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Wireless Monitoring of Patients

Implementation of Wireless Body Area Network

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Patients in hospitals have difficulty with health equipment that is connected with wires to their body. Wired health equipment restricts the mobility of the patient. Moreover, health caretakers are compelled to visit frequently to operate the equipment and take the measurements. Hence, wireless monitoring of patient is very effective solution to that problem.

The main target of this study was to research the current trend and prospect of wireless monitoring of patients in the hospitals. This study also aims to build the prototype system to implement wireless monitoring. In addition to it, this thesis also studies most suitable technique for building the most effective wireless monitoring system.

The sensor nodes and receiver of the prototype were designed. Android phone was used as gateway to receive the data from sensor node and forward the data into receiver. Bluetooth Low energy was used to communicate between sensor nodes and android phone. WiFi is used to communicate between android phone and the receiver which is connected to computer. The sensor readings were at first observed in Arduino Serial Monitor and then sent to sink node. The sensor readings of a body were displayed in android phone and as well as in the website. Real time data of sensor was produced and successfully updated in the website.

The study of results and project showed that wireless monitoring would be very effective by using Interference free, short range and highly secure means of communication. Bluetooth low energy which is suitable option for the system. Design of sensor nodes should be very small because it has to be worn around the body. Hence smaller components should be used.

Keywords	Wireless sensor network, Bluetooth low energy(BLE), Sensor node, Wireless Body area network

Contents

Abbreviations

BCU	Body Control Unit
CCU	Central Control Unit
ECG	Electrocardiogram Sensor
EWS	Early warning score
GAP	Generic Access Profile
GATT	Generic Attribute Profile
IOT	Internet of Things
ISM	Industrial, Scientific and Medical
LAN	Local Area Network
MAC	Medium Access Control
PDA	Personal Digital Assistant
QOS	Quality of Service
UUID	Universal Unique Identifier
WBAN	Wireless Body Area Network
WPAN	Wireless Personal Area Network
WSN	Wireless Sensor Network

1 Introduction

Patients who are hospitalized in intensive care unit or emergency ward need constant monitoring to acquire their vital signs like blood pressure, electrocardiogram, oxygen amount, body temperature etc. Doctors and health professionals study these vital signs to detect any forthcoming health complication. They fetch data from patient by connecting wired health equipment to the patient. Wired equipment adds complication to patients because of difficulty in movement. Moreover, nurses have to frequently visit the patient's wards to take the measurements of vital signs. This would take more time for health professionals to take measurements and operate the equipment. Furthermore, healthcare takers have to be employed for those works. In spite of frequent visit and monitoring, in some occasion health care takers might not able to attend during the serious health complication of patients. Hence, the need of real-time monitoring is very crucial to health care takers.

There are many health care technologies available in the market that offers variety of wireless patient monitoring technologies. Selecting the best and reliable technology is very vital. Wireless monitoring technologies use different Wide Area Personal Network techniques, for examples: Zigbee and Bluetooth to communicate between sensor nodes and the gateway. This study implements Wireless Body Area Network to build the prototype wireless monitoring system. This project studies various WPANs and ultimately uses Bluetooth Low energy as suitable WPAN for communication.

The main target of the study was to design prototype system that could provide real time monitoring of patients. While designing the prototype, the study also aimed at building the reliable, durable and extremely safe system that could provide very accurate medical data of patients or persons to be monitored. The accuracy and confidentiality of acquired data were more emphasized in the project. Hence, Bluetooth Low energy was used because of encryption feature of it. Only Health care takers would have access to the confidential data of patients which were saved in the patient's database server. The authorized persons could have access to data only with secured username and password from the medical website. Along with designing, the project aims at studying the trend and future of wireless body area network in medical applications for instance bio-feedback application, assistance to elderly people and prevention and monitoring of diseases. The prototype used cheap Electrocardiogram Sensor (ECG) in its sensor node design.

2 Wireless Network

Wireless Network is the computer network that uses wireless data connections for connecting various devices in network. Basically, it uses radio waves (Electromagnetic wave) for connection to network.

Wireless Network Types:

- WWANs: Wireless Wide Area Networks. Extends over a large area like cities or country 3G, 4G, GSM
- WLANs: Wireless Local Area Networks. For a small area like a School, Home or University. It uses Radio waves signals. It follows IEEE 802.11standard
- WMANs: Wireless Metropolitan Area Networks: It has range from 30 to 50 km. It is also known as Wimax,
- WPANs: Wireless Personal Area Networks: It follows IEE 802.15.1 for instance Bluetooth and IEE 802.15.4 for instance Zigbee. They are suitable Power efficient, short ranging and Inexpensive devices.
- WBANs: Wireless Body Area Networks: It follows IEE 802.15.6 [1].

Wired networks:

Although wired networks are reliable, constant power supply, stable and have high data transmissions, it has some disadvantages. They are as follows:

- Problems with installation.
- High cost and maintenance and installations.
- Burdensome

2.1 History

The history of WSN can be traced to 1980s. During that time, the United States Defence Advanced Research Projects Agency DARPA launched the distributed sensor networks DSNS programme for its army [2].

2.2 Wireless Sensor Network

Wireless Sensor Network is the deployment of several devices equipped with sensors that each has one particular function in the environment that needs wireless transmission of data. For example: rainfall detector in the forest. These devices are known as sensor nodes. Typical sensor node has sensing hardware wireless transceiver, power supply and processing and computational module, and independent power supply. Modern sensor nodes have become more advanced in term of low power consumptions than early sensor nodes. They use the least power consuming mode of communication like Bluetooth Smart also known as Bluetooth Low energy or Zigbee. Each sensor can function independently and can also communicate with each other to execute the particular function. For Example: Smart agriculture, pollution detectors etc.

The working processes of WSN are listed in the following:

- Transmission of data from sensors
- Communication using Wireless communication modules using any protocol 3G, GPRS, NFC, Bluetooth, RFID
- Processing the information from sink node for example mobile phone.
- Data gatherer or receiver and External systems for transmitting the information to owner.

2.3 Ad-hoc Network

An ad-hoc network is defined as LAN that uses point to point communication. They do not depend on base station to direct the exchange of data to other node in the network. On the other hand, Wireless sensor network communicates by broadcasting technique which has limited sensors, limited power, energy and computational capacity. Wireless sensor nodes are likely to fail more than ad-hoc network. Sensor nodes might not have Global identification ID due to its huge number of sensors [3].

2.4 Wireless Body Area Network

The technological advances in Information and communication technology and electronics like MEMS have paved the way for the Wireless Body Area Network .Wireless body Area network is extended version of WSN to medical applications [4]. Unlike other sensor networks, WBAN has a network of biosensors nodes that are fitted with bio sensors to provide individual health parameters of an individual. Figure 1 depicts the general structure of WBAN. It has sensor node and a gateway device.

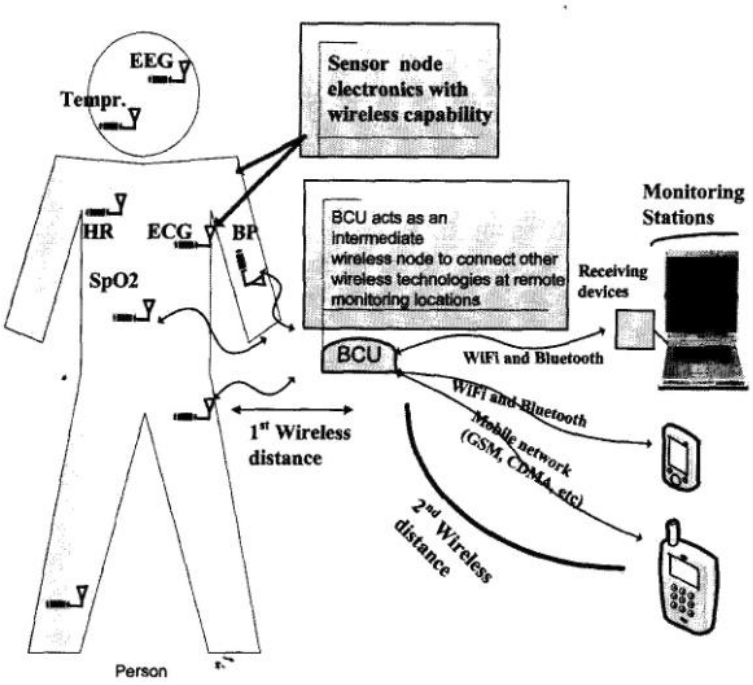


Figure 1 A simple structure of WBAN [5].

Figure 2 Illustrates that Wireless body Area network has contribution from information technology, medicine and engineering. WBAN is small scale network and its communication ranges few meters between sensor nodes and sink.

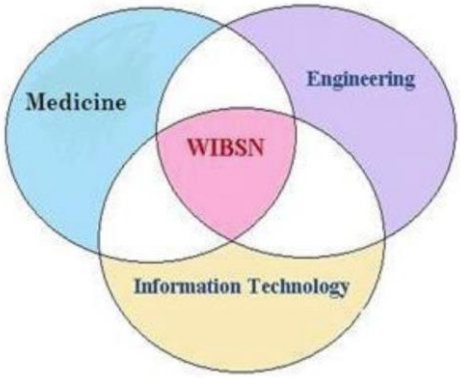


Figure 2 Interdisciplinary sciences involved in WBAN copied from [1].

WBAN has the contributions from many interdisciplinary sciences. Currently WPAN are mostly suitable for industrial application [6]. For example, Bluetooth is suitable for sensor networking application. But Wi-Fi is appropriate for data network with higher data transmitting rate. Different technology and standards are there to support WBAN. IEEE 802.15.6 was designed for WBAN. It offers a continuous health monitoring for people without limiting their daily activities [3]. Figure 3 represents the health networking system network that comprised of possible places for placing the sensors.

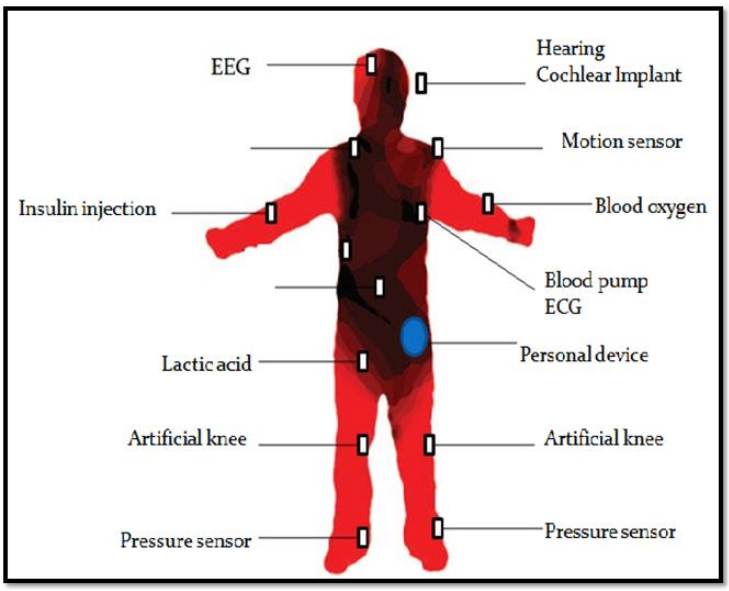


Figure 3 Health Monitoring System reprinted from Ramshedda .K Wireless Body area Network [7].

2.4.1 System Architecture

The typical architecture of WBAN is comprised of three tire communication: Intra BAN communication, Inter BAN communication and Beyond BAN communication [8].

Tier 1 Architecture

This layer has intra communication. The communication is among the body sensors nodes and the master node or sink node. Sensor nodes are placed on human body as on body sensors, wearable sensors or implanted under the skin. The sensor node is capable of sensing, sampling, processing and communication.

Tier 2 Architecture

This layer involves the inter BAN communication between the central unit or master node and the personal devices such as mobile phone or note books. The master node has the user interaction interface. Different sensor nodes have different communication protocols. For example, Bluetooth based sensor nodes have Bluetooth for communication. The sink node is linked with medical server through WLANs, or 2G or 3G [6].

Tier 3 Architecture

This layer connects the personal devices to the internet. This structure has one decision measuring Unit which does an automatic computation. It gathers and sorts out the information. The DMU is linked with medical institutions for example, hospitals; where health care takers can analyse the data [9]. Figure 4 Illustrates the three tier Architecture of WBAN.

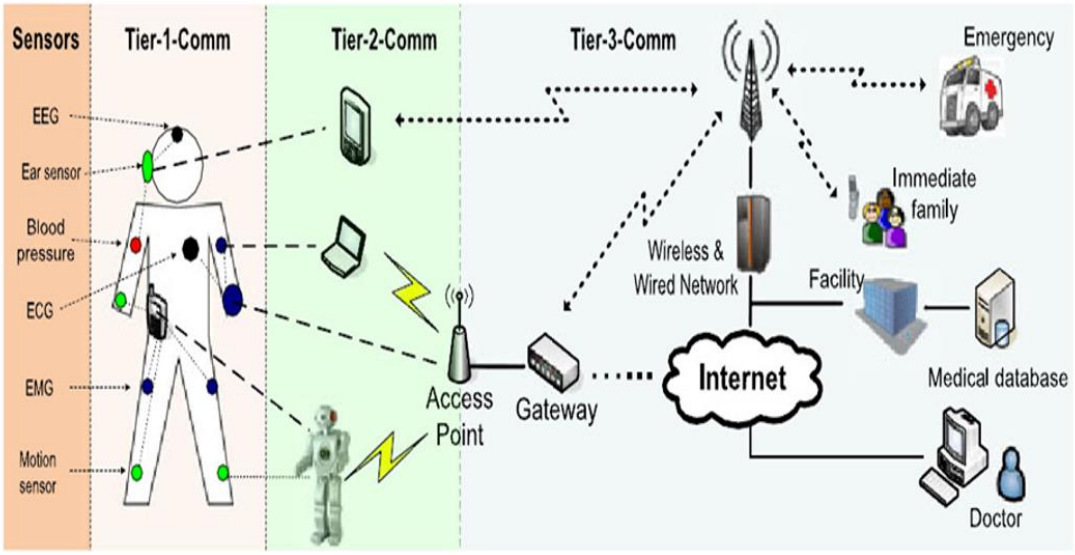


Figure 4 Three tier Architecture of WBAN reprinted from RAJEEV NARAYAN [10].

2.4.2 Gateway

Gateway is also known as Body control Unit or Central control Unit in this WBAN system. Personal Digital Assistant is another popular name for Gateway. The role of Gateway is sink node. They collect the sensor data and process it to forward to remote stations or main health server. They communicate with server using standard telecommunication network for example WiFi or Mobile network [5].

2.5 Monitoring of Vital Signs

There are four primary vital signs for assessing the general physical health of a person .The normal range of readings of vital signs is different with age, weight, gender and overall health of a person [11]. They are listed below:

- Human body temperature
- blood pressure
- Heart beat rate
- Respiration rate often noted as BT, BP, HR and RR.

Table 1 .Early warning scores data gathered from [12].

Score	3	2	1	0	1	2	3
Respiratory rate (breaths/min)	>35	31-35	21-30	9-20			<7
SpO2 (%)	<85	85-89	90-92	>92			
Temperature (C)		>38.9	38-38.9	36-37.9	35-35.9	34-34.9	<34
Systolic BP (mmHg)		>199		100-199	80-99	70-79	<70
Heart rate (bpm)	>129	110-129	100-109	50-99	40-49	30-39	<30
AVPU				Alert	Voice	Pain	Unconscious

The vital signs may also incorporate other measurements known as “fifth vital sign” or “sixth vital sign”. Early warning scores are used to combine these individual values signs into single score. Table 1 shows the table of Early warning score that is made up of individual data from five different vital signs.

Monitoring of vital signs is done by multi monitors that measure and they plot the related vital signs. The monitors are commonly attached into the bedside monitors in critical care units and the anaesthesia machines in operating rooms for real time monitoring.

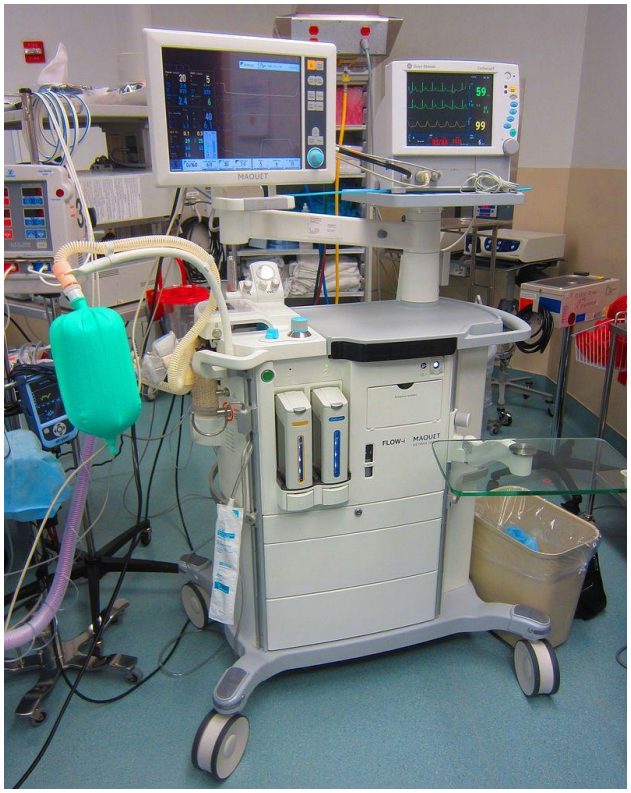


Figure 5 Traditional wired monitoring equipment's reprinted from Diver Dave [12] .

Most often nurses and occasional doctors operate the monitors for continuous monitoring. Figure 5 shows the traditional wired monitoring equipment used in hospitals. It is found that nurses spend one fourth of their time in gathering the data for vital signs. Wireless health monitoring can reduce the time of nurses. From the World Health Organization data, globally 1.4 health caretakers have to take care of 1000 people [6]. The ratio is 2 to 4 physicians per 1000 in developed areas. During the overcrowded situation, patients monitoring is very difficult. WBAN plays a very important role in this case.

3 Existing Technology

The scope of WBAN has increased significantly with the new technology. There has been many researches going on in the past and in the present. Various companies have

started to provide these services. Many medical equipment vendors are producing telehealth monitoring equipment. E-health service is possible from the WBAN. Moreover, it has telemedicine which means proving the health services remotely. These have several advantages that include fast diagnosis, therapeutic care and providing comfort to the patients.

3.1 Holter Monitor

Holter monitor is a portable ECG measuring device with 4 to 7 wires that is attached to CPU [14]. Figure 6 shows the Holter Monitor. It provides real time electrical cardiac activity to detect abnormal signs over a time [14].

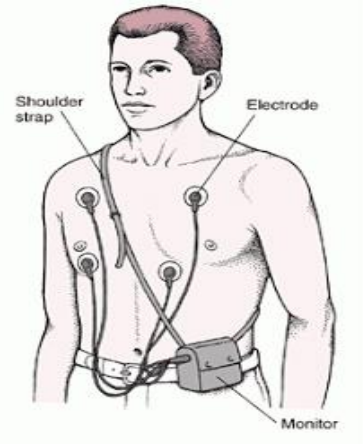


Figure 6 Holter Monitor reprinted from [13].

3.2 Dyna Vision Telemonitoring System

Figure 7 is the Dyna Vision device. Techmedic international has the Dyna Vision Telemonitoring System for telemonitoring. It has integrated Wi-Fi and 3G [15].

Figure 7 Dyna Vision reprinted from [15].

3.3 Health Buddy

American Medical Alert Corp has developed the device known as health buddy that transmits the patient's data remotely to physicians.

3.4 Other Technology

IRhythmtech developed ZIO wireless Patch, a small adhesive and comfortable patch that can be worn any time [16]. Philips Telehealth Solutions has wireless measurement devices for home monitoring using TeleStation [17]. TeleStation is the communication platform between the Philips secure server and communication devices. Similarly Frost and Sullivan is also working on developing the remote patient monitoring technology.

4 WBAN Architecture

4.1 Network Architecture

Different network topologies have been used for wireless Sensor Network depending on the type of the application.

4.1.1 Star Topology

A star network topology has a single base station to transmit and receive the data to a number of remote nodes. However, remote nodes are restricted to communicate with each other's. Although star topology has lower power consumption and has very simple structure, it has one drawback which is the base station has to operate within radio transmission range of all the nodes. This network is weak compared to others because of the dependence on the single node to manage the network.

4.1.2 Mesh Topology

Mesh topology has multi hop or paths to send message from source to destination. Every sensor node connects to every other in a complete mesh. Mesh topology is very suitable for large area.

4.1.3 Tree Topology

This topology has central hub known as root node. The root node is the main communication router. It has hierarchical structure where central hub is one level below from the root node. The star network is formed below the central hub. This is hybrid between the hybrid and mesh network. It is very flexible and strong network while at the same time power consumption is reduced. Zigbee uses this kind of hybrid topology

4.2 Design Requirements

4.2.1 Low Power Consumption

Least power consumption is the fundamental requirement in Wireless monitoring system. Sensors in WBAN must use low power in gathering sensors data than that of wireless communication part does. Hence, reducing the energy consumed during the data transmission can substantially reduce the energy. Different techniques have been tested and proposed so far to minimize the energy consumption of the devices. For instance, energy efficient hybrid system has been offered by Ghamari et al. by using energy harvesting techniques and low power MAC protocols [18]. If the upper layer and application layer utilizes the best technique of sampling and sending data which will be more suitable for its specific purpose, then lower power would be consumed. Therefore, the structure of network and location of sensors have a important function in power reduction [18].

4.2.2 Reliable Data Communication

Data transmission reliability and latency are other significant parts for efficient WBAN technology. A WBAN has wireless channel for communication that is inherently prone to errors. Real time data must be available immediately to healthcare taker. Reliability determines the quality of Wireless monitoring system. For example real-time data can be lifesaver in many cases and can be life threatening in some case of faulty data transmission. Error checking and correction mechanisms can reduce the probable errors in data transmission [9]. The operation of wireless technology in the frequency bands that are not susceptible to interference can increase the reliability of the WBAN. In addition to non-interfering frequency band, the better development of Physical and Medium Access

Control layers can improve the reliability and latency [18] .Therefore, MAC layer protocols designed for particular tasks of specific application can have optimal reliability. Reliability is also determined by its quality of Service (QOS) parameters such energy loss during transmission, delayed profile and delayed jitter [18].

4.2.3 Data Rates

Data rates vary in WBAN system from one application to another application ranging from few kbps to Mbps. Although information can be transmitted in burst it is not energy efficient. The reliability of WBAN system is dependent on its data transmission rates. The devices with lower data transmission have lower probability error.

4.2.4 Security and Privacy

Medical data are very confidential and private. Therefore, protocols have to be designed and defined to prevent the intrusion and altering of patient's data. Data should be passed through secured medium but should not be complex which would drain much battery power.

4.2.5 Wireless Sensors

Sensor node has the transmitter, low power consumption and independent processing capacity. The addition of sleep mode and wake up cycle in the system can minimize rate of power consumption.

4.2.6 Latency

Long response time is not desirable in medical works. Therefore, WBAN should have performance guarantee for real time transmission.

4.3 Standardization

IEEE 802.15.6 standard is designed implementing for Wireless Body Area Network. This standard is suited for less power consuming devices that are worn inside or around the body [19]. This standard aims at standardizing less power, small range and wireless

communicating devices which have the vast range of data rates for specific applications. It operates on ISM frequency band and the frequency bands determined by national medical and regulatory institutes It consists of different physical layers: They are narrow-band, ultra wideband and human body communications layers [19].One of the important features of this standard is advanced security level. This protocol has three layer securities. They are unsecured communication, authentication only mode and authentication and encryption mode.

5 WBAN Wireless Technologies

Various wireless technologies have been used so far in WBAN system. WBAN systems often use the WPAN platforms like Zigbee and Bluetooth for communication. With the recent introduction of Bluetooth low energy, it is the best choice for the WBAN system. Whichever technology is used, it is very crucial to evaluate the designs when the devices operate at 2.4 GHz (ISM band) because of potential interference from the presence of other wireless devices running at same frequency band. This section discusses only Zigbee and Bluetooth Low energy. The prototype design of the project uses the Bluetooth Low energy.

5.1 IEEE 802.15.4 and ZigBee

Zigbee is one of the PANs which have IEEE 8020.15.4 specification which is suitable for high level communication protocols. Zigbee is targeted for mini projects for instance home automation or medical purpose at smaller bandwidth. Because of its sleep mode, battery is consumed at very little amount. It has transmission distance between 10-100 metres line of sight. It has secure networking because it is secured by 128 bit symmetric encryption keys. The disadvantage of Zigbee is it has data transmission rate of 250kbit/s. It is most widely used in WBAN and other applications.

5.2 Bluetooth Low Energy

Bluetooth low energy was first introduced by Nokia in 2006. Today mobile operation systems like iOS (from iPhone 4s onward), Android (4.3 onward), Windows Phone and Blackberry as well as latest mac operating system OX, Linux, Windows and Windows 10 has BLE. It is latest WPAN developed by Bluetooth Special Interest Group (SIG) for novel

applications like healthcare, fitness, beacons security and home entertainment. Bluetooth low energy was specially developed for supporting low power, passive mode, simple device discovery and secure data transfer [18] .

5.2.1 Radio Technology of BLE

Bluetooth Low energy uses unlicensed 2.4 GHz ISM radio band. It has spectrum range from 2402 -24835 MHz which is further divided into 40 individual 2 MHz wide RF channels [20]. For combating against the interferences, it has used frequency hopping spread spectrum technique [21]. The maximum bit rate of BLE is 1 Mbit/s with transmitting power 10mW.

5.2.2 Working of BLE and Concept of BLE

The Bluetooth Low energy protocol architecture is made up of Bluetooth protocol stack. Protocol stack is the set of rules that handles the communication between two layers of stack with outside interface.

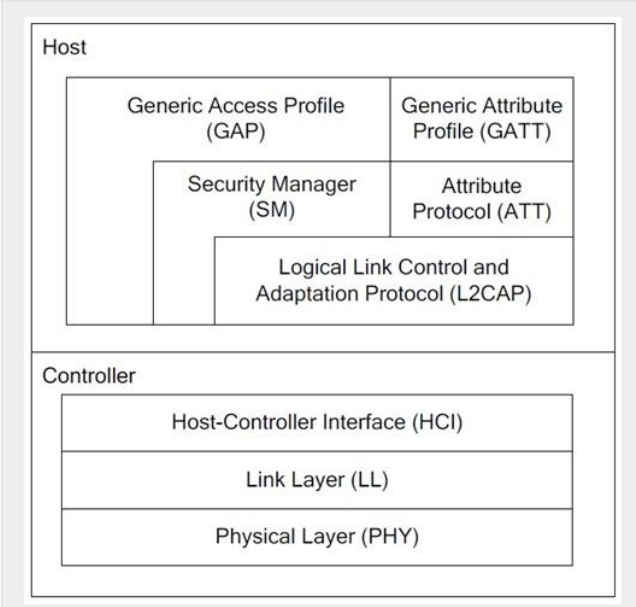


Figure 8 BLE Stack Image reprinted from Texas Instrument [22].

Figure 8 shows the complete BLE stack. General Access Profile manages the connection and advertisement in Bluetooth. It defines roles for devices [23]; Central, peripheral or both for a device. Peripheral devices are devices that advertise the data while central

device is the one that scans and makes the connection and receive the data. Peripheral is also known as GATT server while central as GATT client.

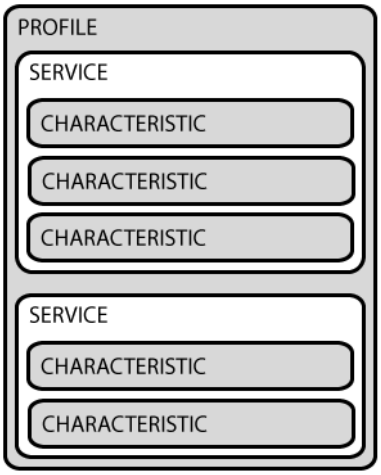


Figure 9 general structure of profile reprinted from Adafruit website [24].

GATT stands for Generic Attribute Profile. It specifies the way for transmitting and receiving the packets of data known as attributes. All application profiles are based on GATT. A GATT profile is has overall definition and specification of how the device should function. Each Attributes are recognized by universal Unique Identifier (UUID) ID. Figure 9 is the illustration of the composition of profile. A profile is actually the collection of already defined Services. For example, Heart Rate Profile has both services of the Heart Rate Service and Device information Service. Services contain the chunk of data known as characteristics. Services are also uniquely identified by UUID.

- Services can be adopted or custom made. Adopted services are the standard services which have predefined with their UUID number by Bluetooth SIG. Adopted Service have 16 bit UUID.
- Custom Services can created by anyone but it needs to have 128 bit UUID.

Characteristics are lowest level of profile which contains the data .Characteristics too have 128 bit UUID to identify it. A standard characteristics adopted by Bluetooth SIG can also be used. Characteristics are also defined to communicate with the Peripheral.

5.3 Suitability for WBAN

Bluetooth Low energy is very appropriate for WBAN applications due to its low data rate, low latency and low energy consumption. It has data rate up-to 1 Mbps. Because it has few channels for pairing BLE devices, it takes less time for device discovery and synchronization. It includes a very simplified protocol stack. It has short range, star network topology with less complex routing algorithms. Bluetooth 4.0 is further divided into two categories: Bluetooth Smart and Bluetooth Smart ready.

5.4 Bluetooth 5

The Bluetooth SIG officially announced on 16 June 2016 and released on 6 December 2016 Bluetooth 5.It has doubled speed , increased range by four times and data broadcasting ability by 8 times than that of Bluetooth 4 [25].

5.5 Other Wireless Technology

There are other existing technologies for ultra-low power wireless technology such as ANT, RuBee, Sensium, Z Wave, Insteon and so on [26].

6 Designing the prototype

The WBAN system consists of Sensor nodes, Gateways or Sink node and data receivers from Gateways. However, this project uses Android mobile phone as Gateway so as to reduce the amount of work and make a thesis project implementable by a single student. As mobile phone has internet, by using an open source Android application, the data received from the sensor nodes are stored in the database and saved in the server.

6.1 Sensor Nodes Design

Sensor node was built using Arduino micro, “Adafruit Bluefruit Le UART Friend” module and ECG sensor. The sensor data are analysed, processed and converted into readable data. There are varieties of options available for BLE modules. Some of the BLE modules whose built in library and examples are easily accessible are:

- Adafruit Bluefruit LE UART Friend [24]
- Spark fun BLE [27]
- RN4020 module [28]
- Red bear Ble nano [29]
- Hm 10, Hm 11 and HM15 [30]

6.1.1 Bluetooth Low Energy Modules

There are many manufacturers of Bluetooth Low energy modules in the market. Most of the modules are based on Nordic Semiconductor Bluetooth Low energy and Texas Instrument Bluetooth Low energy MCU. Bluetooth Low energy is formerly known as Bluetooth Smart. Nordic semiconductor has released few series of Bluetooth Low energy. These series are Micro Blue which is nRF8001 MCU based Bluetooth Low energy. Under Series nRF51, there are nRF51822, nRF51824 and nRF5142 soc microcontrollers. nRF52 series is the advanced multi-protocol series MCU. These support both central and peripheral mode of Bluetooth. They implement Bluetooth 5 protocols. The most popular manufacturers of System on Modules that are based on Nordic Semiconductor BLE are as follows: [31].

- Raytac
- Microchip
- Cypress
- Fanstel Corrp

6.1.2 Adafruit Bluefruit lE UART Friend Module

The prototype of the project uses “Adafruit Bluefruit Le uart friend” Bluetooth Low energy modules. This module has MDBT 40 module manufactured by Raytac Corporation and is actually nRF5122 MCU modules. Figure 10 shows “Adafruit Bluefruit Le uart friend”. The specific features of MDBT 40 module included in “Adafruit Bluefruit Le uart friend” are:

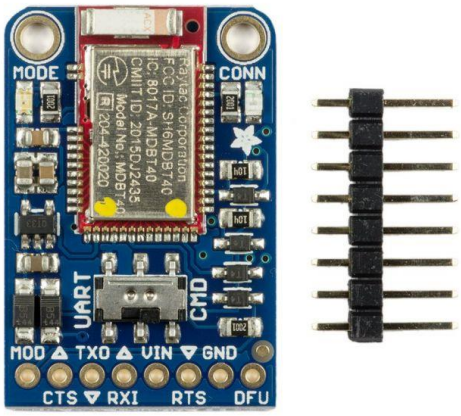


Figure 10 Adafruit Bluefruit LE UART copied from Adafruit.com [24].

List of important features of “Adafruit Bluefruit Le uart friend” are as follows.

- 256 Flash memory
- ARM® Cortex®-M0 core running at 16 MHz
- 32KB SRAM
- 5 volt safe inputs and 3.3 Voltage regulation.
- UART at 9600
- Boot loader with Support with OTA firmware updates [24]

Since the project used UART BLE module not SPI BLE module, there are two ways to communicate with module. There are hardware UART or Software Serial UART.

This thesis project uses Software UART for configuration. Hence, it has used all the pins of “Adafruit Bluefruit le uart friend” module. They are Transmitter pin, Receiver Pin, CTS pin and Reset pin. The entire respective pins configuration is defined in the example code of Adafruit to configure it in the Arduino Micro. Although, the actual MDBT 40 BLE module of Adafruit Bluefurit le UART friend runs on 3.3 voltages, this module has in built voltage regulator. Hence, it can operate under the 5 volts. The transmitter and receiver pins also have to operate under the 3.3 voltage to communicate with the module. However, the module has inbuilt voltage regulator to do the function of regulation.

Mode pin can also be used to configure the BLE module whether in command mode or Non command mode. This module however had switched to choose the UART mode or command mode.

6.1.3 Programming Adafruit Module

The Arduino Micro controller is programmed in the Arduino IDE environment. Because Adafruit has its own firmware and software development kit for its BLE module, its library has to be uploaded in Arduino IDE. Figure 11 is the picture of source code where Adafruit library has been imported.

```
#include "Adafruit_BLE.h"
#include "Adafruit_BluefruitLE_SPI.h"
#include "Adafruit_BluefruitLE_UART.h"

#include "BluefruitConfig.h"
```

Figure 11 Adafruit library included in Arduino and copied from [32].

The module is communicated using set of Already defined AT commands. The Adafruit has open source free examples to test the boards and try AT commands with the module. The inbuilt functions in the example code are actually the methods which have been already defined in the library of Adafruit. Each method has been made up of with AT commands to execute the particular functions.

```
SoftwareSerial bluefruitSS = SoftwareSerial(BLUEFRUIT_SWUART_TXD_PIN, BLUEFRUIT_SWUART_RXD_PIN);

Adafruit_BluefruitLE_UART ble(bluefruitSS, BLUEFRUIT_UART_MODE_PIN,
                      BLUEFRUIT_UART_CTS_PIN, BLUEFRUIT_UART_RTS_PIN);
```

Figure 12 Portion of Arduino code for initializing the Adafruit BLE uart

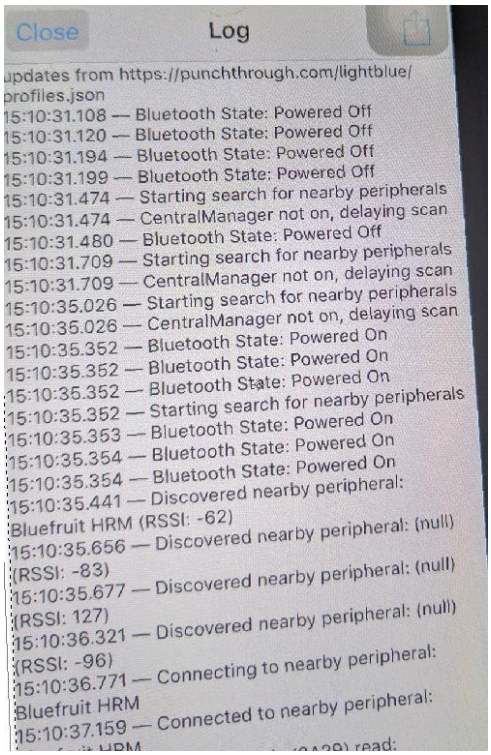
For example the ble object has been created with software serial configuration for the constructors.

It uses factoryReset () method to execute factory Reset with Ble Object. For example, ble.factoryReset () returns the Boolean value of “TRUE” if the factory reset has been successful. This implementation can be found inside the cpp file of adafruit library as the figure 13 showed it.

```
bool Adafruit_BLE::factoryReset(boolean blocking)
{
  println( F("AT+FACTORYRESET") );
  bool isOK = waitForOK();

  _reset_started_timestamp = millis();

  // Bluefruit need 1 second to reboot
  if (blocking)
  {
    delay(1000);
  }

  // flush all left over
  flush();

  return isOK;
}
```

Figure 13 Implementation of reset method in main .cpp file reprinted from github [32].

The above code is the actual implementation of method factory Reset () inside the AdafruitBLE.cpp file in the library of the Adafruit library. Hence, every in built methods of the examples of adafruit are built on AT commands.



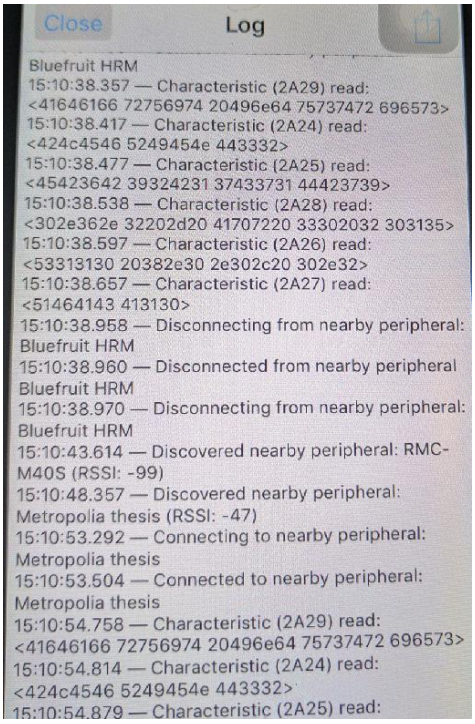


Figure 14 Log of Adafruit BLE modules showing every step in connection in LightBlue Explorer App.

Figure 14 is the Illustration of screenshots for log of every step involved in Bluetooth low energy connection and transmitting of data.

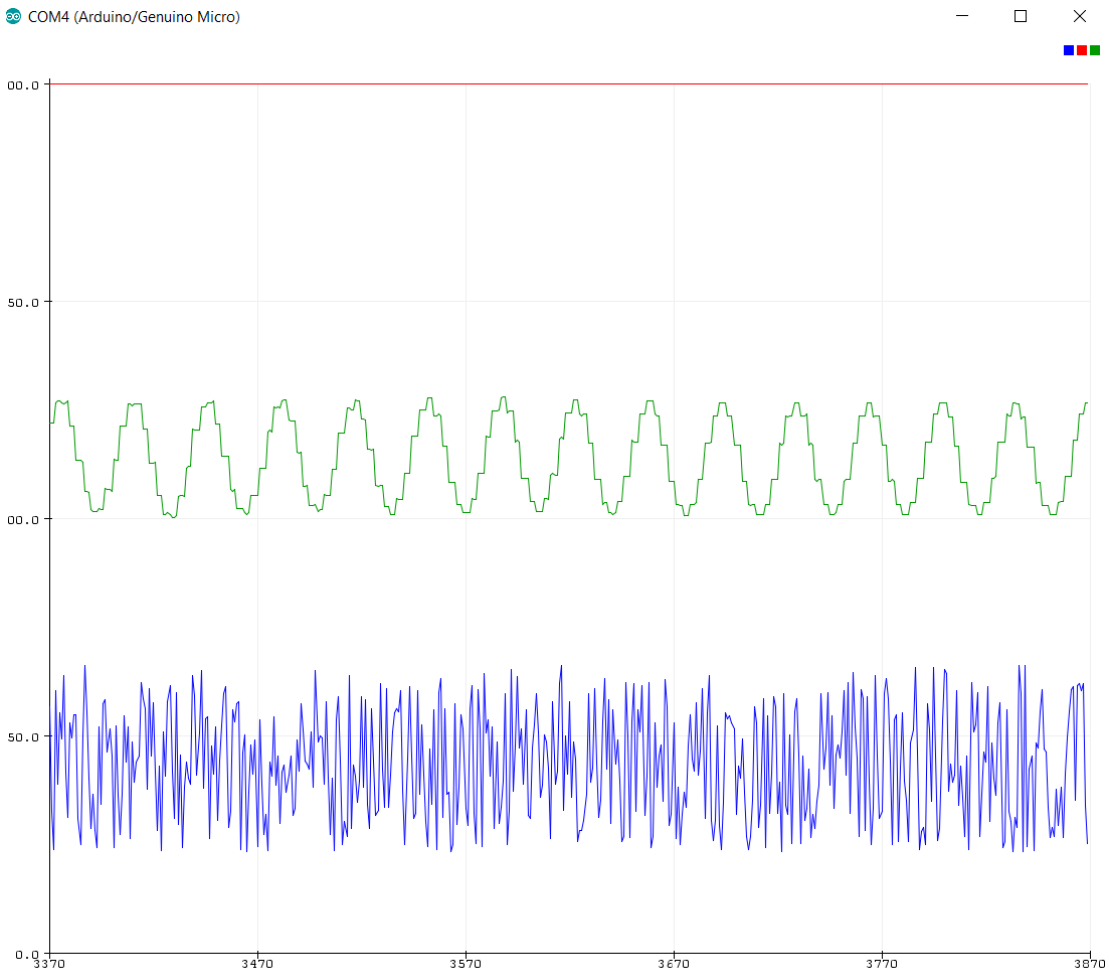


Figure 15 Serial Plot of Pulsesensor reading from Arduino serial plotter.

The serial plot of pulse sensor is shown on figure 15.This project has used adopted Heart Rate Monitor Service. Heart Rate Service has assigned UUID number 0x180 D. [25] This Heart Rate Monitor Service has three characteristics. They are Heart Rate measurement, Body Sensor Location and Heart Rate Control Point.

Heart Rate Measurement is the mandatory characteristics where the notification to the client is the compulsory [25]. Heart Rate Measurement sends the heart rate measurement value to the devices. However, the two other characteristics are optional.

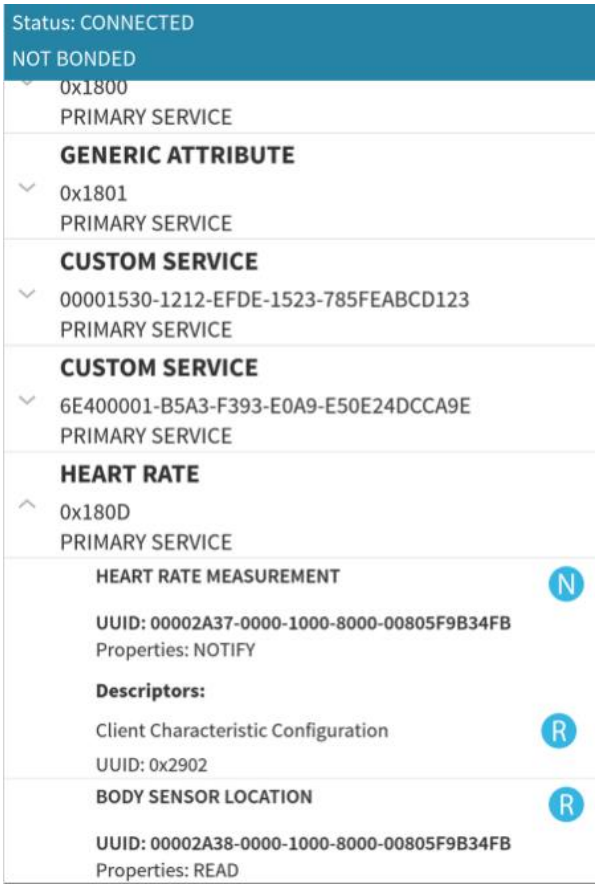


Figure 16 Screenshot from Android app BLE scanner.

Figure 16 is the list of Services available in the “Adafruit Bluefruit Le uart friend” BLE module. It shows that there is Custom Service and Heart Rate Service. Heart Rate Service has two other characteristics. They are Heart Rate Measurement and Body Sensor Location. Heart Rate Measurement Characteristics has notification property while body sensor location has read property.

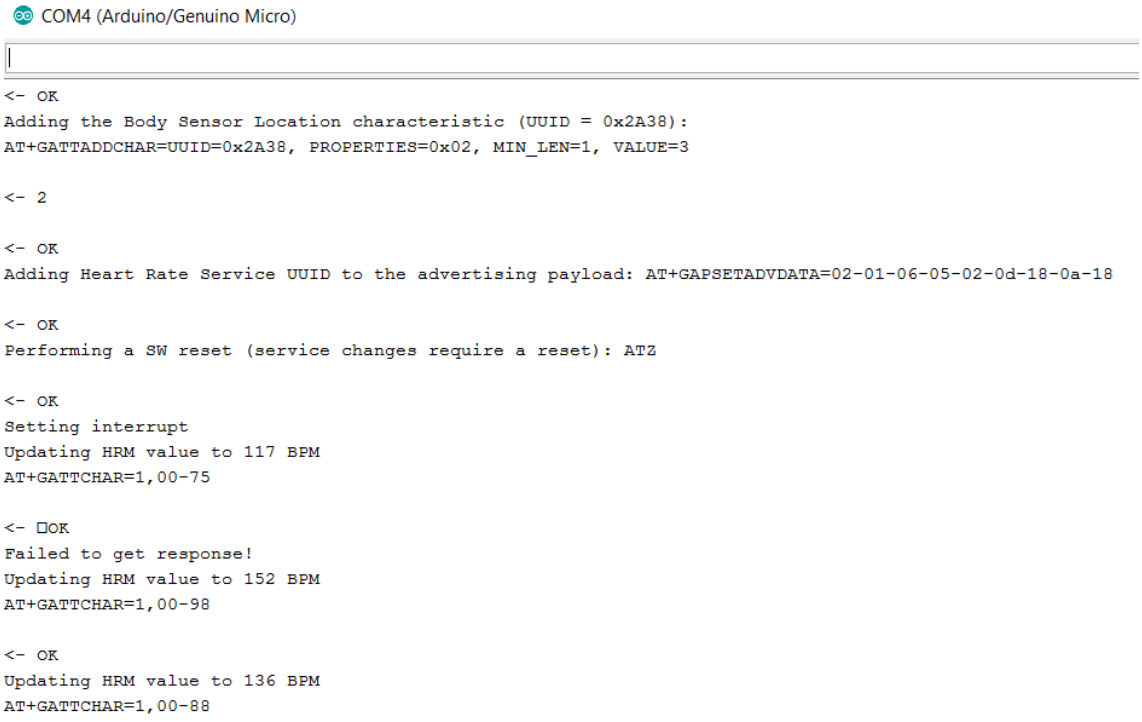


Figure 17 Arduino Serial Monitor showing the process of BLE data sending

Figure 17 shows the processing of data being sent to Android phone. AT commands for configuring the heart rate service and Heart rate measurement Characteristics:

```
AT+GATTADDSERVICE=UUID=0x180 D.
AT+GATTADDCHAR=UUID=0x2A37 0x2A37: the UUID of the Heart Rate
Measurement characteristic
```

AT command to add the Heart Rate Service to advertising mode:

```
AT+GAPSETADVDATA=02-01-06-05-02-0d-18-0A-18
```

AT command to update whenever the value assigned to the heart rate measurement characteristic changed, is

```
AT+GATTCHAR=1, 00-3D
```

In similar way, this study uses Health Thermometer Service to send the thermometer reading required for health purposes.

Assigned UUID of Health thermometer is 0x1809 [25]. This Service includes the following characteristics:

- Temperature Measurement.
- Temperature Type
- Intermediate Temperature
- Measurement Interval

Temperature Type and Measurement Interval characteristics have mandatory read requirement. But the intermediate Temperature and Temperature Measurement have mandatory notification requirement.

6.1.4 HM 10

Initially, the project was tested to do with HM10 module. Use of Adafruit BLE module instead of HM 10 is preferred because HM 10 does not support many profiles though initially HM 10 was ordered due to its cheap price. HM10 was built on Texas Instruments CC2540 or CC2541 chip. Figure 18 picture of HM10.

Figure 18 HM10 BLE Modules.

6.1.5 CYble Proc Module BLE

This study had original plan to build its own BLE module out of Cypress Semiconductor CYble Proc Module. CYBLE PROC Bluetooth 4.1 Module runs on Bluetooth 4.1 protocol. It supports serial communication protocols I2c, UART and SPI. Later on the idea was dropped because of insufficient tutorial materials. Figure 19 the picture of BLE

module that the project had used in the beginning.

Figure 19 BLE module from Cypress reprinted Digikey [33].

6.2 Sensors

Electrocardiogram Sensor

ECG sensor detects every heartbeat. Heart beat is regular contraction or expansion of heart valves to pump blood in or out from one region to another and vice versa. It is measured in Beats per minute (BPM). Beats per minute is the heart beat rate. Heart beat sensor is light and small sensor that converts the heart beat to electric signal associated with cardiac activity. Figure 20 is the ECG sensor.

Figure 20 Pulse Sensor reprinted from Sparkfun.com.

Possible sensors to be used in wireless monitoring:

- Blood Pressure sensor
- Oxygen sensor
- Blood Insulin Sensor

As in Figure 3, there are variety of options for sensors depending the cases and diseases. Bluetooth Special Interest Group has defined many profiles for Low Energy devices. They are predefined list of services compiled by Bluetooth SIG or other authorized company. The list of those health care profiles is

- HTP (Health Thermometer Profile)
- GLP(Glucose Profile)
- CGMP(Continuous Glucose Monitor Profile)
- Pulse Oximeter Profile
- BLP (Blood Pressure Profile)

In addition to health care profiles, there are also Sports and fitness profiles:

- BCS (Body Composition Service)
- CPP(Cycling Power Profile)
- WSP(Weight Scale Profile)

6.3 Gateway Design or Sink Node implementation

Actual gateway or sink node for wireless body area network had to act as personal digital assistant with independent device that has microcontrollers and dual mode of communication. It would receive the data from sensors in BLE medium and at the same time forward the data to the receivers in server side in different mediums. But the prototype in this study uses the android phone as gateway. Android OS version 4.3 or later supports the Bluetooth low energy. Similarly, IPhone 4s and latest version use the Bluetooth low energy. These smart phones contain both WiFi and Bluetooth low energy modules in them. Hence, they can be used as gateway to receive the data from sensor nodes in BLE mode and forward the data to receiver in WiFi mode or directly

update to the server using the internet connection of the mobile phone. There are lot of an open source application that receives the Data from sensor nodes and display the data but they do not have functionality to update it to the server. Hence, either complete application has to be built or an open source application has to be used to work as Gateway. Figure 21 the complete WBAN system that has sensor nodes and Receiver with ESP8266.

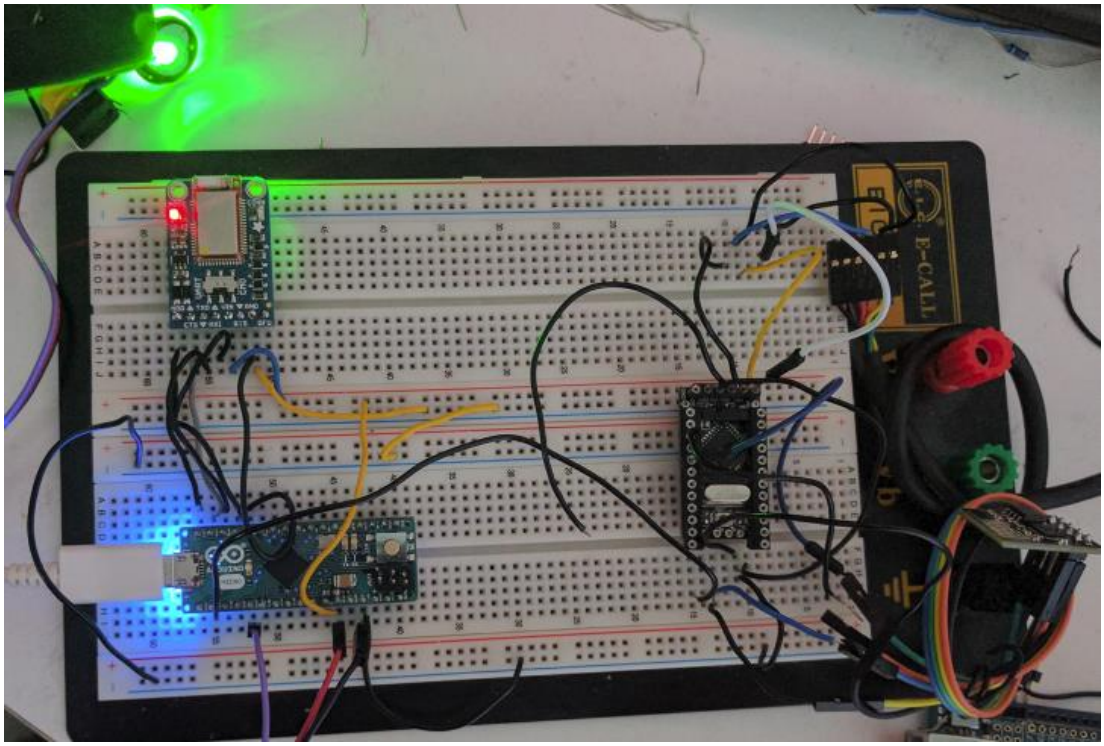


Figure 21 Prototype WBAN Systems

6.3.1 Android Application

The project uses android version of nRF tool box application. This application supports following profiles.

- Heart Rate Monitor
- Proximity Monitor
- Glucose Monitor
- Blood Pressure Monitor

nRF tool box does not have functionality to update the information to the server.

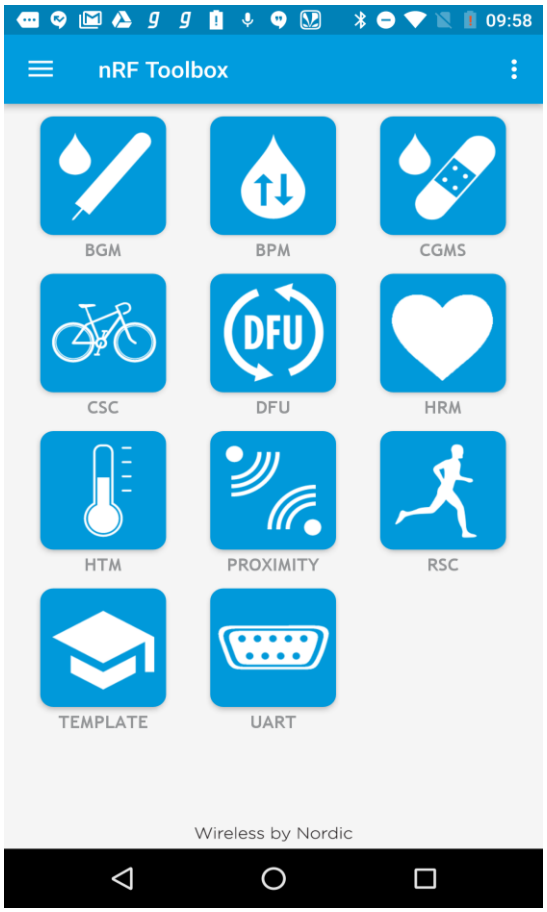


Figure 22.1 nRFtool box layouts.

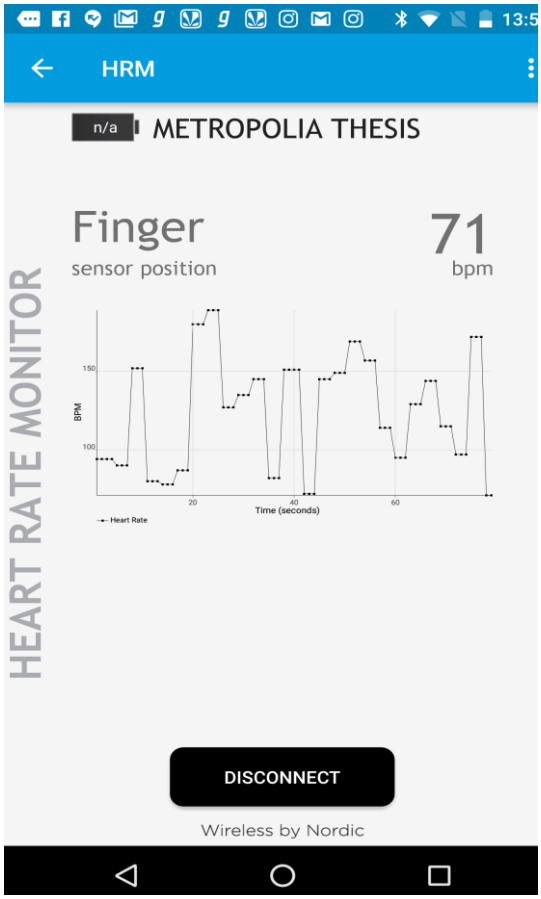


Figure 22.2 nRFtool box, graph of Heart Rate Monitor

Figure 22.1 and Figure 22.2 are the screen shots of nRFtool box. Figure 22.2 is showing the plot of graph from the sensor data received from Adafruit BLE module.
This application does not have functionality to send the information to the receiver. However, it is possible to implement Client server in the application to send the sensor data to the server.

6.3.2 Espressif32

Espressif32 was initially ordered to build the prototype sink node device because of dual mode of communication. They are BLE and WIFI. After some time, the idea was dropped because of insufficient tutorials and resources for Expressif32. Expressif32 is one of the best choices to use as sink node. It is 240 MHz dual core xtensa Lx6 microcontroller

that built in WiFi and Bluetooth features through SPI/DIO or I2C/ UART interfaces. The device that incorporates Espressif32 can be perfect choice for Gateway. It operates at 2.4 GHz. This device has both functionality of either slave device or master device in Bluetooth module. Because of its ultra-low power solution consumption, it is suitable option for gateway. It has CMOA for single chip fully integrated radio and baseband [34]. It has WiFi of 802.11b/g/n and Bluetooth 4.2 as well as Bluetooth Low Energy (BLE). Figure 23 is the picture of Espressif32.

Figure 23 Espressif32 as gateway reprinted from eBay [35]

6.4 Receiver

The actual receiver is the data receiver from Gateway through medium like Zigbee, WI-Fi or other communication medium other than Bluetooth low energy. The receiver is connected with computer which is then connected to the server through internet

6.4.1 Raspberry Pi zero W

The possible choice for receiver and server is Raspberry Pi where Raspberry Pi Wi-Fi dongles has to be used or Instead Raspberry Pi Zero W could be also used. Raspberry Pi zero W has in built WiFi modules to receive the data coming from the Gateway. It has 1 GHz Single core CPU, 512 MB Ram, HDMI port to display the readings received from Gateway.

Figure 24 Raspberry Pi as receiver and server reprinted from Karrika [36]

From figure 24, Raspberry Pi could be suitable option for using receiver.

6.4.2 ESP8266-01 and ESP8266-12

This project uses Arduino Mini pro microcontroller and ESP 8266 Wi-Fi module as in figure 25.1 to update the information in the open source ThingSpeak website.ESP8266 is WIFI chip manufactured by Espressif Systems. ESP8266 Wi-Fi module has TCP/IP protocol stack [27]. It can be controlled by with AT commands. It has on board integrated low power 32 bit CPU and there for it can be independently used by integrating the sensors with is GPIOs. It runs IEEE 802.11b/g/n WIFI. Figure 25.1 is the image of ESP8266-01.

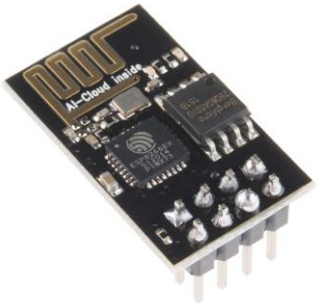


Figure 25.1 ESP8266 used in the project

Reprinted from Sparkfun [27]

Figure 25.2 ESP8266-12 WiFi shield reprinted from addicore.com [43]

It communicates serially with microcontroller. It runs on 3.3 Voltage. The project had initial plan to use the ESP8266-12 chip only and build a PCB board out of it. Figure 25.2 shows the picture of ESP8266-12. But, it has the problem in uploading the code. It

might be because the pin configuration was not successful. Hence, ESP 8266 01 module was used. ESP8266 01 and ESP8266-12 can also be used as independent boards without need of additional microcontroller boards with minimum GPIOS on ESP8266 01. ESP8266 has 32 RISC CP and 64 KiB of instruction RAM and 96 KiB of data RAM [11]. While ESP8266-01 has 6 active pins ESP8266-12 has 20 active pins.

6.4.3 Programming ESP8266 Module

It runs on AT commands which are sent serially from the microcontroller.

AT+CWMODE=1: command to set into client mode.

ESP8266: acts as the TCP client when it sends the data to the thingSpeak website.

AT+CWJAP="WiFi name","WiFi-password": sets the WIFI connection of the ESP8266
AT+CIPSTART="TCP","184.106.153.149","80";

It starts the TCP connection into thingSpeak API, where 80 is the port of the thingSpeak remote server.

AT+CIPSEND= 1, 15;

It sends the data in single connection mode where 15 is the length of the data.

AT+CIPCLOSE AT: command closes the TCP connection.

There are many Open Source Software Development kit available in market for ESP8266.

For example:

- NodeMCU [37]
- Arduino
- MicroPython [38]
- Espruino [39]

Figure 26 Observation of sensor data being uploaded in web from Arduino Serial Monitor

Fig 26 shows the implementation of Arduino code for updating the information in thing-Speak website in Serial Monitor. This code used random values for Heart Beat Rate to update it to thingSpeak website.

6.5 Observation of Sensor Data in Website

This thesis uses open ThingSpeak IOT platform for displaying the different sensors data that the receivers received from the Sink node or Mobile phone. It even stores the data in the cloud. The data can have both public and private access. It can receive the data from different devices like Arduino, Raspberry Pi, BeagleBone and other devices. All

these devices should have one of TCP/IP, HTTP or MQTT protocols to communicate with ThingSpeak. Data can be observed either through the mobile application by authorized persons with user id and password or in the web browser. Data that has been received by ThingSpeak could be analysed and graphically represented.

Process of using “ThingSpeak” platforms are listed below:

- Create ThingSpeak Account or use MathWorks Account
- Create Channel and specify the channel setting values.
- API keys. Use the API keys to read and write to the channel.

This project uses two channels. Channel 1 is used for displaying the ECG sensor data and another channel is used for displaying the Body Temperature data.

7 Results and Discussion

7.1 Findings

The prototype wireless monitoring system was designed. From the results of study, it was found that Bluetooth Low Energy is the best PAN for communicating between sensor nodes and sink node than other commercially available means of wireless communication. Moreover Bluetooth 5 is preferable than that of Bluetooth 4.Since the sensor nodes are worn around the body , the sensor nodes should be as small as possible and therefore smaller components should be used. nRF52832 or nRF52840 is the suitable choice to build sensor node because of its appealing features that includes Bluetooth 5 although the project has used “Adafruit Bluefruit Le uart friend”. The sensors used in sensor nodes should be properly tested separately before integrating in the sensor nodes because the sensors sometime do not give accurate readings. The readings from sensor nodes in the project did not give the stable readings. It was probably because the cheap pulse sensor was not functioning well. The sink node should have Bluetooth Low Energy that should support both central and peripheral mode of communication. Adafruit BLE module used in the project supports only peripheral mode. However its new BLE module based on Nordic semiconductor nRF52832 have both mode of communication. Depending upon

the types of application that require varying latency, lower connection interval will decrease the time it requires to send data from central to peripheral or vice versa. In the application like this project, it requires lower latency. i.e. it needs less amount of time to send the data. Therefore, reduced connection interval technique can be used at the cost of comparatively higher power consumption. The android phone that has nRF tool box android application was used as sink node but it does not have functionality to send the data to receiver over WIFI. The study had original plan to seek the help from experienced android app developer on android application part but it was aborted later. The study also found out that EspressIf32 was best module to be used for designing sink node because of its dual mode of communication. It has both Bluetooth low energy which is actually BLE 4.1 and WIFI mode of communication. While using thingSpeak platform to log the sensor data, it was very slow around 18 to 20 seconds because it has used HTTP POST request.

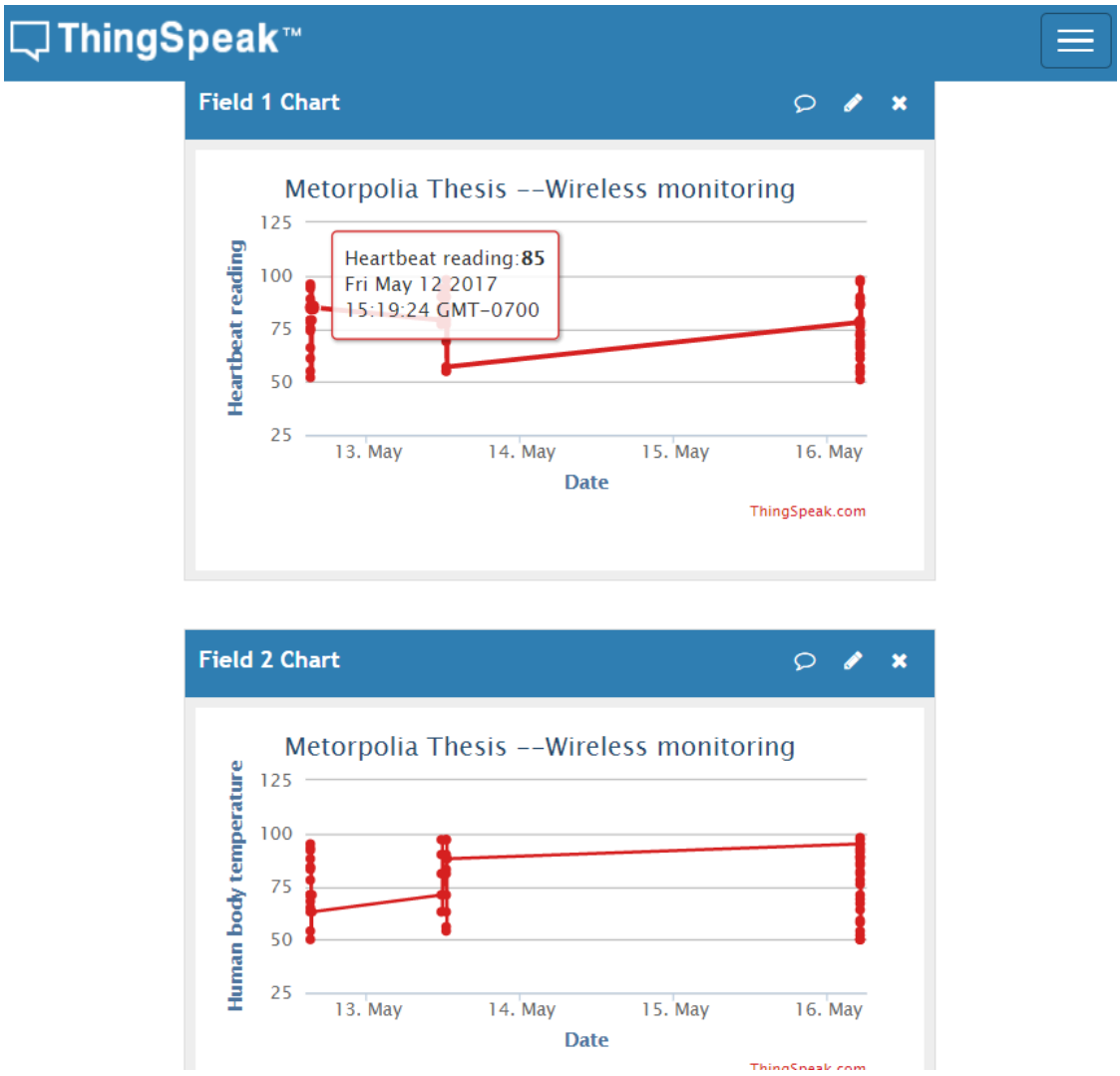


Figure 27 Observation of sensor data in ThingSpeak website.

From figure 27, it shows that sensor data has been updated very slowly. This slow updating of data is problematic to application like Heart Beat sensor reading because it needs frequent data logging. As a whole the primary goal of the study was met.

7.2 Problems Encountered and Solutions

The first major obstacle for designing the prototype was selection of appropriate components. The project was intended to complete by minimum budget. Therefore, at first the only cheap chips were ordered hoping to make a module out of them, but on further research and development the complete functioning module could not be made. For example HM10, CYble pro BLE, nRF52832 and ESP8266-12 chip were ordered because of its cheap price. nRF52832 was 48 pin soc and very small that only machine soldering can solder it. CYBLE PROC Bluetooth 4.1 Module was BLE module but there are not sufficient tutorial materials and examples to use it. Hence, HM 10 was ordered. HM 10 is very cheap. It has very low processing power that it does not support many services required in BLE. Double ESP8266-12 was soldered and necessary components were used soldered to make WiFi shield. But unfortunately, they did not respond. Hence, complete BLE modules were ordered.

This project uses android phone for sink node through open source Android Application nRFtool box. Although the application has feature to connect to sensor nodes and display its readings, it does not have functionality to forward the data to the receiver through WIFI. Hence that open source application has to be edited to in order to send the sensor data to the receiver server. In a real system, there is an independent sink node device. Espressif ESP32 was originally ordered to design the sink node. However, this part was also left for further project because Espressif ESP32 is recently manufactured that there are less tutorials and examples to test.

Although varieties of biomedical sensors can be used in sensor nodes, this project has used only Pulse senor because the project is only building the one prototype system. Furthermore, adding more sensor means, it needs further deep study of working of sensors and it would take more time to implement another independent sensor node for another sensor.

If there were more people involved in the project, then PCB board for sensor nodes and sink nodes could have been developed. Though components required for the developing the sensor boards are ordered for example soc nRF5282, EspressIF ESP32 and Atmel 328P microcontroller , developing the pcb board part have been left for further project. All the components when used in developing the PCB board in the future project have to be very small and SOC because the sensor nodes have be very tiny and in large number. The designed prototype could not be tested independently on body because the sensor node was very big to actually put on the body and it does not have 5 volt external power supply. The USB cable was supplying power to the sensor node. However, the sensor node was tested by taking the pulse reading from the thumb finger and using it on ear-lobe.

8 Conclusion

The primary goal of this project was to research the trend of wireless monitoring and design the most appropriate monitoring system. Although the complete prototype system was not built because this project required the experience of working on android Application, the fully functioning prototype was made using simulated values. As a whole, the prototype worked and primary goal was achieved. Wireless Monitoring of Patients has been researched by many before but because of poor technology in Wireless technology and less number of sensors, the effective system was not developed. Now, there have been significant improvements as well as advancement in the field of MEMS and digital electronics that designing of the system is not very challenging. The availability of many body sensors in addition to the completely revolutionary Personal Area Network Bluetooth 5 have made the wireless monitoring very easy to design.

Suggestion for future work

There are numerous sensors that can use in the body or inside the body for wireless monitoring. Health care takers might need real time data of other health parameters other than that is currently available in future. Hence, research on developing sensors to gather that particular health information can be done. Those sensors can be implemented to this system. Provided with the pace of advancement in Nano technology, wireless monitoring of the patients can also be implemented on Nano scale in near future. Currently most of the wireless technology operates on same ISM bands where most of devices

operate to which there is chances of interferences. Further research on developing new wireless technology that is interference free can be very helpful to make this system very effective. The project uses thingSpeak platform to display the real time data. Because the Espressif ESP8266 Wi-Fi shield uses TCP connection with thingSpeak webserver and use HTTP to update the readings from receiver, the data is updated every 20 seconds. This higher latency is not suitable for wireless monitoring. Hence, a separate server can be made and different protocol can be used which does not delay the updating the data in the website.

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