Path Loss Analysis on Biomedical Monitoring System

by

Che Wan Mohd Hafizul Bin CW Zainordin

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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

____
(DR. NOOHUL BASHEER BIN ZAIN ALI)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

CHE WAN MOHD HAFIZUL BIN CW ZAINORDIN

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First of all, I would like to express thanks to Allah S.W.T. the Almighty whom had given me the strength and ability to complete my Final Year Project (FYP). I am also like to thank my family members because of their supports and help to motivate and moral support throughout the period. They always stood by my side and always remembered me in their prayers.

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ABSTRACT

Path Loss Analysis on Biomedical Monitoring System is an analysis to observe the path loss on interactive real-time wireless communication system that monitor signal from human body. Using sensors and wireless networking, health status of a person can be monitored. Tiny wireless sensor that placed on the human body can be used to create a wireless body area network (WBAN). Wearable system for health monitoring is the key technology to help the transition to be more effective healthcare. This will allow patient to closely monitor the changes in their vital signs and provide feedback to help maintaining at optimal health status. This system can integrated into a telemedical system, to alert medical personnel when life-threatening changes occur. However, wireless communication has its own problem in term of path loss depending on the environment. In addition, human body is one of the environments with high path losses because of wave absorption from the tissues and muscle.

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CHAPTER 1

INTRODUCTION

This section contains four subsections; background of study, problem statement, objective and scope of study. Project background is the overview of the whole project. Problem statement will explain the issues and challenges regarding path losses in wireless communication. The objective will cover on the main aim to achieve at the end of the project, while the scope of study is a description on the scope of knowledge that will cover in this project.

1.1 Background of Study

The rapid growth in sensors technology, integrated circuits with low power consumption and wireless communication has enabled a new generation of wireless sensor networks. These wireless sensor networks are used to monitor many thing in our life for example health status. The Body Area Network field is allowed inexpensive and continuous health monitoring and updates every time to create medical records via server in the internet.

A number of intelligent small sensors can be integrated into a wearable wireless body area network, which can be used for early detection of medical conditions and prevent serious consequences.

A Wireless Body Area Network (WBAN) is term used to describe the application of wearable computing devices on the human body. Wired communication may limit the patient's activities and level of comfort and thus will negatively influence the measured results. So, wireless communication is used to solve this problem so that patients feel comfortable and do not impair their movement.

The wireless network for monitoring human health signal from wireless sensors nodes encompasses into three levels [2]. Level 1 comprises of wearable wireless sensors network with the built-in capabilities of wireless communications, for example Bluetooth ZigBee, and recently 802.15.4.

Then, level 2 consists of the Personal Servers, with wireless capabilities of ZigBee and WLAN through Network Coordinator (NC). The last one is level3 that is completely hospital setup of patient archiving and database management connected to the wide area network (WAN) cloud. In this level, patient's health record will be store in medical server and can be used by any healthcare provider if there is an emergency.

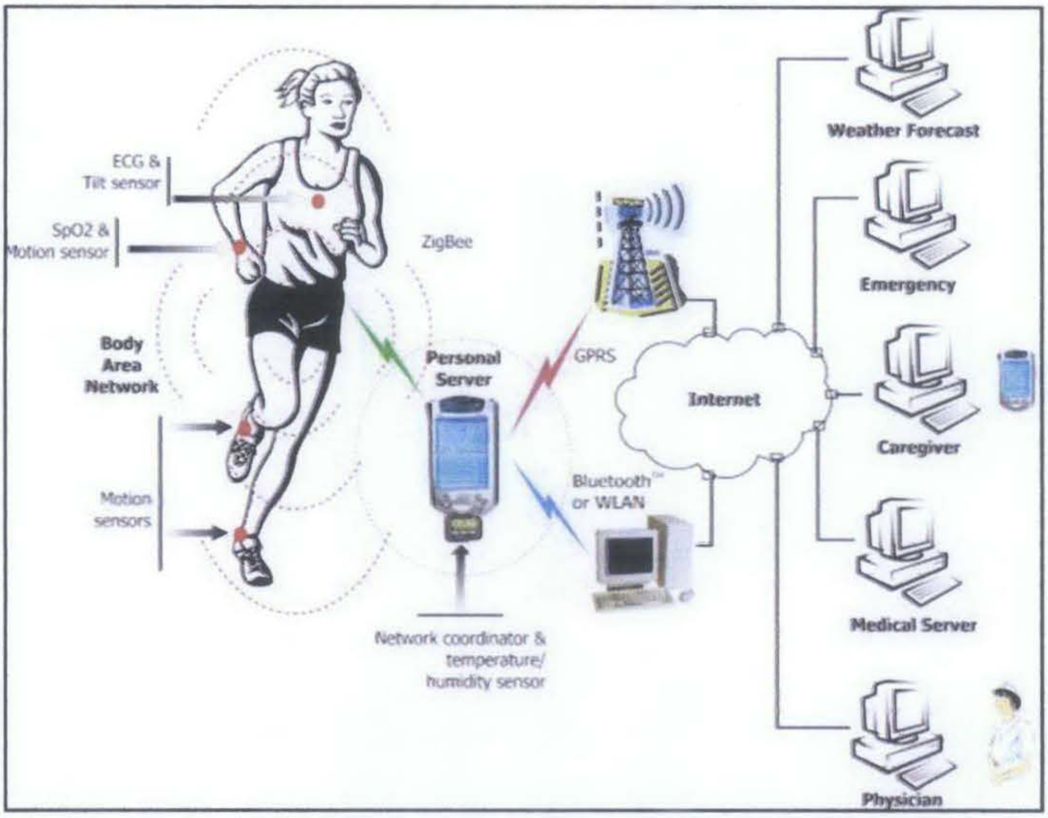

Figure 1: Wireless Body Area Network of Intelligent Sensors [1]

A WBAN can use numbers of sensors depend on the end-user application. Information of sensors can be combined to generate new information such as patient health status. An extensive set of sensors may include the following [1]:

- An ECG (electrocardiogram) sensor for monitoring heart activity
- An EMG (electromyography) sensor for monitoring muscle activity
- An EEG (electroencephalography) sensor for monitoring brain electrical activity
- A blood pressure sensor
- A tilt sensor for monitoring trunk position

• A breathing sensor for monitoring respiration

• Movement sensors used to estimate user's activity

1.2 Problem Statement

There are several problems and challenges with the use of WBAN technology may include [3]:

- Limited energy resources because the node usually very small in size and it is impossible to recharge or replace the battery every time the sensor nodes run out of power.

- Size and weight of sensors used is an important factor in WBAN. Small in size and light in weight is a need in order to place comfortably around patient's body at all the time.

- System and device-level security also need to be consider so that information that contain patient's medical data is secured and can only be access for certain amount of people only such as doctor and medical assistant.

- WBAN can only have limited number of connected device. WSN can have around thousands of nodes connected in one time; meanwhile WBAN can only connected to 20-50 nodes.

- Time delay is important when transmitting data that contains medical information. The patient's health information may need to send to medical assistant instantly if there are any emergency cases.

- The location of several sensor node around body can cause interference because of they are very close to each other.

- The path loss rate is high for WBAN as the wireless signal intends to be absorbed by the tissues and muscle. The absorbed signal will lose its strength before it can reach the receiver [3].

In this paper, we will analysis the path loss in biomedical monitoring system. Path loss is the reduction in power density of electromagnetic wave and normally cause by signal fading and absorption of wave by obstacles [13].

1.3 Objectives

The main objective of this project is to analyze the path loss in WBAN nodes for level 1 which is in the intra-body level. The analysis will compare the path losses in several different type of communication such as Line of Sight (LOS), Non-Line of Sight (NLOS), Single Hop and Multi Hop communication.

Besides, other objectives of the project are written below:

- To understand the working concept of single hop and multi hop communication.
- To investigate the difference of the path losses in LOS, NLOS, single hop and multi hop communication.

1.4 Scope of Study

The designing of WBAN required knowledge and research regarding the multimedia network theory and application. Concept of data communication, data networking and protocol architecture applied to the study. Some part of this project also required knowledge on TCL and C++ programming language in order to work on network simulation (NS-2) in Red Hat Linux operating system.

CHAPTER 2

LITERATURE REVIEW

In this chapter, we will look in depth the existence researches and projects done by others. Together include are the details on how the LOS, NLOS, Single Hop and Multi Hop communication works.

2.1 Wireless Sensor Network

The smart environment depends on real world data from sensors. It detects the relevant information, collect the data, evaluate them, formulate meaningful user displays, and perform decision-making to desire needs. Wireless sensor networks mostly consist of many data network such as, data acquisition network and data distribution network, monitored and controlled by management center [4]. One of the applications of Wireless Sensor Network is Wireless Body Area Network (WBAN).

2.1.1 Wireless Body Area Network

Wireless Body Area Network (WBAN) is a technology used for health monitoring. Wireless sensors node is used to get signal from human body and send to personal server or personal computer to process the data. Wired communication may limit patient's activities and level of comfort, that's why WBAN is introduced. Examples of wireless communication are radio frequency, Bluetooth and ZigBee [2].

2.2 Wireless Body Area Network

A number of recent research efforts focus on wearable system for health monitoring. These are the example research that already been done by engineers around the world.

2.2.1 MIThril, a Wearable Computing Platform

Researcher at the MIT Media Lab have developed MIThril, a wearable computing platform compatible with both custom and off-the-shelf sensors [5]. The MIThril includes electrocardiogram (ECG), skin temperature and galvanic skin response (GSR) sensor. Their goal is the development and prototyping of new techniques of human-computer interaction for body-worn applications. In addition, they demonstrated analysis using 3-axis accelerometer, rate gyros and pressure sensors. MIThril is being used to research human behavior recognition and to create context-aware computing interfaces.

Their important goal [5, 7] it to make their architecture as easy as possible to connect with a wide range of sensor and I/O devices to the system. These sensors and peripherals are off-the-shelf USB devices, such as CCD cameras and audio input/output devices [5]. For software part, MIThril includes FPGA code, Linux OS, UI code signal processing code and prototype applications.

In addition, the MIThril use Inference Engine in order to produce a set of tools for applying statistical machine learning techniques to classifying sensor data in real-time. Enchantment IPCS whiteboard works with inference engine to provide real-time classification and regression to context-aware applications [5].

2.2.2 CodeBlue: Wireless Sensor for Medical Care

Meanwhile, CodeBlue, a Harvard University research project is also focused on developing wireless sensor network for medical applications [6]. They have developed wireless pulse oximeter sensors, wireless ECG sensors, and tri-axial accelerometer motion sensors. Using all these sensors, the formation of ad-hoc network is demonstrated [6].

The sensors, when fitted on patients in hospitals or disaster environment, and use the ad-hoc networks to send vital signs to healthcare giver, facilitating automatic vital sign collection and real-time triage, with pulse oximeter, LCD display, and LEDs indicating patient status [4]. This ad-hoc network is a multi-hop communication where its send the signal from one node to another node until it reach the final destination.

The sensors consist of a low-power microprocessor and low-power transmitter radio. These devices of small amount of memory (4-10 KB) and can be programmed to transmit, and data. The sensors are powered by 2 AA batteries with an operating time up to several months. The basic hardware is based on the MicaZ and Telos sensor nodes, and a custom sensor board integrating the pulse oximeter is attached to the mote devices [4].

2.2.3 UWB Path Loss for Single-Band and Multi-Band

A group of engineers of King Mongkut's Institute of Technology Ladkrabang, Thailand had design a model to measure path loss in residential environment for Ultra-wideband (UWB) radio propagation in single hop and multi hop communication [8]. They also demonstrate the path loss in Line of Sight (LOS) propagation wave.

The model is conducted in a home environment, where there are walls, glass windows, ceilings, doors and furniture. This environment is to examine the path loss of the UWB channel in the modern home environment. The frequency domain of the channel is set from 3 GHz to 7 GHz and 7GHz to 11 GHz [6]. The result shows that the path loss is increase as the distance between the transmitter and receiver increase.

2.3 Wireless Communication Wave Propagation Type

The basic wave propagation type that used in signal transmission from transmitter and receiver will be discussed in this sub topic.

2.3.1 Line of Sight

Line of Sight or LOS is when the signal is travels in a straight line directly from a transmitter to a receiver without passing any obstacle [9]. LOS is an ideal condition where wireless transmission can be reach further distance with better strength and throughput capability. Figure 2 below is to illustrate the LOS condition. In WBAN, Node 1 acts as sensor that transmit signal to the receiver which is coordinator.

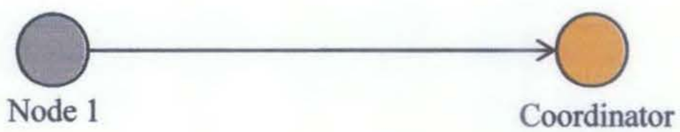

Figure 2: Line of Sight

2.3.2 Non Line of Sight

Non Line of Sight (NLOS) is happen when the signal is travel from the wireless transmitter to the receiver passing an obstacle [9]. The signal may absorbed or reflected before it can reach the receiver. The signal mostly will arrive at the receiver in different paths and lower in strength. In WBAN, human body part is the obstacle between transmitter and receiver. Human tissues and muscles has high absorption rate of signal. Figure 3 below illustrated the NLOS condition where body part is an obstacle.

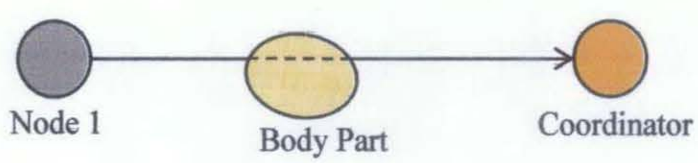

Figure 3: Non Line of Sight

2.3.3 Single Hop Communication

Single Hop communication is a propagation of wave from transmitter to receiver [10]. Based on the Figure 4 below, we can see that all nodes send its signal directly to the coordinator. In WBAN, the nodes are used as different sensors placed around human body that sends health information straight to coordinator.

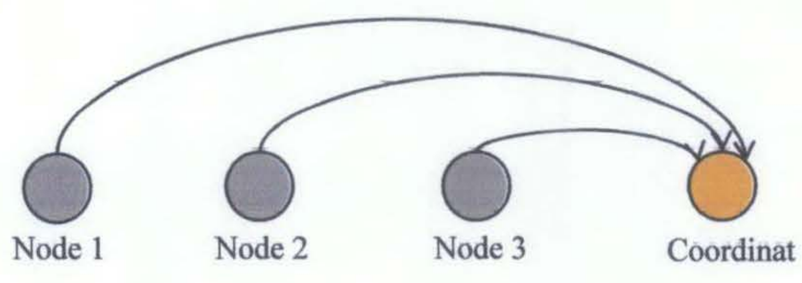

Figure 4: Single Hop Communication

2.3.4 Multi Hop Communication

Multi Hop communication is a propagation of transmitted wave from a node to other node nearer until it reaches the receiver [10]. The data will travel the shortest route. The advantages are it can reduce the transmission power and at the same time lowering time delay. Figure 5 below is a view how the nodes or sensors send the information from node to node until it reaches coordinator.

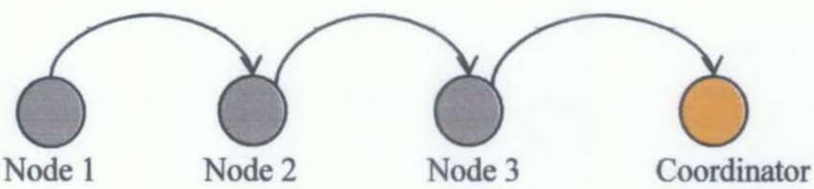

Figure 5: Multi Hop Communication

2.4 Path Loss

Path loss is the reduction in power density of electromagnetic wave and normally cause by signal fading and absorption of wave by obstacles [13]. The signal received by the receiver is normally low in strength if compare when it been transmit. The path loss can be calculated using free space Friis Formula [14].

$$P_{rd(0)} = \frac{P_t G_t G_t \lambda^2}{(4\pi d_{(0)})^2 L} \qquad (1)$$

Based on equation (1), $P_{rd(0)}$ is reference received power, P_t is power transmitted, G_t is transmitter gain, G_r is receiver gain, λ is wavelength, d_0 is reference distance and L is the system loss with typical value of $L \geq 1$.

The path loss value, $P_{r(d)}$ can be calculate using equation (2), where η is the path loss exponent, d is the distance between nodes and $X_{\sigma,\, dB}$ is Gaussian deviation variable:

$$P_{r(d)}\,(dB) = P_{rd(0)}\,(dB) + 10\eta\ \log_{10}\frac{d}{d_0} + X_{\sigma,dB} \qquad (2)$$

CHAPTER 3

METHODOLOGY

In methodology section, we will describe the details of project activities, methods of procedures and tools used during the Path Loss Analysis on Biomedical Monitoring System.

3.1 Procedure Identification

This project has been divided into two phase; FYP 1 and FYP 2. Below is the plan for FYP 1 project development:

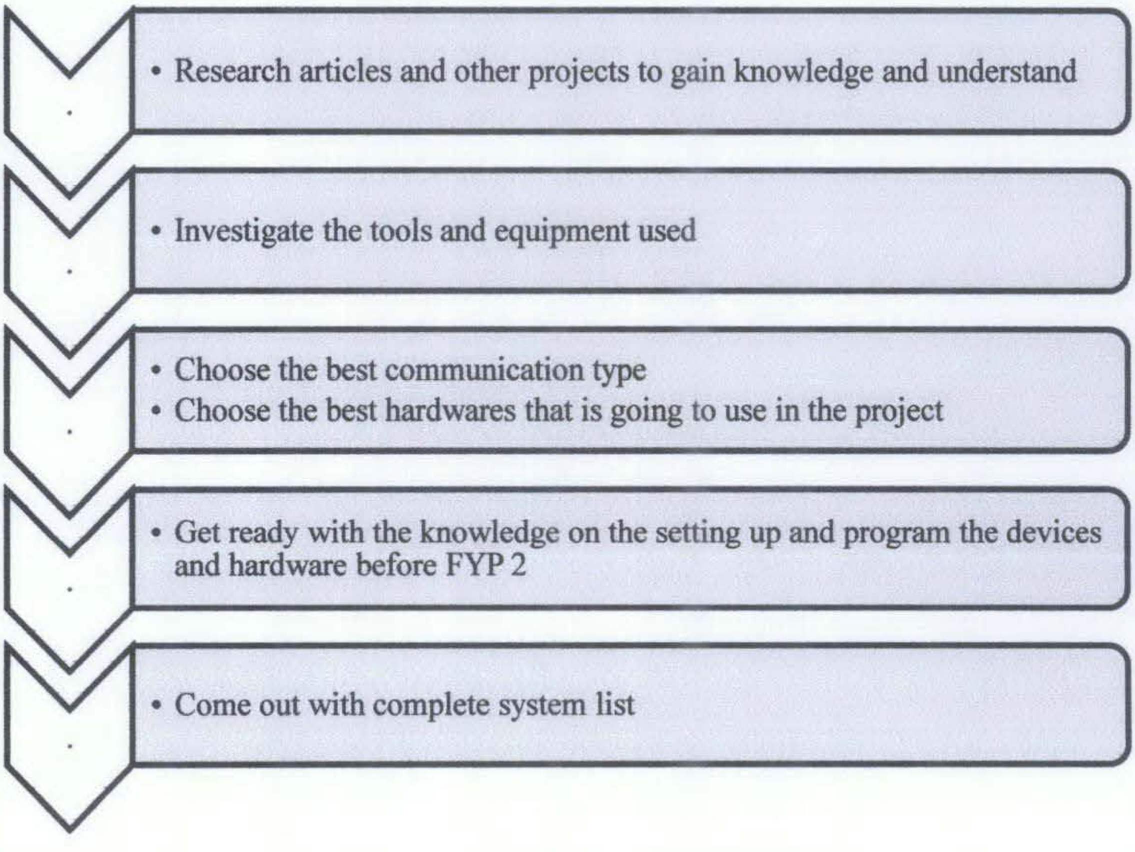

Figure 6: Plan for FYP 1 project development

For FYP2, the project development plan as in the Figure 7 below:

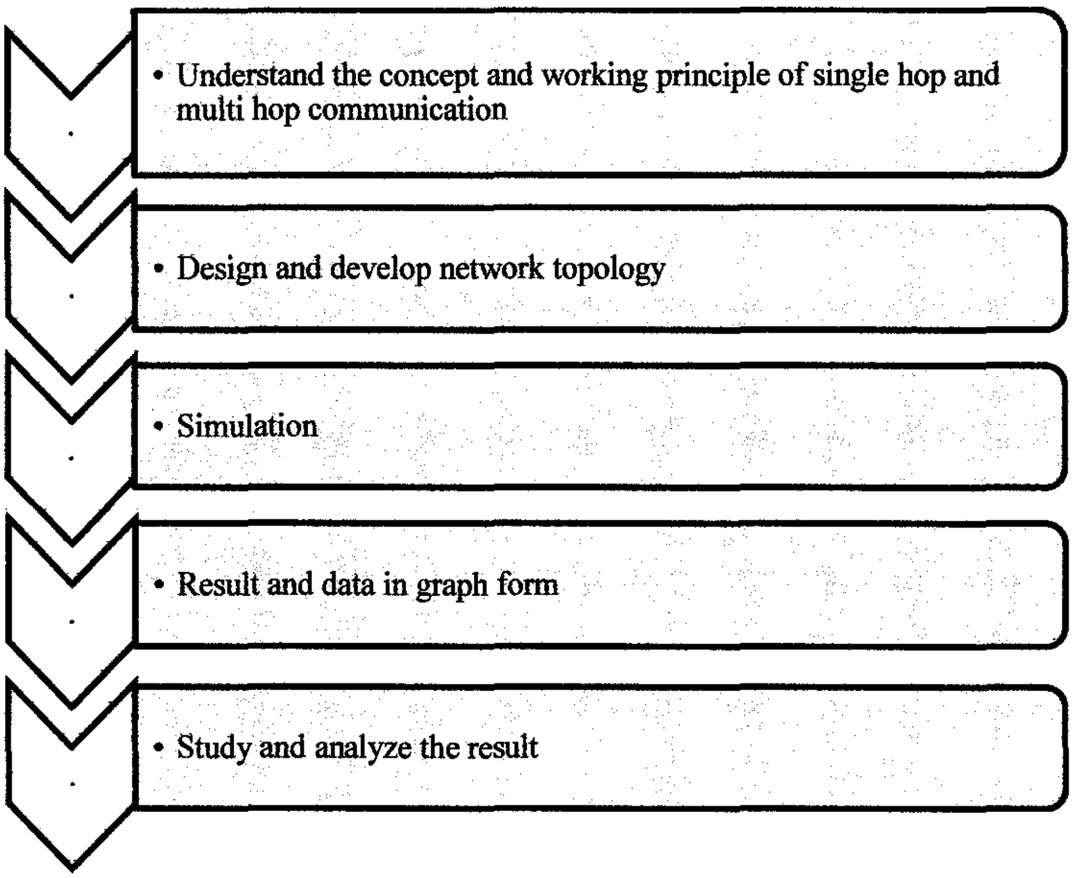

Figure 7: Plan for FYP 2 project development

3.2 Tools and Equipment required

This sub-section highlighted the details of hardware and software used during the project. However, due to unavailability of the hardware, we focused our project on the software and simulation part. The hardware architecture stated is the planned that have been made

3.2.1 Hardware Architecture

Some hardware are already been identified to develop a prototype of Biomedical Monitoring System. These are the component that going to be use:

- Sensor Nodes with IRIS processor/radio board and light, temp, humidity barometric pressure and seismic sensor board (SN21140CA)
- USB Base Station / Gateway (BU2110CA)
- Unpackaged Mote Processor/Radio Board (XM2110CA)
- Data Acquisition Board (MDA300)
- USB Programming Board (MIB520)

Below is the position of the components that going to fit in the human body:

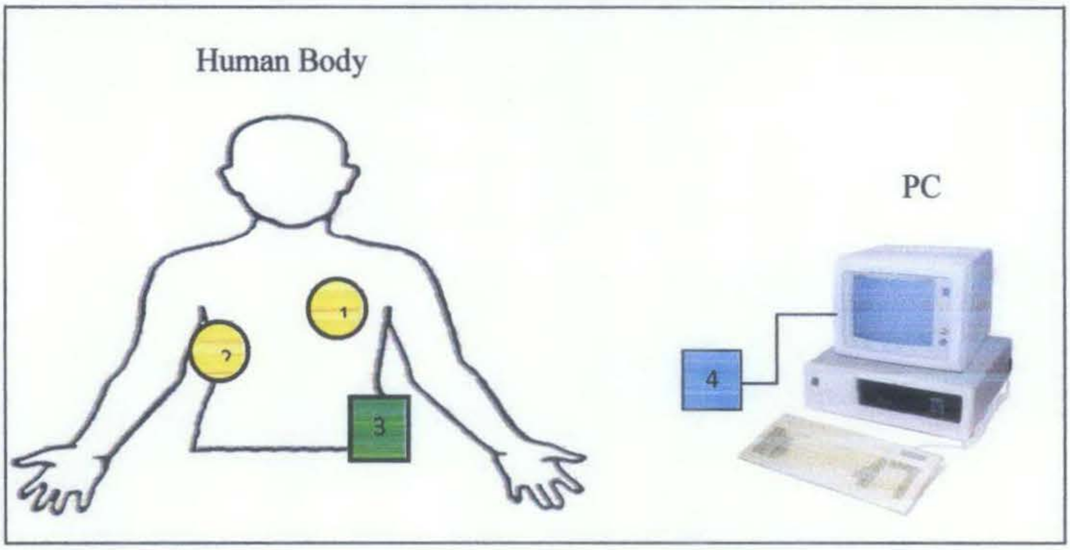

Figure 8: Plan for component positioning

1 and 2 – Sensor Node

- Processor/Radio Board – enable the low-power wireless sensor network
- Sensor Board – multi sensor board including temperature, humidity, barometric pressure and ambient light sensing capabilities

3 – Radio Board – receiver data from Sensor Node and transmit to Base Station

4 – Base Station

- Processor/Radio Board – acts as base station when connected to the USB PC interface
- USB PC Interface Board – provides a USB Interface for data communications

3.2.2 Software Architecture

For simulation purpose, we using Network Simulator or also known as NS that working in Linux platform. NS covers large amount of applications such as network protocols, network types, network elements and traffic models [11]. It is an application that allows user to simulate the desire event or environment in order to get the understanding how the operations of simulated event. Then it allows us to analysis the result and behavior of simulated event using NS simulator.

NS simulator is using two language; C++ and OTcL (and object oriented extension of Tcl) interpreter. C++ language is used as object oriented simulator, meanwhile, OTcL is used as user command script to execute the program [11].

CHAPTER 4

RESULT AND DISCUSSION

Result and Discussion section will highlight the results obtained from the project and followed by discussion related with the result obtain throughout the project. It will include the hardware architecture for WBAN and path loss results from the NS simulation.

4.1 Result

4.1.1 Hardware Architecture

As of now, in depth of literature review on system architecture of WBAN has been done. In addition, these are the list of components to build the whole system:

1. Sensor Nodes with IRIS processor/radio board and light, temp, humidity barometric pressure and seismic sensor board (SN21140CA)
2. USB Base Station / Gateway (BU2110CA)
3. Unpackaged Mote Processor/Radio Board (XM2110CA)
4. Data Acquisition Board (MDA300)
5. USB Programming Board (MIB520)

All the components are in Wireless Sensor Network Development Kits (Part Number: WSN- PRO2110CA) and the estimate price is US$ 2680.00. This information we got after a few conversations by mail with Precision Technologies Pte Ltd. in Singapore.

As the model, we use phantom to replicate real human body. We found that CT Whole Body Phantom (Part Number: PBU-60) is the suitable phantom for this purpose because of its properties that will discuss in discussion part of this report.

To find this phantom that available in Malaysia, few suppliers from all over the world have been contacted. Fortunately, Kyoto Kagaku (Japan's production and sales company based on training model for medical treatment) got distributor in Malaysia; Leeds Dynamic Sdn Bhd. Leeds Dynamic have agreed to lend a part of the phantom for our experimental purpose.

4.1.2 Simulation

Body area network environment consist of multiple nodes that placed closed to each other. 10 numbers of nodes is chosen in the simulation as in WBAN only can have less than 50 numbers of nodes. For simulation on the body area, we set the area to 150cm x 50 cm. The nodes are placed at a distance of 5cm between each other. A constant bit rate (CBR) traffic application has is used with Zigbee communication standard. The setup parameter in Network Simulator is in Table 1:

Table 1: Parameter setup for simulation

Parameter	**Values**
Number of nodes	10
Network coordinator	1
Node Movement	None
Traffic type	CBR
Traffic Direction	Node to Coordinator

The location of node is determined by the value of propagation path loss, exponential η. The η value is varies from 3 to 4 for LOS and 5 to 7 for NLOS [12] depending on the curvature surface of the body. The propagation properties parameter is set as follow:

Table 2: Propagation properties for different body part

Parameter	Propagation Properties			
	LOS			NLOS
	Arm	Torso	Back	Front-Back
η	3.35	3.23	2.18	5.8
$P_{rd(0)}$ [dB]	32.2	41.2	36.8	48.8
$X_{\sigma,\, dB}$ [dB]	4.1	6.1	5.6	6.0
d_0 [cm]	10			

The path loss exponent for WBAN is higher for NLOS where the value is around 5 to 7 at front to back of the body. However, the path loss exponent for LOS is much lower and varies from 2 to 4, for example around the torso, arm and back. The Prd(0) [dB] value is get from simulation on ns-2 meanwhile the reference distance, d0 is set to 10 cm for all situations with the variation of deviation variable. Figure 9 below showing the node placement in NS 2 software.

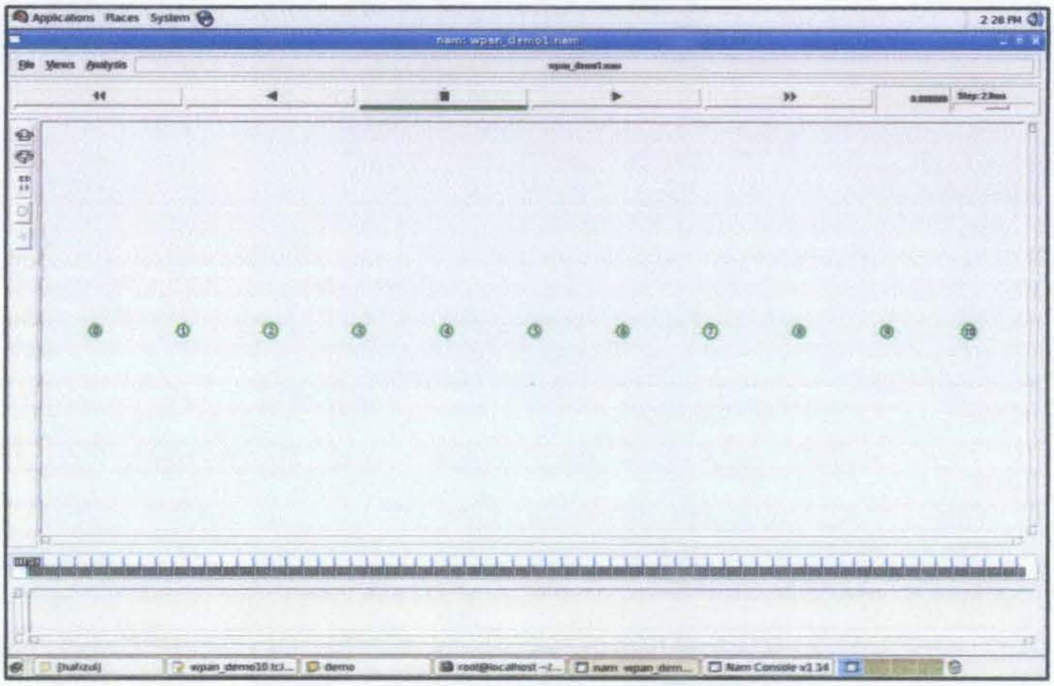

Figure 9: Node placement in NS 2 software

Below are the results of path loss for 4 different location using single hop communication; Arm, Torso, Back and Front-to-Back.

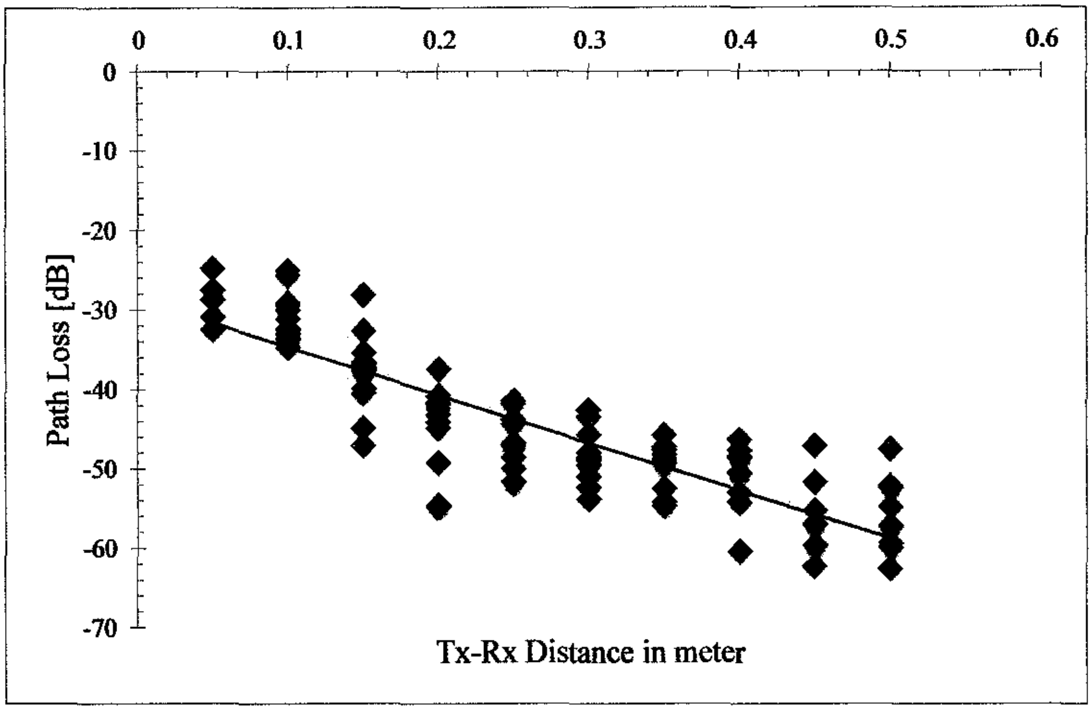

Figure 10: Path loss vs. transmission distance for single hop communication at the arm

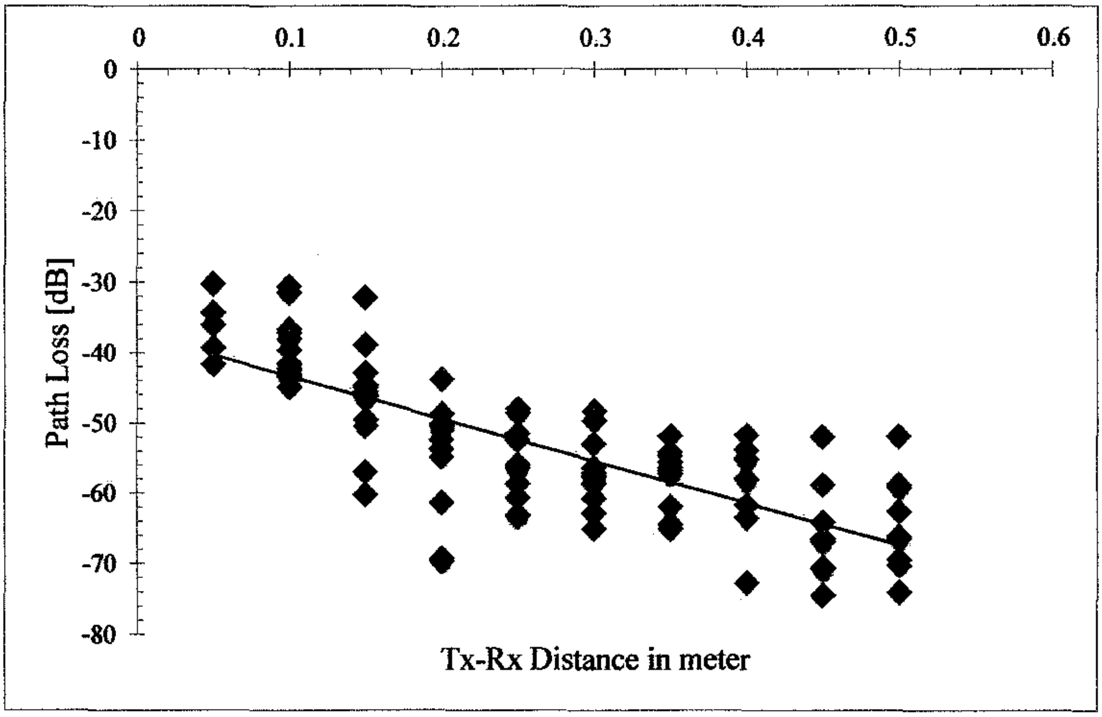

Figure 11: Path loss vs. transmission distance for single hop communication at the torso

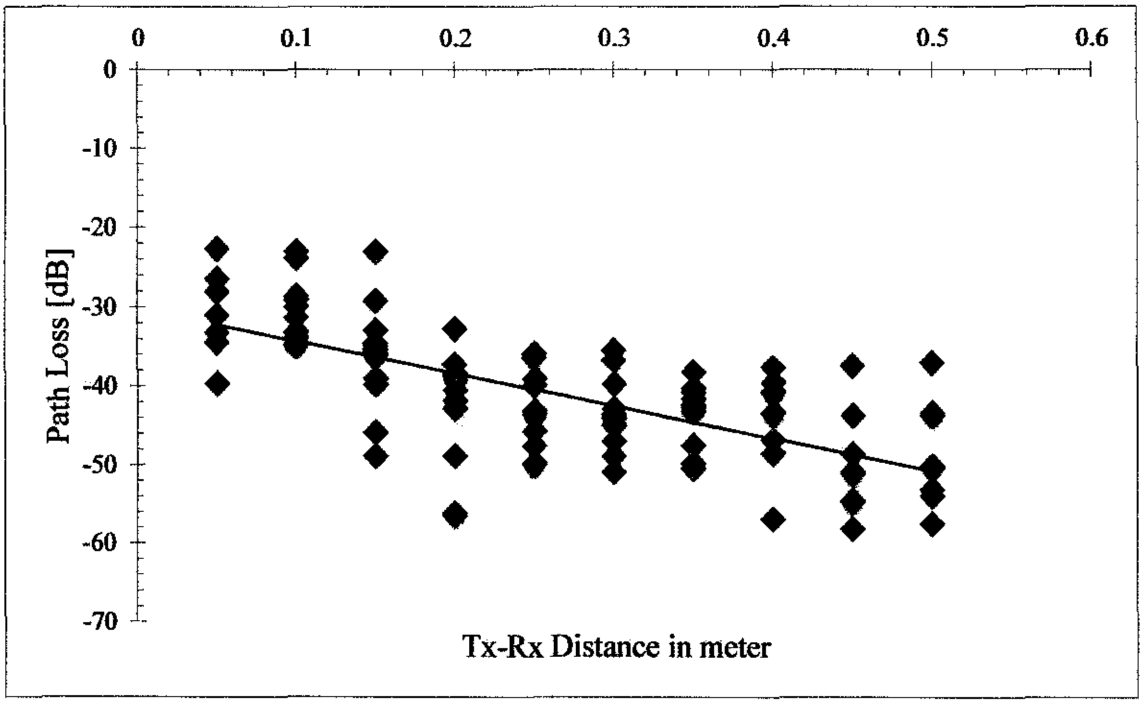

Figure 12: Path loss vs. transmission distance for single hop communication at the back

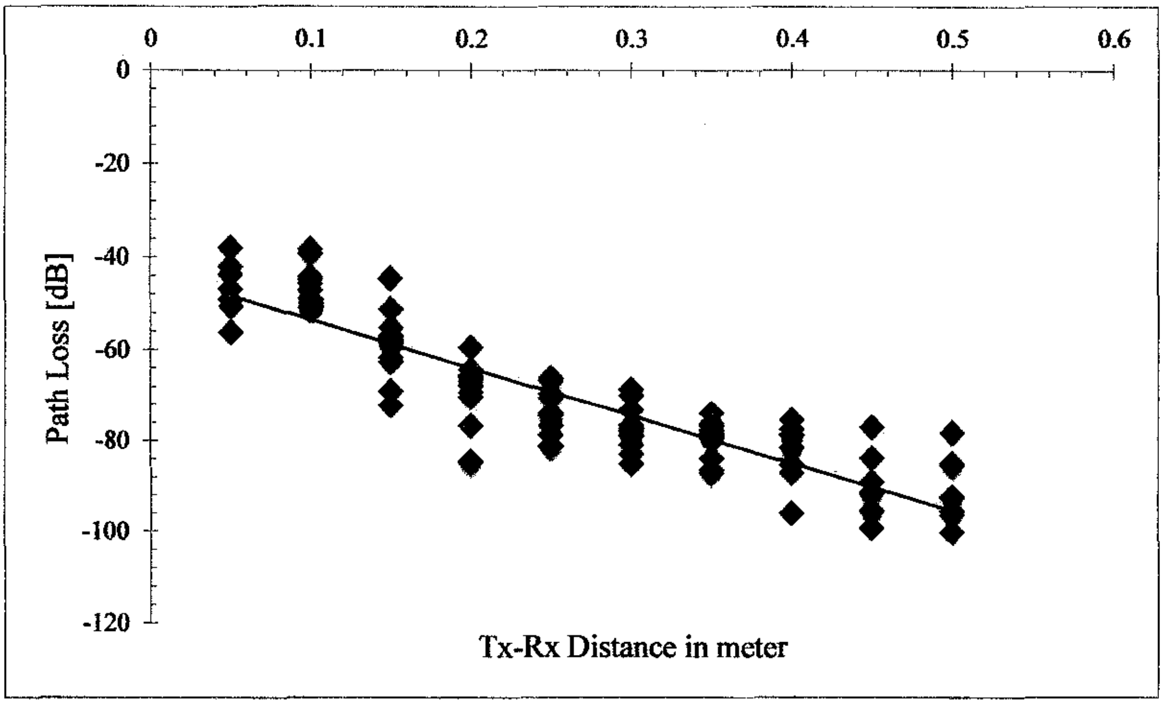

Figure 13: Path loss vs. transmission distance for single hop communication at the front to back

Next is the result for path loss vs. transmission distance for NLOS multi-hop & single-hop communication at front torso to the back:

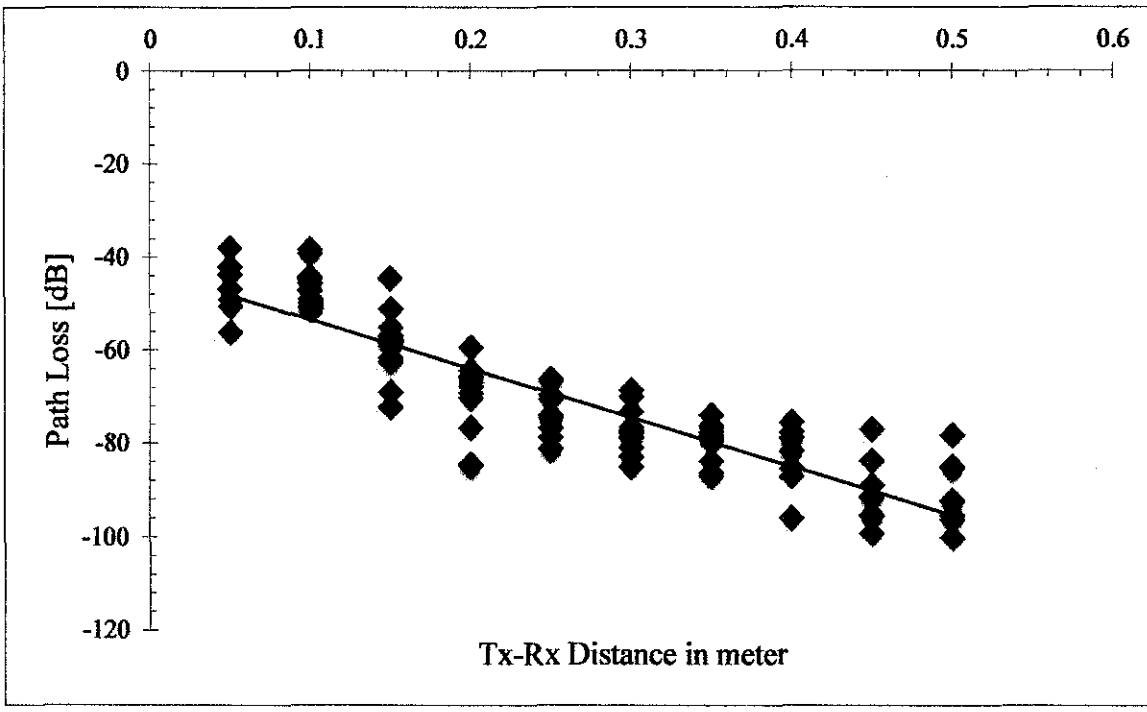

Figure 14: Path loss vs. transmission distance for single hop communication

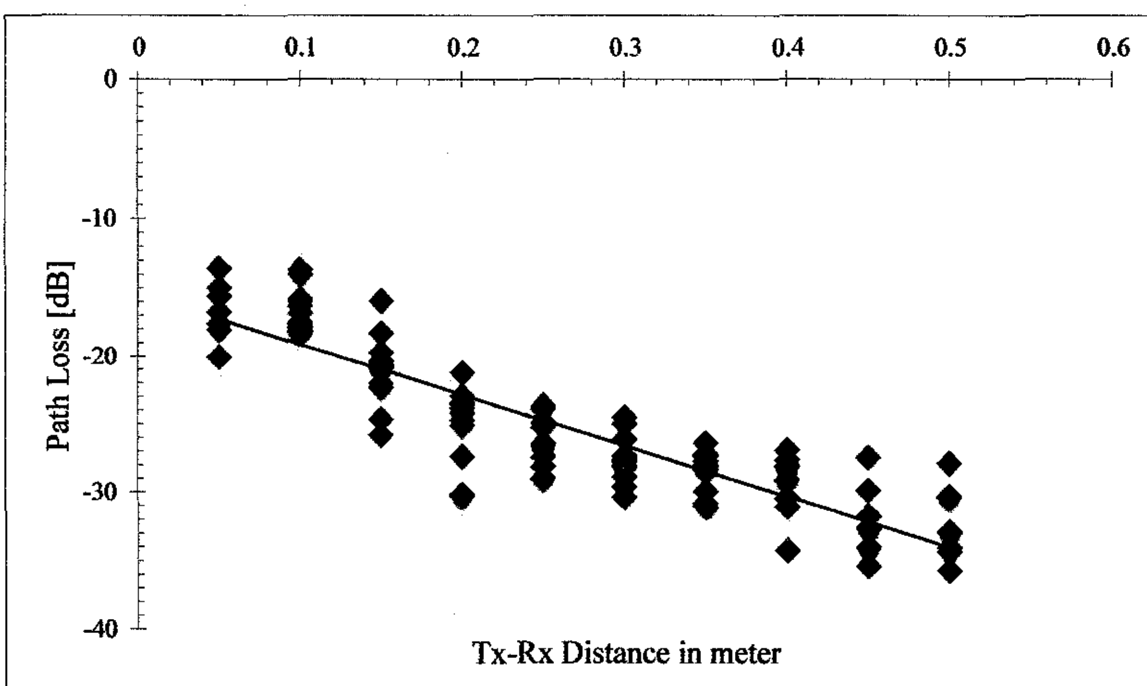

Figure 15: Path loss vs. transmission distance for multi hop communication

4.2 Discussion

4.2.1 Hardware and component

These are the most suitable hardware and component that are suitable to build the biomedical monitoring system. Below are the reasons why this hardware is chosen.

Table 3: List of the chosen component

No	Name of component	Reason
1	Sensor Nodes with IRIS processor/radio board and multi sensor board	Sensor node can be programmed according to user choice type of sensor
2	Radio Board with ZigBee Communication	ZigBee is suitable for sensor network and have low power consumption for long life time
3	USB Base Station / Gateway	USB interface is easy to connect with PC
4	Unpackaged Mote Processor	Allows to connect external sensors of our choice to it
5	USB Programming Board	Can be used to program sensors node
6	Data Acquisition Board	High performance data acquisition board with up to 8 channels of 16-bit ADC analog input

4.2.2 System Block Diagram

In biomedical monitoring system, data and information will travel from the sensor nodes to the base station that connected to PC. Along the travel path, there is several data conversion in order to suit the input of the next node. Below is the block diagram showing how input is converted multiple from one node to another node.

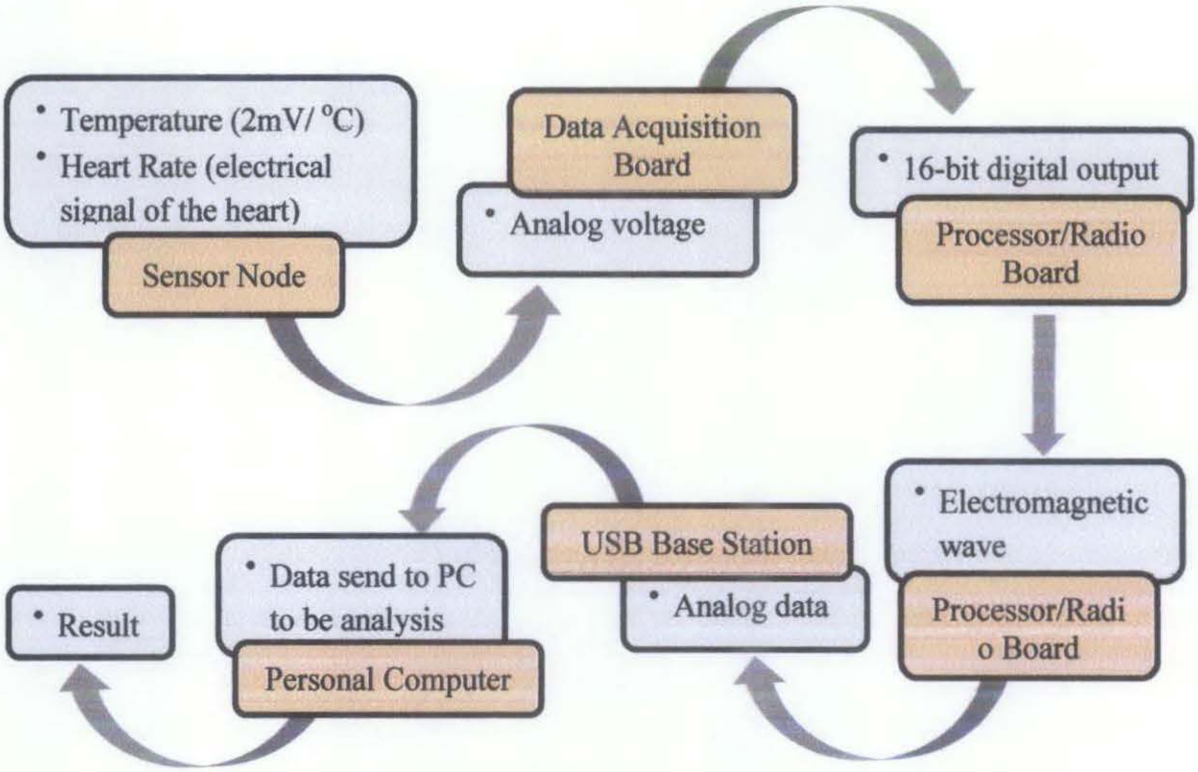

Figure 16: Block diagram of data conversion from node to node

Based on Figure 16, data is travel from sensor node to the PC and will be analysis before it display as result. Temperature and electrical signal of the heart will be detected by the sensor. Sensor node then convert the detected signal into analog voltage before it can be send to Data Acquisition Board. Data Acquisition Board is an analog to digital converter. It converts analog voltage from sensor node into 16-bit digital output.

Processor/Radio Board received digital output from Data Acquisition Board and changes into electromagnetic wave before it can be transmitted to Radio Board at the Base Station part. Radio Board on USB Base Station will receive the transmitted wave and changes it into readable form. Converted analog data from Radio Board is send to PC for analysis before it can be displayed in desired form.

4.2.3 Result Analysis

Due to problems in getting the equipment and hardware, so we have shifted our project to run on simulation. The simulation is running on NS2 where 10 nodes and 1 coordinator are created.

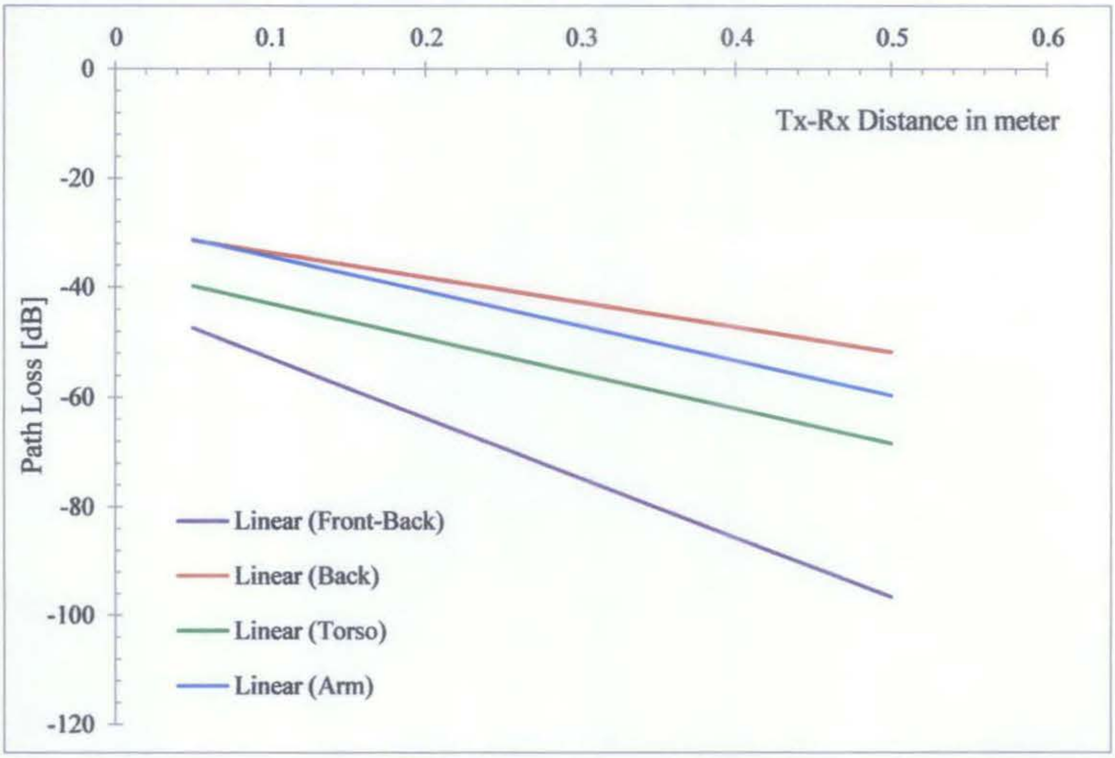

Figure 17: Linear graph for path loss vs. transmission distance for single hop communication at arm, torso, back and front-back

Figure 10 to 13 is showing the path loss vs. transmission distance for single hop communication at the arm, torso, back and front-back respectively. All the graphs then combine together in figure 17 to differentiate the path loss different between the locations. The lowest path loss is at the back and follow by arm, torso and front-back is the highest path loss value among those locations.

The loss along the arm is -45 dB at 30 cm distance between node and coordinator. The other value of path loss, $P_{r(d)}$ at 30 cm for 4 different locations can be seen in table 4 below.

Table 4: Path loss value at 30 cm

Location	Arm	Torso	Back	Front-Back
η	3.35	3.23	2.18	5.8
$P_{r(d)}$ [dB]	-45	-54	-42	-70

The back location is showing the least number of path loss because of the surface which is less curvature with η = 2.18. The flat surface of the back allows the data transmit in a straight line without having any body part to block the transmission.

The path loss for front to back is the highest as the curvature surface and the value for path loss exponent is higher, η = 5.8. NLOS situation is applied for front to back part because there is no straight line from the transmitter and receiver. The transmission of the data is block by the body and most of the wave is absorb by the body.

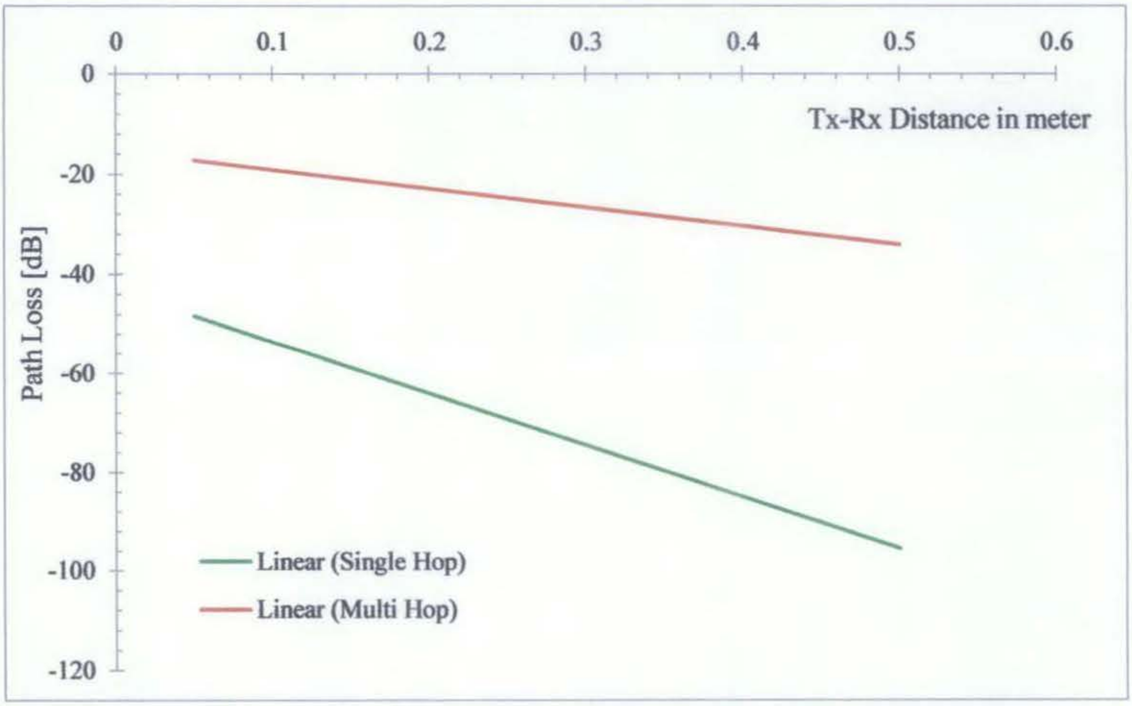

Figure 18: Linear graph for path loss vs. transmission distance for single hop and multi hop communication

Next, we compare the result for path loss for single hop and multi hop communication. Figure 18 is the path loss linear graph for single hop and multi hop communication. Both situations are for data transmission from front to back of the body. We can see the huge different in the path loss value for both communication.

The path loss value for single hop communication is -70 decibel, and -26 decibel for multi hop communication at distance of 30 cm. Table 5 shows the comparison of path loss values.

Table 5: Path loss value for single hop and multi hop at 30 cm

Situation	Single Hop	Multi Hop
$P_{r(d)}$ [dB]	-70	-26

The path loss amount for multi hop at distance 30 cm less 62.85% if compare to path loss for single hop communication. Multi hop communication allows the node to transmit signal to the nearer node until it reach the coordinator. This can reduce the distance travel and allow the signal travel in LOS condition.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This section will include the summarization of the whole project and also some recommendation to improve this project for the future.

5.1 Conclusion

A path loss environment model shows that non line of sight (NLOS) has higher path loss than line of sight (LOS) situation. The NLOS situation is caused by curvature surface that block the signal transmission from node and coordinator.

The path loss in multi hop communication shows 62.85% lower than single hop communication. Multi hop communication can reduce the distance between node and coordinator and allow the signal transmit in LOS situation. Finally, the whole result shows us that the path loss is increase with distance.

5.2 Recommendation

For the next step, we recommended to apply the multi hop communication for hardware assembly according to design architecture. The sensors node will be program with the best sensor for academic presentation and easy to understand. Data or information of human body will display in real time graph so that it user can view the data history.

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APPENDIX

```
# Define options
set val(chan)          Channel/WirelessChannel  ;# Channel Type
set val(prop)           Propagation/Shadowing  ;# radio-propagation model
set val(netif)         Phy/WirelessPhy/802_15_4
set val(mac)            Mac/802_15_4
set val(ifq)           Queue/DropTail/PriQueue   ;# interface queue type
set val(ll)            LL                 ;# link layer type
set val(ant)            Antenna/OmniAntenna       ;# antenna model
set val(ifqlen)        50                 ;# max packet in ifq
set val(nn)            10                 ;# number of mobilenodes
set val(rp)            AODV               ;# routing protocol
set val(x)             1.5
set val(y)             0.5

set val(nam)           single-hop.nam
set val(traffic)   cbr   ;# cbr/poisson/ftp

#read command line arguments
proc getCmdArgu {argc argv} {
    global val
    for {set i 0} {$i < $argc} {incr i} {
        set arg [lindex $argv $i]
        if {[string range $arg 0 0] != "-"} continue
        set name [string range $arg 1 end]
        set val($name) [lindex $argv [expr $i+1]]
    }
}
getCmdArgu $argc $argv

set appTime1        0.0 ;# in seconds
set appTime2        0.3 ;# in seconds
set appTime3        0.7 ;# in seconds
set stopTime       100 ;# in seconds

# Initialize Global Variables
set ns_            [new Simulator]
set prop [new Propagation/Shadowing]
$prop set pathlossExp_ 3.35
$prop set std_db_ 4.1
$prop set dist0_ 0.1
$prop seed predef 0
set tracefd    [open ./1_arm.tr w]
$ns_ trace-all $tracefd
if { "$val(nam)" == "single-hop.nam" } {
```

```
    set namtrace    [open ./$val(nam) w]
    $ns_ namtrace-all-wireless $namtrace $val(x) $val(y)
}

$ns_ puts-nam-traceall {# nam4wpan #}          ;# inform nam that this is a trace file for
wpan (special handling needed)

Mac/802_15_4 wpanNam namStatus on          ;# default = off (should be turned on
before other 'wpanNam' commands can work)


# set up topography object
set topo       [new Topography]
$topo load_flatgrid $val(x) $val(y)

# Create God
set god_ [create-god $val(nn)]

set chan_1_ [new $val(chan)]

# configure node

$ns_ node-config -adhocRouting $val(rp) \
                -propInstance $prop \
                -llType $val(ll) \
                -macType $val(mac) \
                -ifqType $val(ifq) \
                -ifqLen $val(ifqlen) \
                -antType $val(ant) \
                -propType $val(prop) \
                -phyType $val(netif) \
                -topoInstance $topo \
                -agentTrace OFF \
                -routerTrace OFF \
                -macTrace ON \
                -movementTrace OFF \
                -energyModel "EnergyModel" \
        -initialEnergy 1000 \
                -idlePower 1.0 \
        -rxPower 0.0361 \
        -txPower 0.01672 \
                -sleepPower 0.001 \
                -transitionPower 0.2 \
                -transitionTime 0.005 \
                -channel $chan_1_
        #-energyModel "EnergyModel" \
        #-initialEnergy 1 \
        #-rxPower 0.3 \
        #-txPower 0.3 \
```

```
for {set i 0} {$i < $val(nn) } {incr i} {
        set node_($i) [$ns_ node]
        $node_($i) random-motion 0              ;# disable random motion
}

source ./single-hop.scn

# Setup traffic flow between nodes

proc cbrtraffic { src dst interval starttime } {
   global ns_ node_
   set udp($src) [new Agent/UDP]
   eval $ns_ attach-agent \$node_($src) \$udp($src)
   set null($dst) [new Agent/Null]
   eval $ns_ attach-agent \$node_($dst) \$null($dst)
   set cbr($src) [new Application/Traffic/CBR]
   eval \$cbr($src) set packetSize_ 70
   eval \$cbr($src) set interval_ $interval
   eval \$cbr($src) set random_ 0
   #eval \$cbr($src) set maxpkts_ 10000
   eval \$cbr($src) attach-agent \$udp($src)
   eval $ns_ connect \$udp($src) \$null($dst)
   $ns_ at $starttime "$cbr($src) start"
}

proc poissontraffic { src dst interval starttime } {
   global ns_ node_
   set udp($src) [new Agent/UDP]
   eval $ns_ attach-agent \$node_($src) \$udp($src)
   set null($dst) [new Agent/Null]
   eval $ns_ attach-agent \$node_($dst) \$null($dst)
   set expl($src) [new Application/Traffic/Exponential]
   eval \$expl($src) set packetSize_ 70
   eval \$expl($src) set burst_time_ 0
   eval \$expl($src) set idle_time_ [expr $interval*1000.0-70.0*8/250]ms ;# idle_time +
pkt_tx_time = interval
   eval \$expl($src) set rate_ 250k
   eval \$expl($src) attach-agent \$udp($src)
   eval $ns_ connect \$udp($src) \$null($dst)
   $ns_ at $starttime "$expl($src) start"
}

if { ("$val(traffic)" == "cbr") || ("$val(traffic)" == "poisson") } {
   puts "\nTraffic: $val(traffic)"
   puts [format "Acknowledgement for data: %s" [Mac/802_15_4 wpanCmd ack4data]]
   set lowSpeed 0.5ms
   set highSpeed 1.5ms
   Mac/802_15_4 wpanNam PlaybackRate $lowSpeed
```

```
  $ns_ at [expr $appTime1+0.1] "Mac/802_15_4 wpanNam PlaybackRate $highSpeed"
  $ns_ at $appTime2 "Mac/802_15_4 wpanNam PlaybackRate $lowSpeed"
  $ns_ at [expr $appTime2+0.1] "Mac/802_15_4 wpanNam PlaybackRate $highSpeed"
  $ns_ at $appTime3 "Mac/802_15_4 wpanNam PlaybackRate $lowSpeed"
  $ns_ at [expr $appTime3+0.1] "Mac/802_15_4 wpanNam PlaybackRate $highSpeed"
  eval $val(traffic)traffic 6 0 0.2 $appTime1
  Mac/802_15_4 wpanNam FlowClr -p AODV -c tomato
  Mac/802_15_4 wpanNam FlowClr -p ARP -c green
  if { "$val(traffic)" == "cbr" } {
        set pktType cbr
  } else {
        set pktType exp
  }
  Mac/802_15_4 wpanNam FlowClr -p $pktType -s 4 -d 6 -c blue
  Mac/802_15_4 wpanNam FlowClr -p $pktType -s 3 -d 1 -c green4
  Mac/802_15_4 wpanNam FlowClr -p $pktType -s 2 -d 0 -c cyan4
  $ns_ at $appTime1 "$node_(4) NodeClr blue"
  $ns_ at $appTime1 "$node_(6) NodeClr blue"
  $ns_ at $appTime1 "$ns_ trace-annotate \"(at $appTime1) $val(traffic) traffic from node
4 to node 6\""
  $ns_ at $appTime2 "$node_(3) NodeClr green4"
  $ns_ at $appTime2 "$node_(1) NodeClr green4"
  $ns_ at $appTime2 "$ns_ trace-annotate \"(at $appTime2) $val(traffic) traffic from node
3 to node 1\""
  $ns_ at $appTime3 "$node_(2) NodeClr cyan3"
  $ns_ at $appTime3 "$node_(0) NodeClr cyan3"
  $ns_ at $appTime3 "$ns_ trace-annotate \"(at $appTime3) $val(traffic) traffic from node
2 to node 0\""
}

proc ftptraffic { src dst starttime } {
  global ns_ node_
  set tcp($src) [new Agent/TCP]
  eval \$tcp($src) set packetSize_ 60
  set sink($dst) [new Agent/TCPSink]
  eval $ns_ attach-agent \$node_($src) \$tcp($src)
  eval $ns_ attach-agent \$node_($dst) \$sink($dst)
  eval $ns_ connect \$tcp($src) \$sink($dst)
  set ftp($src) [new Application/FTP]
  eval \$ftp($src) attach-agent \$tcp($src)
  $ns_ at $starttime "$ftp($src) start"
}

if { "$val(traffic)" == "ftp" } {
  puts "\nTraffic: ftp"
  puts [format "Acknowledgement for data: %s" [Mac/802_15_4 wpanCmd ack4data]]
  set lowSpeed 0.20ms
  set highSpeed 1.5ms
  Mac/802_15_4 wpanNam PlaybackRate $lowSpeed
```

```
  $ns_ at [expr $appTime1+0.2] "Mac/802_15_4 wpanNam PlaybackRate $highSpeed"
  $ns_ at $appTime2 "Mac/802_15_4 wpanNam PlaybackRate $lowSpeed"
  $ns_ at [expr $appTime2+0.2] "Mac/802_15_4 wpanNam PlaybackRate $highSpeed"
  $ns_ at $appTime3 "Mac/802_15_4 wpanNam PlaybackRate $lowSpeed"
  $ns_ at [expr $appTime3+0.2] "Mac/802_15_4 wpanNam PlaybackRate 1ms"
  ftptraffic 19 6 $appTime1
  ftptraffic 10 4 $appTime2
  ftptraffic 3 2 $appTime3
  Mac/802_15_4 wpanNam FlowClr -p AODV -c tomato
  Mac/802_15_4 wpanNam FlowClr -p ARP -c green
  Mac/802_15_4 wpanNam FlowClr -p tcp -s 19 -d 6 -c blue
  Mac/802_15_4 wpanNam FlowClr -p ack -s 6 -d 19 -c blue
  Mac/802_15_4 wpanNam FlowClr -p tcp -s 10 -d 4 -c green4
  Mac/802_15_4 wpanNam FlowClr -p ack -s 4 -d 10 -c green4
  Mac/802_15_4 wpanNam FlowClr -p tcp -s 3 -d 2 -c cyan4
  Mac/802_15_4 wpanNam FlowClr -p ack -s 2 -d 3 -c cyan4
  $ns_ at $appTime1 "$node_(19) NodeClr blue"
  $ns_ at $appTime1 "$node_(6) NodeClr blue"
  $ns_ at $appTime1 "$ns_ trace-annotate \"(at $appTime1) ftp traffic from node 19 to
node 6\""
  $ns_ at $appTime2 "$node_(10) NodeClr green4"
  $ns_ at $appTime2 "$node_(4) NodeClr green4"
  $ns_ at $appTime2 "$ns_ trace-annotate \"(at $appTime2) ftp traffic from node 10 to
node 4\""
  $ns_ at $appTime3 "$node_(3) NodeClr cyan3"
  $ns_ at $appTime3 "$node_(2) NodeClr cyan3"
  $ns_ at $appTime3 "$ns_ trace-annotate \"(at $appTime3) ftp traffic from node 3 to
node 2\""
}

# defines the node size in nam
for {set i 0} {$i < $val(nn)} {incr i} {
        $ns_ initial_node_pos $node_($i) 2
}

# Tell nodes when the simulation ends
for {set i 0} {$i < $val(nn) } {incr i} {
   $ns_ at $stopTime "$node_($i) reset";
}

$ns_ at $stopTime "stop"
$ns_ at $stopTime "puts \"\nNS EXITING...\""
$ns_ at $stopTime "$ns_ halt"

proc stop {} {
   global ns_ tracefd val env
   $ns_ flush-trace
   close $tracefd
   set hasDISPLAY 0
```

```
   foreach index [array names env] {
      #puts "$index: $env($index)"
      if { ("$index" == "DISPLAY") && ("$env($index)" != "") } {
            set hasDISPLAY 1
      }
   }
   if { ("$val(nam)" == "single-hop.nam") && ("$hasDISPLAY" == "1") } {
            exec nam single-hop.nam &
   }
}

puts "\nStarting Simulation..."
$ns_ run
```