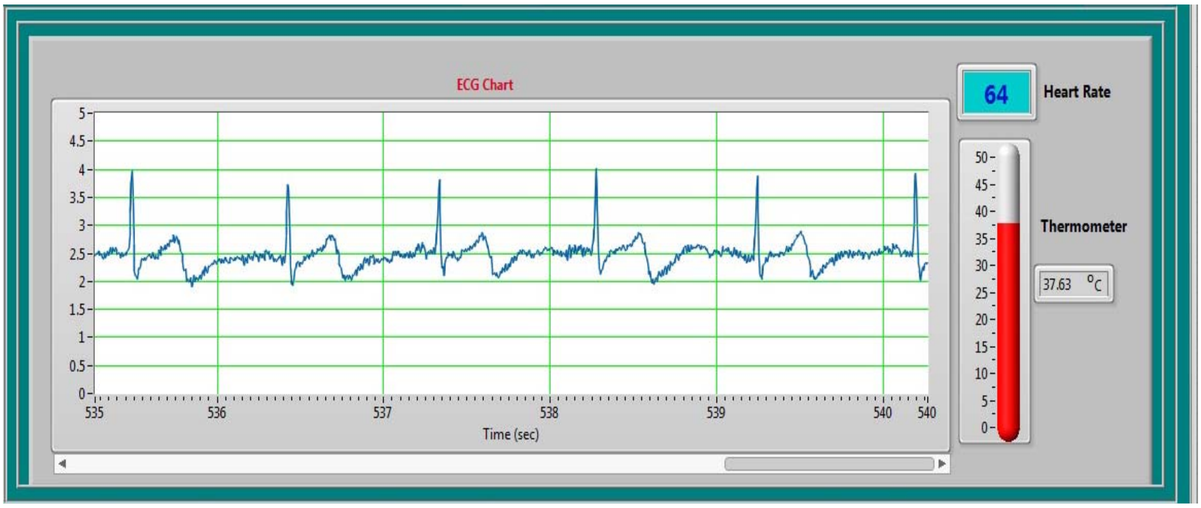


Fig. 5.8 ECG-lead-I /limb electrodes/200 (samples/s)

ECG-Lead-I as shown in figure 5.9 using chest electrodes and samples at 200 samples per second, the figure 5.10 shows the SD-card reading.

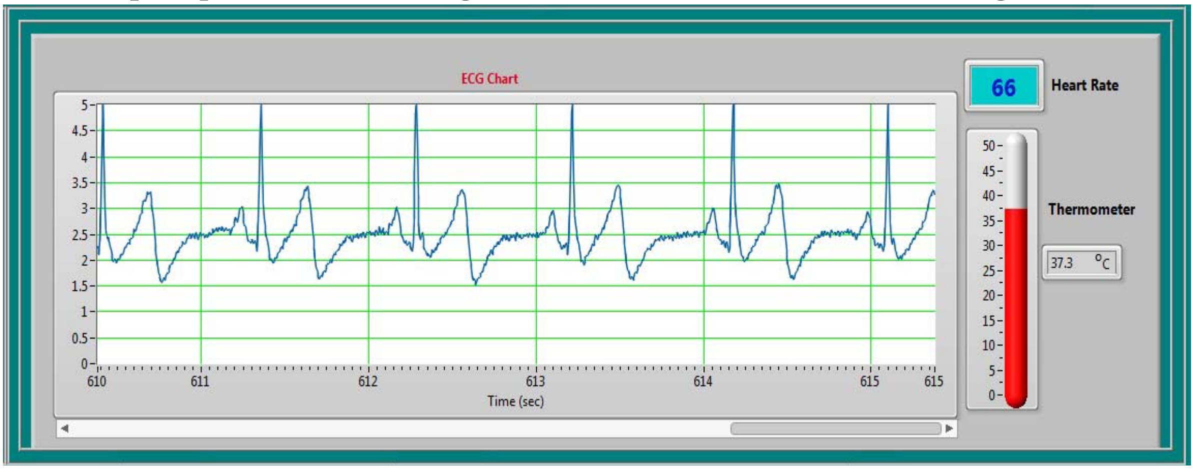


Fig. 5.9 ECG-lead-I /chest electrodes/200 (samples/s)

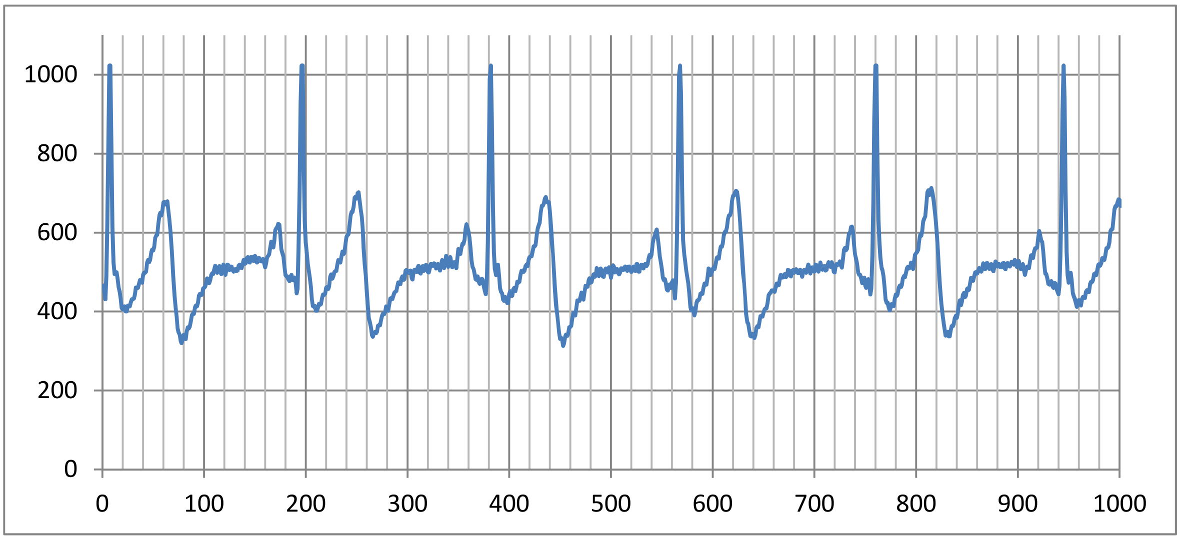


Fig. 9.10 ECG-lead-I /chest electrodes/200 (samples/s)

By same method we can read ECG-Lead-II as shown in figure 5.11 using limbs electrodes and samples at 200 samples per second.

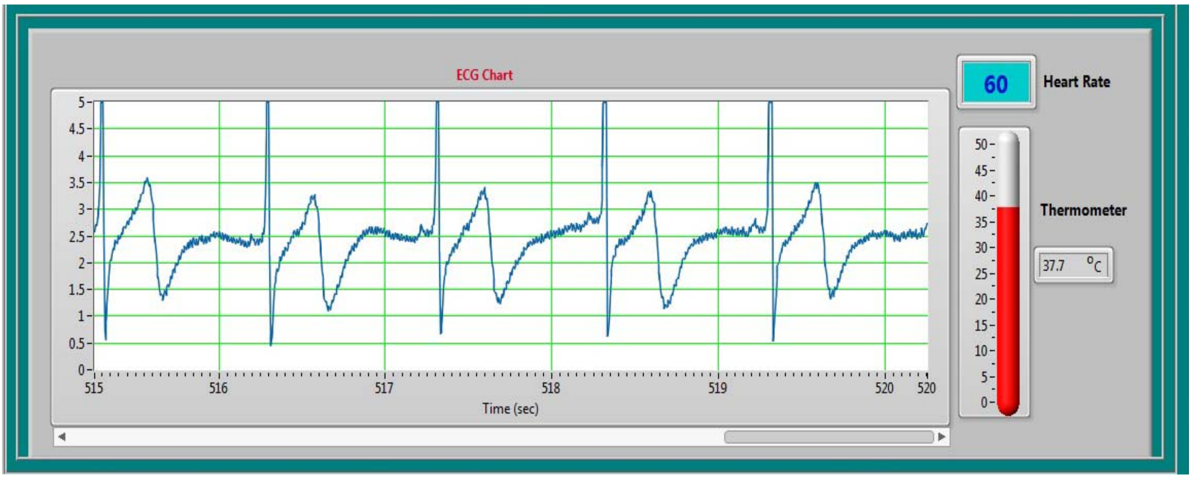


Fig. 5.11 ECG-lead-II /chest electrodes/200 (samples/s)

The designed healthcare system is shown in figure 5.12. The complete WSN layout in intensive care of Merjan Hospital is shown in figure 5.13. All nodes connected with the Base station through the GW and the base station display data that received from the nodes. Finally, the hospital result for multi-patients is shown in figure 5.14.

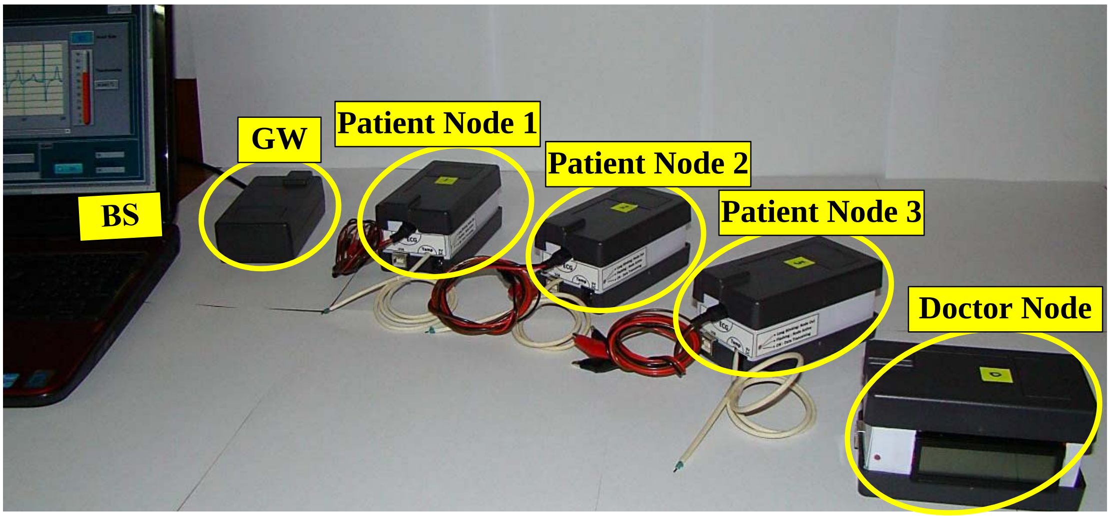


Fig. 5.12 Prototype healthcare system

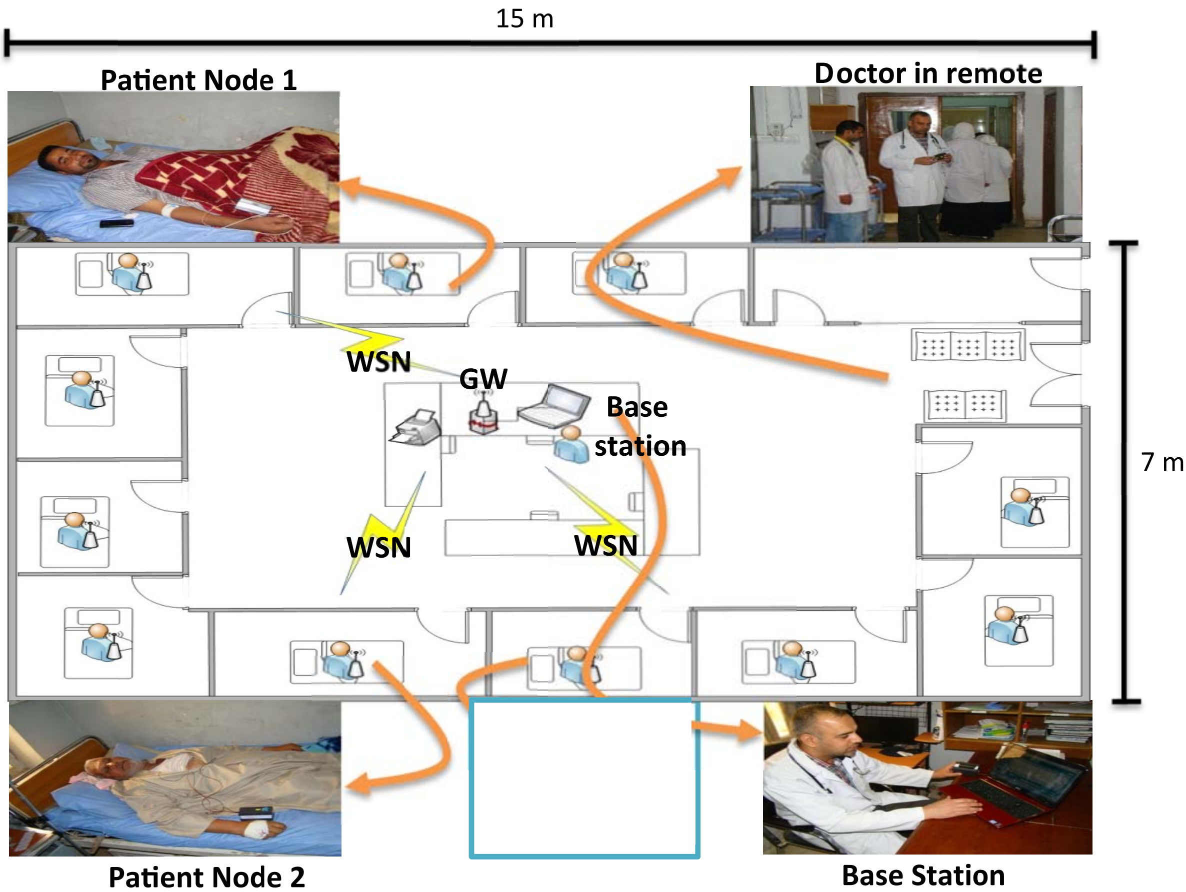


Fig. 4.13 Intensive Care Unit layout in Merjan Hospital- Babylon

Fig. 5.14 ECG-lead-II /chest electrodes/200 (samples/s)

For the home healthcare system, the patient web monitoring page is shown in figure 5.15 which contains two measured values. These values are the HR and the Temperature. The web display the values as a historical graph for each patient, the HR value and the temp value are the last values uploaded to the site. Additionally the web displays the graph for a selected period such as 5 min, 1 hour, or 3 months as shown in figure 5.16.

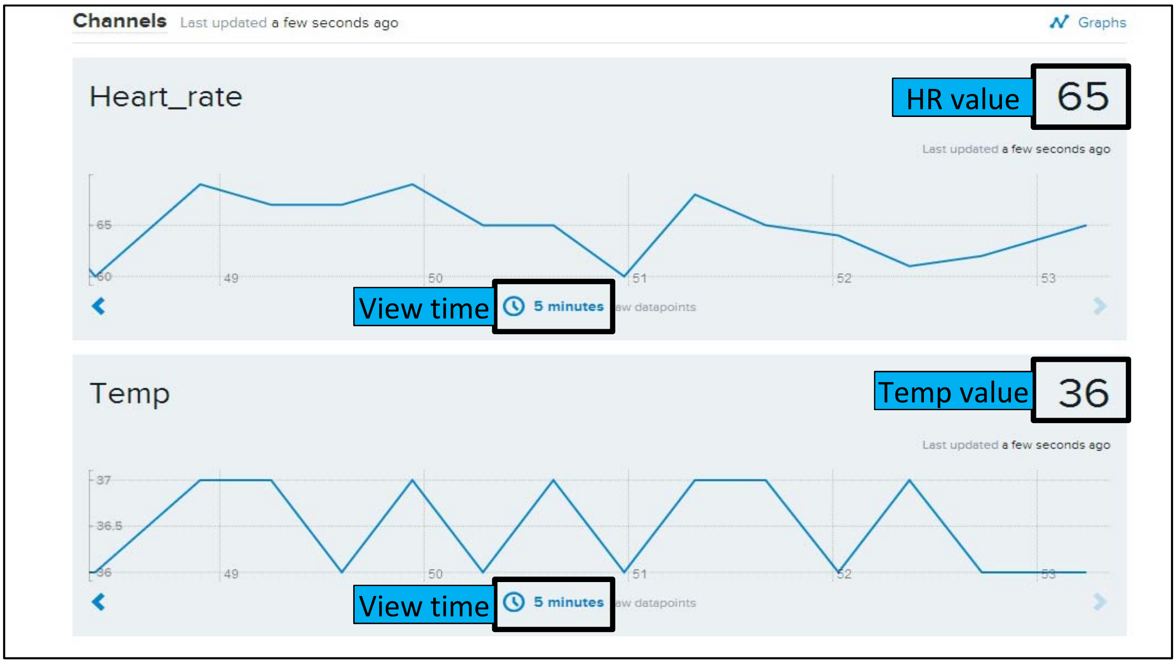


Fig. 5.15 Web page view for 5 min

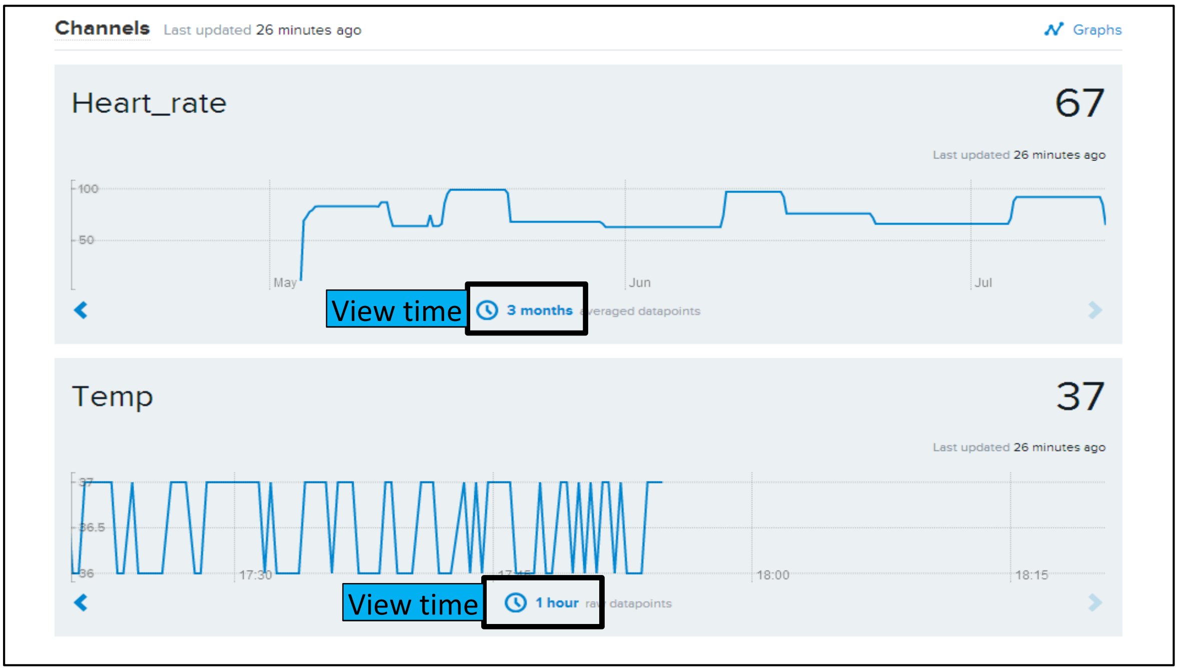


Fig. 5.16 Web page view for different time period

5.2 Discussion

The result discussion is described as the following:

- We are focusing on the ECG result because it has different method, it is the important signal in the monitoring issue, and it is difficult to read.
- All figures are drawn using excel software are charted using the recorded values, so it is not a real-time. The results that have been stored in the SD card are identical to the results that we have displayed by the wireless system.
- We are taking the ECG reading using the limbs and the chest methods.
- The Limbs electrodes which are reusable electrodes have more noise and less energy.
- The chest electrodes which are disposable electrodes have less noise and more energy.
- The sampling rates used are 200 and 1450 sample per second. The 200 is used for monitoring and diagnostic applications and the 1450 is used for pacemaker applications.
- The 1450 uses all MCU resources however the 1000 is enough for pacemaker. We used the 1450 to test the system performance and it is efficient at this rate so we can use any proper sampling rate less than the 1450 for a certain application.
- We configure the system to work at 200 samples per second which is efficient for monitoring and diagnostic requirements applications.
- We check the HR values with another equipment to validate the algorithm results.
- Some temperature values in the previous results are calculated by the MCU and the other by the LabVIEW.
- There is no error between reading using the wires and the wireless.

- The system is installed and tested in Merjan Hospital – Babylon city for many patients, the patient data that has been measured in hospital and the results is shown in figure 5.14. This figure shows the received data from the patient node. Personal data are stored in the node using setup operation before this operation. The ECG displayed is real-time ECG from patient node, also the HR and temperature.
- The system is tested under the supervision of the doctors in the hospital and after many program runs they tell us that the results displays on the GUI are very satisfactory with confidence.
- In relation to the home healthcare system, We setup the patient node to send the data each 1 min for testing the system. The GW receives the data wirelessly without any error. After that, the GW is feeding the web page successfully. We test the system using slow internet service which is available in our country.

Chapter Six

Chapter Six

Conclusions and Future Works

6.1 Conclusions

The thesis conclusions are summarized into the following aspects:

- The real-time patient data is a good feature to take the decision as soon as possible by the doctor in charge and save the patient life.
- The stored data is a good issue for statistical studies and medical research.
- The system is flexible for any new requirements such as adding new sensors, changing the network topology, or updating the GUI.
- The system is low cost where the patient node cost 130$ and doctor node cost 103$.
- The coverage of the wireless system is about 30 meters in diameter and that is enough for ICU. In order to increase the coverage area is simply done by changing the transceiver (XBee).
- According to the obtained results and the certification of the specialists at hospital, the presented healthcare system is very useful and applicable for hospital and home cares. Where many doctors can display the data for any patient from any PC or smartphone connected to internet using a simple web page.
- In relation to the home healthcare system which offers a good feature for monitoring the patient from any location using simply web page. This web can be displayed using any PC or smartphone connected to internet. So many doctors can display the data for any patient.

6.2 Future Works

The implemented system can be improved by applying some of the following points:

- Improve the patient node by adding five ECG card for 12-leads diagnostic ECG, where the MCU has 6 analog inputs.
- Change the LCD used in the doctor node by more resolution LCD to send the ECG signal for any patient to be monitored. That will be a good feature for this node.
- Adding SpO_2 and blood pressure sensors to patient nodes.
- Implement a portable ECG which is a node with high resolution LCD to display the ECG directly.
- Design a data base for the patients measured data.
- Integrate the alarm system to the GSM mobile network for sending the alarm messages which recently known as m-health.
- Improve the analyze system at the BS to diagnostic the complex arrhythmia cases.

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Appendix A

A.1. Patient Node program (MCU)

A.2. Doctor Node program (MCU)

A.3. Internet Gateway Node program (MCU)

A.1. Patient Node program (MCU)

```
#include <SD.h>
#include <avr/power.h>
#include <avr/sleep.h>

File myFile;
const int analogInPin0 = A0;  // Analog input pin that the ECG connection
const int analogInPin2 = A2;  // Analog input pin that temprutre sensor
const int ecgEn=7;           //power ECG
const int tempEn=10;         //power temp
int   ecg = 0;              // analoge value read from ECG
int ecgOld=0;               // save oled ecg
int   Vt = 0;               // analoge value read from the port 0-1023
int HR=0;
int sum=0;
int samp=10;
int th=80;
char Ps;
char Pdata[100]="Mohamed;Ahmed;male;22;26/3/2013";
int xs=0;
int select;                 //operations selection

void setup()
 {
  Serial.begin(9600);
  analogReference(EXTERNAL);
  pinMode(ecgEn, OUTPUT);
  pinMode(tempEn, OUTPUT);
  if (!SD.begin(4)) {           //4 used for SD card
    Serial.println("initialization failed!");
    return;
    myFile = SD.open("Log1.txt", FILE_WRITE);
    myFile.println("Start ok");
    myFile.close();
    }
 }

void sleepNow()
 {
 set_sleep_mode(SLEEP_MODE_IDLE);   // sleep mode is set here
 sleep_enable();                  // enables the sleep bit in the mcucr register
 power_adc_disable();             // Disaple unnecessary functions
 power_spi_disable();
 power_timer0_disable();
 power_timer1_disable();
 power_timer2_disable();
 power_twi_disable();
 sleep_mode();          // here the device is actually put to sleep!!
                    // THE PROGRAM CONTINUES FROM HERE AFTER WAKING UP
 sleep_disable();       // first thing after waking from sleep:
                    // disable sleep...
 power_all_enable();
```

```
  }

void loop()
{
if (Serial.available() > 2) {  //received data
  select = Serial.parseInt();
  switch (select){
  case (2):{
    do{
      Ps=Serial.read();         // read the personal data
      Pdata[xs]=Ps;             // store it
      xs++;
      delay(5);     //some delay
      }while(Ps!='\n');
      Serial.println(Pdata);
    }
    break;
  case (3):{
    samp=Serial.parseInt();
    th= Serial.parseInt();
    samp=samp*200;
    th=th*10;
    byte j=0;
    Serial.println('n' );   // pationt data
    Serial.println(Pdata);
    digitalWrite(ecgEn,HIGH);
    myFile = SD.open("Log1.txt", FILE_WRITE);
    myFile.print("Start data for:");
    myFile.println(Pdata);
    myFile.println("t");
    digitalWrite(tempEn,HIGH);
    Serial.println('t');
    for (int i=0; i<=5; i=i++){
      delay(1000);
      Vt = analogRead(analogInPin2);
      Serial.println(Vt);
      myFile.println(Vt);
      }
    myFile.close();
    digitalWrite(tempEn,LOW);
    analogReference(DEFAULT);
    delay(1000);
    myFile = SD.open("Log1.txt", FILE_WRITE);
    myFile.println('e');
    Serial.println('e');
    for (int i = 1; i <= samp ; i = i++){
      ecg = analogRead(analogInPin0);
      if (ecg > th & ecgOld< th){
        j=j+1;
      }
     ecgOld=ecg;
     myFile.println(ecg);
     Serial.println(ecg);
```

```
    }
   myFile.close();
   samp=samp/200;         // calculate the sampling time
   HR=(j*60)/samp;        // calculate the HR
   Serial.println('h');   // start sending HR
   Serial.println(HR);    // sending HR
   myFile = SD.open("Log1.txt", FILE_WRITE);
   myFile.println('h');
   myFile.println(HR);
   myFile.println("End of Data");
   myFile.close();
   digitalWrite(ecgEn,LOW);
   Serial.println('d');
   delay(50);
   }
   break;  //(3)
  } //swicth
sleepNow();     // sleep function called here
} //if
}
```

A.2. Doctor Node program (MCU)

```
#include <avr/power.h>
#include <avr/sleep.h>
#include <LiquidCrystal.h>
String St1;
String St2;
String St3;
String Stt;
int bstate=0;
boolean show=false;
LiquidCrystal lcd(12, 11, 5, 4, 3, 2);
void setup()
 {
 lcd.begin(16, 2);
 Serial.begin(9600);
 pinMode(6,OUTPUT);
 pinMode(13,OUTPUT);
 digitalWrite(6,LOW);
 show=false;
 }

void sleepNow()
 {
 set_sleep_mode(SLEEP_MODE_IDLE);   // sleep mode is set here
 sleep_enable();                    // enables the sleep bit in the mcucr register
 power_adc_disable();               // Disaple unnecessary functions
 power_spi_disable();
 power_timer0_disable();
 power_timer1_disable();
 power_timer2_disable();
 power_twi_disable();
 sleep_mode();          // here the device is actually put to sleep!!
                        // THE PROGRAM CONTINUES FROM HERE AFTER WAKING UP
 sleep_disable();       // first thing after waking from sleep:
                        // disable sleep...
 power_all_enable();
 }

void loop()
{

 if (Serial.available() > 2) {  // receive data
    int NodeNo = Serial.parseInt();
    int HRs = Serial.parseInt();
    int TEs = Serial.parseInt();
    int HRv = Serial.parseInt();
    int TEv = Serial.parseInt();
    Serial.println('k');
    show = true;
    digitalWrite(6,HIGH);
    switch (NodeNo){
      case 1: St1="Node(1): ";
```

```
        break;
        case 2: St1="Node(2): ";
        break;
        case 3: St1="Node(3): ";
     }
     switch (HRs){
        case 1: St2="High HR=";
        break;
        case 2: St2="Low  HR=";
        break;
        case 3: St2="No ECG =";
        break;
      }
      switch (TEs){
        case 1: St3=",High Temp.=";
        break;
        case 2: St3=",Low  Temp.=";
        break;
        case 3: St3=",No Temp.  =";
        break;
      }
      Stt=St1+St2+String(HRv)+St3+String(TEv);
      lcd.print(Stt);
      Serial.println(Stt);
  }
  if (show == true) {
     for (int positionCounter = 0; positionCounter < 13; positionCounter++) {
     // scroll one position left:
     lcd.scrollDisplayLeft();
     delay(200);
     bstate=digitalRead(13);
     if (bstate == HIGH) {
      digitalWrite(13, LOW);
      }
     else {
      digitalWrite(13, HIGH);
     }
   }
  }
}
```

A.3. Internet Gateway Node program (MCU)

```
#include <SPI.h>
#include <Ethernet.h>
#define APIKEY        "key"
#define FEEDID        number
#define USERAGENT     " agent "
int HR;
int Temp;
byte mac[] = {
IPAddress ip(192,168,0,102);
// initialize the library instance:
EthernetClient client;
char server[] = "api.cosm.com";   // name address for cosm API
unsigned long lastConnectionTime = 0;         // last time you connected to the server, in milliseconds
boolean lastConnected = false;               // state of the connection last time through the main loop
const unsigned long postingInterval = 60*1000; //delay between updates to cosm.com

void setup() {
 Serial.begin(9600);        // start serial port:
  if (Ethernet.begin(mac) == 0) {             // start the Ethernet connection:
   Serial.println("Failed to configure Ethernet using DHCP");
   Ethernet.begin(mac, ip);            // DHCP failed, so use a fixed IP address:
 }
 delay(5000);
 Serial.println(100);
}

void loop() {
 if (Serial.available() > 0){
    Serial.println("OK");
    HR=Serial.parseInt()  ;
   Temp=Serial.parseInt();
} //serial avialable
 if (!client.connected() && lastConnected) {
   Serial.println();
   Serial.println("disconnecting.");
   client.stop();
 }
  if(!client.connected() && (millis() - lastConnectionTime > postingInterval)) {
   if (client.connect(server, 80)) {
   Serial.println("connecting...");
   // send the HTTP PUT request:
   client.println("PUT /v2/feeds/number.json HTTP/1.1");
   client.println("Accept: ");
   client.println("X-ApiKey: FcxL95dCPEQ7Vwa90M-TET7HE3OSAKxVRHc3NlFQdkw3cz0g");
   client.println("Content-Length: 126");
   client.println();
   char Str2[3] = {'{', '"','\0'};
   client.print(Str2);
   client.print("title");
   char Str3[4] = {'"', ':','"','\0'};
   client.write(Str3);
```

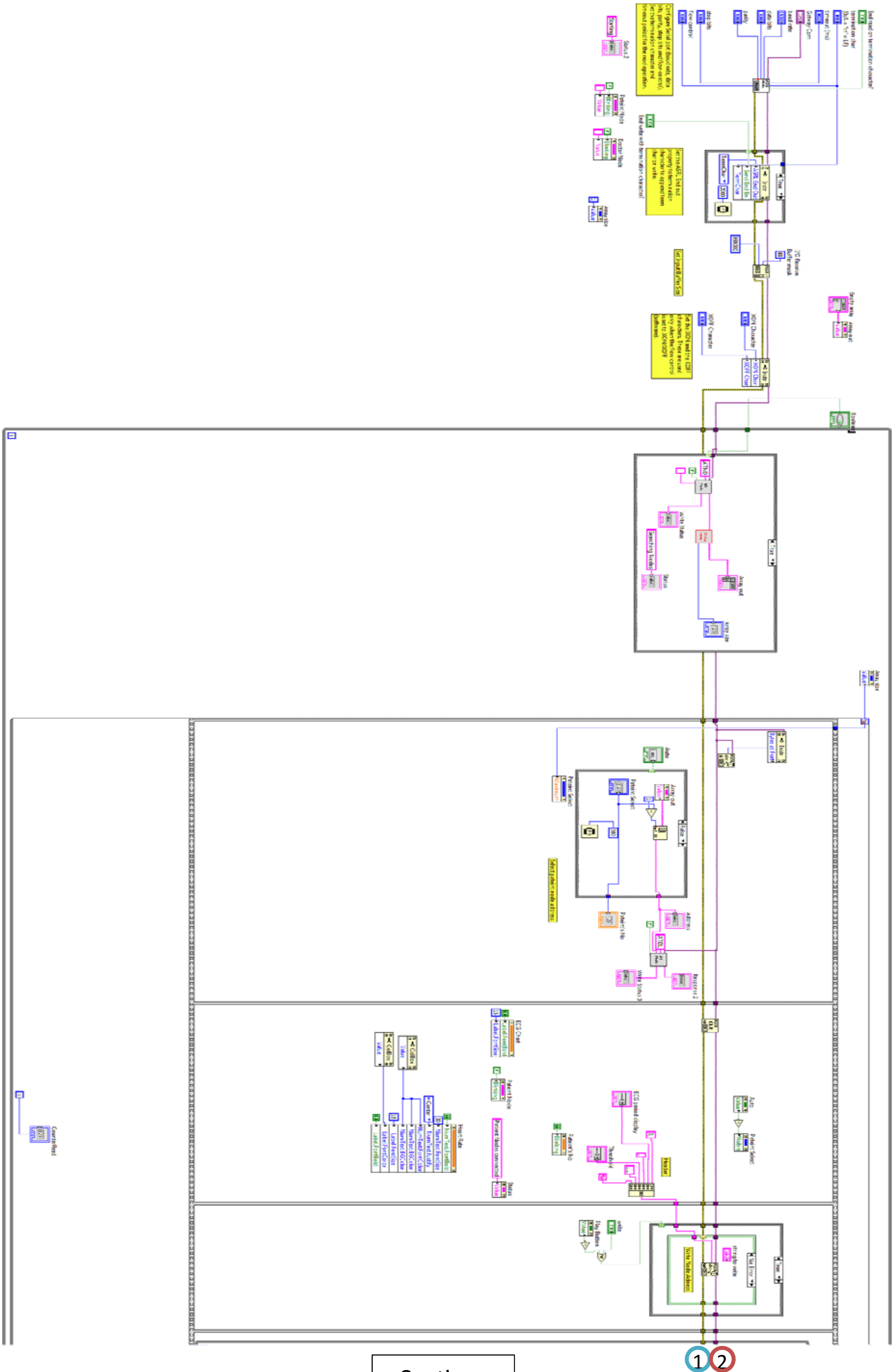
```
    client.print("one");
    char Str4[4] = {'"', ',','"','\0'};
    client.print(Str4);
    client.print("version");
    char Str5[4] = {'"', ':','"','\0'};
    client.print(Str5);
    client.print("1.0.0");
    char Str6[4] = {'"', ',','"','\0'};
    client.print(Str6);
    client.print("datastreams");
    char Str7[6] = {'"', ':' , '[' , '{' , '"' ,'\0'};
    client.print(Str7);
    client.print("id");
    char Str8[4] = {'"', ':','"','\0'};
    client.print(Str8);
    client.print("Heart_rate");
    char Str9[4] = {'"', ',','"','\0'};
    client.print(Str9);
    client.print("current_value");
    char Str10[4] = {'"', ':','"','\0'};
    client.print(Str10);
    client.print(HR);
    char Str11[6] = {'"', '}',',','{','"','\0'};
    client.print(Str11);
    client.print("id");
    char Str12[4] = {'"', ':','"','\0'};
    client.print(Str12);
    client.print("Temp");
    char Str13[4] = {'"', ',','"','\0'};
    client.print(Str13);
    client.print("current_value");
    char Str14[4] = {'"', ':','"','\0'};
    client.print(Str14);
    client.print(Temp);
    char Str15[5] = {'"', '}' , ']' , '}'  ,'\0'};
    client.println(Str15);
   }
  else {
    // if you couldn't make a connection:
    Serial.println("connection failed");
    Serial.println();
    Serial.println("disconnecting.");
    client.stop();
  }
  }
    Serial.println(100);
    lastConnected = client.connected();
if (client.available()) {
    char c = client.read();
    Serial.print(c);
  }
}
```

Appendix B

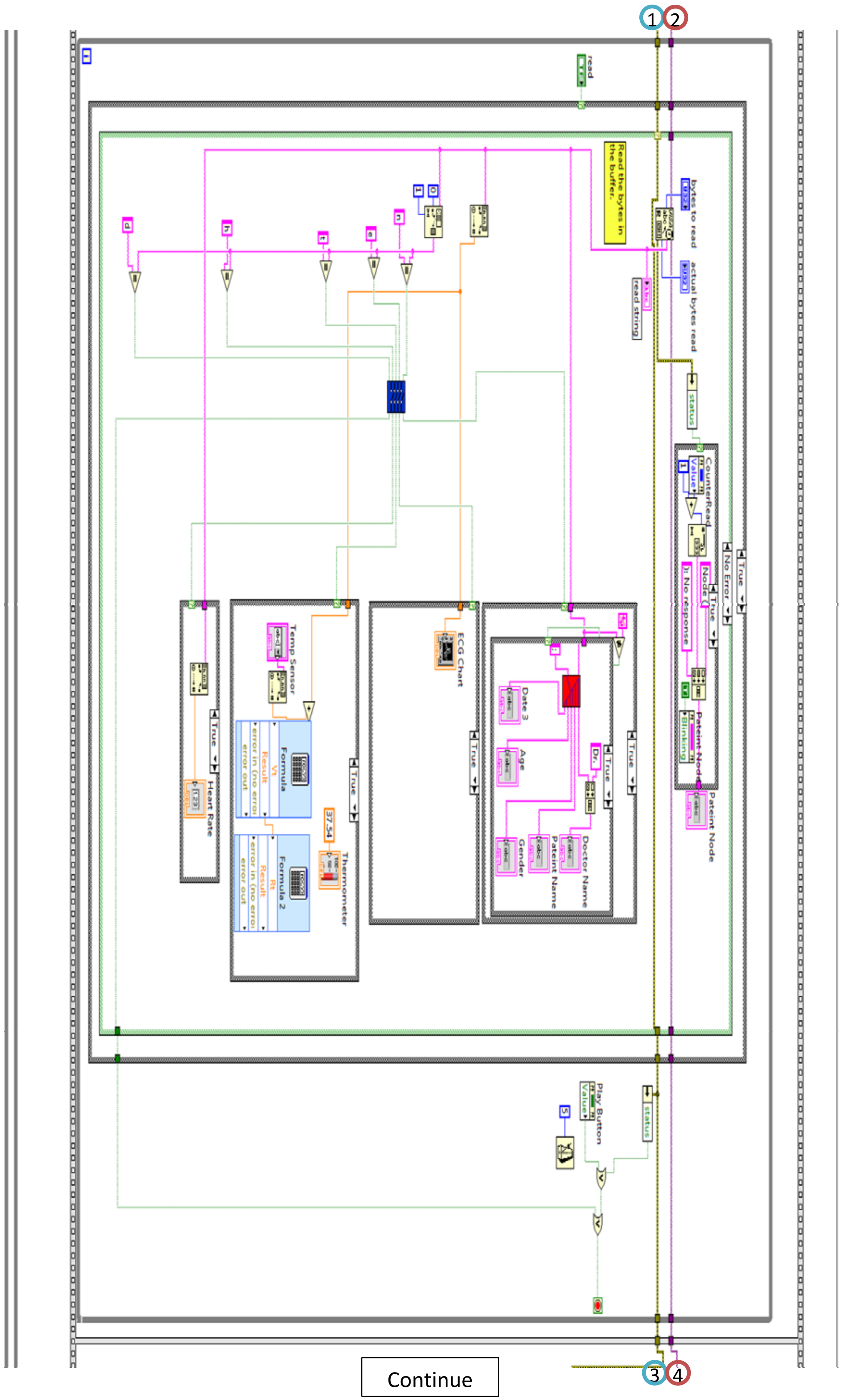
B.1 LabVIEW block diagram for monitoring GUI

B.2 LabVIEW block diagram for Setup GUI

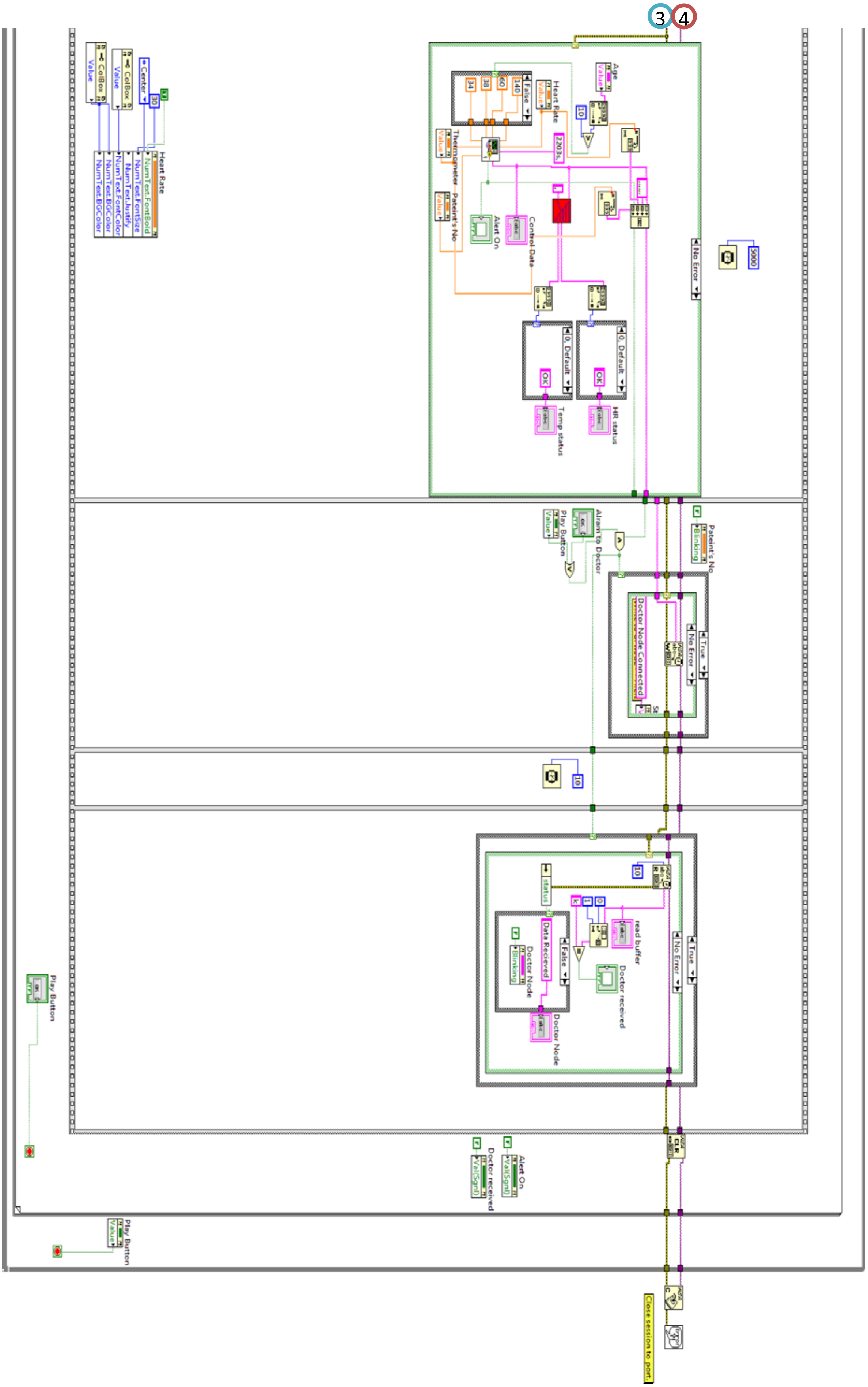
B.1 LabVIEW block diagram for monitoring GUI



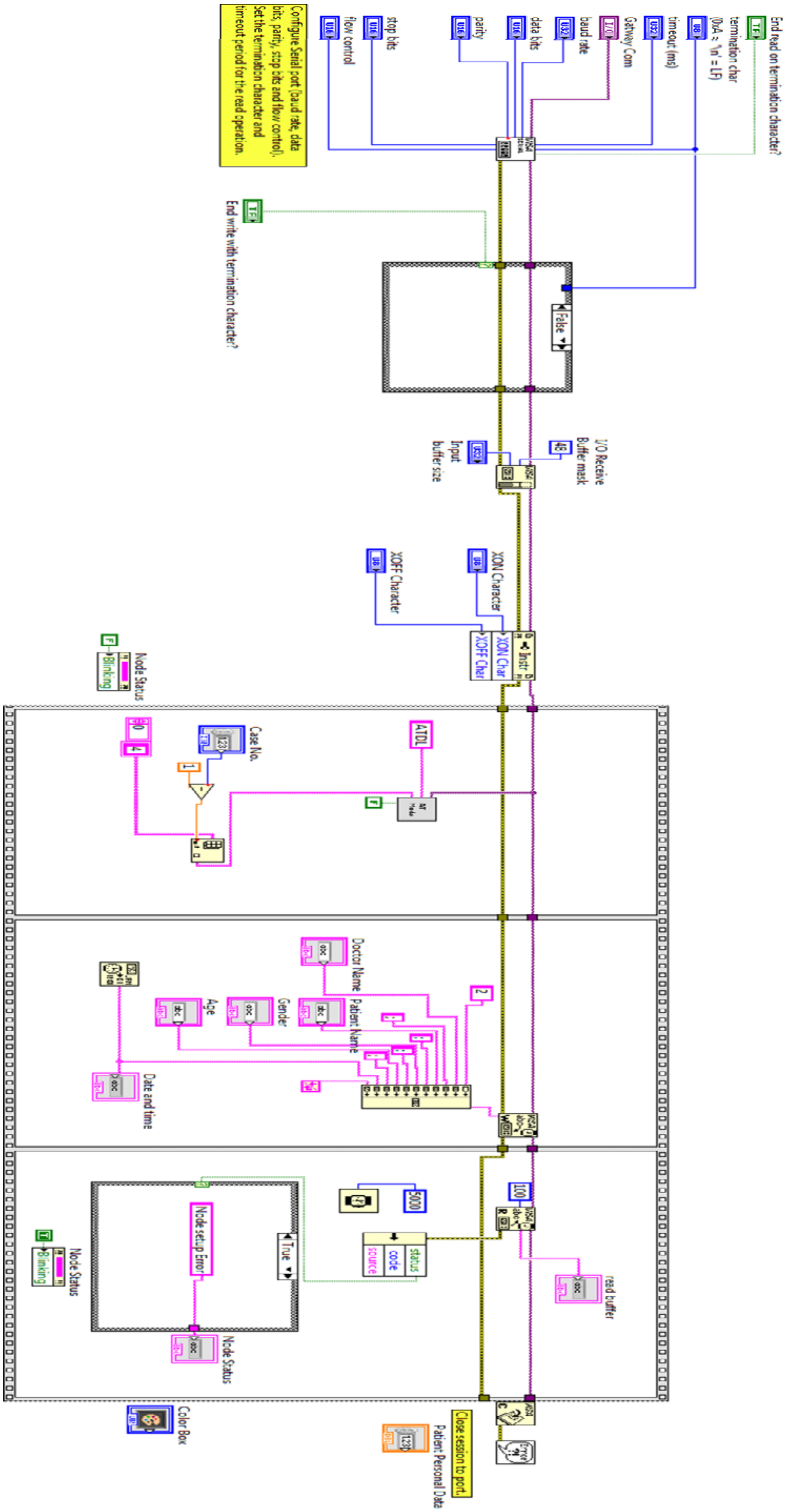
Continue


1
2
read
Read the bytes in the buffer.
bytes to read
actual bytes read
read string
status
CounterRead
No Error
True
Pateint Node
Heart Rate
Temp Sensor
Formula
Formula 2
Thermometer
37.54
ECG Chart
Date 3
Age
Gender
Pateint Name
Doctor Name
Dr.
Play Button
3
4

Continue


3
4
Heart Rate
Age
Thermometer - Pateint's No
Control Data
Alert On
HR status
Temp status
No Error
Alarm to Doctor
Play Button
Pateint's No
Doctor Node Connected
read buffer
Doctor received
Data Recieved
Doctor Node
Close session to port

B.2 LabVIEW block diagram for Setup GUI



Appendix C

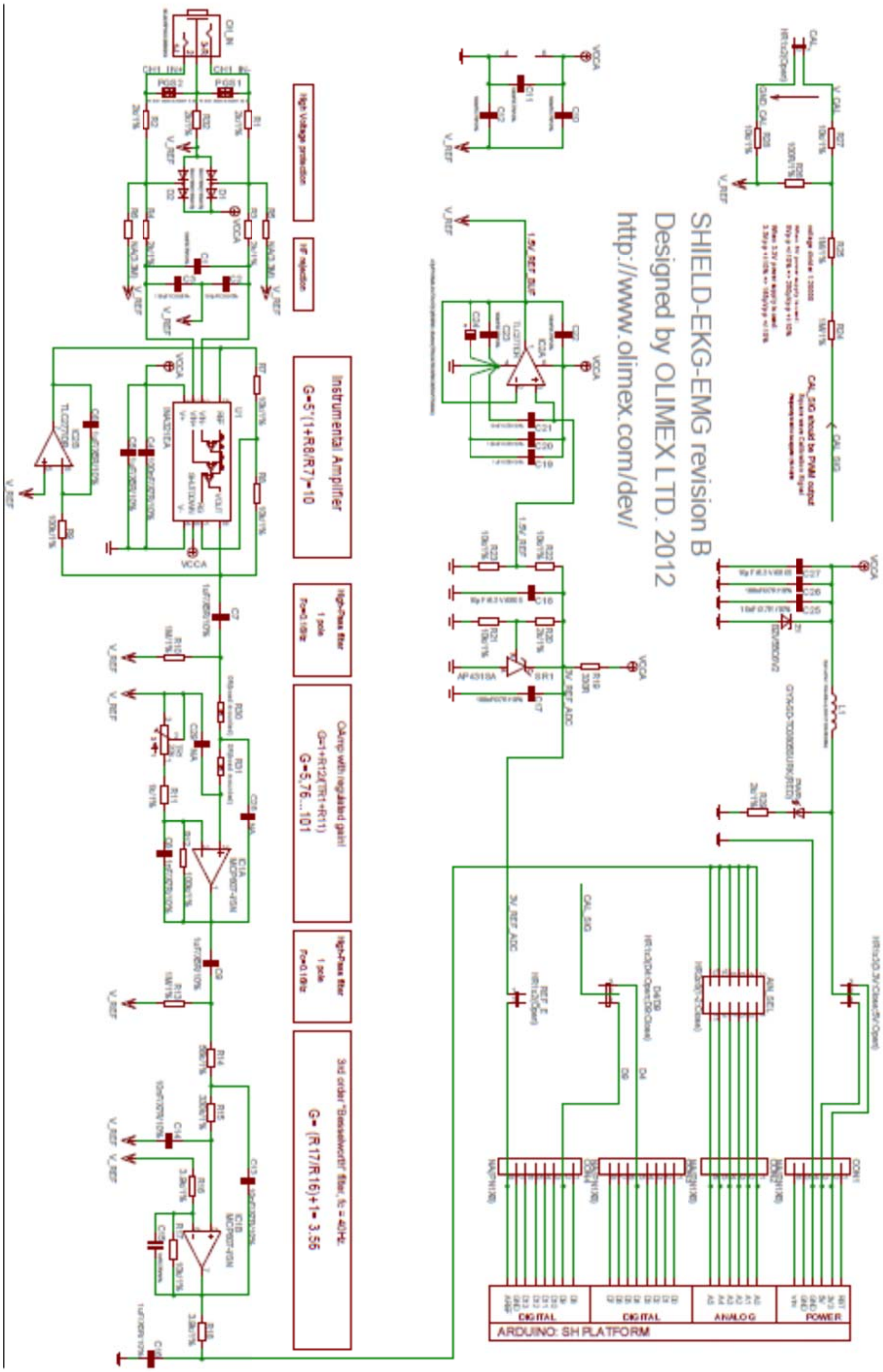
C.1. OLIMEX ECG card circuit

C.2. NTC Specifications

C.3. Atmel MCU Specifications

C.4. XBee Specifications

C.1. OLIMEX ECG card circuit



C.2. NTC Specifications

THERMAL RESPONSE TIME (63% RESPONSE)

Series	Still Air	Still Water*
MA100 Catheter Assembly	15 sec.	2.0 sec.
MA200 Oral-Rectal Assembly	35 sec.	0.6 sec.
MA300 Skin Surface Assembly	45 sec.	2.0 sec.

* Response time provided is for assembly plunged from 25°C air to 5°C still water

TOLERANCE CODE AND TEMPERATURE RANGE

Temperature Range °C	Tolerance Code		
	A ± °C	B ±°C	C ±°C
0-20	.15	.2	.25
20-35	.1	.15	.2
35-39	.05	.1	.15
39-42	.075	.15	.2
42-45	.1	.15	.2
45-50	.15	.2	.25

DATA:

Our biomedical series thermistor chips and sub assemblies are designed to be interchangeable over a 0°C to 50°C range. Best overall stability is maintained when exposure and storage temperatures remain below 70°C.

CODING:

MA XXXXX - XXX - X

TOLERANCE CODE: REFER TO TABLE

RESISTANCE CODE:*
232 = 2,252 OHMS
302 = 3,000 OHMS
502 = 5,000 OHMS
103 = 10,000 OHMS
103(Y) = 10,000 OHMS

*Refer to Resistance vs. Temperature Table

RESISTANCE VS. TEMPERATURE

TEMP °C	2252 OHMS	3k OHMS	5k OHMS	10k OHMS	103(Y) OHMS
0	7352.90	9795.16	16325.3	32650.5	29491.24
1	6988.42	9309.62	15516.0	31032.1	28157.49
2	6643.38	8849.98	14750.0	29499.9	26891.19
3	6317.41	8415.73	14026.2	28052.4	25688.61
4	6009.39	8005.39	13342.3	26684.6	24546.22
5	5718.10	7617.37	12695.6	25391.2	23460.72
6	5442.68	7250.46	12084.1	24168.2	22428.99
7	5182.12	6903.35	11505.6	23011.2	21448.12
8	4935.54	6574.88	10958.1	21916.3	20515.34
9	4702.12	6263.93	10439.9	20879.8	19628.07
10	4481.09	5969.48	9949.14	19898.3	18783.87
11	4271.72	5690.57	9484.28	18968.6	17980.43
12	4073.33	5426.28	9043.80	18087.6	17215.58
13	3885.28	5175.78	8626.30	17252.6	16487.30
14	3706.99	4938.27	8230.45	16460.9	15793.65
15	3537.90	4713.01	7855.01	15710.0	15132.82
16	3377.47	4499.30	7498.83	14997.7	14503.11
17	3225.23	4296.48	7160.80	14321.6	13902.89
18	3080.70	4103.95	6839.92	13679.8	13330.64
19	2943.46	3921.13	6535.22	13070.4	12784.92
20	2813.11	3747.48	6245.80	12491.6	12264.39
21	2689.26	3582.49	5970.82	11941.6	11767.75
22	2571.54	3425.68	5709.47	11418.9	11293.80
23	2459.64	6276.61	5461.01	10922.0	10841.39
24	2353.22	3134.84	5224.74	10449.5	10409.44
25	2252.00	3000.00	5000.00	10000.0	10000.00
26	2155.69	2871.70	4786.16	9572.32	9602.89
27	2064.02	2749.59	4582.64	9165.29	9226.41
28	1976.76	2633.34	4388.89	8777.79	8866.62
29	1893.67	2522.10	4204.34	8408.68	8522.70
30	1814.51	2417.19	4028.66	8057.31	8193.89
31	1739.09	2316.73	3861.22	7722.43	7879.43
32	1667.22	2220.99	3701.65	7403.29	7578.65
33	1598.51	2129.52	3549.20	7098.42	7290.88
34	1533.20	2042.50	3404.18	6808.36	7015.50
35	1470.89	1959.39	3265.65	6531.31	6751.92
36	1411.58	1880.47	3134.12	6265.75	6499.57
37	1354.91	1804.94	3008.23	6016.47	6257.93
38	1300.77	1732.82	2888.03	5776.05	6026.49
39	1249.08	1663.96	2773.26	5546.53	5804.78
40	1199.72	1598.20	2663.67	5327.34	5592.33
41	1152.57	1535.39	2558.99	5117.97	5388.73
42	1107.52	1475.38	2458.97	4917.94	5193.56
43	1064.47	1418.03	2363.39	4726.77	5006.43
44	1023.30	1363.17	2271.95	4543.91	4826.98
45	983.97	1310.80	2184.66	4369.33	4654.86
46	946.02	1260.25	2100.92	4200.84	4489.73
47	909.99	1212.24	2020.40	4040.81	5331.28
48	875.92	1166.85	1944.76	3889.51	4179.20
49	842.96	1122.95	1871.59	3743.17	4033.22
50	811.42	1080.93	1801.55	3603.10	3893.05

STANDARD ASSEMBLIES

100FA - Series 100, .070" diameter molded plastic tip, 30 gauge PVC insulated ribbon cable.

100FD - Series 100, .070" diameter molded plastic tip, 32 gauge bifilar heavy isomid insulation.

100DD - Series 100, .050" diameter kapton sleeve with 32 gauge bifilar heavy isomid insulation.

100BF - Series 100, .030" diameter kapton sleeve with 38 gauge bifilar heavy isomid insulation.

200LC - Series 200, .156" diameter aluminum tip, 30 gauge teflon leads.

300TA - Series 300, .375" diameter stainless steel cup, 30 gauge PVC insulated ribbon cable.

300TB - Series 300, .375" diameter stainless steel cup, 30 gauge teflon insulated ribbon cable.

100GG - Series, 100, .080” diameter molded plastic tip, 28 gauge kynar insulated twisted pair.

C.3. Atmel MCU Specifications

Features

- High Performance, Low Power AVR® 8-Bit Microcontroller
- Advanced RISC Architecture
  - 131 Powerful Instructions – Most Single Clock Cycle Execution
  - 32 x 8 General Purpose Working Registers
  - Fully Static Operation
  - Up to 20 MIPS Throughput at 20 MHz
  - On-chip 2-cycle Multiplier
- High Endurance Non-volatile Memory Segments
  - 4/8/16/32K Bytes of In-System Self-Programmable Flash progam memory (ATmega48PA/88PA/168PA/328P)
  - 256/512/512/1K Bytes EEPROM (ATmega48PA/88PA/168PA/328P)
  - 512/1K/1K/2K Bytes Internal SRAM (ATmega48PA/88PA/168PA/328P)
  - Write/Erase Cycles: 10,000 Flash/100,000 EEPROM
  - Data retention: 20 years at 85°C/100 years at 25°C[1]
  - Optional Boot Code Section with Independent Lock Bits
    In-System Programming by On-chip Boot Program
    True Read-While-Write Operation
  - Programming Lock for Software Security
- Peripheral Features
  - Two 8-bit Timer/Counters with Separate Prescaler and Compare Mode
  - One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture Mode
  - Real Time Counter with Separate Oscillator
  - Six PWM Channels
  - 8-channel 10-bit ADC in TQFP and QFN/MLF package
    Temperature Measurement
  - 6-channel 10-bit ADC in PDIP Package
    Temperature Measurement
  - Programmable Serial USART
  - Master/Slave SPI Serial Interface
  - Byte-oriented 2-wire Serial Interface (Philips I^2C compatible)
  - Programmable Watchdog Timer with Separate On-chip Oscillator
  - On-chip Analog Comparator
  - Interrupt and Wake-up on Pin Change
- Special Microcontroller Features
  - Power-on Reset and Programmable Brown-out Detection
  - Internal Calibrated Oscillator
  - External and Internal Interrupt Sources
  - Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby, and Extended Standby
- I/O and Packages
  - 23 Programmable I/O Lines
  - 28-pin PDIP, 32-lead TQFP, 28-pad QFN/MLF and 32-pad QFN/MLF
- Operating Voltage:
  - 1.8 - 5.5V for ATmega48PA/88PA/168PA/328P
- Temperature Range:
  - -40°C to 85°C
- Speed Grade:
  - 0 - 20 MHz @ 1.8 - 5.5V
- Low Power Consumption at 1 MHz, 1.8V, 25°C for ATmega48PA/88PA/168PA/328P:
  - Active Mode: 0.2 mA
  - Power-down Mode: 0.1 µA
  - Power-save Mode: 0.75 µA (Including 32 kHz RTC)

8-bit AVR® Microcontroller with 4/8/16/32K Bytes In-System Programmable Flash

ATmega48PA
ATmega88PA
ATmega168PA
ATmega328P

Rev. 8161D–AVR–10/09

C.4. XBee Specifications

1.2. Specifications

Table 1-01. Specifications of the XBee Series 2 OEM RF Module (PRELIMINARY)

Specification	XBee Series 2
Performance	
Indoor/Urban Range	up to 133 ft. (40 m)
Outdoor RF line-of-sight Range	up to 400 ft. (120 m)
Transmit Power Output (software selectable)	2mW (+3dBm)
RF Data Rate	250,000 bps
Serial Interface Data Rate (software selectable)	1200 - 230400 bps (non-standard baud rates also supported)
Receiver Sensitivity	-95 dBm (1% packet error rate)
Power Requirements	
Supply Voltage	2.8 – 3.4 V
Operating Current (Transmit)	40mA (@ 3.3 V)
Operating Current (Receive)	40mA (@ 3.3 V)
Power-down Current	< 1 uA @ 25^{o}C
General	
Operating Frequency Band	ISM 2.4 GHz
Dimensions	0.960" x 1.087" (2.438cm x 2.761cm)
Operating Temperature	-40 to 85º C (industrial)
Antenna Options	Integrated Whip, Chip, RPSMA, or U.FL Connector
Networking & Security	
Supported Network Topologies	Point-to-point, Point-to-multipoint, Peer-to-peer & Mesh
Number of Channels (software selectable)	16 Direct Sequence Channels
Addressing Options	PAN ID and Addresses, Cluster IDs and Endpoints (optional)
Agency Approvals	
United States (FCC Part 15.247)	Pending
Industry Canada (IC)	Pending
Europe (CE)	Pending

Antenna Options: The ranges specified are typical when using the integrated Whip (1.5 dBi) and Dipole (2.1 dBi) antennas. The Chip antenna option provides advantages in its form factor; however, it typically yields shorter range than the Whip and Dipole antenna options when transmitting outdoors. For more information, refer to the "XBee Series 2 Antenna" application note located on MaxStream's web site http://www.maxstream.net/support/knowledgebase/article.php?kb=153

الخلاصة

الحفاظ على حياة الانسان ورعايته هو السبب الرئيسي وراء تطور نظم المراقبة للرعاية الصحية (Healthcare monitoring system). ان هذه النظم هي المسؤولة عن عرض الانشطة الحيوية للانسان (المريض) مثل تخطيط القلب (ECG) ومعدل نبضات القلب (Heart rate) و نسبة الاوكسجين في الدم وغيرها. لقد شهدت نظم مراقبة المرضى بالاعتماد على شبكة الاستشعار (التحسس) اللاسلكي (WSN) زيادة كبيرة على نطاق واسع في السنوات السابقة ولحد الان. وكان من اهم اسباب انتشار هذه النظم اهمية الحياة البشرية وتوفر التقنيات المناسبة لتنفيذها.

في هذه الرسالة قام الباحث بتصميم نظام مراقبة المرضى يعمل في الوقت الحقيقي بالاعتماد على شبكات الاستشعار اللاسلكي (عن بعد).حيث يتحسس ويعرض النظام تخطيط القلب (ECG) ومعدل ضربات القلب (HR) ودرجة حرارة المريض. يعتبر تخطيط القلب هو المتحسس الرئيسي في هذا النظام حيث يتم حساب معدل نبضات القلب برمجيا من اشارة تخطيط القلب. بينما يتم قياس درجة حرارة الجسم باستخدام الثرمستور. اشارة تخطيط القلب تعرض على شكل رسم بياني بدقة عالية في واجهة المستخدم الرسومية. وكذلك يتم عرض معدل نبضات القلب ودرجة حرارة الجسم في نفس الواجهة.

يتميز النظام بواجهة المستخدم الرسومية (GUI) سهلة الاستخدام وبسيطة الادارة من قبل الطبيب المختص. وبالاضافة الى ان النظام يستطيع كشف أي جهاز جديد (عقدة) وفي حالة حدوث أي فشل لاي عقدة فان النظام يحدد المشكلة ويعطي رسالة لغرض معالجتها. ان لهذا النظام القدرة على الاندماج مع النظم الاخرى وخصوصا الانترنت وكذلك من السهل تطوير هذا النظام مع المتطلبات الجديدة من قبل المتخصصين. ولقد تم اضافة جهاز خاص بالطبيب (عقدة الطبيب) يحمله في حالة خروجة من وحدة العناية المركزة ليتمكن من خلاله من استلام رسائل الانذار في حال حدوث أي طارئ لاي مريض. تم انجاز تطوير للنظام الرئيسي ليصبح نظام مراقبة المرضى في البيت بالاعتماد على شبكات الاستشعار (التحسس) اللاسلكي والانترنت ليمكن الطبيب من مراقبة معدل نبضات القلب ودرجة حرارة الجسم للمريض خارج المستشفى.

تم تنفيذ النظام بكافة خطواته والتي تشمل اختيار المواد ومن ثم تشغيلها وبرمجتها ومعايرتها لتمكن النظام من تزويد المعلومات الصحيحة إلى واجهة المستخدم الرسومية. وفيما يتعلق بالشبكة

المستخدمة في هذا النظام فهي نجمية (Star) تعمل على بروتوكول زكبي (ZigBee) اما النظام الخاص بواجهة المستخدم الرسومية لقد تم تنفيذه باستخدام برنامج اللابفيو (LabVIEW).

يمكن ان يعمل هذا النظام في مراقبة المرضى في المستشفيات او مراقبة المرضى في المنزل. تم تنفيذ النظام وإختباره في ردهات مستشفى مرجان التخصصي في بابل حيث تم إجراء الاختبار الحقيقي على مرضى في الردهات وبحضور أطباء إختصاص من المستشفى وبعد إطلاعهم ومراقبتهم للنتائج المستحصلة أثنوا ثناءاً كبيراً على المنظومة وما تقدمه من خدمات طبية وعلمية على حد سواء.

وزارة التعليم العالي و البحث العلمي
جامعة بابل
كلية الهندسة
قسم الهندسة الكهربائية

منظومة مراقبة الرعاية الصحية اعتماداً على شبكات التحسس اللاسلكي

رسالة
مقدمة إلى كلية الهندسة في جامعة بابل
كجزء من متطلبات نيل درجة الماجستير
في علوم الإلكترونيك والاتصالات

من قبل

اكرم جدوع خلف

بأشراف

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