ENERGY EFFICIENT MODEL FOR DEPLOYING WIRELESS BODY AREA NETWORKS USING MULTI-HOP NETWORK TOPOLOGY

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REG. NO 11/01713

A RESEARCH PROJECT SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE IN

DATA COMMUNICATION

FACULTY OF COMPUTER SCIENCE & INFORMATION MANAGEMENT

KCA UNIVERSITY

JULY 2013

DECLARATION

I declare that this research Project is my original work and has not been previously published or submitted elsewhere for award a degree. I also declare that this Research project contains no material written or published by other people except where due reference is made and author duly acknowledged.

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ABSTRACT

Wireless body area networks (WBANs) offers a lot of application opportunities in the area of health care. Recent developments in sensors and radio communication technologies have motivated many researchers to design WBAN systems for application in healthcare provision. Power consumption is still a limiting factor in realizing a WBAN with a very long lifetime.

In order for wireless body area networks to ensure widespread use and adoption, some of the design constraints should be solved to promote uptake and meet social expectations. As a result, design of energy efficient WBANs is required to enhance battery life at the same time ensure that sensor nodes are small enough to be conveniently worn or implanted in the body. Energy consumption in WBANs happens during sensing, processing and communication.

This research focused on designing an energy efficient model during communication between sensors. The parameters were simulated and implemented using MATLAB and Simulink simulation software. The sensors are randomly localized on a plane and distance between them calculated.

The model uses a relay between the sensors and the coordinator to reduce power consumption by sensors during signal transmission. The relay is dedicated to retransmitting signals only.

Key Words: Wireless Body Area Network (WBAN), Energy efficiency, Sensor, MATLAB, Relay.

ACKNOWLEDGEMENT

This thesis arose in part out of two years of study at KCA University. It is my pleasure to thank those who made this thesis possible in my humble acknowledgement.

I owe my deepest appreciation and gratitude to my supervisor Dr. Cyrus Wekesa, who has provided his exceptional insight and consultation in the development of my research project. He has positively influenced me in many ways. His novel ideas and enthusiasm kept me motivated and encouraged throughout the entire research project period.

I would like to acknowledge Prof. Ddembe W. Williams, who has been invaluable in developing my thesis; through him I have completed everything on time.

I am indebted to all the faculty lecturers and many of my colleagues for their valued assistance and togetherness. This thesis was realized with their support and help.

Last but not least, I would like to sincerely appreciate everybody who played any part in realization of this; sorry that I could not mention you personally by your names, thanks a lot.

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DEDICATION

To my Wife Florence and Sons Dan, Allan and Alvin. You are my Inspiration.

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LIST OF ACRONYMS

WBAN	Wireless Body Area Networks
MAC	Media Access Control
SNR	Signal to Noise Ratio
BER	Bit Error Rate
OQPSK	Offset Quadrature Phase Shift Keying
AWGN	Additive White Gaussian Noise
QOS	Quality of Service
MICS	Medical Implant Communication System
UWB	Ultra Wide Band
ISM	Industrial Scientific and Medical
FFD	Fully Function Device
RFD	Reduced Function Device
FFD	Fast Fourier Transform
LOS	Line of Sight
NLOS	Non Line of Sight
MATLAB	Matrix Laboratory

CHAPTER 1: INTRODUCTION

1.1 Background

A Wireless Body Area Network (WBAN) is a set of low-power and lightweight wireless sensor devices that are used to monitor various human body functions or the surrounding environment. This technology supports many helpful applications, including ubiquitous healthcare and end user electronics applications. Energy efficiency is one of the vital design considerations as wireless networks find application in healthcare, because of the limited battery life of sensors, terminals and other mobile devices.

A Wireless Body Area Network (WBAN) offers many application opportunities in medicine, health care, multimedia and sports. These application areas are motivated by the unrestrained liberty at which people can move and work with the sensor implanted on worn on their bodies. A WBAN connects independent sensor nodes that can be deployed in the clothes worn by people, on the body or under the skin of a person, with communication happening wirelessly over radio frequencies. According to the design and deployment, these nodes are normally positioned in a star or multi-hop topology (Wout J. etal, 2011).

1.2 Problem Statement

WBAN is a wireless network which enables communication among sensor nodes operating on the body surface or inside the human body to collect information on various body parameters and even motions. In the deployment of WBAN networks, communication between the sensor devices is of the critical design consideration. Communication between sensor nodes needs to consume minimal power and offer high reliability. In the recent past, a lot of the research in the area of WBANs has been directed to areas like sensor circuitry, minute sensor design, processing of signals by the sensors protocols in WBAN implantation and other related issues, (Min Chen. et al, 2010).

Star topology is associated with high power consumption in relaying data over long range single-hop point-to-point links. The issue of on-body sensor movement, wireless connection links which are unreliable and changing from time to time and the importance of reliability and fast data signal transmission at minimal energy use are some challenges facing deployment of WBANs (Wout J et al, 2011).

Recent developments in reduced power wireless transmission, communication and signal processing have triggered enormous attention in the deployment and design of wireless technology in healthcare and biomedical research, as well as WBANs. Among the issues of utmost importance in WBANs is low power consumed by the circuitry of the sensor, signal processing and transmission of the data. The sensor nodes implanted in or worn on the body have small battery capacity or can get little energy from their surroundings. Thus to prolong the life of the network, mechanisms to conserve energy has to be adopted. As such efforts towards design of sensors which used less power is alive among many researchers. Protocol design and network set up can be optimized to reduce energy used.

The use of wireless transceiver which consumes low power to minimize the amount energy required normally will lead to a small coverage area in signal transmission. This implies that a multi-hop topology is one of the best design choices for implementing WBANs, (Majid N. et.al 2010).

A lot of research has been conducted towards developing power efficient WBANS. The focus has been on protocol design, energy efficient MAC schemes, use of wake up radio concept where the sensor sleeps when it is not communicating and wake up only when it has data to send (Al Ameen et al, 2012)

(Wout J et al, 2012) investigated energy consumption in star and multi-hop topologies and found that multi-hop topology is associated with lower power consumption but the sensors closer to the coordinator uses a lot of energy to transmit signal from sensor nodes further away.

This research proposes a multi-hop topology model which uses a relay between the coordinator and distant sensor nodes. The relay is dedicated to transmit signals from distant nodes only while sensors closer to coordinator transmit directly to the coordinator.

1.3 Objectives

1.3.1 Main Objective

The main objective of this research is to develop an energy efficient model for deploying WBANs using multi-hop network topology.

1.3.2 Specific Objectives

The specific objectives of this research are:

i. Identify factors affecting energy consumption in WBANs

ii. Design an energy efficient model for deploying WBANs using multi-hop network topology

iii. Test and validate the model.

1.4 Justification of Study

The World Health Organization (WHO) observes that caring for the old people is becoming a significant challenge, at the same time a sizeable group of people suffer from lifestyle related diseases such as obesity and other chronic diseases because of their inactive lifestyles in their day to day life. This situation continues to worsen the declining quality of services offered by the near overwhelmed health care systems, (Min Chen. et al 2010). WBANs will play a very big role in monitoring the aged, the environments they stay in and other parameters of interest. The information collected is used to trigger an action like insulin injection for diabetic people or transmitted to the relevant people who are responsible for monitoring them.

To enhance WBANs adoption the devices are suppose to be small enough as not to interfere with the wearer. This research will compliment other efforts towards reducing power consumption in WBANs considering that energy efficiency is one of the main challenges in deploying WBANs. In WBAN technology, research has been carried out and various models proposed which seeks to reduce power consumption.

Several design issues are considered in WBAN deployment including scheduling, topology control, node placement in relation to other devices, and node localization. The other critical areas of concern are; energy consumption during signal relay and sensing, network duration, and the distance the signal can cover. These issues are important because it is quite cumbersome to keep changing batteries on thousands of micro sensors after they are deployed. These are the main critical issues attracting much research work by various researchers and enthusiasts alike. (Navid et al 2011).

(Reusens E. et al 2009) underscores the importance of energy efficient topologies in WBAN. They observe that radios used in the design and deployment of WBANs are miniaturized thus does not allow use of large batteries which could otherwise prolong the network duration.

(Emil Jovanov & Aleksandar Milenkovic, 2011), identifies low power operation, sensor integration, system integration and user localization and identification as four technical issues which influence the uptake of ubiquitous health monitoring applications. Low power operation allows design of smaller batteries, which enhance wear-ability and ease of use eliminating the need for frequent battery changes/recharging.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This research aims to investigate the energy efficiency in multi-hop wireless body area networks. Some research has been carried out in Wireless Body Area Network (WBAN) architecture and energy consumption both in star and multi-hop topologies.

WBAN connects independent nodes (e.g., sensors and actuators) that are deployed around the body like in the clothes worn by persons, placed on the skin or deployed a few millimeters below the skin. The network typically covers a few centimeters around the body and the network nodes are connected through a wireless communication link. The deployment normally is implemented using multi-hop or a star, (Wout J. etal 2011). WBAN has attracted applications in various such as electronics for consumer applications and other innovations which enhances ubiquitous healthcare. The general network topology used in wireless body area networks is the star topology with sensor nodes relaying data to a central processing node for data fusion. Generally, multi-hop communication is used in regular senor sensor networks with network connection being guarantee by use of router between the nodes. Implementations of involve signals being transmitted in one hop to the network coordinator/sink, (Min Chen. et al, 2010)

Some issues have been highlighted as regards WBAN design and deployment. Among the critical considerations are issues like scheduling, topology control, node placement in relation to other network devices, and node localization. Other important concerns which has attracted much interest from researchers includes energy consumption of the network devices, lifetime of the nodes and the entire network, and range of signal strength. All these issues are considered as the most critical since replace batteries on thousands of micro sensors could be impossible after these networks are deployed. Much work has been done to try and address these issues, many works exist that take these issues into account in designing communication protocols used deployment of WBAN, media access control (MAC) protocols and physical layer, (Meenakshi Bansal and Navroop Kaur 2011).

The deployment and adoption of WBAN depends on how the design constraints are addressed. Some of the issues are highlighted by (Min Chen. et al 2010);

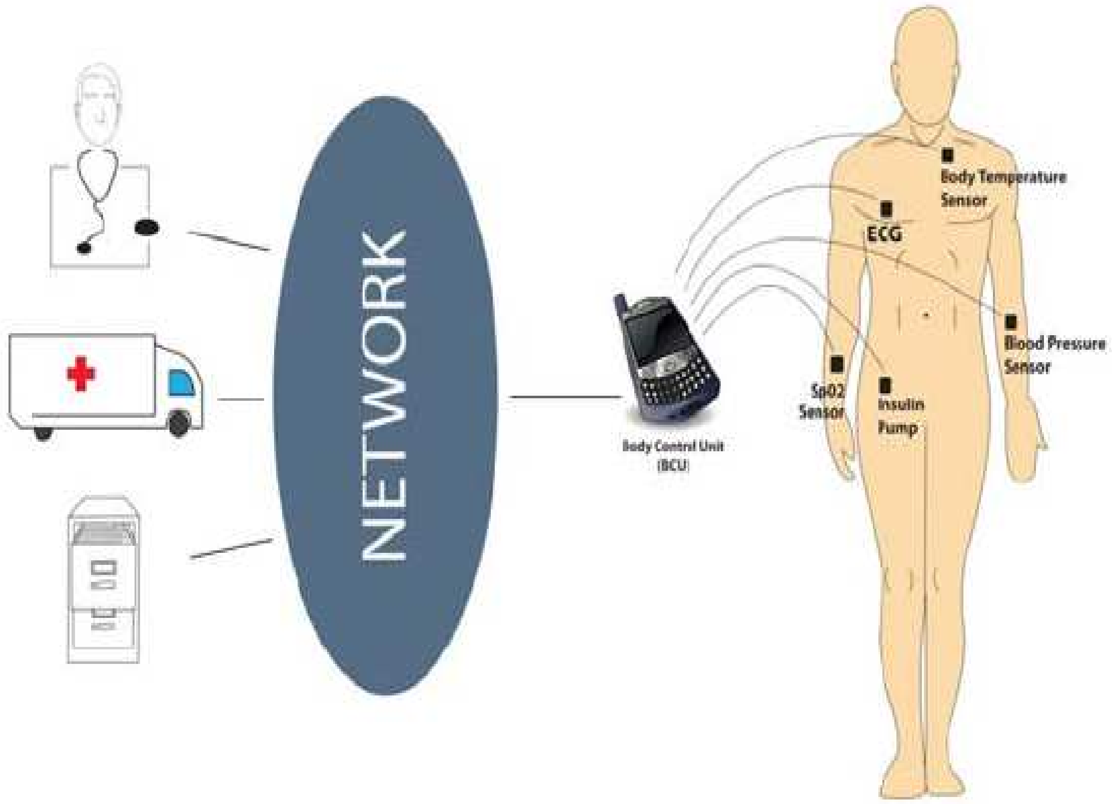
> "Several design issues must be addressed in order to enable the deployment and adoption of BANs. At the hardware level, body sensors must be small, thin, non-invasive, wireless-enabled, and must be able to operate at a low power level. From the communications perspective, it is imperative to design appropriate medium access control (MAC) protocols to ensure higher network capacity, energy efficiency, and adequate quality of service (QOS). At the application level, innovative architectures should be implemented for the corresponding applications".

Energy consumption is a very key parameter in deployment of WBANs, it is therefore imperative that energy demands of WBANs should be as small as possible. WBAN consumes energy during sensing, communication and data processing. A lot of energy is consumed during communication, (Meenakshi B and Navroop 2011). In the last few years researchers have been looking at various techniques for realizing energy efficient design and assembly. Numerous ways have been proposed to minimize power consumption including addressing architecture challenges, assembling, operating system schemes and efficient integrated circuit designs.

2.2 State of the Art in WBAN

2.2.1 WBAN Architecture

Figure 1: WBAN Architecture



Source: (Laurie Hughes, 2012)

WBAN consist of various components which work together to collect, process, store, and transmit data from the body to specific points where the data is required for monitoring, interpretation or emergency response. The basic components are sensor nodes, control unit/sink and a gateway which connects the sensors to the wider network.

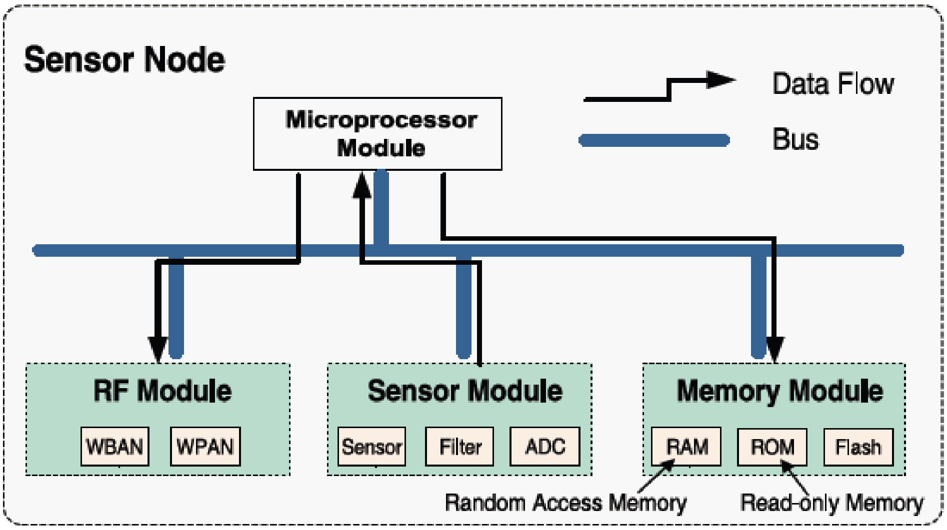
2.2.1.1 Sensor nodes

Sensor nodes are designed to collect analog signals from the body. Sensors can be used to collect physiological data, human movement or environmental phenomena. The functions of sensors are detection of signals, signal processing and transmission of the signals using a radio transmitter or transceiver.

Nodes can be of any of the following types:

- Nodes inserted under the skin: This is a sensor node inserted into the human body either under the skin or deep into the body tissues.
- Deployed on the body surface: A sensor node placed on the body surface or around the body but not exceeding two centimeters away.
- Externally deployed: A sensor node that is not touching the body, normally between two centimeters and five metres away.

Figure 2: Sensor Modules



Source: (Min Chen et al 2011)

2.2.1.2 Control Unit/Sink

The sink/control unit plays the role of data collection from the sensor nodes via the wireless radio channel link and transmits the data to a local as well as to remote devices like personal computers for further analysis and monitoring.

The sink has a microcontroller and a wireless transceiver to control all the activities between the nodes and the external WBAN.

2.2.2 WBAN Communication Technologies

2.2.2.1 IEEE 802.15.1/Bluetooth

This is a communication technology used for signal transmission within limited coverage area, normally not more than ten metres in diameter with data rates of 3 Mbps.

Bluetooth devices operate in the 2.4 GHz industrial scientific and medical (ISM) band, using frequency hopping among 791 MHz channels at 1,600 hops/sec nominal rate to prevent interference. Three different classes of devices are specified by Bluetooth standard. These classes have varied transmission power with each having certain coverage area ranging from 1 to 100 m. It supports both data and voice applications though it is associated with high bandwidth and low latency thus its use in ubiquitous health care, (Min Chen et al 2011). The limitation of this technology is its high power consumption.

Bluetooth Low Energy technology is not very different from the standard Bluetooth. It offers ultra-low power consumption and reduced cost, but still preserves the other features of Bluetooth. Bluetooth Low Energy technology was introduced by Nokia company in the year 2004. It was designed to enable wireless connection between small devices and mobile terminals. Those devices are normally too small to meet the power requirements of the regular Bluetooth radio but they are the best options for use in heath-monitoring and related applications.

The other features which Bluetooth Low Energy technology which from regular Bluetooth includes; data packet format, radio transceiver design and baseband digital signal processing, (Mehmet R. Yuce and Jamil Khan, 2011).

2.2.2.2 IEEE 802.15.4/ Zigbee

This is the most commonly used standard in low power devices because of its support for low power consumption. Zigbee implements some functions in the MAC layer including; network beacons generation by the coordinator, synchronization, MAC association and dissociation, encryption and CSMA/CA schemes.

The standard comes with:

i. Application layer: This is layer where application framework is specified and defined to support varied applications.

ii. Network layer: This layer enables network connection and helps in

The 802.15.4 standard is incorporated in Zigbee to implement media access control and physical layer functions and offer full protocol stack. Figure 3 below shows Zigbee protocol stack.

Zigbee standard operates in the following frequency bands:

i. 868 MHz – this is used across Europe in healthcare applications.

ii. 915 MHz – used in the USA as the industrial scientific and medical frequency band.

iii. 2.4 GHz – this is the frequency band used globally as ISM frequency band in healthcare applications (ISM worldwide). The 2.4 GHz ISM band is the most popular and has data rates of up to 250 kb/s happening over up to sixteen channels, (Laurie Hughes et al, 2012).

The 802.15.4 standard allows sensor nodes to be configured in two models:

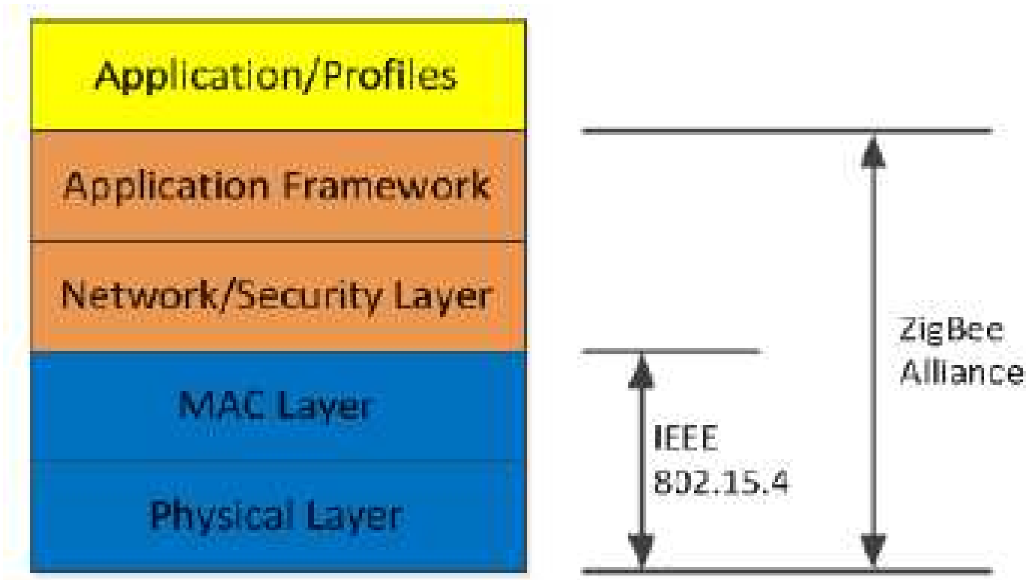
i. Fully Function Device (FFD). The sensor in this model is able to transmit and receive from all the devices in the network set up. It is usually supplied with power from other external sources.

ii. Reduced Function Device (RFD). The sensor device in this model is design to accomplish limited functions. It is normally deployed with inbuilt source of power thus the reduced roles.

Data transmission can happen from the sensor device to the coordinator, from the coordinator to the sensor device or between sensor devices. The control of data transfer is a function of the device. The devices can poll the coordinator for data transfer, a feature which makes Zigbee energy conserving since the device can sleep when it is not sending.

Zigbee has two modes for multiple access scheme; beacon and non-beacon enabled modes.

Figure 3: Zigbee Protocol Stack



2.2.2.3 Medical Implant Communication System (MICS)

MICS is a short range standard applied often in gathering sensor signals from various parts of the body in wireless body area networks. Multi-hop structure is used as the design choice to implement this. The MICS is a short range standard thus its application is limited to implant and on body sensors which are often a few millimeter from the skin. MICS has very low power emission making it the best option for use with sensors in universal health coverage monitoring system as compared to ultra wide band

2.2.2.4 Ultra Wide Band (UWB)/IEEE 802.15.6

This technology offers very big bandwidth and high data rates for data transmission. It is not prone to interference thus promises reliability in emergency applications when used with Global Positioning System (GSI). UWB is used to position and locate transceivers in a network. This is very important in medical facilities where more often than not, there are normally emergencies which require localization. The technology is associated with the limitation due its receiver complexity thus not fit for deploying wearable applications in health monitoring.

2.2.3 WBAN Channel Characterization

The wireless connection between WBAN devices can occurs at various channel frequencies. Most available designs use the industrial, scientific, and medical (ISM) frequency bands or ultra-wide band (UWB). The channel specification of the WBAN is a critical process in the design and deployment of WBAN, including an estimation of the path loss between two nodes on the body and other characteristics (Reusens E. et al, 2009).

2.2.3.1 Radio communication

A WBAN inter connects tiny sensor devices. Radio technology is used in signal transfer. Radio communication is frequency-based wireless networking technology that enables sensor nodes to communicate over selected frequencies. This area attracted much interest over the years and has fueled research in the area of a body-centric wireless communication channel. The evaluation of the propagation modes has been largely influenced by the increasing focus in wireless applications on the body. Use of the Medical Implant Communication System (MICS) at 402 MHz to 405 MHz, allows bands of 300 kHz to be achieved.

However, due to the high availability of components for wireless body sensor networks both the industrial, scientific, and medical (ISM) bands between 400 MHz and 2.45 GHz, and the ultra-wideband (UWB) frequency allocation between 3.1 GHz and 10.6 GHz are frequently seen in actual implementations. More recently there is an interest in investigating the performance of WBANs operating at millimeter wavelengths and in particular at 60 GHz.

Radio communication is influenced by path loss and fading processes. The task force TG6 of the IEEE 802.15.6 working group has highlighted channel modeling issues for WBAN (Yazdandoost et.al, 2009). The work highlights various scenarios which can be implemented as shown in the table below;

Table 1: List of Radio Communication Scenarios

Scenario	Description	Frequency Band	Channel Model
S1	Implant to Implant	402-405 MHZ	CM 1
S2	Implant to Body Surface	402-405 MHZ	CM 2
S3	Implant to External	402-405 MHZ	CM 2
S4	Body Surface to Body Surface (LOS)	13.5, 50, 400, 600, 900 MHZ 2.4, 3.1-10.6 GHZ	CM 3
S5	Body Surface to Body Surface (NLOS)	13.5, 50, 400, 600, 900 MHZ 2.4, 3.1-10.6 GHZ	CM 3
S6	Body Surface to External (LOS)	900MHZ 2.4, 3.1-10.6 GHZ	CM 4
S7	Body Surface to External (NLOS)	900 MHZ 2.4, 3.1-10.6 GHZ	CM 4

Source: (Yazdandoost and Sayrafian, 2010)

2.2.3.2 Fading

In WBAN communication, channel fading can occur due to various reasons, including; reflection, energy absorption, shadowing by body and posture and diffraction. Fading can be classified either as small scale or large scale.

2.2.3.2.1 Types of Fading

There are three types of fading considering the effects of multipath:

Small Scale Fading: Small scale fading occurs when there are rapid variations in phase and amplitude of the signal which are received in a particular area due to changes in posture and the location of the sensor device on the body.

Flat Fading: This arises when the bandwidth of the mobile channel is greater than the bandwidth of the transmitted channel. Flat fading is one in which all frequency components belonging to a received radio signal changes simultaneously in the same proportion.

Large Scale Fading: Large scale fading occurs due to motion over large areas, particularly the distance between on-body antenna positions and external node. The received signal power changes slowly because of signal attenuation which is influenced by the geometry of the path profile.

2.2.3.2.2 Small scale fading

Many models have been used to describe the occurrence of this type of fading. The commonly used models are:

Rician fading model: This model is characterized by a non fading component called the line of sight. Rician distribution characterizes the amplitude gain. It is a stochastic model for the influence of transmission channel on radio signal.

Rayleigh fading model: It is similar to the Ricean fading channel model. The Rayleigh fading is basically caused by multipath reception. It is a statistical model for the influence of a signal transmission channel on a radio signal. It can be a good model representation for tropospheric and ionospheric transmission as well as capturing the effect buildings and various urban developments on radio signals. Rayleigh fading is suitable for communication between receiver and transmitter without a line of sight.

Additive White Gaussian Noise Model: This model adds a linear white noise with a constant spectral density and Gaussian distribution of amplitude to the transmission channel. It is a good model for space and satellite communication channels.

Rayleigh and Rician fading channels can be used to capture behavior of real-world communication channels in wireless networks like WBAN. The main parameters which can be simulated includes time dispersions, Doppler effect shifts and multipath scattering effects arising from relative mobility between the receiver and the transmitter

2.2.3.3 Path loss

Path loss in WBAN is affected by both distance and frequency. The path loss model in dB between the transmitter and receiver as function of distance d based on Friis formula in free space is described by, Yazdandoost and Sayrafian (2010)

$$PL(d) = PL_0 + 10n\log_{10}(d/d_0) \tag{1}$$

Where:

PL_0 refers to the path loss at distance d_0

N refers to the path loss exponent.

2.2.3.4 MAC layer

This layer defines the way signals are transmitted. In this layer, the challenge is achieving an optimum balance between reliability, latency and power consumption. In practice, an Asynchronous media access control is normally used with Zigbee to prevent network signal collisions. Carrier sense multiple access with collision avoidance and other mechanisms are generally used to implement this. The sensor lifetime is enhanced by implementation of protocols which are not energy intensive (Ruden, et al, 2011).

MAC protocols use various techniques to reduce power consumption:

i. Transmission schedule and listening periods – Mac protocols use this technique to synchronize and maximize data transfer.
ii. Turning off radios – This normally happens during longer idle periods. The protocol reduces the amount of energy requires by the device.
iii. Low-power listening (LPL) approaches – involves use schemes polling by the primary device for data transmission or reception. This eliminates energy loss through idle listening.

Several other power efficient MAC protocols have been developed and investigated. MAC protocols have been surveyed by (Garth V. et al, 2012). It has been shown that many MAC protocols offer greater energy conservation and best node-to-node data delay over the IEEE 802.15.4 MAC.

2.3 Review of Available WBAN Simulation Tools

Simulation is a very essential tool to study WBANs and thus the choice of a particular tool should be informed by the accuracy required, details, and scalability as well as performance, (Unruly and Syafnidar, 2011)

(Egea-Lopez, 2005) highlights some key aspects in the choice of a simulation tool:

> 'However, obtaining reliable conclusions from research based on simulation is not a trivial task. There are two key aspects that should be evaluated before conducting experiments: (1) The correctness of the model and (2) the suitability of a particular tool to implement the model.'

Several simulation tools are available for various networks. Simulation researchers have studied various tools both commercial as well as open source:

2.3.1 Optimized Network Engineering Tool (OPNET)

OPNET is a commercial network simulation tool used for research and teaching in institutions of higher learning. It's discrete and object-oriented simulator used for general purposes. OPNET has very many features including analysis tools, model library, planer and OPNET modeler thus its wide application in performance modeling in network industries as well as in evaluation of local and wide area networks (Nurul and Syafnidar, 2011)

2.3.2 MATLAB/SIMULINK

MATLAB (Matrix Laboratory) is software developed by Matworks Inc. for simulation and modeling high performance computation, analysis and visualization. Scientific researchers opt for MATLAB largely because the software is flexible, reliable, analytical capabilities and very good graphics (Qutaiba et al, 2012)

Simulink is a program that extends the usability and application of MATLAB with a graphical interface for modeling, simulation and analysis of dynamic systems. It allows changing of parameters to check the effect of the variation (Nurul and Syafnidar, 2011).

2.3.3 OMNeT++

OMNET++ is a discrete event simulator used for simulation of ad hoc networks and other problem areas both wired and wireless. It provides simulation platforms and tools where one can create simulations (Nurul and Syafnidar, 2011).

OMNET++ has a graphical user interface, modular architecture, abstraction and protocol implementation, (Qutaiba et al, 2012).

2.3.4 NS-2/3 (the Network Simulator)

NS-2/3 is a discrete event and object-oriented simulator designed for network simulation. It has found wide application in wireless sensor networks because of its scalability (Madani et al, 2010).

2.3.5 TOSSIM (TinyOS mote Simulator)

TOSSIM is a simulator which can represent discrete events in sensor networks. It can monitor transmitted packets since it has an external system for communication. TOSSIM can be used to visualize simulations (Qutaiba et al, 2012).

2.3.6 GloMoSim/QualNet (Global Mobile Information System Simulator)

It's a parallel, general purpose simulator which is library based with capability to simulate several nodes thus use in studying large wireless networks like WSNs (Madani et al, 2010)

Table 2: Simulators used in Some Selected IEEE Journals and Conference Papers Published from 2007 to 2009

Simulator	IEEE Transactions on Communications IEEE/ACM	Transactions on Networking	IEEE GLOBECOM	IEEE INFOCOM	IEEE ICC	Overall (%)
ns-2	14%	57%	45%	39%	59%	42.8
OPNET	6%	4%	8%	3%	17%	7.6
MATLAB	78%	32%	29%	32%	13%	36.8
QualNet	-	1%	5%	12%	3%	4.2
GloMoSim	-	1%	1%	3%	3%	1.6
OMNet++	-	-	2%	-	2%	0.8
Others (user written program)	2%	5%	10%	11%	3%	6.2
Total	100%	100%	100%	100%	100%	100

Source: (Nurul I. and Syafnidar A. 2011)

2.4 Simulation Phases

Simulation is a process which involves a number of stages;

2.4.1 Problem Formulation

This phase entails understanding the problem of interest, organizing the system into objects and activities into a form which can be executed experimentally. Getting the solution to the problem requires one to choose the way to achieve it from the potential solutions. At this stage inputs, outputs and processes are identified to enable building of the conceptual model in the next phase.

2.4.2 Conceptual Model

At this stage, the structure and layout of the objects and attributes are built to reflect all the features of the system. The output should give a picture of how the components interact and critical areas of the system.

2.4.3 Collection and Analysis of Input/output Data

This step involves studying the attributes identified in the preceding phase to enable one to obtain input/output data of the system. The attributes are classified as either stochastic or deterministic.

2.4.4 Modeling

In this phase, the conceptual model and the data collected for output/input are used to develop an elaborate representation of the system. The structure and behavior of the system is defined using the attributes, interfaces and methods already identified in the previous phases.

A model is developed showing how the attributes and variables relate and any assumptions made are highlighted.

2.4.5 Simulation

At this stage the model developed in the previous phase is implemented using a chosen simulation tool. There are various programs and tools which can be used to achieve this. Algorithms are developed and translated to specific programming language or model for simulation.

2.4.6 Verification and Validation

Verification and validation is done in almost all the phases of simulation. Verification checks the consistency among the conceptual model, system model and simulation model while validation involves comparison of the model and system reality.

2.4.7 Experimentation

The objects of the conceptual model are used to run the simulation. Different ways are use to set up experiments and data outputs are collected/observed.

2.4.8 Output Analysis

During this phase various tools are used to analyze and visualize the outputs. The process allows better understanding of the system.

2.4.9 Advantages of Simulation

- Enables simulation of complex
- Eliminates the complexities of analyzing difficult

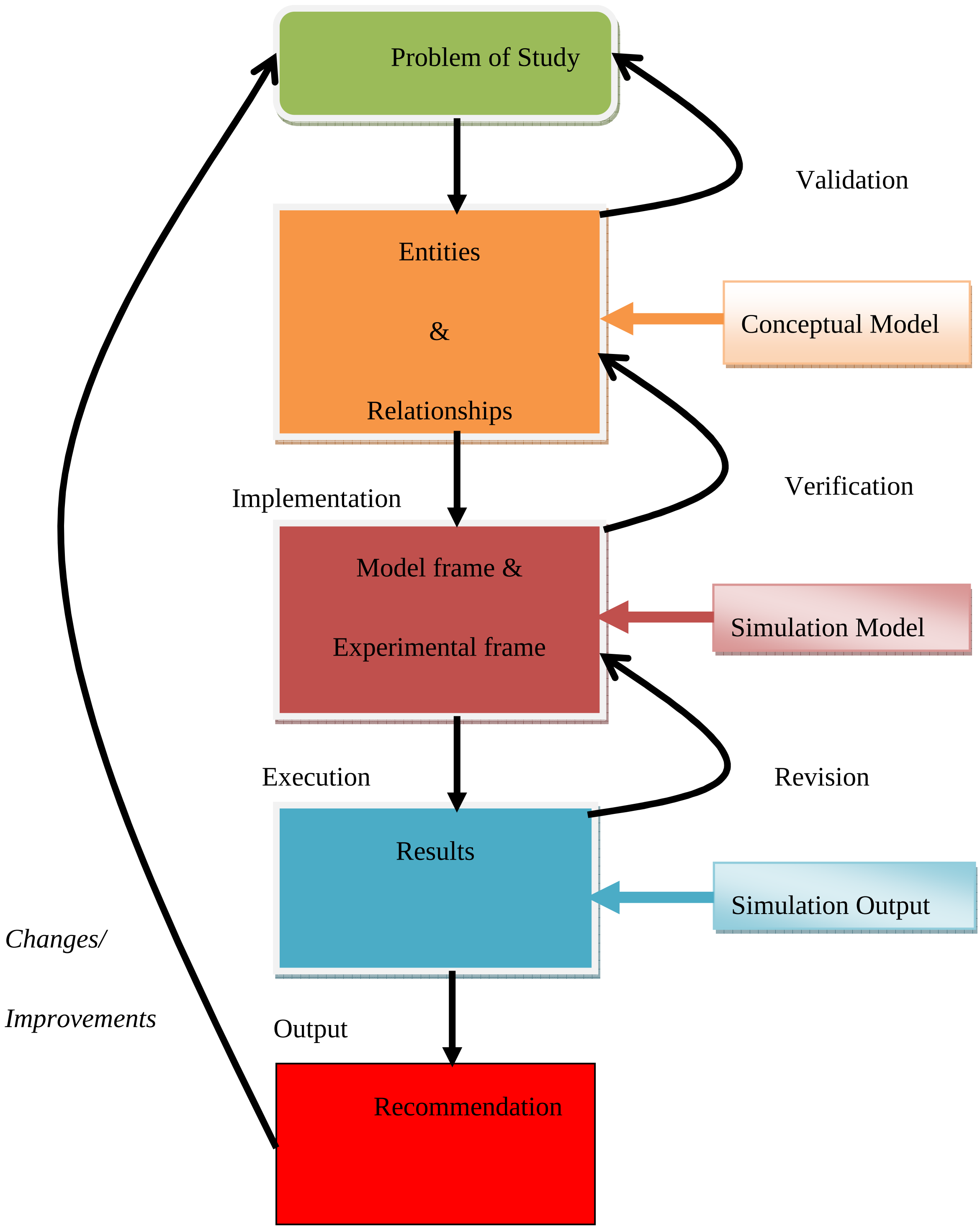
- Allows prediction of behavior by using sensitivity analysis and varying model parameters.
- Enables easy system changes thus leading to system improvements
- Enhances greater understanding of analytical problems

2.4.10 Disadvantages of Simulation

- Simulation lacks accuracy, the model is not an exact replica of the real-world systems
- Simulation may not allow study of several parameters at once

2.4.11 Simulation Phases Chart

Figure 4: Simulation Phases Chart



CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This chapter discusses the methodology used to be able to achieve the stated objectives of the research project. There are various methods which can be used in research.

This research is focused on energy efficiency thus much of the work will be simulation and analysis. The study identifies use of secondary data from previous work on application of star and multi-hop topologies in deployment of wireless body area networks. This method enables comparison of the two topologies in terms of their efficiency and energy consumption. This approach will also enhance the process of identifying energy consumption factors in WBAN.

3.2 Current Methods

3.2.1 Actual Design

This method entails actual assembly of all the components required to develop a real world product. This method requires a lot of time for designing, sourcing of components and actual development of the product.

This method provides actual parameters when used thus allows the developer to vary various parameters during experiments be able appraise the design in the actual application.

The cost, availability of materials and time factor is the main limitation of this method.

3.2.2 Analytical Approach

This method involves breaking down a larger problem of focus into small parts to enhance easy solving. This entails application of various formulas and tools to achieve the solution. Each parte becomes a smaller and easier to handle.

This method is easier to use since it entails identifying the components and subject them to closer examination.

The disadvantage of this method is that it does not have the visual aspect. It is not easy to understand especially by people who are not experts in the field of focus.

3.2.3 Simulation

This method involves use of a simulation program to represent an actual system. This entails defining the parameters of interest and identifying a suitable simulation tool to capture the relationships and behavior of the actual system.

Simulation is widely used in research because it lends itself well to represent the actual system in a cheaper way. It also allows variation of the system parameters to execute what if analysis. This method gives a visual output thus makes it easier to understand how a system works. It is also easier to execute and takes a shorter period of time. Simulation allows very high level of detail to be included with the only limitation being one's imagination, programming skills and the hardware being used for simulation.

However simulation is only an estimate of the actual system thus solutions may not be accurate. Any errors in input will alter the output.

Simulation doesn't produce a tangible project, it is just a simulation.

3.4 Proposed methodology

3.4.1 Introduction

In this research, simulation is chosen as the primary method to carry out the work. As indicated earlier, simulation provided the required convenience, time and cheaper alternative to realize the aims of this research.

Simulation is a widely used technique for representing real-world systems, normally dynamic. The model mimics a real system allowing use of simulation tools and emulators running on computers to study various systems. There are a number of simulation tools which can be used to simulate various scenarios in WBANs studies as described in the previous sections.

Simulation is used in this research to enable the study of effects of various factors on signal transmission in WBAN.

3.4.2 Characteristics of Proposed Methodology

MATLAB R2009a and Simulink simulation program is used for this project to be able to capture how radio signals are affected by various factors in multi-hop topologies. This simulator can represent various network processes including routing, protocol clustering and provide statistical information of the various network devices such as the residual energy devices and show the transmission channels.

Simulink is a graphical user interface application which enhance the use of MATLAB to model and simulate various systems. Simulink offers various blocks for building different simulation models. The systems are developed on screen using components from various blocks. Many elements of block diagrams are available from various block sets such as communication and signal processing block sets. During model development, Simulink and MATLAB can be used together allowing data transfer between the two interfaces without any limitation.

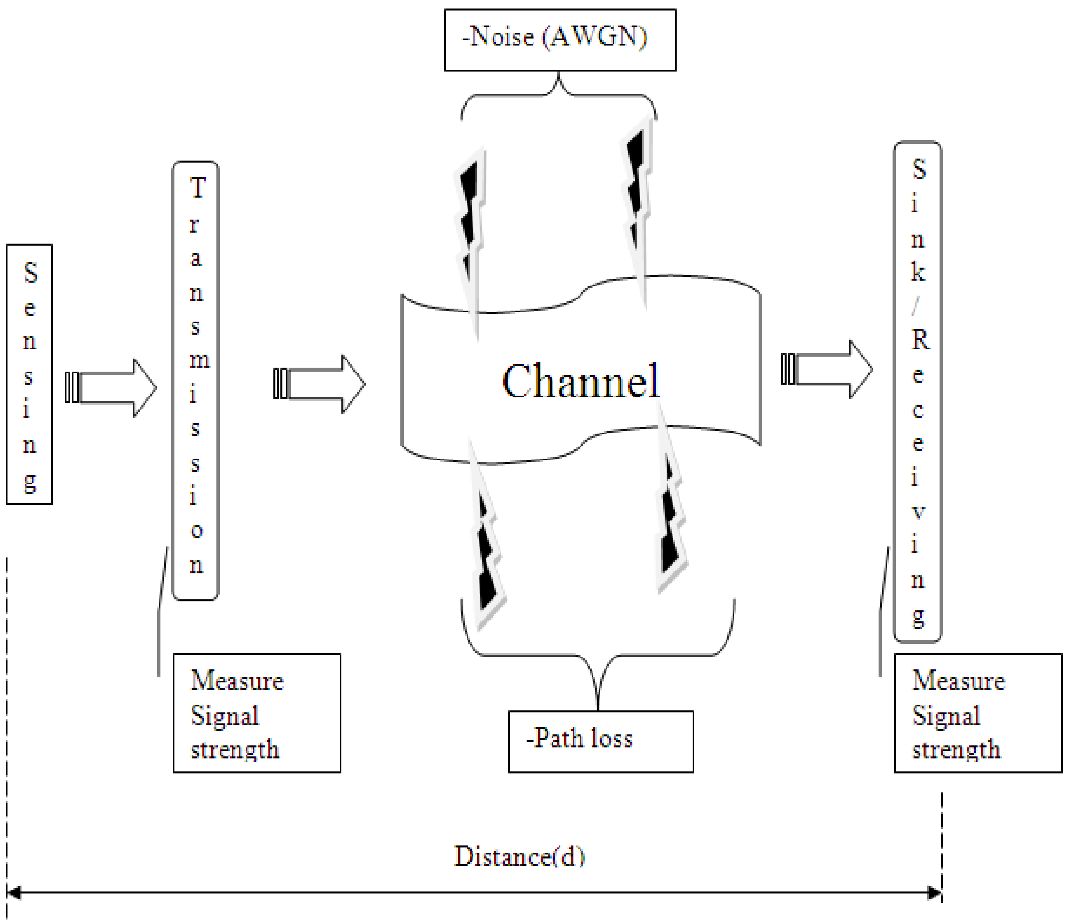
CHAPTER 4: CONCEPTUAL MODEL

4.1 Conceptual Design

The conceptual model is based on a typical WBAN for various applications, with focus on the factors which affect energy consumption during communication between nodes, relays and the sink.

The model outlines the relations between the various components, their attributes and interfaces.

Figure 5: General Conceptual Model



4.1.1 Model components

4.1.1.1 Sensing Unit

This carries the sensors which collect data from various parts of the body. The sensors collect physical signals like pressure, movement, temperatures etcetera. The sensor picks these analog signals which are then transferred by the transmitter.

4.1.1.2 Transmitter

The transmission unit basically relays the collected data from the sensors to the receiver. The other parameters of importance in relaying of signals are distance and signal strength. The distance separating the transmitter and receiver is measured to get the optimal distance which will use minimum power to send the signal. The signal strength is measured at the transmitter and receiver to be able to establish the optimal distance.

4.1.1.3 Channel

The channel describes the parameters between the transmitter and the receiver. There are a number of channel parameters which will influence transmission of signals including:

Noise: This is composed of any interference from the environment which may affect the signal transfer between the transmitter and the receiver. The kind of noise represented in this model is additive white Gaussian noise (AWGN).

Path loss: The path loss component is also factored in this model. This component is affected by distance and body movement. Path loss differs depending whether it is a line of sight or non line of sight communication.

4.2 Data/Input Data

4.2.1 Node Location

Node placement is achieved by using a MATLAB code to randomly generate node positions on 150 cm plane/graph. The choice of 150 cm graph was informed by using an average height of a person 150 cm.

The nodes are randomly placed on the graph and the distance between the reference point (coordinator) and the nodes are calculated using the algorithm below. The x and y coordinates of the sensors are used to calculate the distance by applying Pythagorean Theorem.

If the distance between the coordinator and the sensor node is less than or equal to a predetermined distance (R), the sensor transmits to the coordinator. Otherwise it transmits to the relay.

For all node pairs

Distance between nodes, n_i,n_j *and reference point (coordinator)*

$X=abs(x_i-x_j)$

Y=abs(yi-yj)

$Distance=sqrt(X^2+Y^2)$

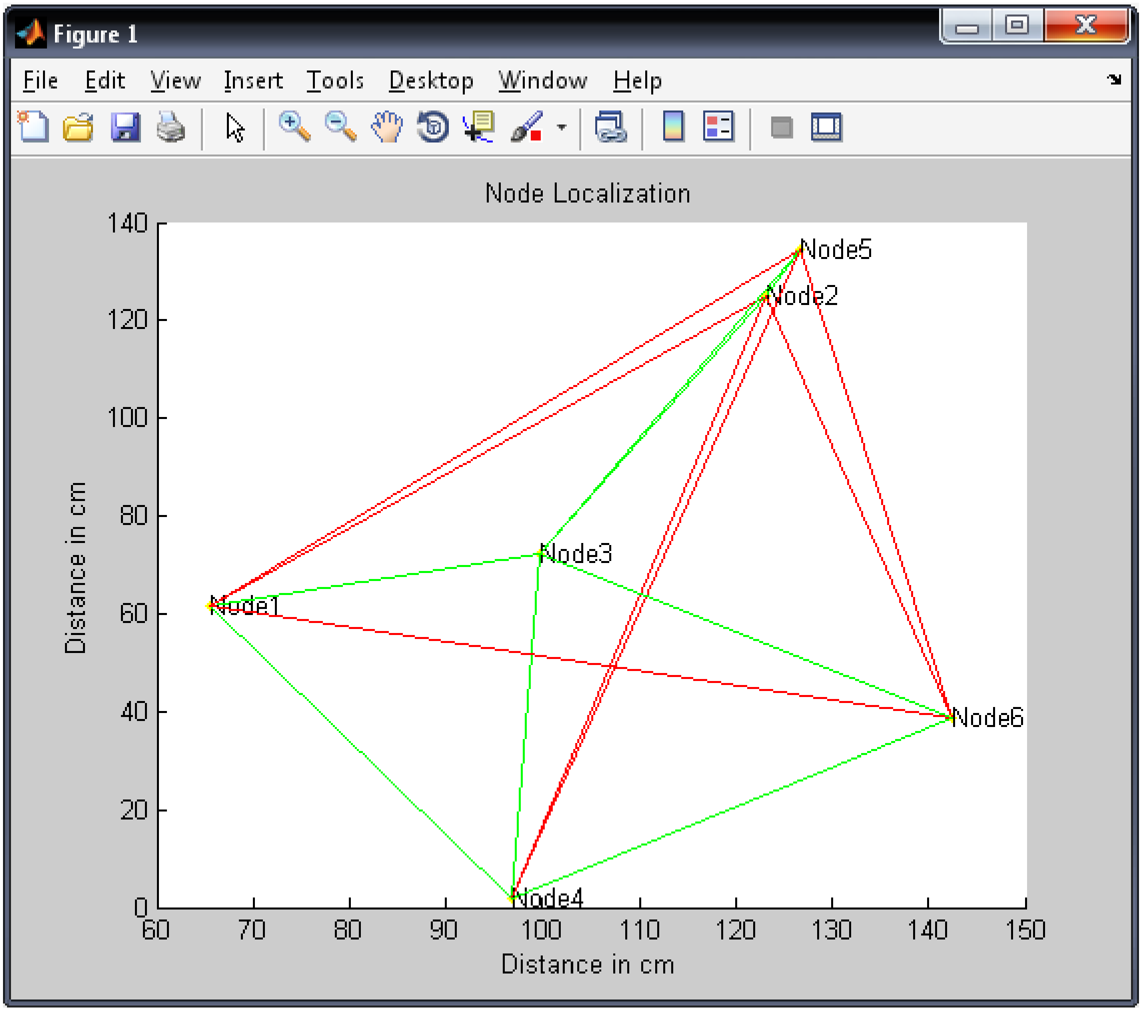
If $Distance_{i,j}<=R$,

Connect = coordinator

Else

Connect = Relay

Figure 6: Random Nodes Localization Chart



The distance between the nodes pairs from MATLAB simulation are shown in the table below:

Table 3: Distances Between Node Pairs

Node Pairs	Distance (cm)
1 – 2	85.6401
1 – 3	35.9114
1 – 4	67.6729
1 – 5	95.1741
1 – 6	80.4471
2 – 3	57.6061
2 – 4	125.9178
2 – 5	10.2681
2 – 6	88.5481
3 – 4	70.5833
3 – 5	67.8456
3 – 6	54.4830
4 – 5	136.1085
4 – 6	58.5161
5 – 6	95.1741

4.2.2 Radio Propagation Energy Model

The radio energy model used in this project was proposed by (Reusens E. et al, 2009). This model uses the distance (d) between the transmitter and the receiver and assumes the loss of energy due transmission channel (d^2). The model equations are shown below:

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d) \quad (2)$$

$$E_{Tx}(k,d) = E_{Tx-elec} \times k + E_{amp} \times k \times d^2 \quad (3)$$

$$E_{Rx}(k) = E_{Rx-elec}(k)E_{Rx}(k) = E_{Rx-elec} \times k \quad (4)$$

$$E_{Rx}(k) = E_{Rx-elec} \times k \quad (5)$$

Where;

E_{Tx} is transmission energy in Joules

E_{Rx} is energy consumed by the receiver in Joules

$E_{Tx-elec}$ are energies required by the circuitry of transmitter and receiver in nJ/bit.

E_{amp} is the energy required by the amplifier circuit in J/bit.

k is the packet size in bits

Since in WBAN there is attenuation due to path loss, a path loss coefficient parameter *n* is added to the equation above thus can be written as:

$$E_{Tx}(k,d) = E_{elec} \times k + E_{amp} \times n \times k \times d^n \quad (6)$$

The parameters in the above equations depend on the type of transceivers used. There are two transceivers commonly used in WBANs, Nordic nF 2401A and Chipcon CC2420.

Nordic nF 2401A is a single chip and consumes low power. The bandwidth of both transceivers is 2.4Ghz.

Nordic nF 2401A transceiver is chosen for this project because its low power consumption. The parameters of the two transceivers are given in table 5 below

Table 4: Radio Parameters of Nordic nF 2401A Transceiver

Parameter	nF 2401A	CC2420	Units
DC Current(Tx)	10.5	17.4	mA
DC Current(Rx)	18	19.7	mA
Supply Voltage(min)	1.9	2.1	V
$E_{Tx - elec}$	16.7	96.9	nJ/bit
$E_{Rx - elec}$	36.1	172.8	nJ/bit
E_{amp}	1.97e-9	2.71e-7	J/bit

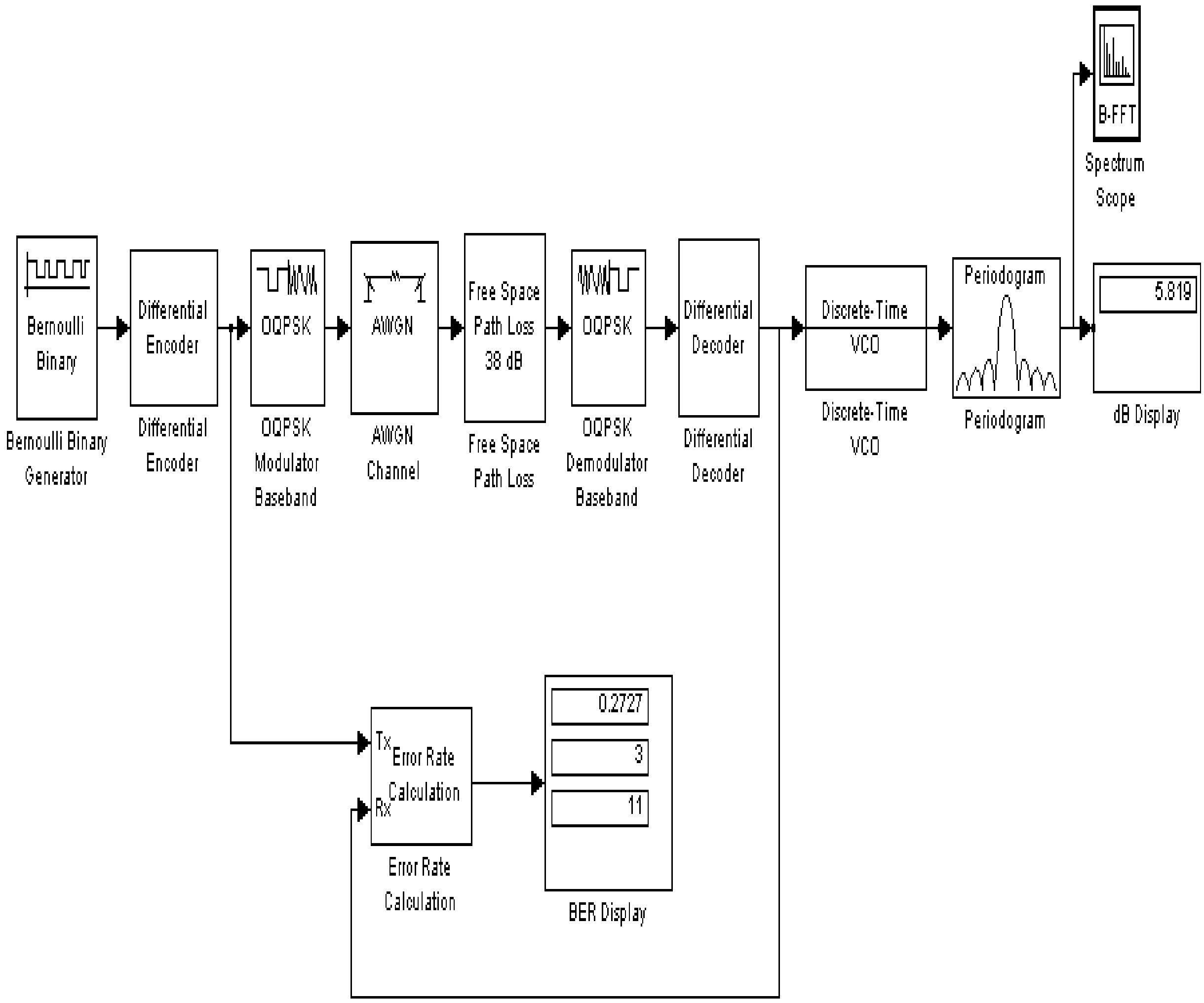
CHAPTER 5: IMPLEMENTATION AND TESTING

5.1 Implementation

5.1.1 Simulation Model

The simulation was done using Simulink. The simulation model is as shown below.

Figure 7: Simulation Model



The components of the simulation model are explained below:

5.1.1.1 Bernoulli Binary Generator

The Bernoulli Binary Generator block uses the Bernoulli distribution to randomly produce binary numbers. The Bernoulli distribution with parameter p produces zero with probability p and one with probability 1-p. The Bernoulli distribution has mean value 1-p and variance p(1-p). The Probability of a zero parameter specifies p, and can be any real number between zero and one.

5.1.1.2 Differential Encoder

The Differential Encoder block performs signal encoding on the binary input signal. The output is the logical difference between the present input and the previous output. More specifically, the input and output are related by

The input can be either a scalar or a vector. The initial output value is formed by getting the logical exclusive-OR of this value with the initial input value.

5.1.1.3 OQPSK Modulator Baseband

The OQPSK Modulator Baseband block is used to perform signal modulation. It uses offset quadrature phase shift keying method to execute this process.

It receives the encoded signal from the binary encoder before the signal is released to the transmission channel.

5.1.1.4 AWGN Channel

This block represents a typical transmission channel by adding interference to the signal. The block adds white noise the signal so that effects of the interference can be captured.

The relative power of noise in an AWGN channel is typically described by quantities such as

- Signal-to-noise ratio (SNR) per sample. This is the ratio of the signal strength to that of noise.
- Ratio of bit energy to noise power spectral density (Eb/No). This quantity is used by BERTool and performance evaluation functions in this toolbox.
- Ratio of symbol energy to noise power spectral density (Es/No)

The relationship between Es/No and Eb/No, both expressed in dB, is as follows:

$E_S/N_O(dB) = E_b/N_O(dB) + 10\log_{10}(k)$

Where k is the number of information bits per symbol.

The relationship between Es/No and SNR, both expressed in dB, is as follows:

5.1.1.5 Free Space Path Loss

The Free Space Path Loss block represents channel parameters which affects signal transfer. The distance between the receiver and transmitter is the main variable affecting signal power loss. The block varies the amplitude of the received signal element by a value determined by carrier frequency and distance or loss parameter when decibels is used.

In this simulation, distance and carrier frequency parameters are used since distance between the nodes was calculated and the frequency for ISM band is 2.4 GHz.

This block accepts a column vector input signal. The input signal to this block must be a complex signal. The reciprocal of the loss is applied as a gain, e.g., a loss of +20 dB, which reduces the signal by a factor of 10 corresponds to a gain value of 0.1.

5.1.1.6 OQPSK Demodulator Baseband

The OQPSK Demodulator Baseband block is used in signal demodulation. The block takes in the baseband representation of the input signal and demodulates it.

The block outputs integer symbol values from 0 to 3 or 2-bit binary representation of the integers depending on the set type of output parameter.

5.1.1.7 Differential Decoder

This block plays a very important role in converting binary input bit to equivalent signal element which can be transmitted through the channel.

5.1.1.8 Bit Error Rate Calculation

This block calculates the rate of error occurrence in the received signal. It does this by comparing transmitter output data and receiver data output.

The output of this block is normally connected to the bit error display block.

5.1.1.9 Bit Error Display

The Display block is used to show the bit errors in the signal received calculated in the bit error calculation block.

The output is displayed in three rows. The upper row shows the error rate, the middle row shows the error bits and the lower row displays the number of comparisons.

5.1.1.10 Display

It shows the data of its input on its display icon.

5.1.1.11 Spectrum Scope

This block is used to calculate and display outputs at various times of the input. The input can be sampled or frame-based matrix or vector.

This block is used to produce a spectrum of the signal. It can produce time domain spectrum or frequency spectrum.

5.1.1.12 Voltage Controlled Oscillator

This block produces a signal which shifts from the optimum frequency with a value proportional to the input signal.

This block produces an output signal which can be used to represent the magnitude of a signal.

5.1.1.13 Periodogram Block

This block calculates an approximation components of the spectrum which not parameters. It is used to show the graphical variation of an input over time at different times.

CHAPTER 6: DISCUSSION OF FINDINGS AND CONCLUSION

6.1 Discussion of Findings

From the results of the simulation it is evident that path loss varies upwards with increase in distance. Figure 7 in the previous section shows a steady rise in path loss with increase in distance between the transmitter and the receiver. This implies that when a relay is used, the interference on the signal due to free space path loss is reduced thus enhancing energy reduction during transmission.

Node placement in relation to coordinator and relay can be varied to achieve optimal distance separating the transmitter and receiver.

The RSSI parameter can be used to check the signal strength. From the simulation model, a peridogram is used to capture this on magnitude verses frequency plot as shown below.

6.2 Performance Metrics

6.2.1 Path Loss Calculation

Path loss shows the relative strength between the transmitted power at the sending node and received power at the receiver.

The path loss between the sending and the receiving antenna was calculated as a function of distance parameter using the formula described earlier in equation (1):

$$PL(d) = PL_0 + 10n\log_{10}(d/d_0)$$

The path loss can also be calculated as function of both distance and frequency using the formula

$$PL = 20\log_{10}(4\pi df/c) \quad (7)$$

Where d is the distance between the transmitter and receiver, f is the frequency and c is the speed of light. In free space, path loss coefficient *n* used is 3.38 since LOS is assumed in this work (Elias J and Mahaoua A, 2012)

In WBAN *n* varies from 3 to 4 for line of sight (LOS) transmission and 5 to 7.4 for non line of sight (NLOS) transmission.

The distance was measured between the node and the relay as well as the coordinator. In this investigation the 2.4 GHz frequency is used as it is freely available and it is has been a choice of many researchers in WBAN designs in this band. The path loss exponent in free space is two (2) as highlighted by (Reusens E. et al, 2009).

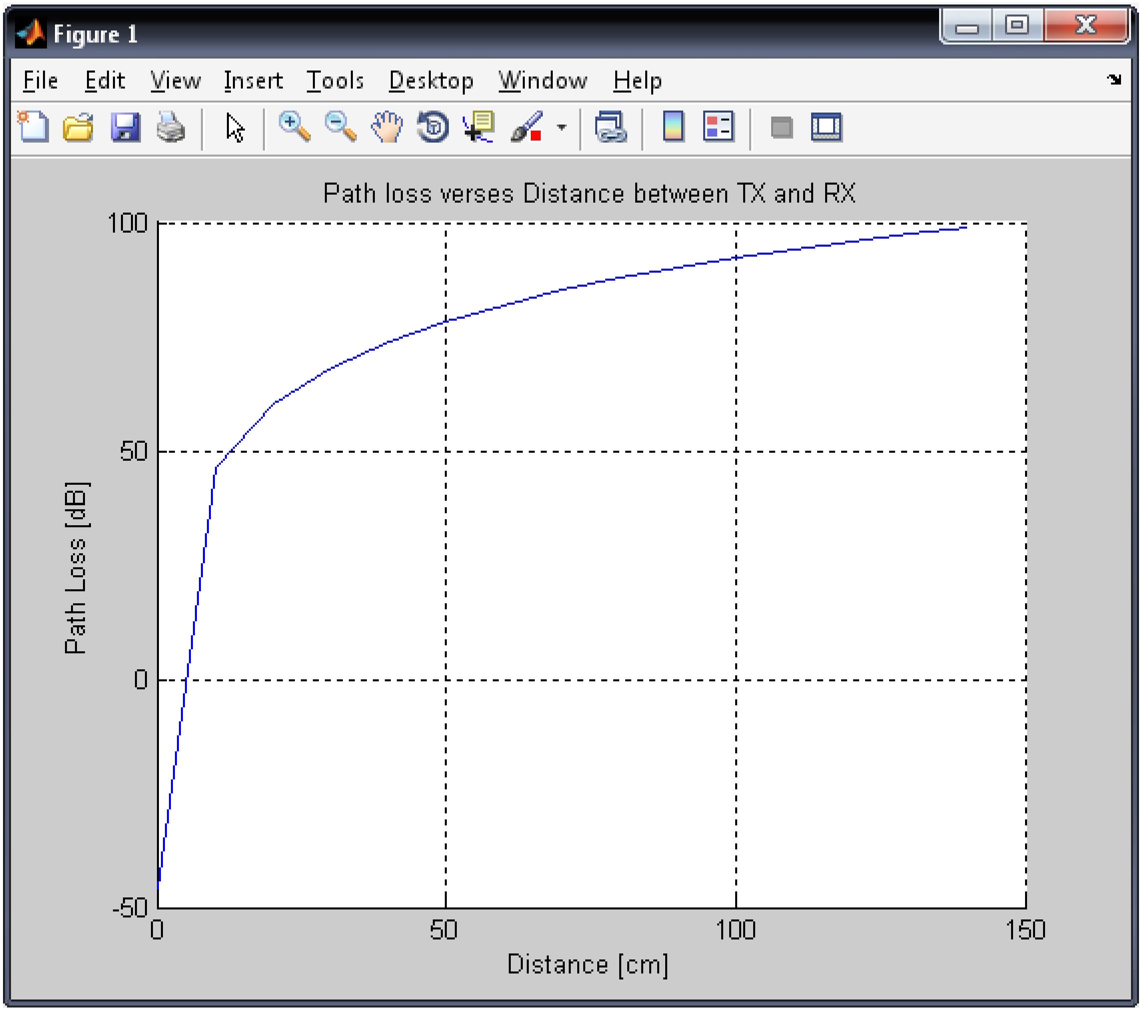
MATLAB was used to randomly generate sensor nodes within a range of 150 cm and algorithm to allow connection between the sensor and the coordinator if the distance is less than or equal to the predetermine distance (R) otherwise the relay is used to send sensor data to the coordinator. In this case the optimum distance chosen was 75 cm, though this can be varied.

Table 5: Path Loss and Distance Data from MATLAB

Distance (cm)	Path Loss
0.10	-45.9559
10.10	46.3465
20.10	60.1102
30.10	68.1863
40.10	73.9233
50.10	78.3762
60.10	82.0160
70.10	85.0942
80.10	87.7613
90.10	90.1142
100.10	92.2192
110.10	94.1236
120.10	95.8623
130.10	97.4618
140.10	98.9429

A plot of path loss against distance depicted an increase in path loss with distance as shown in the figure below:

Figure 8: Plot of Path Loss versus Distance Chart



6.2.2 Energy Dissipation of the radio model

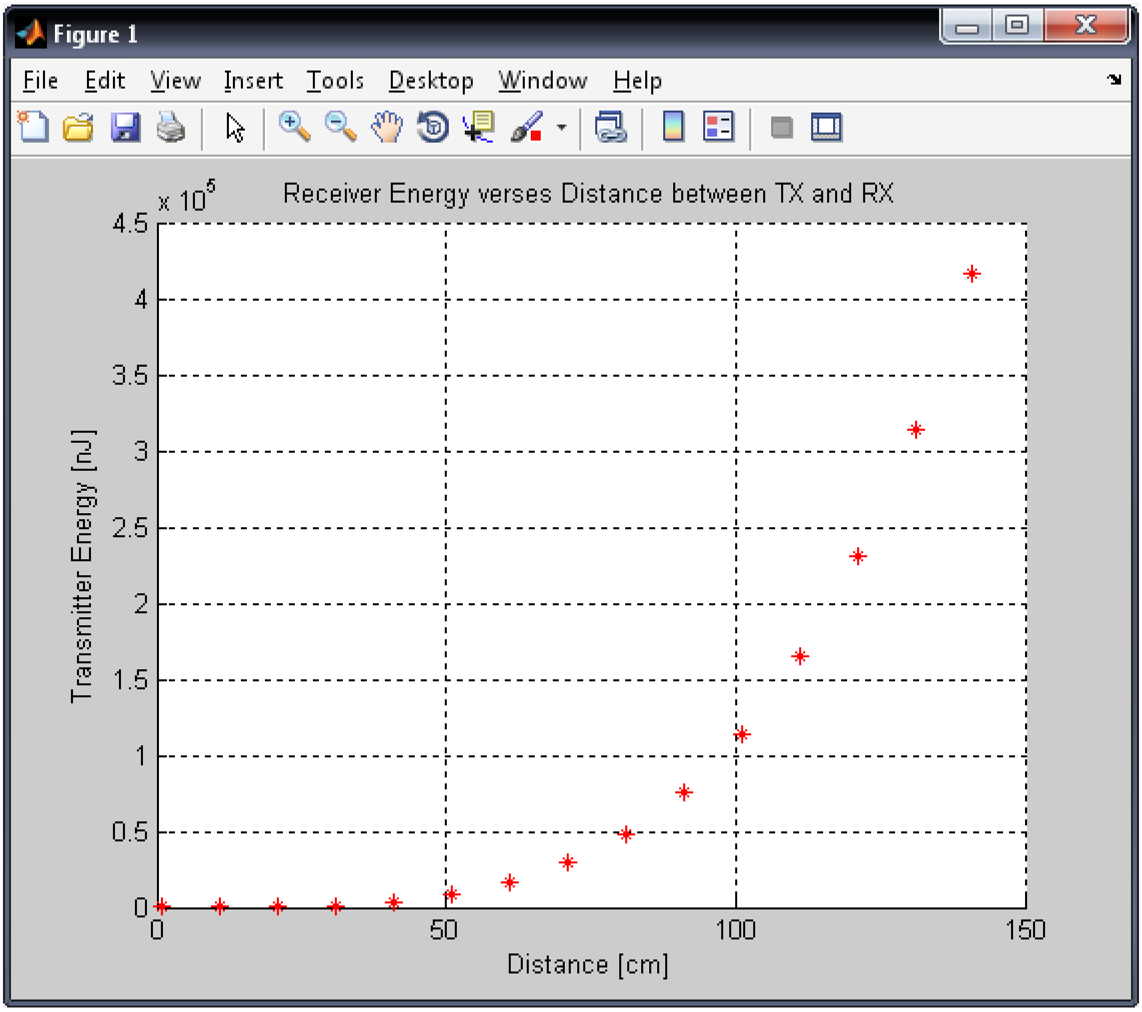
The energy required to transmit data at a rate of 250 Kb/s for a period of 0.01 seconds was investigated.

6.2.2.1 Transmitter Energy

Table 6: Transmitter Energy and Distance Data from MATLAB

Distance (cm)	Transmitter Energy (nJ)
0	0.0061
10	20.9859
20	257.9027
30	1.1688e+003
40	3.4581e+003
50	8.0651e+003
60	1.6155e+004
70	2.9115e+004
80	4.8547e+004
90	7.6264e+004
100	1.1429e+005
110	1.6485e+005
120	2.3038e+005
130	3.1351e+005
140	4.1707e+005

Figure 9: Plot of Transmitter Energy verses Distance



6.2 Conclusion

In this research project, I proposed an energy efficient model for deploying WBAN using multi hop topology by use of a relay between the sensor nodes and the coordinator. The model uses an optimum distance to place a relay for retransmitting signals from nodes beyond the specified distance. The simulation showed that the nodes uses lower energy to send signals through a relay.

The energy consumption graph showed that the relay can be placed at a distance of between 50cm and 75 cm to achieve energy efficiency.

Path loss was used as a performance metric and it showed that the further the nodes from the coordinator, the higher the path loss. Use of the relay reduces path loss. However, the relay also adds to the cost of system design since it will require higher hardware specifications to be able to transmit signal from the nodes. This challenge can be solved by replacing relay batteries periodically when they get depleted.

The transmitter energy required also was shown to increase with distance. This implies that when a relay is used, lower energy will be dissipated during signal transmission.

6.3 Further Work

This area of energy efficiency in WBAN is of utmost importance in deploying WBAN for medical and health monitoring. In this research, the effect of distance between the receiver and transmitter on power consumption was the main variable investigated. The receiver signal strength indicator can be used to check the power of the signals at the receiver.

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APPENDICES

Appendix A

This appendix contains the source code use to plot Path Loss versus Distance as presented in chapter 4

```
clear all;

%Code calculates path loss

%path loss plot against distance

%Distance between coordinator and sensor is 75 cm when relay is used

% and 150 cm if there is no relay.

f=2.4*10^9

c=3*10^10

pi=3.14

d=[0.1:10:150]

PL = 20*log((4*pi*d*f)/c)

figure;hold;

plot(d,PL)

xlabel('Distance [cm]')

ylabel('Path Loss [dB]')

title('Path loss verses distance between TX and RX')
```

Appendix B

This appendix contains the source code for generation random nodes and calculating distances between node pairs using MATLAB.

```
clear all;

% Localization of the sensor nodes

% Sensor nodes are randomly distributed on a plane of

% of 150 cm

% Nodes are dimmed connected if the distance between

% them is less than or equal to 75 cm

noOfNodes = 6;

rand('state', 4);

figure(1);

clf;

hold on;

L = 150;

R = 75; % maximum range;

Xlabel('Distance in cm')

Ylabel('Distance in cm')

netXloc = rand(1,noOfNodes)*L;
```

```
netYloc = rand(1,noOfNodes)*L;

for i = 1:noOfNodes

plot(netXloc(i), netYloc(i), '. y');

text(netXloc(i), netYloc(i),['Node' int2str(i)]);

title('Node Localization')

for j = 1:noOfNodes

distance = sqrt((netXloc(i) - netXloc(j))^2 + (netYloc(i) - netYloc(j))^2)

if distance <= R

matrix(i, j) = 1; % there is a link;

line([netXloc(i) netXloc(j)], [netYloc(i) netYloc(j)], 'Color', 'g');

else

matrix(i, j) = inf;

line([netXloc(i) netXloc(j)], [netYloc(i) netYloc(j)], 'Color', 'r');

end;

end;

end;
```

Appendix C

MATLAB code used to Calculate Transmitter Energy (ETxkd) and Plot Transmitter Energy Verses Distance

```
clear all;

%Receiver energy calculation

%Plot of Transmit Energy verses Distance

Etxelec = 16.7*10^-9

Erxelec = 36.1*10^-9

n=3.88

d=[0:10:150]

k=250*10^3

Eamp = (1.97*10^-9)

figure;hold;

for d = [1:10:150]

ETxkd = k*(Etxelec +(Eamp*n*d^n))

ERxk = Erxelec*k

plot(d,ETxkd,'r*:')

xlabel('Distance [cm]')
```

```
ylabel('Transmitter Energy [nJ]')

title('Receiver Energy verses Distance between TX and RX')

grid

end
```