# Transmitting Patient Vitals Over a Reliable ZigBee Mesh Network

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*Abstract*—**Real-time measurements and display of vitals are integral part of patients health monitoring with limited resources. Wireless sensor networks that communicate in a mesh acquire and transmit such critical parameters, making a medical environment efficient. With limited resources, both equipment and medical staff, the system must be reliable, and capable of dynamic updating on patient status. System must be able to sustain at least single contingency. We designed a signal conditioning circuit and firmware that converts finger pulse into beats per minute (BPM), which is then displayed on a remote station dynamically via ZigBee. Testing was performed to measure the reliability of transmitting data over a wide range of distances through high traffic areas (both human and Wi-Fi). We show that such systems can provided enhanced reliability in a limited resourced environment and have the potential to be deployed in disaster recovery situations.**

*Index Terms*—**medical, wireless, heart rate, monitoring**

## I. INTRODUCTION

In a clinical setting, the diagnosis and treatment of patients involves several biological parameters that need to be measured on a real-time basis. Some of these critical parameters are: pulse rate, temperature, blood pressure, electrocardiogram (ECG), and blood oxygen level. Wireless sensor networks that communicate in a mesh collect and transmit such critical parameters, making a medical environment more reliable and efficient through their self-healing nature. With limited resources, both equipment and medical staff, the system must be reliable, and capable of dynamic updating on patient status. System must be able to sustain at least single contingency. Firstly, a primary station acting as a router must be supported by a hot standby station in case of system failure. Secondly, medical staff (doctors and nurses) looking after patients must have real-time contextually sensitive environment that informs the appropriate staff the real-time status update of test/diagnostics currently being perform of what patient, when and where the event is occurring, and by which medical staff. Further, equipment vital to the health and well being of a patient must contain self-diagnostic capabilities to notify staff of fault. For example, a low battery indication on a sensor that monitors heart rate can notify staff that the battery must be changed. We designed a signal conditioning circuit and firmware that converts finger pulse into beats per minute (BPM). BPM data is then displayed on a remote station via ZigBee. Testing was performed to measure the reliability of transmitting data over a wide range of distances through high traffic areas (both human and Wi-Fi). We show that such systems can provided enhanced reliability in a limited resourced environment and have the potential to be deployed in disaster recovery situations.

This paper will include a brief overview of the ZigBee standard, the applications associated with it and also how it compares with other wireless protocols (Section II). We discuss the objectives and scope of the circuit design to acquire data from the sensor and transmit over a ZigBee device (Section III). The ZigBee application layer protocol is then described in detail to show how patient vitals are transmitted (Section IV) from sensor to display monitor (Section V). We close with a discussion on related work (Section VI)and conclude with some final remarks (Section VII).

## II. ZIGBEE OVERVIEW

This section will give an overview about the 802.15.4 ZigBee standard and the applications associated with it. It will also briefly discuss the advantages and disadvantages ZigBee has as compared with other wireless protocols.

As an IEEE 802.15.4 standard, ZigBee was conceived in 1998, standardized in 2003 and revised in 2006 by the ZigBee Alliance. The main asset of the protocol is to create wireless personal area networks, built from low powered digital radios. ZigBee operates over 16 channels in the 2.4 GHz frequency band which is commonly known as the ISM band. This band is used for Industrial, Scientific and Medical (ISM) usage and requires no licensing allowing free usage to the public. "ZigBee is the only standards-based wireless technology designed to address the unique needs of low-cost, low-power wireless sensor and control networks in just about any market. ZigBee also connects the widest variety of devices into easy-to-use networks givingunprecedented control of the devices [that is] used every day at home, work or even play" [1].

With over 100 members, the ZigBee alliance is a non-profit organization which consists of businesses, universities and government agencies from around the globe. (ZigBee Alliance) The main goal of the alliance is to create products which will help build ZigBee modules for applications which require low power consumption. The members of the alliance are given full access to developing ZigBee hardware and documentations. The biggest contribution comes from the

eleven promoters of ZigBee which play an influential role in the development and distribution of the standard.

ZigBee is used in many applications which require long lasting battery power and long distance communication. ZigBee is also offers many low cost modules which help in research and development of many up and coming applications in the future. ZigBee applications often require reliability, low power consumption and cost effective development and deployment.

### A. Other Wireless Protocols

As shown in Table I, ZigBee offers features such as long lasting battery life and unlimited network size as compared to other wireless protocols. Another practical feature that the ZigBee standard provides is its ability to transmit data by passing on the information through other ZigBee to reach its final destination. This is done by establishing ZigBee coordination nodes to allow a great increase in the network transmission range.

TABLE I
ZIGBEE COMPARED TO OTHER WIRELESS STANDARDS

|  | ZigBee | Wi-Fi | Bluetooth |
|---|---|---|---|
| Standard | 802.15.4 | 802.11b | 802.15.1 |
| Application Focus | Monitoring & Control | Web, Email, Video | Cable Replacement |
| Battery Life (days) | 100–1000+ | 0.5–5 | 1–7 |
| Network Size | Unlimited ($2^{64}$) | 32 | 7 |
| Max Data Rate (Kb/s) | 20–250 | 11,000+ | 720 |
| Transmit Range (M) | 1–100+ | 1–100 | 1–10+ |
| Advantage | Reliability, Power, Cost | Speed, Flexibility | Cost, Convenience |

## III. REMOTE SENSOR DESIGN

The Medical ZigBee Network consists of a single optical heart rate sensor which is used to receive analog heart beating signals. The signal is then sampled and digitized at the slave node using Delta Sigma ADC and using an RF Basic transmission protocol, the data is transmitted wirelessly to the master node. At the master node, the ADC value is transmitted to a PC using UART and RS-232 cable where the heart beat is then displayed on a monitor. The system is a one way communication from the slave to the master node. As shown in Figure 1, in an ideal situation the sensor and the slave node are located in the patient's room and the status of the patient is then monitored and examined in a controller room.

### A. Optical Heart Rate Sensor

When the heart pumps, it pushes blood through the circulatory system in a repeating cycle. Each heart beat starts the cycle of blood flow through the chain of arteries, veins and capillaries. When the heart muscles contract it creates a high pressure pulse of blood into the arteries. This contraction will cause the veins of the human finger to expand with more blood. Blood will absorb more light as compared to the surrounding tissue. This change in light can be measure as a cyclic change resulting in beats per minute.
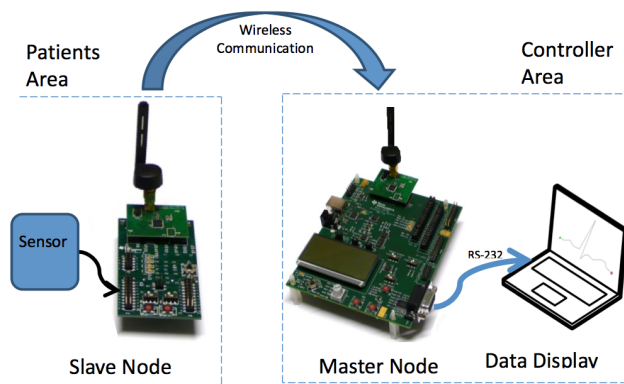


Fig. 1.   Medical ZigBee Network Overview



Fig. 3.   Optical Heart Beat Sensor (Front View)

As shown in Figure 2, the signal detected by the photo-sensor is in the micro volts therefore it is amplified by two amplifiers with a gain of 100, giving a net total gain of 10,000. The band pass filters are then used to eliminate DC and high frequency components, such as 60 Hz which may cause interference. After the signal is conditioned, it is ready to be digitalized, framed inside a packet to be sent wirelessly to the master node.

In order to make an optical heart rate sensor, the equipment must be immune to noise as well as comfortable and safe for the patient. The sensor must then be physically connected to the patient so that heart rate data can be collected accurately. To accomplish this, a kitchen utility clip was drilled on both sides, inserting the IR LED and the photo sensor directly across from each other as shown in Figure 3.

In order to comply with different finger sizes, an adjusting screw was implemented to widen or narrow the gap between the teeth of the clip. The circuit design was built on a prototype board as shown in Figure 4 and Figure 5. The circuit design also features test points and an LED which blinks with every pulse.
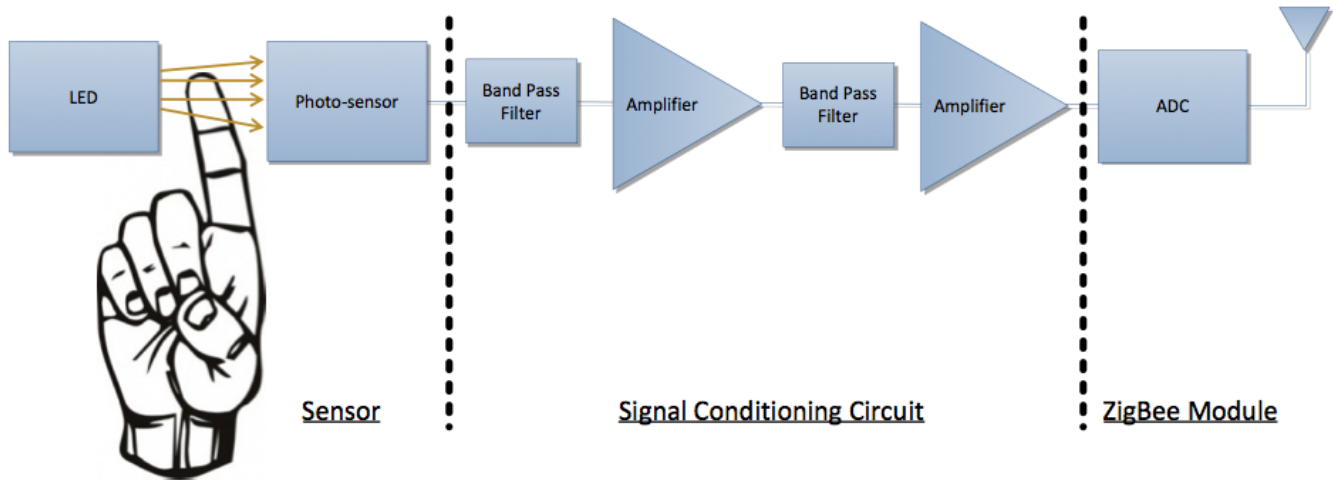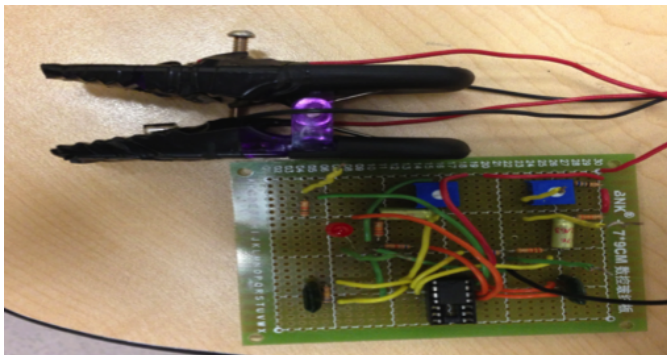
Fig. 2. Optical Heart Beat Sensor



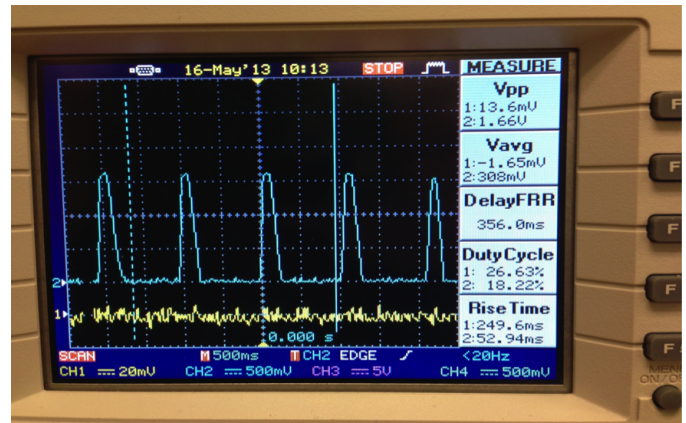Fig. 4. Complete Optical Heart Beat Sensor
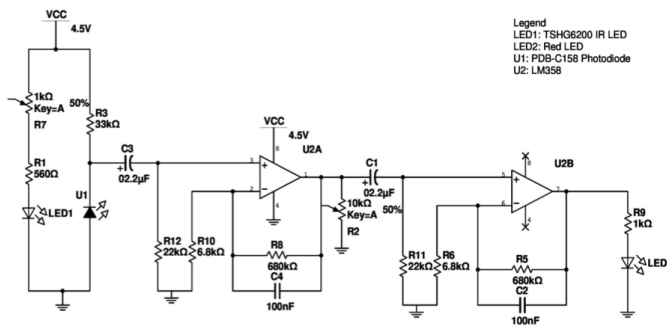


Fig. 6. Testing of Optical Heart Beat Sensor



Fig. 5. Heart Beat Sensor Schematic

In order to test the function of the optical heart beat sensor, the pulse was examined at the input and output of the amplifiers. As shown in Figure 6, using the oscilloscope, the input signal (CH1) was not measurable because it is in the micro volts region. However, the output signal (CH2) of the amplifier shows a pulse with peak amplitude of approximately 2.2 volts.

The output of the amplifier was designed to be no more than 3.0 volts due to the maximum threshold voltage the input pins

of the ZigBee module. After the pulse signal was tested to be within the region, it was ready to be implemented with the ZigBee, which will change the analog medical signal into a digital value.

## IV. DATA PROTOCOL DESIGN

In order to connect the sensor to the PC, the medium used is the ZigBee network. At the sensor node, analog signal is digitized. Then From the sensor node to the master node, ZigBee uses BasicRF transmission protocol to send ADC values. When the master node receives the data, it uses an RS-232 (UART) to send data serially to the COM port of the PC.

The ZigBee standard offered a basic transmission protocol called BasicRF. This protocol offered a peer-to-peer network, making all nodes equal and does not make use of coordinator and gateway nodes. The maximum frame payload length is 103 bytes.

As discussed earlier, the ZigBee implementation was broken down into three major sections. Each section required its own
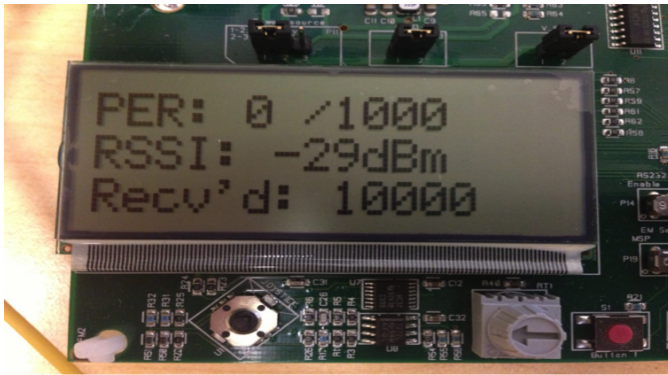
Fig. 7.   PER and Receiver Signal Sensitivity Test



Fig. 8.   Data Display Monitor



Fig. 10.   Cardiac Monitor from ECG Sensor

method of testing. For the ADC conversion, a constant voltage value was given into the ADC input pin. The digital value was then used to calculate the voltage value being sampled. For other parts of the ZigBee implementation, programming software such as SmartRF Packet Sniffer was used to analyze the packets being transmitted. As seen in the packet sniffer, the frame complies with the BasicRF transmission protocol which is used for data transmission in this project.

Transmission range was another characteristic of the ZigBee which was tested. To do this, the ZigBee transmission was both tested indoor and outdoor. Indoor the transmission range reached approximately 105 feet whereas outdoor, it was able to reach up to 600 feet. Also, as shown in Figure 7, the Packet Error Rate (PER) and the receiver sensitivity was measured using a program provided by TI [2]. The PER was measured to be approximately 0% at close proximity and the receiver sensitivity could reach down to -99dBm.

The serial transmission of data from the master node to the PC was accomplished using UART and tested on Hyper-Terminal to make sure the ADC values are being transmitted correctly. the values coming through the serial port contain both a delimiter and a Tag, accompanied by the ADC value (e.g.: **;o75;**, where "o" is the tag , 75 is the ADC value, and the semi-colon is the delimiter).

## V. DATA DISPLAY MONITOR

To display a graphical interface, a Java based software program called NetBeans was implemented to create a monitoring display in the controller area. NetBeans requires object oriented programming and uses a platform which is used in other programming software, such as for a creation of mobile applications.

The data display monitor was tested to acquire an average for beats per minute (BPM) over 10 beats. As shown in Figure 8, the data display monitor for the optical heart rate sensor shows an averaged BPM and a real time graphical plot. The BPM for a healthy person is from 55 to 100 BPM.

## VI. RELATED WORK

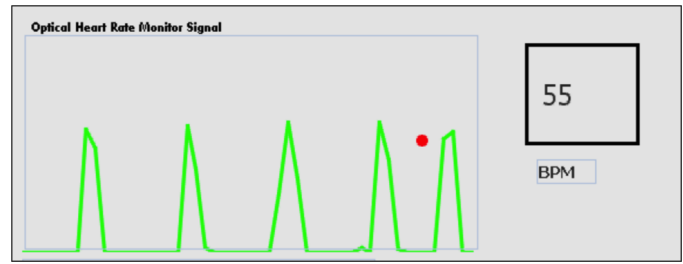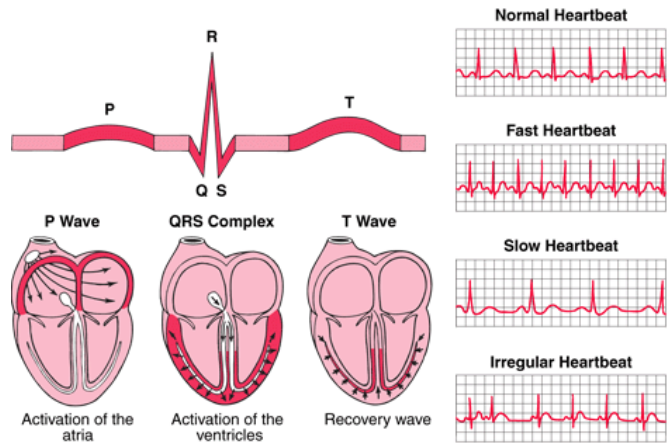There has been previous work done in the area of wireless heart rate monitoring. However, our work surpasses the current literature in a number of key areas: reduction in sensor noise, improved sensor accuracy, increaded transmission range and coverage. We now compare what others have done to our own work.

Navya et al. [3] developed a multi-sensor systems that used ZigBee to transfer vitals information. Unlike Navya, our circuit design minimized the noise created by sensor itself. We achieved this by introducing a band pass and notch filters to eliminate DC and high frequency components. In addition, we also moved from using a 5.0V output to a 3.0V output to further reduce sensor noise and increase accuracy.

Dinh and Wang [4] purposed a wireless device that had the transmission range for the coverage of a residential house. Our device is meant to cover large sections of disater recovery area to allow for patient mobility and at the same time improve transmission reliability. As compared to Huang et al. [5] system which had a maximum range of 100 meters, our system's maximum range is up to 200 meters, twice theirs. This is important for two reasons: cost and reliability. Longer communication ranges help reduce equipment cost because not as many routers/repeaters would need to be purchased and installed. Reliability would increase and transmission error rates would decrease as there would be a reduction in the amount of transmission hops, but at the cost of energy efficiency [6].

Purnima et al. [7] design incorporates GSM based sms alerts which could drain battery life and provide no additional purpose and unwarranted expense.
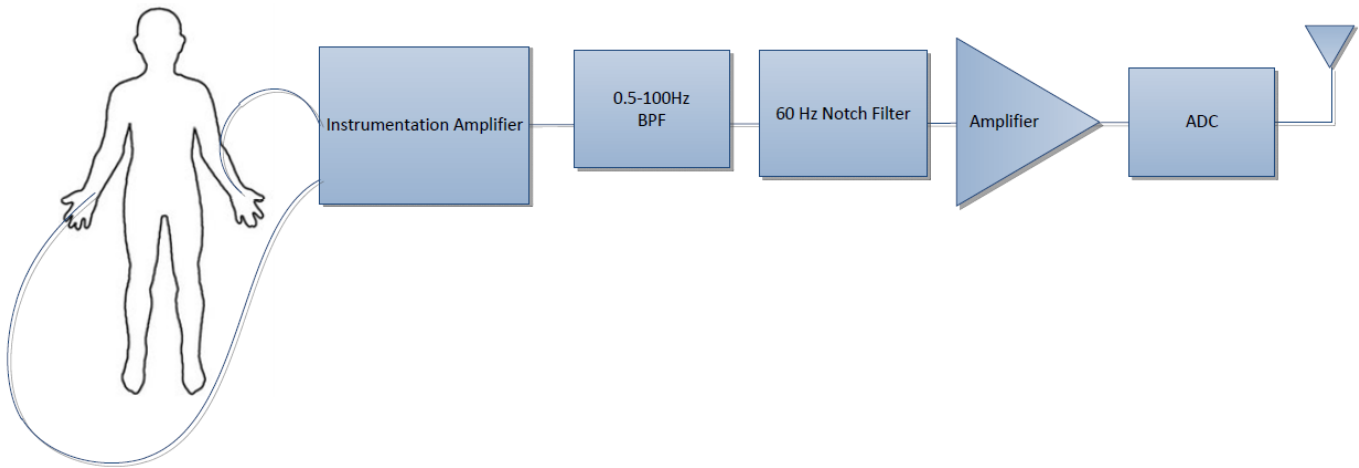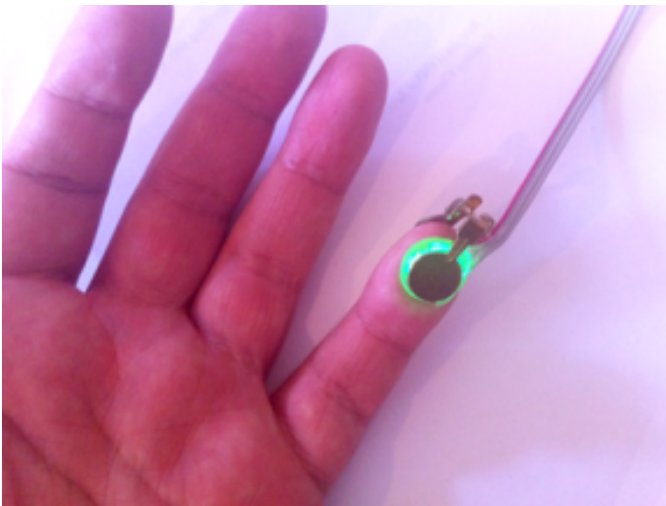
Fig. 9.   ECG Sensor Design



Fig. 11.   Smaller Sensor Design

## VII. Conclusions

The Medical ZigBee Network enhanced many aspects that meets the medical personnel. Although the Medical ZigBee Network was created with a single optical heart rate sensor, there is room for development in many different aspects of the sensor. For the optical heart rate sensor, in order to reduce noise and improve accuracy, the sensor can be made smaller making it more light weight. As shown in Figure 11, smaller sensor design will be more practical for the medical staff as well as more comfortable for the patients finger. Another sensor which was considered for the project was the electrocardiogram (ECG). This sensor uses electrodes and senses the physical contraction of the veins to create a cardiac monitor as shown in Figure 10. From the cardiac monitor, medical staff will be able to analyze the BPM of the heart as well as any irregular heartbeats which may occur in a patient. To build an ECG sensor for the ZigBee network, the medical equipment act in accordance with some requirements such as:

output signal of 100 mV $\leq$ VMAX $\leq$ 1.0V, band-pass filter $f_1 = 0.5$ Hz, $f_2 = 3$ Hz, notch filter for 60Hz, total output voltage no greater than 3.6V, and, achieve ground isolation from patient. The block diagram for the ECG sensor is shown in Figure 9.

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