

**COMPARATIVE PATH LOSS MODEL FOR WIRELESS SENSOR
NETWORK VIA PINE FOREST AROUND BEACH**

SUPANUCH SEESAIPRAI

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Thesis
entitled
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.....
Miss Supanuch Seesaiprai
Candidate

.....
Assoc. Prof. Supachai Phaiboon,
D.Eng. (Electrical Engineering)
Major advisor

.....
Asst. Prof. Pisit Phokharatkul,
D.Eng. (Electrical Engineering)
Co-advisor

.....
Asst. Prof. Bunlur Emaruchi,
Ph.D. (Environmental Systems Engineering)
Co-advisor

.....
Asst.Prof. Auemphorn Mutchimwong,
Ph.D.
Acting Dean
Faculty of Graduate Studies
Mahidol University

.....
Mrs. Supaporn Kaittisin,
Ph.D. (Electrical and Computer Engineering)
Program Director
Master of Science Program in
Technology of Information
System Management
Faculty of Engineering,
Mahidol University

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was submitted to the Faculty of Graduate Studies, Mahidol University
for the degree of Master of Science
(Technology of Information System Management)

on
February 7, 2013

.....
Miss Supanuch Seesaiprai
Candidate

.....
Mrs. Supaporn Kaittisin,
Ph.D. (Electrical Engineering and
Computer Engineering)
Chair

.....
Assoc. Prof. Supachai Phaiboon,
D.Eng. (Electrical Engineering)
Member

.....
Asst. Prof. Pisit Phokharatkul,
D.Eng. (Electrical Engineering)
Member

.....
Mr. Kairoek Choeychuen
Ph.D. (Electrical Engineering and
Computer Engineering)
Member

.....
Asst. Prof. Bunlur Emaruchi,
Ph.D. (Environmental Systems
Engineering)
Member

.....
Asst. Prof. Auemphorn Mutchimwong,
Ph.D.
Acting Dean
Faculty of Graduate Studies
Mahidol University

.....
Mr. Worawit Israngkul,
M.S. (Technical Management)
Dean
Faculty of Engineering
Mahidol University

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Supanuch Seesaiprai

COMPARATIVE PATH LOSS MODEL FOR WIRELESS SENSOR NETWORK VIA PINE FOREST AROUND BEACH

SUPANUCH SEESAIPRAI 5236792 EGTI/M

M.Sc. (TECHNOLOGY OF INFORMATION SYSTEM MANAGEMENT)

THESIS ADVISORY COMMITTEE: SUPACHAI PAIBOON, D.Eng. (ELECTRICAL ENGINEERING), PISIT PHOKHARATKUL, D.Eng. (ELECTRICAL ENGINEERING), BANLUR EMARUCHI, Ph.D. (ENVIRONMENT SYSTEMENGINEERING)

ABSTRACT

The objectives of this study were to investigate and compare newly built models for the measurement of energy loss of radio waves using a wireless sensor network with the standard model in finding the path loss of data transmission through pine tree obstacles. The research location was Sirindhorn International Park in Petchburi Province. The measurement systems included the ZigBee 2.4 GHz, a fixed signal transmitter CW, and a wave spectrum analyzer. The experiment was carried out via obstacles, which were the pines around the beach. The methods of study consisted of the design of the measurement and transmission of the data system using sensors to measure the distance in collecting the characteristics of the sea waves and the wireless sensor network that was used for data transmission. Then the information obtained was analyzed and used for designing a new energy loss measurement model of sea waves via pine trees, which resulted in two new models: log-distance and $Af^b d^c$ model.

Next, the log-distance model was compared to the plane earth path loss model, and $Af^b d^c$ was compared to Weissberger, ITU-Recommendation and COST 235 so as to identify the difference of the frequencies and distances in the data transmission.

The research results and comparison of the new models were displayed in graphs; the log-distance model was shown in a logarithm graph, while the $Af^b d^c$ model was demonstrated in a linear graph. The outcomes obtained will be used for analysis and creation of a new model among obstacles that consist of other types of trees with various sorts of leaves and trunks. When results were compared to other models, it was found that the new models were closest to the COST 235 model typed out-leaf, due to the characteristics of the pine leaves being small and round with a diameter of 0.8 mm.

KEY WORDS: SEA WAVE ENERGY SENSOR / WIRELESS SENSOR NETWORK / PINE TREE / PATH LOSS MODEL

91 pages

แบบจำลองการสูญเสียตามวิถีเชิงเปรียบเทียบสำหรับเครือข่ายเซ็นเซอร์ไร้สายผ่านป่าสนริมทะเล
 COMPARATIVE PATH LOSS MODEL FOR WIRELESS SENSOR NETWORK VIA PINE FOREST
 AROUND BEACH

ศุภนุช สีใสไพโร 5236792 EGTI/M

วท.ม. (เทคโนโลยีการจัดการระบบสารสนเทศ)

คณะกรรมการที่ปรึกษาวิทยานิพนธ์: ศุภชัย ไพบูลย์ D.Eng. (ELECTRICAL ENGINEERING),
 พิสิษฐ์ โกคาร์ตันกุล D.Eng. (ELECTRICAL ENGINEERING), บัณฑิต เอเมะรุจิ Ph.D. (ENVIRONMENT
 SYSTEM ENGINEERING)

บทคัดย่อ

งานวิจัยนี้นำเสนอแบบจำลองเชิงประจักษ์ สำหรับวัดการสูญเสียพลังงานคลื่นวิทยุของเครือข่ายเซ็นเซอร์แบบไร้สาย สถานที่ที่ใช้ในการทำวิจัยคืออุทยานสิ่งแวดล้อมนานาชาติสิรินธร จังหวัดเพชรบุรี ระบบการวัดประกอบด้วยอุปกรณ์ ZigBee 2.4 GHz, ตัวส่งสัญญาณ CW แบบคงที่, เครื่องวิเคราะห์สเปกตรัมของคลื่น และได้ดำเนินการโดยผ่านสิ่งกีดขวางที่เป็นต้นสนบริเวณรอบ ๆ ชายทะเล กระบวนการเริ่มต้นด้วยการออกแบบระบบการวัดและการรับส่งข้อมูล โดยระบบการวัดใช้เซนเซอร์วัดระยะทางในการเก็บคุณสมบัติของคลื่นทะเลและรับส่งข้อมูลโดยใช้เครือข่ายเซ็นเซอร์แบบไร้สาย จากนั้นจึงนำข้อมูลที่ได้อามาวิเคราะห์และนำไปออกแบบแบบจำลองการวัดการสูญเสียพลังงานคลื่นทะเล โดยผ่านต้นสนที่ได้จากการทดลอง ซึ่งการทดลองจะได้แบบจำลองใหม่ 2 แบบ คือ แบบจำลอง log-distance และแบบจำลอง $Af^b d^c$

เพื่อประเมินประสิทธิภาพของแบบจำลองที่สร้างขึ้นใหม่ จึงนำมาเปรียบเทียบกับแบบจำลองที่เป็นที่รู้จักในการหาการสูญเสียของข้อมูลเมื่อผ่านสิ่งกีดขวางที่เป็นต้นไม้ โดยนำแบบจำลอง log-distance มาเปรียบเทียบกับ The plane earth path loss model เพื่อเปรียบเทียบผลลัพธ์เมื่อระยะทางในการรับส่งข้อมูลเปลี่ยนแปลง และนำแบบจำลอง $Af^b d^c$ เปรียบเทียบกับแบบจำลอง Weissberger, ITU-Recommendation และ COST 235 เพื่อเปรียบเทียบเมื่อความถี่และระยะทางในการรับส่งข้อมูลเปลี่ยนแปลง

ผลจากการทดลองและเปรียบเทียบของแบบจำลองใหม่จะนำมาแสดงในรูปแบบของกราฟ ซึ่งแบบจำลอง log-distance จะแสดงในกราฟรูปแบบ logarithm ส่วนแบบจำลอง $Af^b d^c$ จะแสดงในกราฟรูปแบบ linear จากผลลัพธ์ที่ได้จะสามารถนำไปวิเคราะห์และสร้างแบบจำลองใหม่โดยผ่านสิ่งกีดขวางที่เป็นต้นไม้อื่นๆ ซึ่งมีลักษณะของใบและลำต้นแตกต่างกันออกไป และเมื่อเปรียบเทียบกับแบบจำลองอื่นๆ แล้วพบว่าแบบจำลองใหม่ใกล้เคียงกับแบบจำลอง COST235 แบบ out leaf มากที่สุด เนื่องจากลักษณะใบสนมีขนาดกลมและเล็ก ซึ่งมีเส้นผ่านศูนย์กลางเพียง 0.8 mm.

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CHAPTER I INTRODUCTION

1.1 Problem Statement

In 2011 Thailand showed an increase of 0.4% in the consumption of final energy. The increase in 2011 showed that the consumption of final energy is in decline in comparison to the increase of the year before as due to the massive flooding occurred during the end of that year.

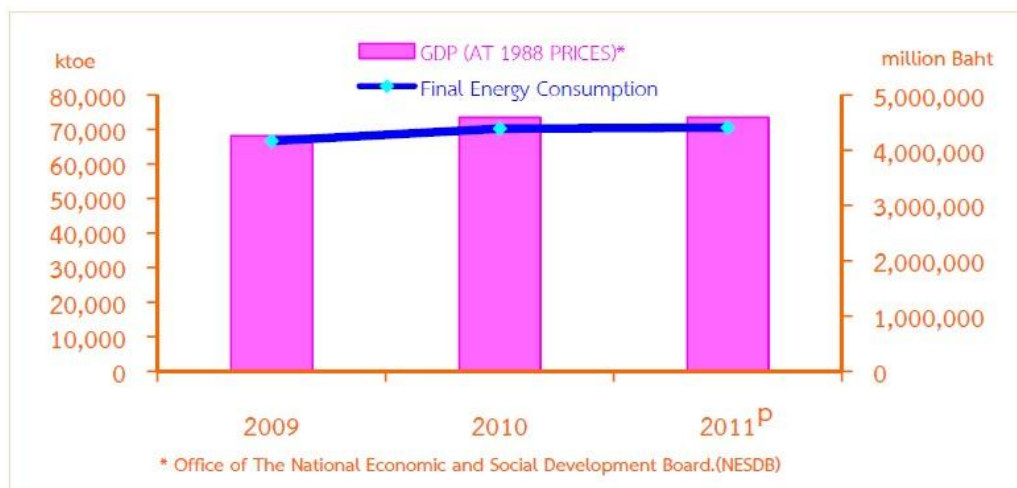


Figure 1.1 The final energy consumption of Thailand in 2011 (NESDB)

It has been discovered that petroleum was at the highest in consumption, which was 49.9% of all the final energy use; following by electricity, traditional renewable energy, coal and lignite, commercial renewable energy, and natural gas, which were 18.0 percent, 13.1 percent, 9.3 percent, 6.4 percent, and 6.3 percent respectively.

FINAL ENERGY CONSUMPTION	QUANTITY (ktoe)			GROWTH (%)	
	2009	2010	2011 ^P	2010	2011 ^P
Final Energy Consumption	66,698	70,247	70,562	5.3	0.4
● Commercial Energy	54,243	56,829	56,807	4.8	(0.04)
- Petroleum Products	31,661	32,096	33,078	1.4	3.1
- Electricity	11,521	12,724	12,681	10.4	(0.3)
- Coal & Its Products	7,493	8,240	6,563	10.0	(20.4)
- Natural Gas	3,568	3,769	4,485	5.6	19.0
● Renewable Energy	12,455	13,418	13,755	7.7	2.5
- Commercial RE*	4,057	4,943	4,529	21.8	(8.4)
- Traditional RE**	8,398	8,475	9,226	0.9	8.9

* Including solar, fuel wood, charcoal, paddy husk, bagasse, agricultural waste, garbage and biogas.
** Including fuel wood, charcoal, paddy husk and agricultural waste.

Figure 1.2 The consumption of final energy categorized (NESDB)

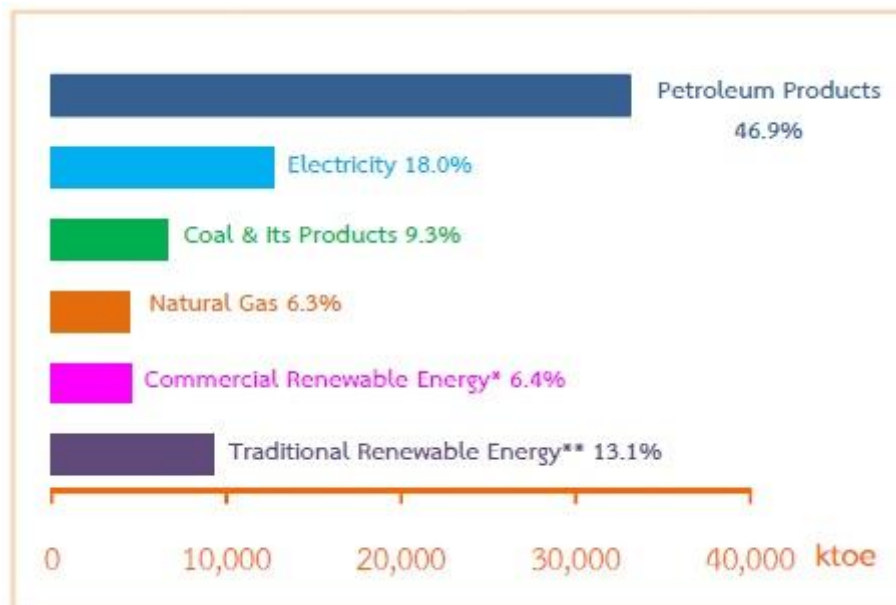


Figure 1.3 The final energy consumption (NESDB)

Based on the government's policy in attempts to promote the more use of the alternative energies that can be produced within the country (including energies from the sun, wind, water, biomass, biogas, wastes, biological fuels (Ethanol and Biodiesel), natural gases for cars), the consumption of alternative energies in 2011 in the forms of electricity, heat, biofuel, and natural gases had increased from last year about 19.4 percent, which was 12.1 percent of the entire final energy consumption.

ALTERNATIVE ENERGY CONSUMPTION	QUANTITY (ktoe)			GROWTH (%)
	2009	2010	2011 ^P	2011 ^P
1. Electricity (Solar, Wind, Hydro, Biomass, Garbage and Biogas)	282	304	988	225.0
2. Heat (Solar, Biomass, Garbage and Biogas)	3,557	4,443	4,529	1.9
3. Biofuel				
- Ethanol	335	329	323	(1.8)
- Biodiesel	463	475	661	39.2
4. Natural Gas Vehicles (NGV)	1,260	1,597	2,036	27.5
Total	5,897	7,148	8,537	19.4
5. Final energy consumption	66,698	70,247	70,562	0.4
6. Percentage of alternative energy consumption	8.8	10.2	12.1	

Figure 1.4 The amount the alternative energy consumption of 2011 (NESDB)

The forms of energy consumption include electricity, heat, biofuel, and natural gas for cars, which are 11.6 percent, 53.0 percent, 11.5 percent, and 23.9 percent respectively.

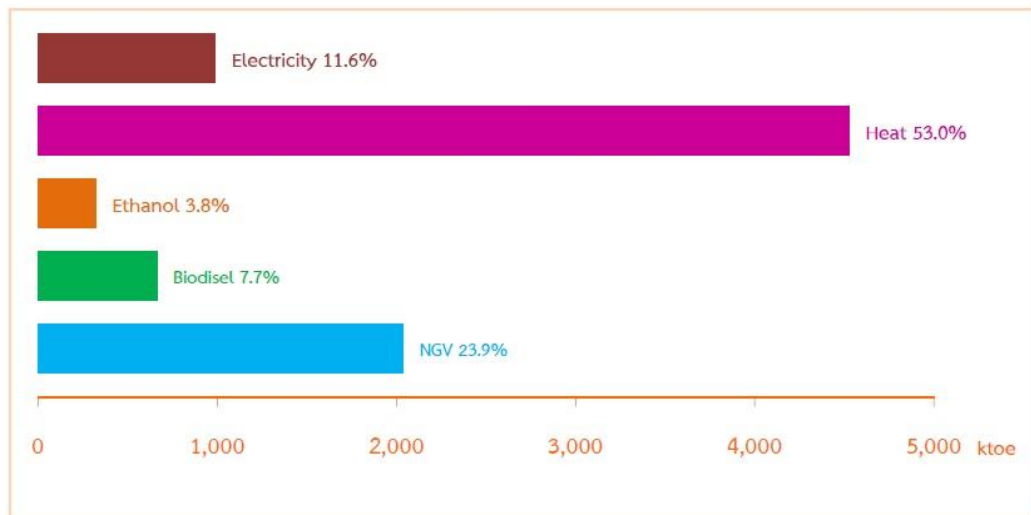


Figure 1.5 The amount of alternative energy consumption of 2011 (NESDB)

Thailand is showing an inclining trend in the increase of electricity consumption yearly and in the near future that may cause a severe shortage of electricity. This is a result of the resources used for power production such as coal, natural gas, petroleum, etc. are in a rapid and consistent decrease. These resources are not renewable; therefore, they cannot be reproduced. Today, alternative energy resources that can be produced within the country have been of great interest, for examples, the sun, wind, water, etc. However, due to many of the obstacles like the solar energy can only be produced during the day, the investment cost is very high, urbanization, which hinder the exploitation of wind power and water energy, the searching for new energy that cost effective and infinite goes on and one of them is electricity from ocean waves because ocean waves allow the process of power production both days and nights. Moreover, the oceans are vast and seen as a clean energy obtained from nature that will not affect the environment and lastly it is a long lasting energy source.

The process of electricity production from ocean waves includes exploring and collecting data on the properties of ocean waves by using Xbee-Pro module, which is a wireless sensor network (WSN). The obtained data is used to calculate the ocean wave's energy and to experiment the permeation of the waves through obstacles. Many related researches tested on "path loss" through trees such as a

research on the loss of the spread of the waves by using the reflection of magnetic power from satellite pictures to indicate the differences of geography. The measurement of the actual place is used for comparison with a standardized equation of the wave's spread by Allsebrook (1977). The results from the differences in geographical areas such as forests, plantations, etc. are collected as a standard value that can be used for reference for the entire country. This is useful in calculating the boundaries of the wave spreads of cell side and the blind spots of the satellite signals more precisely. There is no WSN in a coastal environment, but by using WSN and figuring out formulas related to the wave spreads in the coastal environment that has pine trees in the frequency of 2.4 GHz. This research project, therefore, collects data on the properties of ocean waves by applying WSN and find formulas for the wave spreads in the coastal environment that has obstacles for instance pine trees, mangroves, etc., which will be used in designing WSN to find the ocean wave energy.

Because the researcher sees the importance of exploiting the ocean waves as an alternative energy, and therefore, create a system to continually measure the data obtained from the ocean wave energy by using Wireless Sensor Network to help sending signal reports how much ocean wave energy is received, which is to be used in electricity production from ocean waves. This is a project that develops an alternative sustainable energy resource that originates from the oceans. The location designated for this research is Sirindhorn International Environmental Park in Petchaburi Province.

1.2 Objectives

- 1.2.1 To collect information on wave energy.
- 1.2.2 To study the speed of the data collection of the obstacles.
- 1.2.3 To study path loss from polarization of XBee-Pro through an environment that does not have an obstacle and a hindering environment.

1.3 Scope of work

1.3.1 To study path loss and built new path loss model using Wireless Sensor Network via pine trees around beach.

1.3.2 To study the operation and installation of XBee-Pro, which is a module for Wireless Sensor Network that uses 2.4 GHz frequency in sending and receiving data.

1.3.3 To study the data collection via the use of an open source program.

1.3.4 To study the data access and used for wave energy analysis.

1.3.5 To show results in a form of graphs that can tell the ratio of the path loss.

1.4 Expected Result

1.4.1 To obtain a sea wave energy measurement system via using wireless sensor network.

1.4.2 To obtain a model for wireless sensor network radio wave energy loss measurement system via pine trees and the path loss rate of wave spread from polarization of XBee-Pro via an environment with and without obstacles, which results are shown in graphs.

1.4.3 To obtain the compared results of the newly built models those are close to the standard model with appropriate frequencies.

CHAPTER II

LITERATURE REVIEWS

In this chapter involves the study of various related theories and works that help define the scope and methodology of this research.

2.1 Wireless Sensor Network (WSN)

Wireless Sensor Networks (WSN) is a tool that consists of small sensors used for monitoring the properties of the environment that is of interest and processing the information to create new knowledge about the environment around us or automatically meeting the changes of the environment. WSN arises from a combination of an embedded system technology and a wireless data transmission between sensor nodes with the network ad-hoc feature. The highlight of the sensor network that relies on ad-hoc protocol is that the basic equipment installation for the network is unnecessary similarly to WLAN network or GSM. Moreover, with the small and power-friendly design of the sensor nodes, they can be installed in a variety of environment.

The wireless sensor network is a network of the sensor nodes that includes many sensor nodes that catch and store data and then transmit it back to the original node (Sink Node) that needs the data by relying on the sensors to send the information from one sensor to the next.

WSN causes a new computing paradigm called 'proactive computing', instead of the computer waiting for human commands as in the usual interactive form, in the proactive computing system it can assume the environment that humans desire and can proceed in special cases without a human command.

Proactive computing is created by WSN that allows the computer to receive and process data from the real world precisely and promptly without a data feed from human, hence, the proactive computer can be programmed to react to the environment

that is expected to occur without waiting on human commands as in the interactive system. For instance, sensors can be programmed to organize irrigation or a fertilizer distribution system in agriculture, smoke detectors can send signal to the fire station when a fire occurs, domestic electricity is used to adjust temperature according the user's desire, climate data is collected and construction structure is analyzed.

2.1.1 Basic tools of WSN

WSN includes tiny sensors called 'mote' that has been developed by Intel and University of California (UC) at Berkeley. Mote is a small computer for temperature and humidity measurement or other environmental conditions. It takes regular batteries to operate and to transmit between other motes by applying ad-hoc wireless network, until the data reaches a computer that stores the information. Mote has limitations that push developers to designing hardware and software together with the communication system of mote to consume as less power as possible. Over more, WSN developers have enhanced a tool that allows users without much knowledge in computer engineering to use and create WSN applications at ease. [1, 3, 5, 7] In 1967, Tamir [1] examined the radio wave propagation in forest environments at the band of 1-100 MHz, the forest configuration was considered with a dissipative slab. The lateral wave propagated over large foliage depth. Subsequently, Tamir [2] extended the theoretical study on the propagation in forested environment with the consideration of the ground effects on radio wave propagation in the frequency range of 2-200 MHz.

Weissberger's modified exponential decay model [3] where a ray path was blocked by dense, dry, in-leaf trees found in temperate climates. It is applicable in situations where propagation is likely to occur through a grove of trees rather than by diffraction over the treetop.

ITU Recommendation (ITU-R) [4] was developed from measurements carried out mainly at UHF, and was proposed for cases where either the transmitting or the receiving antenna is near to a small grove of trees so that the majority of the signal propagates through the trees. This model is commonly used for frequencies between 200 MHz to 95 GHz.

In the COST 235 model [5], measurements were performed over two seasons, when the trees are in-leaf and when they are out of leaf. This model is applicable for frequencies between 200 MHz to 95 GHz.

2.1.2 Essential Properties of the Wireless Sensor Network

The major important properties of WSN that need to be considered in the development

2.1.2.1 Energy Efficiency because of the compact design of the sensor nodes and limited energy sources such as batteries, solar power, wind energy and vibration power, sensor nodes need use energy efficiently.

2.1.2.2 The ability in expansion of the network (Scalability)
WSN has to be able to accommodate the growth in number of the sensor nodes and to withstand a malfunction in the network like the loss of battery power, the network must have robustness and fault tolerance and to be able to press on.

2.1.3 Wireless Network Sensor Protocol

When a lot of sensor nodes work together as a network, we call it ‘a wireless sensor network’ that has a communicating method that allows them to work together in collecting data from the network and then send it to a base station node. The part that controls this network is called, ‘data transmission wireless sensor network protocol. Protocol routing is works in searching routes for data transmission between base station and data collecting nodes.

The protocol for the wireless sensor network is divided according to working levels where the first two levels involve with the hardware standard (PHY) and the media access methods (MAC) are mostly about hardware. These two levels are defined as a standard by IEEE (IEEE 802.15.4 WPAN Low Rate), but on the higher levels based on the standard of the network level (OSI Model) has to do with the networking and the routing of the data transmission. There has been no standardization for the wireless sensor network, therefore, a company named, ‘ZigBee Alliance’, has stepped in as so to develop a technology for wine land and instituted standards to use the network level up to the API level.

2.1.4 Protocol Stack

The wireless sensor network emphasizes on power energy because of the limited power resources which affect the design of the wireless sensor and the network. As a result, the protocols stack of ‘Open System Interconnection (OSI Model) is developed by being classified into three levels as in Figure 3. Each level is responsible for assisting the immediate upper level and getting help from the immediate lower level. For the levels that work as connecting levels to ensure that each level works according to its design, however, different uses reflect on different protocols stacks.

2.1.4.1 Physical Layer is responsible for the physical transmission of data such as the frequency periods, modulation and channel coding. In Thailand this level uses the public frequency and the output power in compliance with the law.

2.1.4.2 Data Link Layer is responsible for the data transmission between the sensors, medium access control (MAC) and the error control of the data so that each sensor unit communicates correctly and reliably. At present, accessing the transmission channel of the sensors is a random access, because the wireless sensor networking involves the exploitation of many tiny sensors and it has no proper structure which the control model can be very difficult and besides the random access of the transmission channel allows equal probability for each channel.

2.1.4.3 Network Layer is responsible for sending and receiving the network data. Due to WSN uses multi-hop in transmitting data from the sensor nodes to base station, configuring routes is its primary duty for this level.

2.1.4.4 Power Plane looks after the efficiency of the power consumption of the sensor nodes and WSN. It can work cross layers, for example, the sensor nodes that have diminishing power will decrease power in data transmission in PHY layer with the network layer assisting in find routes which are suitable with less remaining.

2.2 The Network Standards 2550 B.E.

The network standards used in WSN will be standards for a particular group that has been developed and launched in researches and practical works as oppose to the internet.

2.2.1 ZigBee is improved by ZigBee Alliance on the standards of IEEE 802.15.4 uses a public frequency of 2.4 GHz with a physical speed of 250 kbps and range of 10-75 meters.

2.2.2 Wibree is developed by Nokia Research Center where Bluetooth has been modified to consume less power, which allows Wibree to work in two different forms: Wibree stand-Alone Chip which runs on low energy for small data transmission and Bluetooth-Wibree Dual-Mode which can run both Bluetooth and Wibree with 2.4 GHz frequency and a physical speed of 1 Mbps and range of 5-10 meters.

2.2.3 IPv6 over Low power WPAN (6LoWPAN) is developed by 6LoWPAN working group who aims to allow IPv6 to work alongside with IEEE 802.15.4 standards as so to communicate between sensor nodes in the practical environment where they work with different programs via IPv6.

2.3 Network Consideration

2.3.1 Energy Consumption Efficiency

Due to the limited power resources of the sensor nodes, the power energy stored is a key factor for the longevity of the sensor nodes and WSN.

2.3.2 The Delay of Data

In using WSN, some forms of use need the data to be transmitted quickly or to have it delayed no more than its limit after the sensor nodes collect the data. For instance, tsunami warning and wild fire, the delay sensitivity will have a vital effect on the control system.

2.3.3 The Accuracy of the Sensors and their Data Process

The sensors must be accurate and most precise so that the data is most correct.

2.3.4 Damage Tolerance

It is possible that the sensors may malfunction; therefore, WSN has to adjust its structure to continue working such as having secondary routes for the network and data transmission.

2.3.5 Data Transmission Ability

It can be categorized into the ability to send data between the sensor nodes and the ability to send data between WSN in a case of the data is not transmitted at the same time. The sensor nodes data sending is fairly important, but however, in the case of sending mass data simultaneously, the transmission ability relies on the operation of WSN.

2.3.6 The amount of the sensor nodes in the WSN

This amount depends solely on the cost and the effectiveness in selecting the wireless sensor network.

2.4 The improvisation of WSN

The exploitation of the wireless sensor network can be grouped into querying and tasking.

2.4.1 Querying

When the wireless sensor network is queried for data, the sensor nodes with this information will answer back to WSN as in Figure 7.1, for example, in agriculture where the sensor nodes are asked for the data about the humidity and temperature, they will immediately provide the information that has been stored in the nodes.

2.4.2 Tasking

WSN is also responsible for checking different events that have been assigned. The sensor nodes then notify with data via WSN immediately as in Figure 2.1 For example, in a wild fire warning WSN has been assigned to monitor the temperature and smoke, the sensor nodes will send out a signal back immediately when a temperature and smoke that have been set are detected.

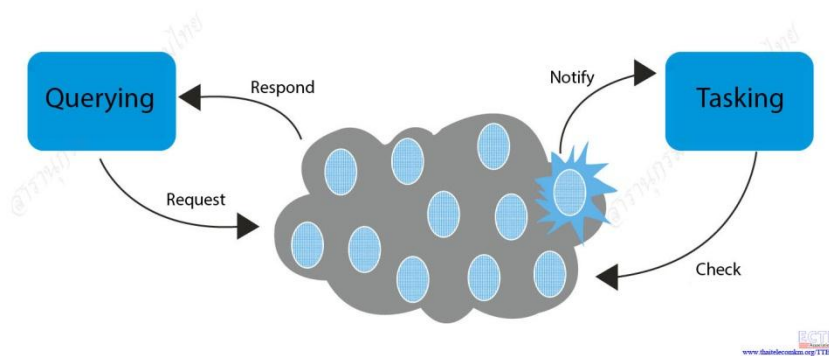


Figure 2.1 The operation of WSN in Querying and Tasking (Thaitelecomkm)

2.5 Sensor Node

Sensor node is hardware that is designed to be compact with less power consumption, which is responsible for detecting data such as temperature, humidity, light, movement, sound and data process. It has a wireless transmission channel embedded and it consists of 4 vital parts:

2.5.1 Power Unit

It deals with energy conversion from the power generators such as solar cells, windmills, power vibration and batteries into electricity that will be used by the sensor nodes.)

2.5.2 Sensing Unit

This unit checks on the physical data through sensors and the data will be converted from analog to digital so that the processor can analyze it.

2.5.3 Processing Unit

It receives the digital data from the sensing unit and processes it and keeps it in storage.

2.5.4 Transmission Unit

It is the wireless communication channel for data transmission between sensor nodes.

Sensor node has a position finding system so that the operating system of WSN is much more complete. The system can identify the source of data precisely. For example a GPS Receiver which can identify the node's position and then pass on the data to be processed.

2.6 Sensor Node Model

The operation of the sensor node model is to measure and store the data from the environment and then process the information by creating WSN is shown in Figure 2.2.

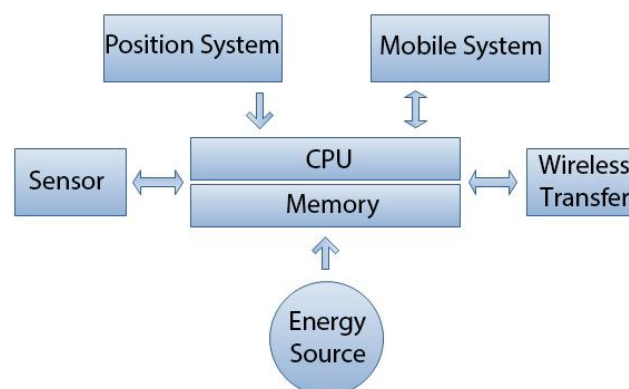


Figure 2.2 The components of the Sensor Node Model

The components of the sensor node model are importance for the operation of WSN follow in Figure 2.2 and how the relation of components works by each component.

2.6.1 Main Components

2.6.1.1 Sensor detects the environment parameter such as humidity, temperature, the density of light, smoke, acceleration, vibration, movement, depth and acidity, etc.

2.6.1.2 Transceiver Unit is responsible for the wireless data transmission in ISM band as so to transmit data between the sensor node models.

2.6.1.3 Processing unit is connected to the sensors to give commands and to receive information from the sensors and then store it the memory awaiting queries or to immediately send the data via WSN. The main processor may take the data from the position finding system or control the movement of the sensor node model. Moreover, the main processing unit takes care of the processing and routing of the data transmission.

2.6.1.4 Power unit is where the power energy is stored and distributed to all the parts of the sensors. The power generator receives energy from its sources if the sensor node model has one.

2.6.2 Additional Components

2.6.2.1 Positioning unit is a unit that identifies the positions of the sensor node model by using GPS. The information of the positions will then be processed, for example, finding routes to send data and finding a position for the movement of the sensor nodes.

2.6.2.2 Mobilizing unit is responsible for maneuvering the sensors' positions with different purposes such as organizing the structure of the network, tracing an object and tracking for signals.

2.6.2.3 Power generator unit works a power generator from the environment such as wind power, heat from chemical reactions and vibration, etc. and turn these into electricity to be used and stored replacing the energy that was used which extends the life of the wireless sensors.

2.7 Control and Application of the Wireless Sensor Networks.

In controlling a lot of motes, many researchers at UC Berkeley have developed the operating system (OS) named, 'TinyOS', which is open source software. And today OS has been accepted as a standard in WSN industry with TinyOS system that works on every mote. It controls the use of mote's energy and operation especially in wireless communication that is known for heavy energy consumption. TinyOS deals with data transmission between motes in multi-hop. A packet is sent from one mote to an immediate mote working in this manner until the data reaches its destination. This sort of transmission uses less energy and very effective. Over more, concerning the data processing, TinyOS reads from the sensors and processes the information obtained from motes by commanding applications on TinyOS. Programs cannot be installed on every mote, but the programs can be sent and installed onto motes in WSN similarly to spreading a computer virus on the internet.

TinyOS developers enhance the program by using NesC language which can be used in improving WSN applications also. NesC is modified to accommodate Event Driven and Component-based Model which help enhance concurrent and data aggregation easily. Aggregation allows applications to minimize the data transmission which saves a lot of energy such as in finding the averaged temperature from all the motes, the application can program each mote to calculate the mean from the mote from which it receives the data and then passes on an output to other motes until the data reaches its terminal destination where a computer displays the result to the user. This method transmits less data than sending it from all the motes to the receiving-end computer and calculates the final mean only once. In addition, researchers at Intel and UC Berkeley have developed TinyOS system that allows user to pull out the data from the sensors by using SQL, which helps WSN researchers worldwide to enhance their applications more efficiently.

2.7.1 The properties of sensor node model and WSN

2.7.1.1 The sensor node model that has a modest cost that is required in great amount and is suitable for one-time-only use.

2.7.1.2 The compact design of the sensors which allows them to be embedded in different environments.

2.7.1.3 The sensor node model that is able to work under limited power source.

2.7.1.4 The sensor node model and WSN those are able to self-manage without the assistance of human.

2.7.1.5 A great amount of sensors that can spread out covering working areas of WSN for data collection.

2.7.1.6 The sensor nodes are tolerant and durable when some other sensors are damaged.

2.7.1.7 The wireless sensor network is very flexible, which can instantly be changed.

2.8 The properties of Mote

The design and operation of mote depend on the applications, nevertheless, no matter what type of work mote is being used for, mote still has its limitation and that is power. It must be efficient with power to prolong its working life as long as it can. In general mote has its lifespan of about 1 year from using two AA batteries. However, its lifespan is varied according to the frequency of usage in monitoring the environment and in the data transmission in the applications. The microchip of mote will be in the power-save mode, 'standby', for most of the time and will operate when assigned. This microprocessor uses very little energy of about 1 mill watt during its operation and 1-10 micro watt(s) during standby mode. Mote has a very small memory when compared to a regular computer and with a RAM of less than 10 Kilobytes. It uses 100 Kb for storing software and about 1 Megabyte for a permanent memory storage. The figure below shows an example of mote as the size of a photo film container that has been developed by the researchers at UC Berkeley that is used for monitoring humidity and other climate conditions in agricultural study.

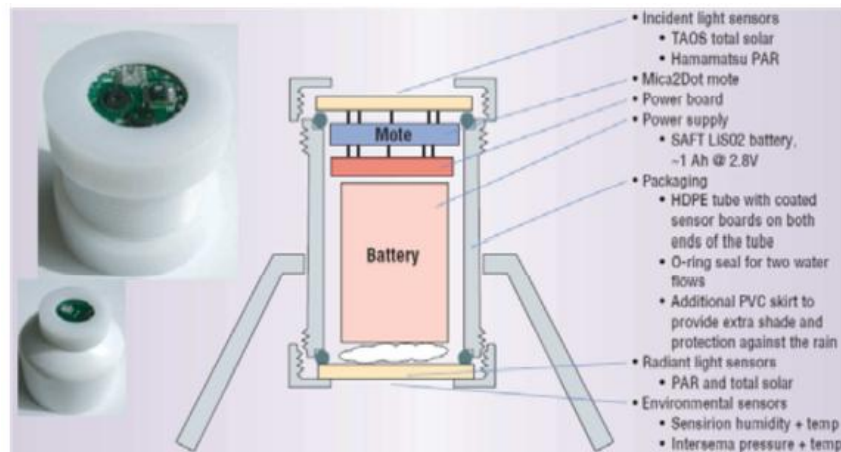


Figure 2.3 Picture of Mote's components

For the micro sensors, Mote uses various types of technology that are compact and power saving as same as the microprocessor, for instance, analog-to-digital converters (ADC) that convert voltage signals received from the sensors that are used to detect mists to be the digital signal that the microprocessor accepts. In addition, MEMS technology is used to building sensors of various types that can produce digital signals for the processor also, for example, the sensors for monitoring acceleration that is used to initiate airbags, sensors for detecting the body heat and air pollution. Moreover, Intel is building sensors that are biochips that are used to detect bio chemicals.

The development of mote's communication uses a radio communication system with low power that is produced by the same technology as 802.11 (WiFi) Network, PDA that can connect to the internet and telephones. Because of mote has to be energy saving in communicating, hence, it has been designed to use Ad-hoc wireless network to transmit information to the neighboring mote and on to the next until it reaches its destination. Moreover, the researchers have improved a tool that is able to add energy to mote also such as a solar cell system and a power vibration.

Today the development of mote is not only done in a university's laboratory, but also in industry that has produced various types of mote for different applications. At present the prices of mote are in the range of 50-100 USD and are expected to climb down to 5 USD in five years' time. Intel and Crossbow Technology

are improving a system that will help save the energy used in communication of mote by restricting the radio system's ability of mote meanwhile a High Bandwidth 802.11 (WiFi) Gateway is being in use, which has a stable power source that is an electrical plug used as the main communication means within WSN. In this case mote will send data to Gateway close to it and then the Gateway will send the data on to the other motes and Gateway in WSN. This kind of communication is called, 'heterogeneous sensor network'. Over more, Intel has developed mote that is able to process data and communicate with high performance named 'iMote'. This iMote consists of a 32 bit microprocessor and Bluetooth that are used in mobile phones and in computer laptops for communicating between iMotes.

2.9 ZigBee

ZigBee is a wireless technology used in communicating data via compact sensors of ten thousands embedded in different sections of buildings, offices, factories, and homes.

In the past few years the Wireless Sensor Network has become a research interest worldwide. The latest topic that has been studied is the standard technology of IEEE 802.15.4 and ZigBee that have brought forward the research findings in a form of products. By connecting WSN on IEEE 802.15.4, the physical layer will work with three frequencies that are 2.4 GHz, 896 MHz and 915 MHz for 2.4 GHz, there are 16 communicating channels with a speed of 250 Kbps; 896 MHz has 10 communicating channels with a speed of 40 Kbps; and 915 GHz has only 1 communicating channel with a speed of 20 Kbps. The network relies on the standard system of IEEE 802.15.4 where the network layer is able to apply with Star, Mesh and Ring Topology. With this ability, Maxstream has invented ZigBee that has marked abilities such as compact design, energy saving and able to connect with outer equipment via Serial RS232 ports that are suitable for WSN that accommodates IEEE 802.15.4. By ZigBee being able to accommodate mesh, it has to find routes by itself (Multiple Routing Algorithms) whereas Maxstream has produced a protocol (Aodv Protocol) for ZigBee already.

ZigBee is a wireless communicating technology that communicates via compact sensors embedded in office buildings, factories and even homes. ZigBee is

derived from the behavior of bees where bees fly in a zigzag motion and communicate based on position, distance, and direction of the food they are searching for.

This type of technology is a transmission of data via microchips embedded in different locations until the data reaches its destination and then downloads the information onto a computer for data analysis. This information can be about temperature, movements of living things, air pollution, the amount of water and gas pipes, by applying solar power or small batteries. These gadgets use a small amount of energy which allows them to be embedded far away for ten years.

The characteristics of ZigBee include accessing signal channels via Carrier Sense Multiple Access with Collision Avoidance (CSMA – CA) and are able to access multiple channels as to avoid collision. The normal distance is about 50 meters that has star topology, peer-to-peer and mesh.

2.9.1 The standard protocol of ZigBee

The protocol stacks IEEE 802.15.4 ZigBee [4] that is designed for Low-Rate Wireless Private Area Networks (LR-WPAN). The receiver is a connector that allows normal computers to know the environment of our world. There are many receivers designed for different uses such as the measurer of temperature, humidity, and object movements. The receivers continue to be improved from covering huge areas to from node to node without communication, which is a flip side. ZigBee Alliance is an industrial group who work together to create products for control and observation that use wireless networks that are reliable, efficient, and energy saving, which work under the world standard. This industrial group is not looking for profit and is growing very rapidly. It includes leading semi-conductor producers, OEM (Original Equipment Manufacturing) provider and the world's direct users. The network receiver of ZigBee is designed under the standard of IEEE 802.15.4 that comprises of a physical layer and MAC layer as shown in the Figure 2.4.

2.9.1.1 Application Layer these levels have an application framework that access and operate on that particular layer.

2.9.1.2 Application Support Sub-Layer it is responsible for building frames and transmits data.

2.9.1.3 Network Layer this level finds routes for the data that may be in same network or in different ones.

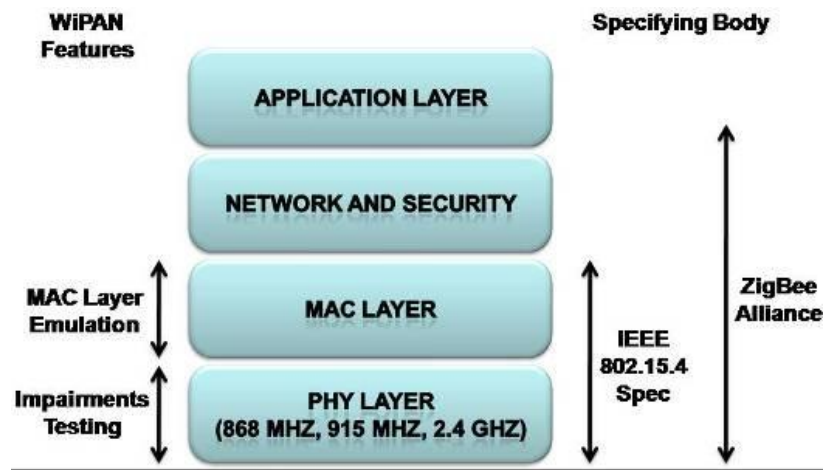


Figure 2.4 WiPAN Mapping on ZigBee Protocol Stack (eefocus)

The hardware architecture ZigBee is categorized into two types. Table 1 shows RFD (Reduce Function Device) and FFD (Full Function Device). The FFD has a complete operating function that can be a coordinator, but on the other hand, RFD is restricted to power saving and low cost, therefore, its unnecessary functions have been taken out like routing. In Table 2.2 in the ZigBee network shows that FFD is commanded to be a coordinator which works as an administrator controlling and managing the coordinator's network that has a neighbor table of the device that is found in immediate areas. This causes the coordinator to have a big memory space and to use a lot of power to run due to the fact that it has to communicate with its clients constantly. Usually it has 2-4 Kb of memory and the memory of FLASH program that can expand up to 64 Kb. The amount of memory temporary use depends on the number nodes that the coordinator is communicating with. From the approximation of memory temporary use of 4 Kbs, it can be connected to a least 30 devices.

Table 2.1 Table is showing the types of ZigBee.

Device Type	Services Offered	Typical Power Source	Typical Receiver Configuration
Full Function Device (FFD)	Most or all	Mains	On when Idle
Reduced Function Device (RFD)	Limited	Battery	Off when Idle

Table 2.2 Table is displaying the responsibilities of ZigBee.

ZigBee Protocol Device	IEEE Device Type	Typical Function
Coordinator	FFD	One per network Forms the network ,allocates Networkaddresses, holds binding table.
Router	FFD	Optional. Extends the physical range of the network. Allows more nodes to join the network. May also perform monitoring and/or control functions.
End	FFD or RFD	Performs monitoring and/or control functions.

ZigBee when compared to the standard of various wireless systems as shown in Table 3, it can be seen that the technology of Bluetooth and Wi-Fi consumes a lot of power, which is not suitable for the use of receiver networks. The rate of data transmission does not necessarily have to be super-fast because the data is inquired periodically.

Table 2.3 Picture showing the comparison of the wireless technology

	ZigBee	Bluetooth	Wi-Fi
Standard	802.15.4	802.15.1	802.11b
Memory requirements	4 – 32 KB	250 KB+	1 MB+
Memory requirements	Years	Days	Hours
Nodes per master	65,000+	7	32
Data rate	250 Kb/s	1 Mb/s	11 Mb/s
Range	300 m	10 m	100 m

2.9.2 Star Network

This consists of connecting nodes for ZigBee and other endpoint equipments in the star network. These endpoint devices communicate only with connecting nodes. If an endpoint device needs to communicate with other endpoint devices, it has to send data via the connecting nodes. Or in other word, the connecting nodes transmit data to receivers as shown in Figure 2.5.

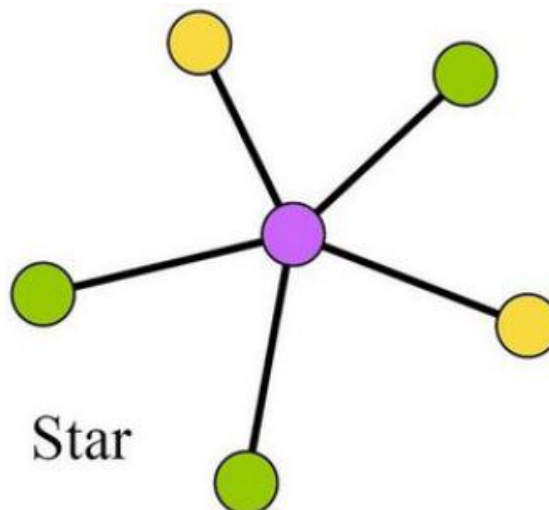


Figure 2.5 Star network (zigsense)

2.9.3 Cluster Tree

In this network, the endpoint devices are able to connect to connecting nodes or ZigBee protocol routers that have two responsibilities, which are increasing the number of nodes that can be connected in the network and expanding the size of the network. Because is the router sends information to different points in the network whereby the receivers do not have to be in the radio signal range as shown in Figure 2.6.

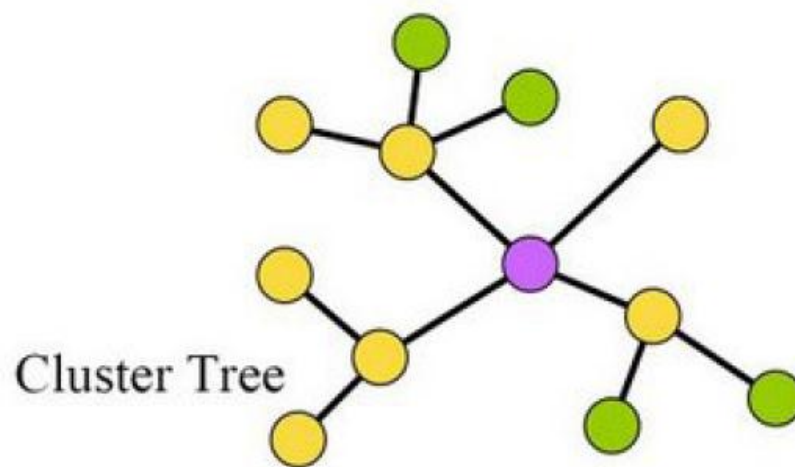


Figure 2.6 Cluster Tree (zigsense)

2.9.4 MESH Network

Mesh network can be used with the cluster tree except for FFD. It can transmit data to other FFD's directly without going through the cluster tree. The data sent to RFD has to be connected to RFD device prior to that. The advantage of this type of connection is to lessen the delay rate of the transmission and to increase the reliability of the system as shown in Figure 2.7.

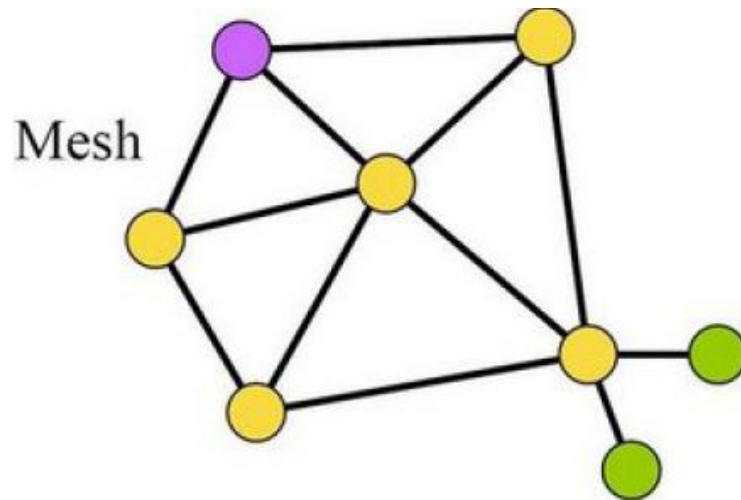


Figure 2.7 Mesh Network (zigsense)

Cluster tree and Mesh network are also known as ‘Multi-Hop, meanwhile star network is a Single-Hop. ZigBee protocol network is a network that connects to multiple devices all at once. This means that the connecting points in the network has equal chance of accessing the main used in communication. There are two ways of connecting multiple devices: Beacon and Non-Beacon. Non-Beacon is a connection of every connecting point within the network and can transmit data any time that a channel is available, while Beacon allows the connecting points to transmit data according to a preset period only.

2.9.5 Aodv Protocol

Aodv is a protocol used with X-Bee Module which can be compared with routing message between mobile computers or nodes in sending messages to the neighboring nodes as to get to the nodes that the origin cannot get to directly. During the data transmission, Aodv protocol will be finding the shortest routes and will not loop. Aodv protocol can control the diversion of routes and is able to find a new route if a mistake is occurred.

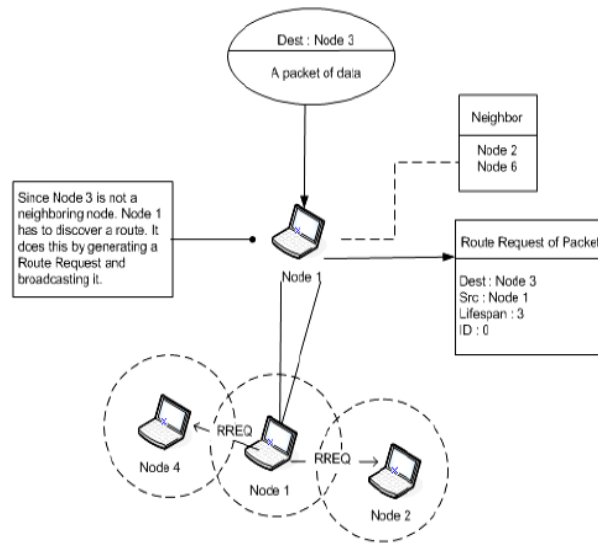


Figure 2.8 Operation of AodvProtocol (Sripatumuniversity)

From Figure 2.8 it is an example of data transmission via one node that needs to send data to the third node where the first node has 2 neighboring nodes that are node 2 and node 4. Therefore, node 1 cannot directly communicate to node 3. So it has to command RREQ to go to node 2 and node 4. Once these two nodes receive RREQ message from node 1 with two conditions that if these nodes know a path to the destination node or itself being the destination, they will send back a message saying 'Route Reply Message' to node 1, but if this does not apply, they will send back, 'Rebroadcast RREQ' to the neighboring nodes. But node 1 has not received a reply another RREQ will be sent out again to extend a lifespan and then create a new ID number attached to it.

2.9.6 Properties of Aodv

2.9.6.1 It only finds the needed paths.

2.9.6.2 It uses number in storing correct data.

2.9.6.3 It continues to collect data.

2.10 ZigBee is divided into 3 operating characteristics.

2.10.1 Coordinator

It works as a connector between end device and router by defining a varied address for the network.

2.10.2 End Device

It is at the endpoint which receives signals from the sensors.

2.10.3 Router

It transmits data via different paths of network and finds the shortest routes with the least time taken.

2.11 The design of communication between X-Bee Modules

For this project X-Bee Module is chosen in data transmission whereby it is under the ZigBee protocol standard. The advantage of X-Bee module is the ability to mesh connections and also point-to-point for long range.

2.11.1 The properties of X-Bee Module

2.11.1.1 Working frequency 2.4 GHz

2.11.1.2 Antennais Whip type

2.11.1.3 Operating Range Indoor Maximum height of 300 feet or about 100 meters.

2.11.1.4 Operating Range Outdoor (Line-of-Sight type) Maximum height of 1 mile or about 1,500 meters.

2.11.1.5 Delivery Capacity 60 mW (18 dBm).

2.11.1.6 Signal Reception Sensitivity 100 dBm.

2.11.1.7 The operation of ports: this can be defined by software, X-CTU, to work as an analog input for the circuit that converts the analog signals into digital output with 10 bit HD.

2.11.1.8 Power 2.8 up to 3.4 V.

2.11.1.9 ElectricalCurrent when sending data of 215 mA, receiving data of 55 mA, less than 10 A in the mode which reduces the power usage +3.3 V.

2.11.1.10 The temperature between 40 to 85 degrees.

2.11.2 The properties in Data Communication

2.11.2.1 It can run as the master or slave equipment.

2.11.2.2 The data transmission rate via radio frequency 250,000 bits per second.

2.11.2.3 Baud Rate is 1,200 up to 115,200 bits per second.

2.11.2.4 The conventional structural form point-to-point, point-to-multipoint and applicable with equipment under 802.15.4 standard.

2.11.2.5 Address Option the PAN ID, channels and addresses that can be encoded up to 65,000 codes.

2.11.2.6 Wave Spread Technology is DSSS (Direct Sequence Spread Spectrum)

2.11.2.7 Compatible with API and AT commands which can be defined via software.

This project has applied Mesh network in data transmission according to ZigBee Protocol. This kind of network is able to connect to multiple devices simultaneously, which means all the connecting points in the work are equally able to access the main used in communication. The benefit of this kind of network is to decrease the transmission delay and to increase the reliability of the system.

2.12 Sea Wave

Waves from winds, earthquakes, volcanic eruptions, and winds prevailing over the water causing the surface to rise in a form of waves and the wave height allows us to know the strength of the winds. When the waves move away from their origin, they will gain mass or get bigger as they collect smaller waves along the way. When the waves reach the shore, they will hit the ground first causing the waves to be very high and the front of the waves will curve up in parallel to the shore, this phenomenon is called, 'refraction of waves'.

A wave consists of the top of the wave called, 'crest', and the bottom of the wave is called, 'trough', which is the drop from the wave top to the bottom of the

wave. Amplitude is the height of the wave. The current of the wave has a circular motion which occurs at the water surface and under the water. The circular motion of the water is smaller when the depth of water increases. In shallow water trough moves and hits the floor and the motion is more oval. When the wave moving towards the shore, the wave top continues to move very quickly while trough has a lot of friction from the wave being high off the ground and rolling forward, and then hits the shore where the wave breaks into foams and bubbles. This event is called, 'breaker or surf'. The wave that reaches the shore that is less slant, it is called, 'swash'. And when a wave hit the shore and disperses, it is called 'backwash'. The influence from the wave action is a cause of land erosion directly. Land erosion from constant waves at the sea shore is simplified into various types as the following.

2.12.1 Washing

The washing means to erode during the breaker which pushes the water up on the land and then reverses into the sea.

2.12.2 Abrasion

Abrasion is a type of erosion that involves sands and pebbles caused by the sands and gravels being pulled back on rocks along the shore into the water.

2.12.3 Plucking

The Plucking is an erosion of waves in a form of rocks hit by waves and their fragments come off.

2.12.4 Notching

The notching is when waves erode the rocks with constant shore breaking causing some kind of caves below cliffs.

CHAPTER III

MATERAILS AND METHODS

In this chapter, the research methods will be discussed in the areas of sea wave data transmission via both obstructed and unobstructed environments of the tool, ‘XBee-Pro module’, which is a wireless sensor network.

3.1 Tools exploited in the research

3.1.1 Hardware

WSN	XBee-PRO Modules Infrared Distance Sensor
CPU	Intel® Core™2 Duo CPU
RAM	at least 1.66 GH
Hard Disk	at least 1.5GB
Monitor	Super VGA Monitor
Peripherals	Mouse, Keyboard, Printer and DVD-Rom

3.1.2 Software

Operating System	Microsoft Windows 7 Ultimate
WSN program	X-CTU Arduino
PDF View Tool	Adobe Acrobat 7.0 Professional
Other Tool	Microsoft Word 2003 Microsoft PowerPoint 2003 Microsoft Visio 2003

3.2 Step and Research Methodology

In order for this research to be effectively completed, the research procedure was divided into 7 steps as followed by Figure 3.1.



Figure 3.1 Methodology Framework Diagram

3.2.1 Designing a sea wave energy measurement system

The WSN was used to measure energy for sea wave via displacement transducer and 2.4 GHz ZigBee module as shown in Fig. 3.2. The measured data was send to the monitoring station where is at a housing on the beach. The radio wave propagates though the pine forest on the sea side. In order to continue the radio wave from the sensor to monitoring station, the repeaters are used in the wireless network. This requires the path loss model of the pine forest for designing the network.

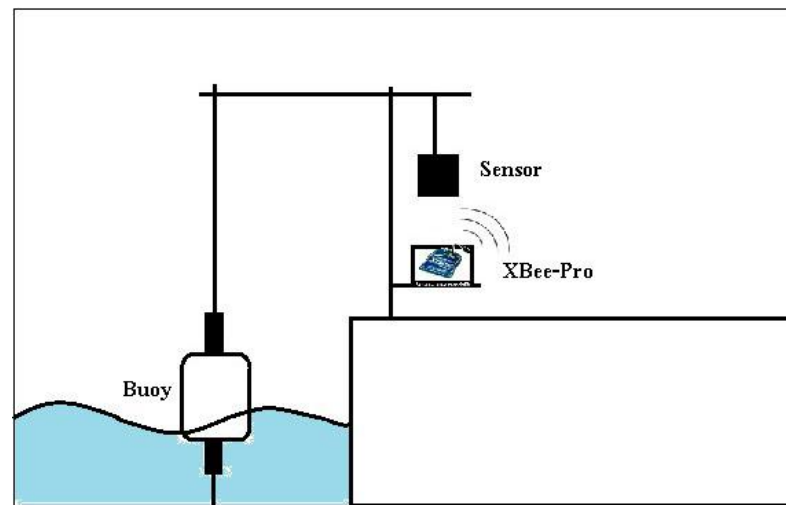


Figure 3.2 Sea Wave Energy Measurement Systems

The measurements were performed at a frequency of 2.4 GHz. The equipment for propagation measurement consisted of a fixed CW transmitter and a portable spectrum analyzer. The transmitter consisted of HP 83732B signal generator (with 18 dBm output) and a quarter wave dipole antenna. We used HP 8593E spectrum analyzer with a 30 dB low noise amplify (LNA) and a quarter wave dipole antenna for signal strength measurement as shown in Figure. 3.3 and 3.4. The transmitting antenna was placed inside the forest at a constant height of 3.9 m. The antenna polarization is bolt vertical and horizontal alignments. For each measurement point, at least 36 samples in grid points with quarter wavelength separation were taken to local average power. During the measurements, the wind speed was also recorded and there is a restriction on human obstruction so as to obtain naturally path loss.

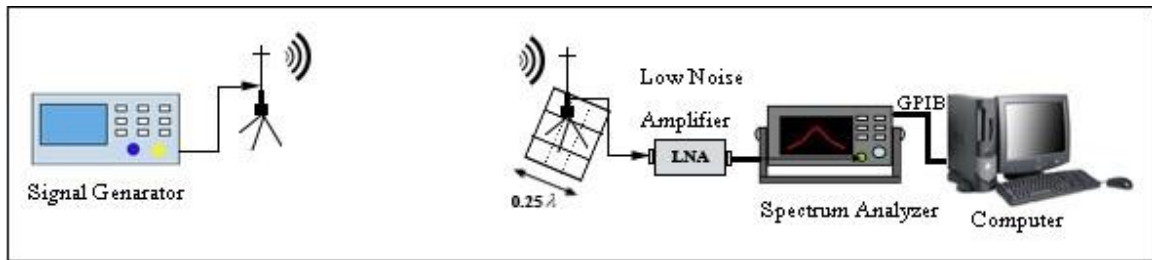


Figure 3.3 Depicting the Operation of the Wireless Sensor Network System without Obstruction

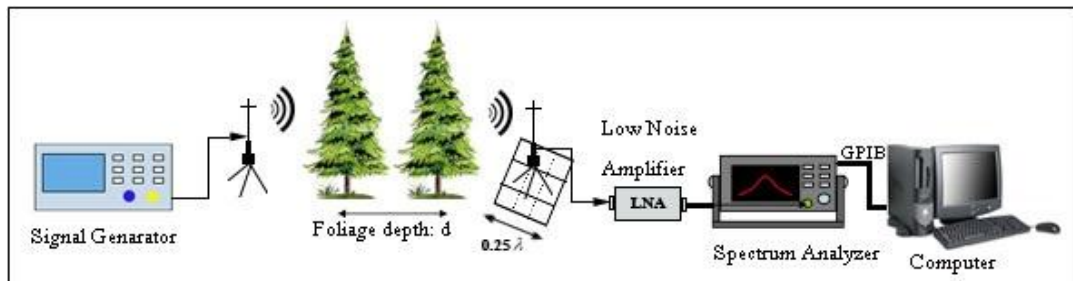


Figure 3.4 Depicting the Operation of the Wireless Sensor Network System with Obstructions



Figure 3.5 Photograph of the Measurement Set Up

3.2.2 Designing Hardware/Software and Installation

3.2.2.1. Hardware used in the Study

3.2.2.2 XBee-Pro Module includes

- XBee-Pro it is a wireless sequential communication module via radio wave with high frequency of 2.4 GHz.

- ZX-XBee232 it is a board connecting XBee Module to a computer sequential port that was used in data transmission and value setting so that the XBee Module could be used (In the package, a connecting cord for connecting a sequential port to a direct power adapter was included.

- ADX-XBee5V it is a board for XBee Module and equipment using +5V as shown in Figure 3.5 and 3.6

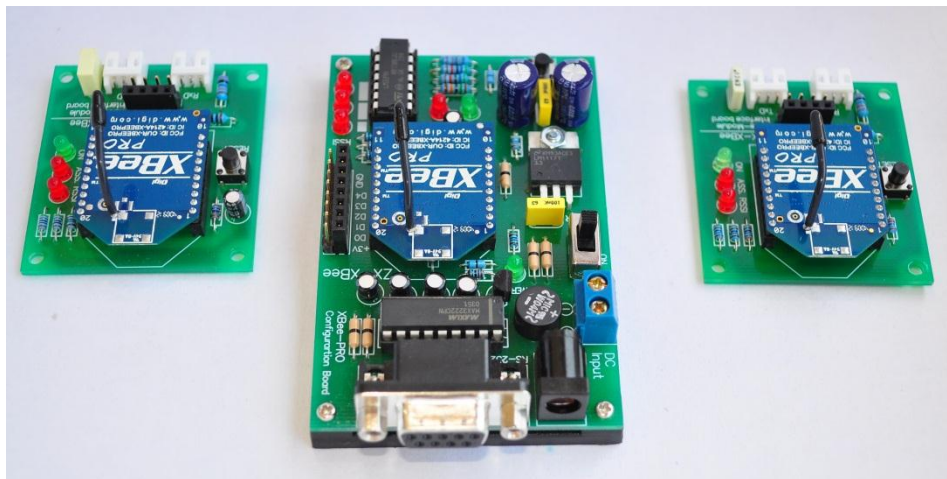


Figure 3.6 XBee-Pro Modules

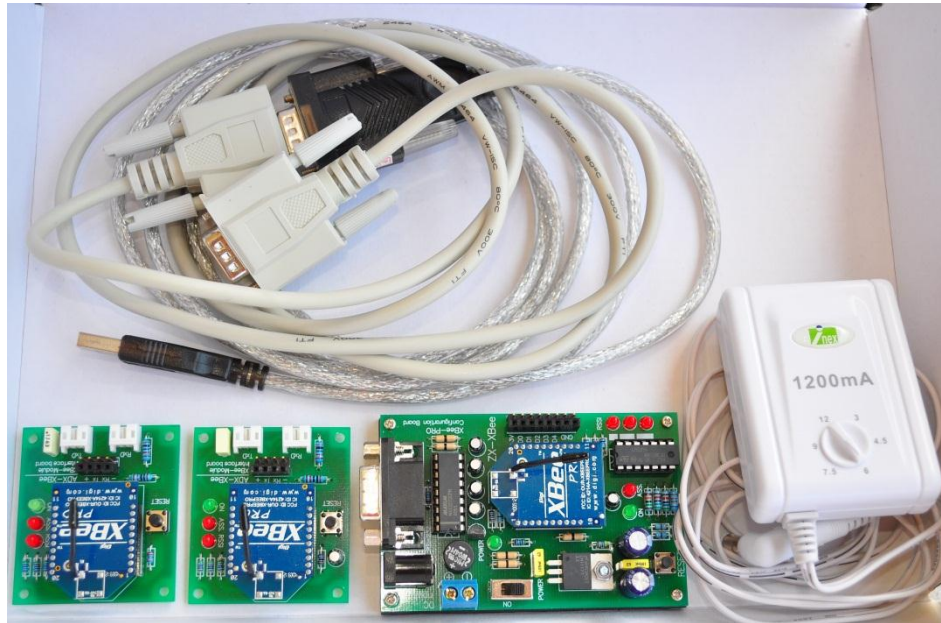


Figure 3.7 The equipment of XBee-Pro Module Package

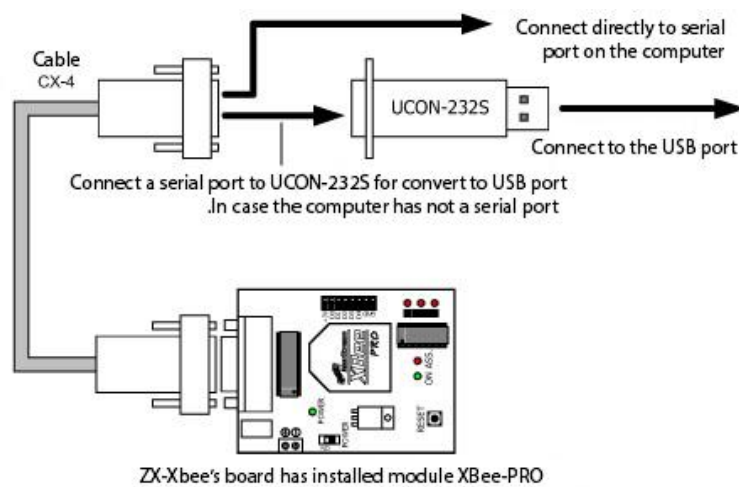


Figure 3.8 Components of XBee-Pro Module connected to a computer to be used as a data receiver

3.2.2.3 POP-168 consists of

- POP-168 Module as shown in Figure 3.9
- POP-INTERFACE Board as in Figure 3.9
- CX-4 cable cords for the sequential port connection

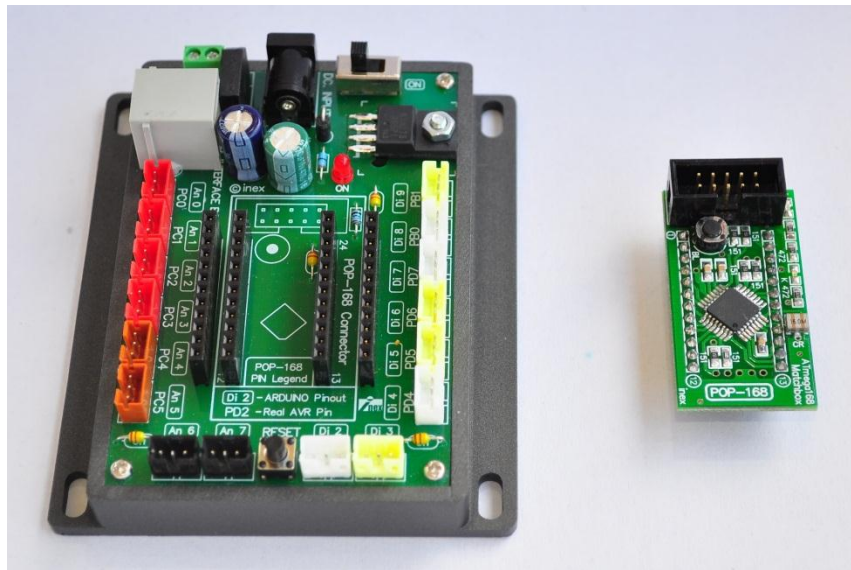


Figure 3.9 POP-168 Modules and POP-INTERFACE Board

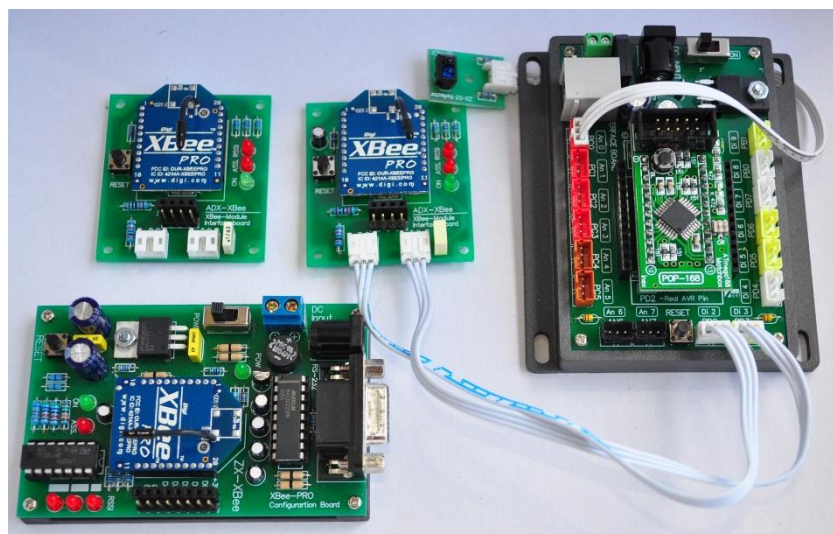


Figure 3.10 POP-168 Module connected to a sensor and a data sender

3.2.2.4 Software Interface used in this research includes

- X-CTU

X-CTU is a Windows-based application provided by Digi., which is a software interface that helps updating firmware, operation testing, and

adjusting the parameter and Xbee-Pro Module. X-CTU is designed to function with all Windows-based computers that run Microsoft Windows 98 SE and above. X-CTU can either be downloaded from Digi's website or an installation CD.

- Arduino

Arduino is a tool that enables computers to receive external signals and to send signals to control outer equipment more effectively than using a desktop PC. The main board is designed with a single microchip computer with a development program for compiling and uploading program for Arduino POP-168 Module. Arduino also can produce a useful gadget that receives signals from a switch or a sensor and control light bulbs, motors, or other equipment. Arduino project can be either autopilot or hooked up to a PC program. A board can be self-made or bought from a certain store, but for the Arduino development program can be downloaded for free online.

3.2.2.5 Antenna

XBee is clearly separate series by data transfer range with a word is "Pro" In low series have transmission power is 1-2 mW have range around 100-120 meter. In series PRO transmission power is 50-60 mW have range around 1500 meter. XBee can make range depend on environment and antenna cause of 2.4 GHz is a high frequency has more distortion and obstruction have more effect with range. The ranges of XBee transmission as spec at datasheet depend on antenna. XBee have 4 antenna are Wire, Chip, UFL and SMA, but this project used Wire Antenna range and stability is follow as the spec.

3.2.2.6 Feature Summary

- Operating Frequency ISM Band 2.4 GHz. The ISM Band means frequency of research which allowed using in Industrial, Scientific and Medical (ISM)

- Have some antenna are Chip Ant, Whip Ant, UFL Con, RPSMA con.

- Supply Voltage between 2.8-3.4 V

- Power Down Current < 10uA

- Have RF data rate is 250 Kbps

- Have Serial interface data rate between 1200 – 115200 Bps

- Have Spread Spectrum is DSSS (Direct Sequence Spread Spectrum)

- Determination addressing have stack is set PAN ID for one network, set channel and set address in each device.

3.2.2.7 XBee Transmission, Antenna and noise

XBee is uses 2.4 GHz is same frequency as Bluetooth or Wireless Lan, thus the signal have noise when uses with other wireless device as wireless Lan and wireless phone (2.4 GHz cordless telephones). For experimentation XBee have transmission resulted signal are drop a bit but sometime work fine. Frequency 2.4 GHz is called microwave signal. The mainstream of microwave signal is positions of device are in line of sight (no obstruction) It will get powerful. For XBee transmission power of Pro series is 50-60 mW in datasheet have shown 1.5 km (line of sight). If not line of sight, the range will decrease by obstruction and environments see at this table below.

Table 3.1 Distance of XBee on each type.

Module	Antenna Type	Outdoor Distance (Visual Line-of-Sight)	Indoor Distance (Office Building)	Indoor Distance (Warehouse)
XBee	Chip	470 ft. (143 m)	80 ft. (24 m)	-
	Whip	845 ft. (258 m)	80 ft. (24 m)	84 ft. (26 m)
XBee-PRO	Chip	1690 ft. (515 m)	140 ft. (43 m)	-
	Whip	4382 ft. (1335 m)	140 ft. (43 m)	355 ft. (108 m)

Table 3.2 Spec XBee on each series.

Feature	Series1	Series2	Series1 Pro	Series2 Pro
Power Input	3.3V @ 50mA	3.3V @ 40mA	3.3V @ 215mA	3.3V @ 295mA
Max data rate (Air)	250kbps	250kbps	250kbps	250kbps
Power Output	1mW output (+0dBm)	2mW output (+3dBm)	60mW output (+18dBm)	50mW output (+17dBm)
Distance	300ft (100m) range	400ft (120m) range	1 mile (1500m) range	1 mile (1600m) range
Antenna	Wire,Chip,UFL,SMA	Wire,Chip,UFL,SMA	Wire,Chip,UFL,SMA	Wire,Chip,UFL,SMA
Peripheral	6 10-bit ADC input pins 8 digital IO pins	6 10-bit ADC input pins 8 digital IO pins	6 10-bit ADC input pins 8 digital IO pins	6 10-bit ADC input pins 8 digital IO pins
Upgrade Firmware	Local	over-air configuration(ZB)	Local	over-air configuration(ZB)
Network	Point to point and multi-point networks	Point to point / multi-point / Mesh Network	Point to point and multi-point networks	Point to point / multi-point / Mesh Network

XBee Whip antenna is ready-made. Pattern wave propagation of whip antenna have a good spread and have advantages are dimension not too big and have increase gain (+3 dBm), then it have range of transmission as spec in datasheet follow as Figure 3.11.

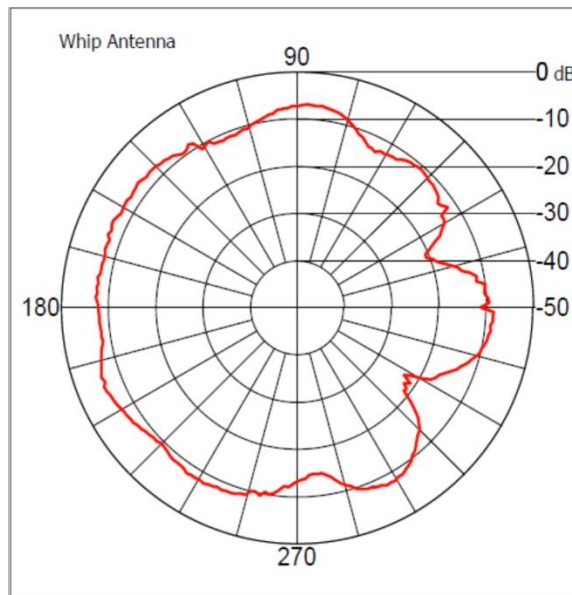


Figure 3.11 Spread of wire antenna

3.2.2.8 Sampling

Most microcontrollers have a peripheral on them called an Analog to Digital Converter (ADC). This is a very useful feature that converts a voltage (analog) on a pin to a number (digital) that can be manipulated in a program. The ADC will convert the voltage to a number that we can use in our program, but in order to decipher what that number means we have to know what voltage that number is representing. Basically, we have to convert the number back to a voltage.

The first need to know two numbers that are dependent on the system configuration: the voltage that the system is running on (usually 3.3V or 5V) and the maximum range that the ADC number can report. The maximum range for the ADC is dictated by the ADC size, and is usually defined as a number of bits (8-bit, 10-bit, 12-bit, etc.). This project used 5V and analog inputs have a 10-bit resolution (2^{10}). The maximum range for a 10-bit ADC is 1024. The actual numbers in the range are 0-1023, but the important part for this conversation is that there are 1024 discrete numbers. It is can convert to decimal system are 1024. So that is 1024 states, divided in the range 0-5V.

$$\frac{5V}{1024 \text{ States}} = 0.00488V \text{ per state (4.88 mV per State)}$$

Basically means that can read the Arduino analog inputs and get a value between 0 and 1023. Each increase in this value signifies roughly a 4.88mV increase in the voltage measured. Once got know these two numbers it is can calculate how the numbers relate. The voltages are usually represented in millivolts (mV). This is the equation that describes how the ADC value is created.

$$\text{ADC Value} = \frac{(\text{Voltage on pin(mV)}) * 1024}{5000}$$

3.2.2.9 Installation

- X-CTU Installation

Double click on setup_x-ctu.exe as in the picture below.

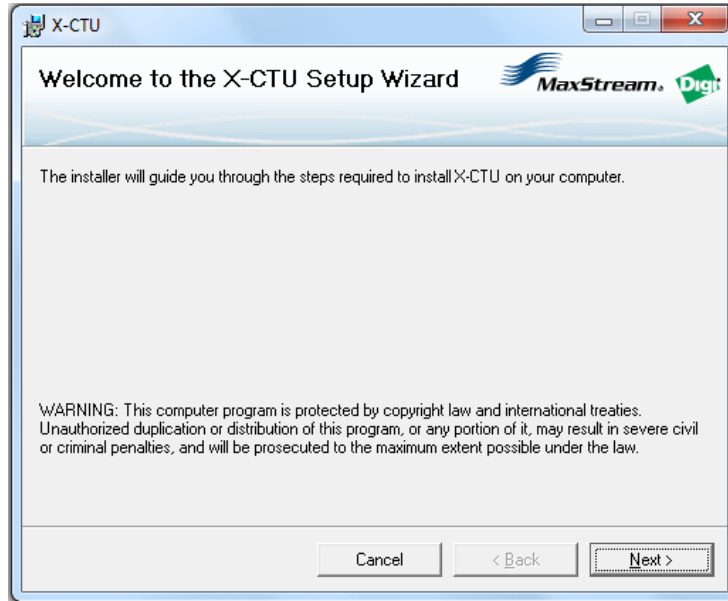


Figure 3.12 Install the program, X-CTU.

After clicking on the ‘Next’ button, an agreement window will pop up. Choose ‘I Agree’ to accept the copyrights of the program as show in Figure 3.13.

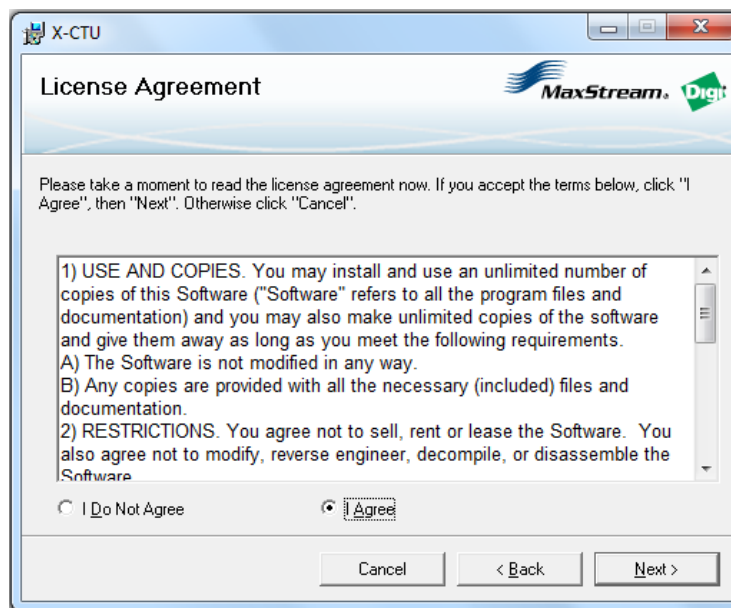


Figure 3.13 Accept the copyrights of the program as part of the installation process

After clicking on 'Next', a window will pop up for choosing a drive for data storage as shown in Figure 3.14.

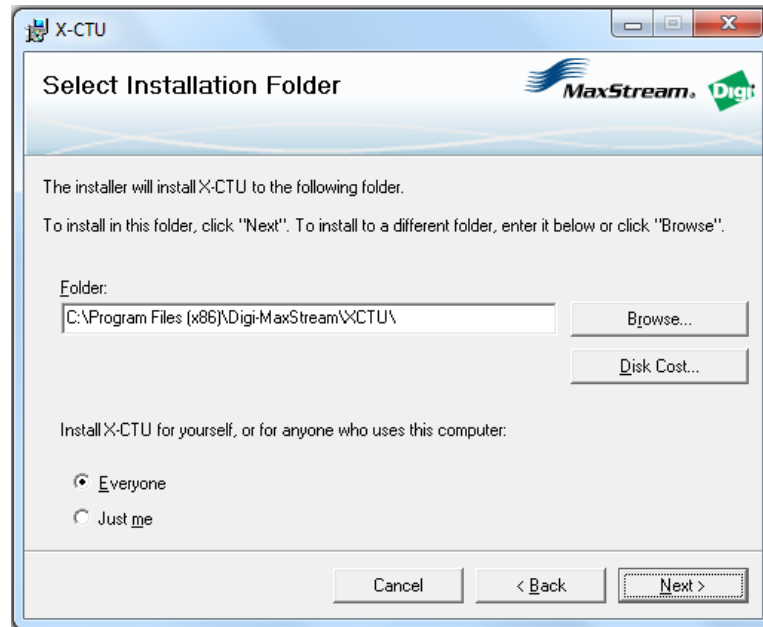


Figure 3.14 Select an Installation Folder

After clicking on 'Next', a window will pop up showing the program is being installed as shown in Figure 3.15.

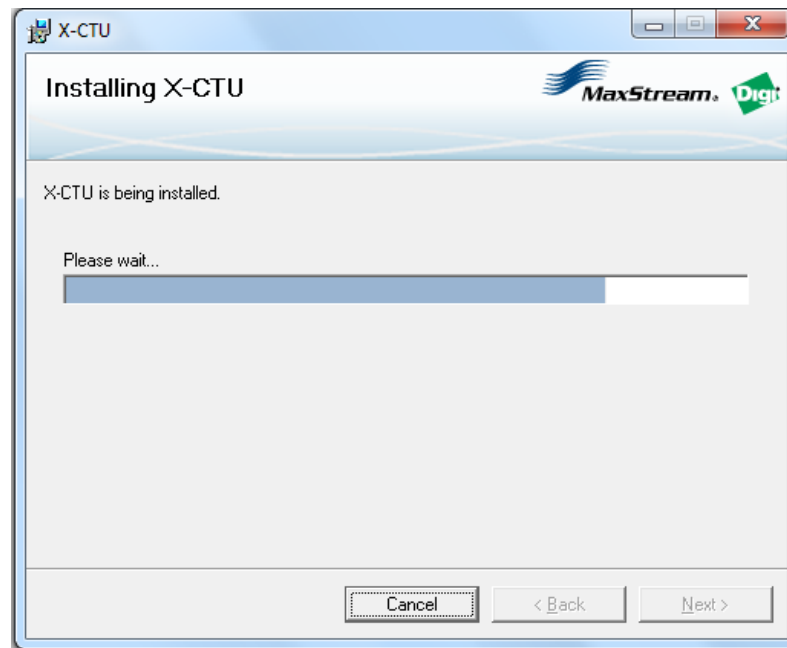


Figure 3.15 Installing X-CTU

During the program installation, a window will pop up and ask if you want to update firmware as shown in Figure 3.16.

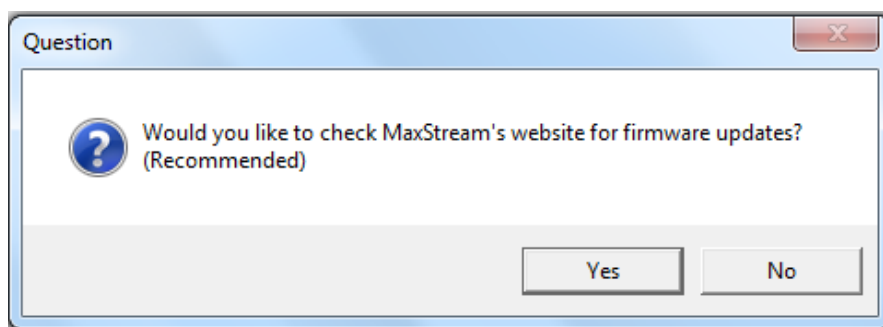


Figure 3.16 Check for firmware updates

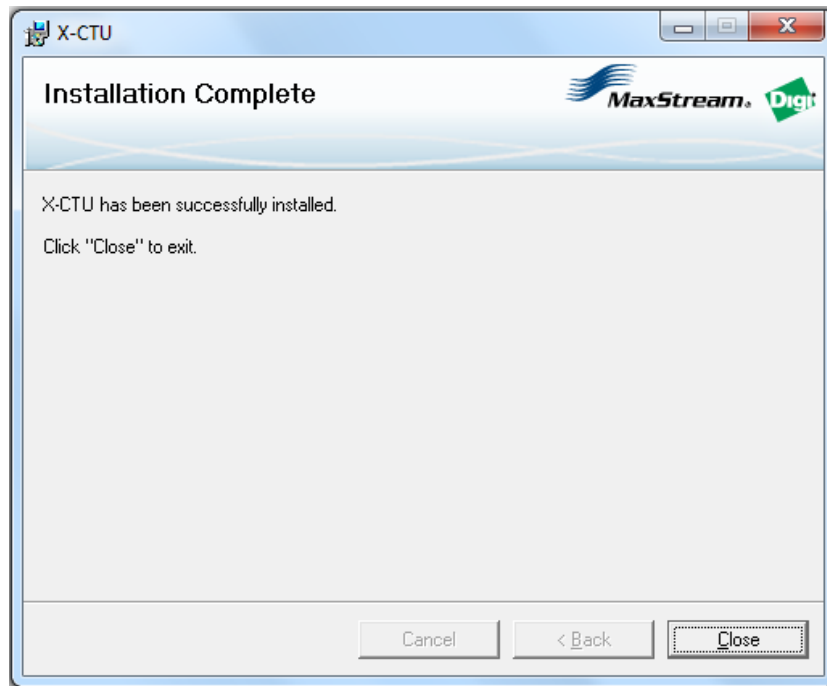


Figure 3.17 Installation complete

After the installation has been completed, open the X-CTU program as to connect to, X-Bee Pro, the tool used for data transmission. When adjusting the com port setup, all the ports that are connected between the computer and the transmission tool where the following values should be set to Baud=9600, Flow Control=NONE, Data Bits=8, Parity=NONE, Stop Bits=1 will be shown in Figure 3.18.

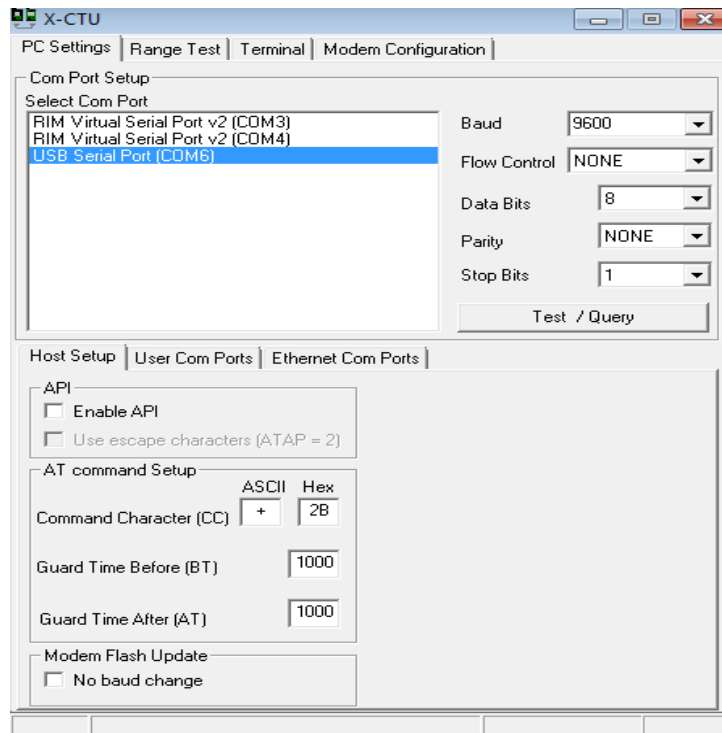


Figure 3.18 X-CTU Setup

After setting the desired values of X-CTU, click ‘Test/Query’. A window will show the successful connection of the equipment together with explaining in details the modem type and modem firmware version as shown in Figure 3.19.

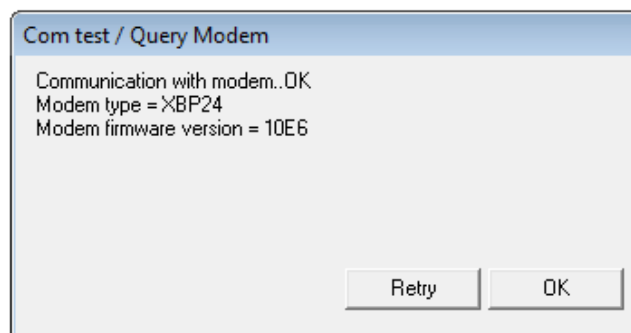


Figure 3.19 Com test/Query Modem

On the X-CTU's screen the connection to port COM6 will be shown, choose 'Tab Modem Configuration'. For each version of X-Bee, it contains a firmware that has already been programmed by the factory, which its value setting can be checked by clicking on 'Read'. Setting parameter can be done through X-CTU where the data sender known as 'End Device' (CE=0) and MY=1; and for the receiving end known as 'Coordinator' CE=1 and MY=2, and both of their baud rate of X-Bee are set to 9600 bps (BD=3) as shown in Figure 3.20.

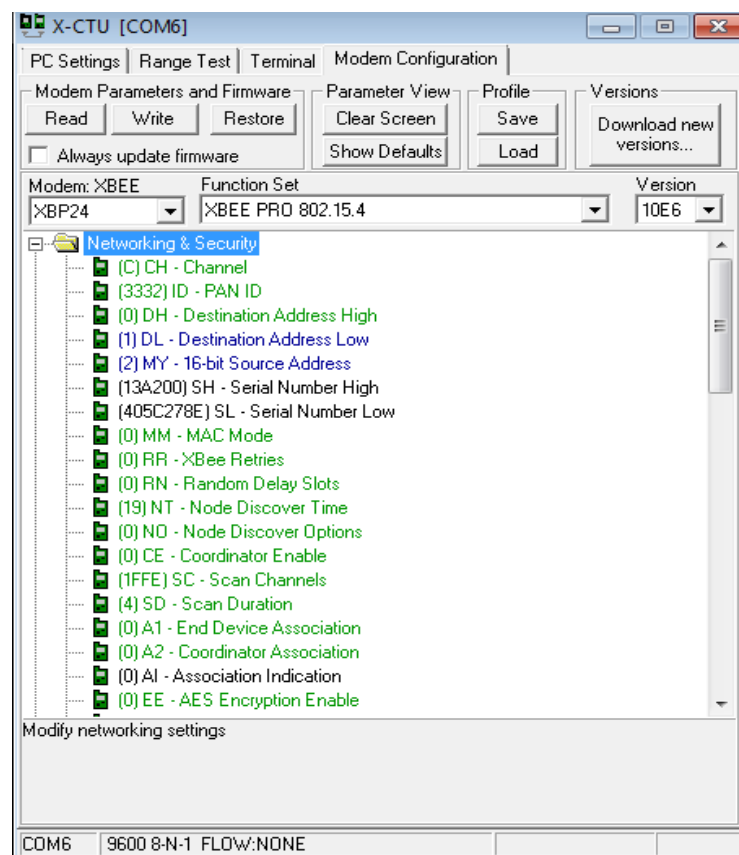


Figure 3.20 X-Bee Pro Configurations

Choose ‘Tab Range Test’ to test the data transmission as shown in Figure 3.21.

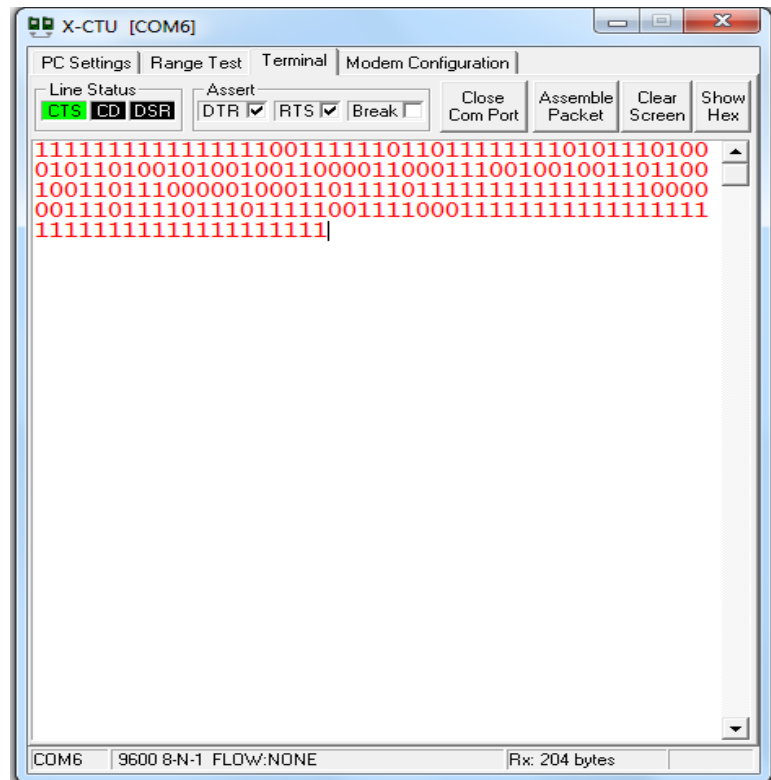


Figure 3.21 Send and Receive Test

- Arduino Installation

Double click on ‘ArduinoSetup.exe’, and then a window will pop up as shown in Figure 3.21, click ‘Next’ all the way until the setup is complete as shown in Figure 3.22 – 3.25.



Figure 3.22 Arduino's installation

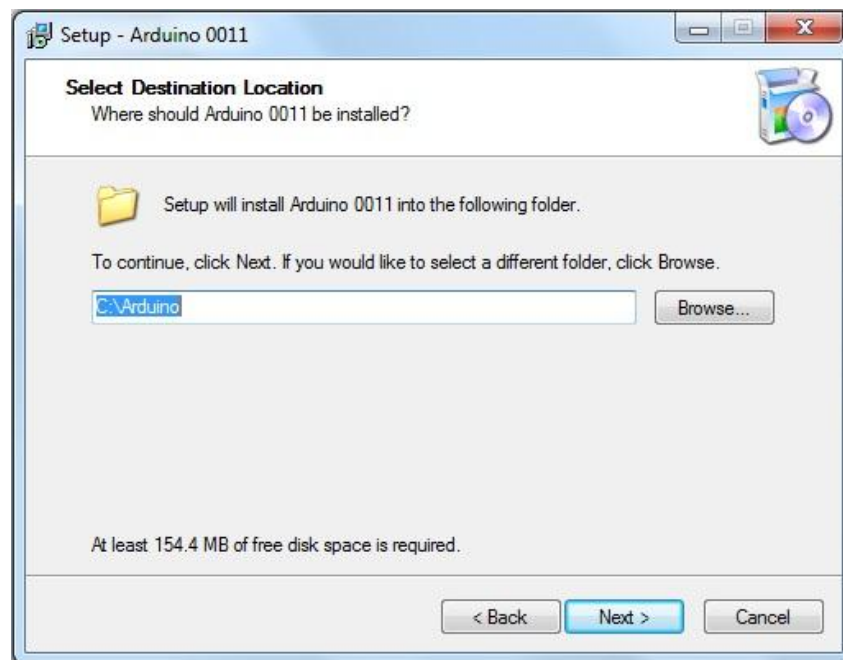


Figure 3.23 Select Destination Locations

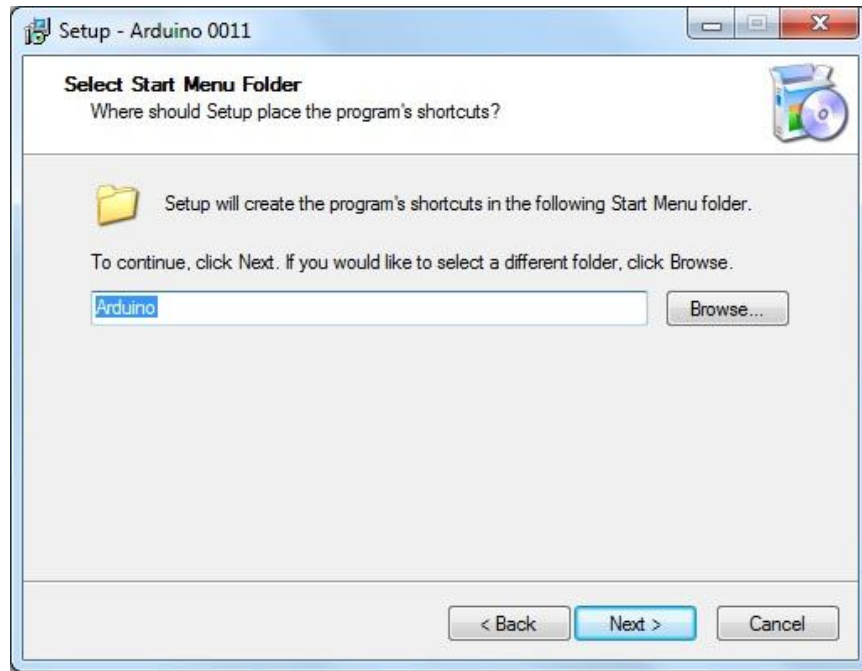


Figure 3.24 Select a Menu Folder

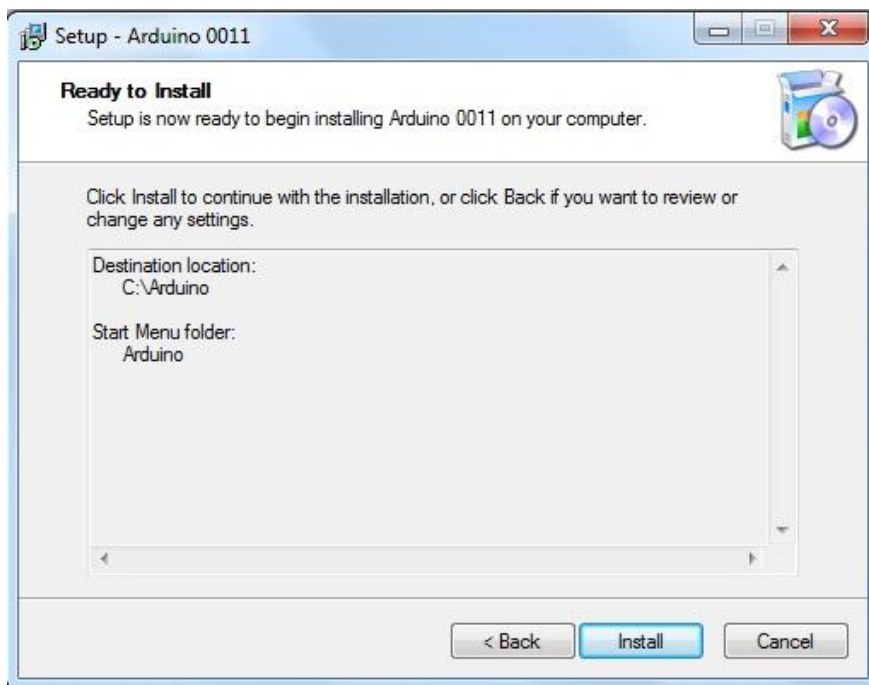


Figure 3.25 Ready to Install

After clicking 'Install', a window will appear showing the program being installed as shown in Figure 3.26.

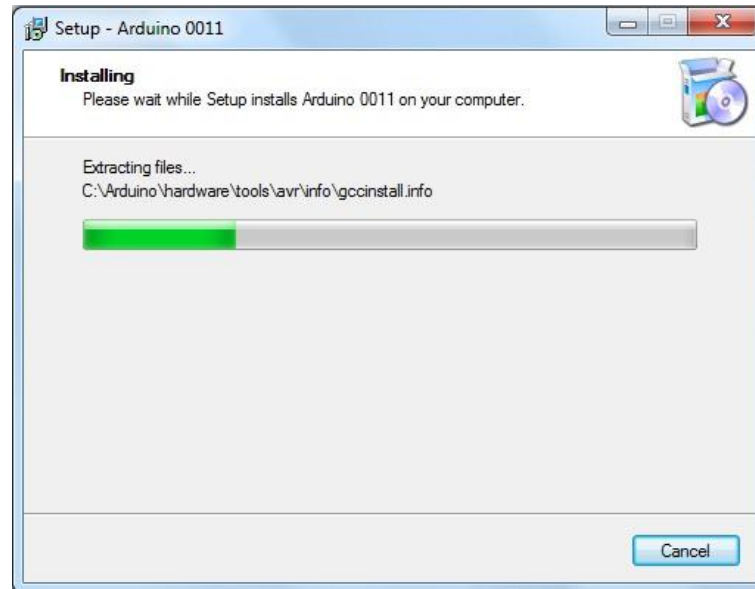


Figure 3.26 Installing Arduino

After installing Arduino has been successful, open the program to write a command of the ocean wave signal receiver as shown in Figure 3.27.

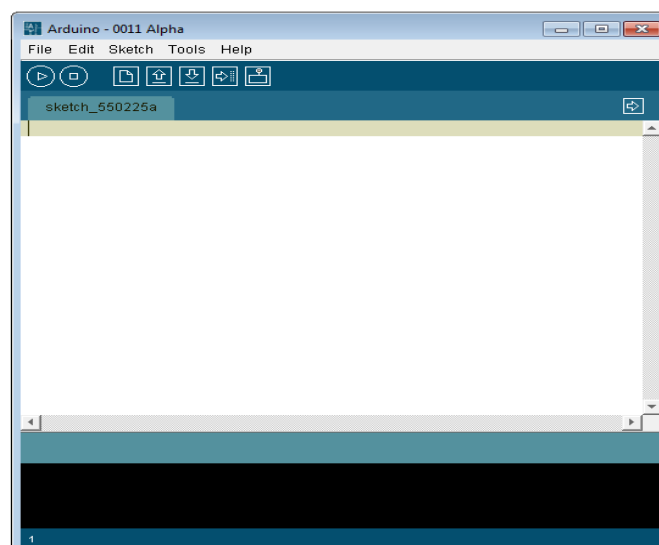


Figure 3.27 Program interface, Arduino

When using Arduino for the first time, the values of the incorporated hardware will need to be set such as the microphone control, etc, and the sequential ports of the computer also need to be connected. After the values have been set, later, every time the program is used it will apply the previously set values by choosing Tool > Board > POP-168 as shown in Figure 3.28.

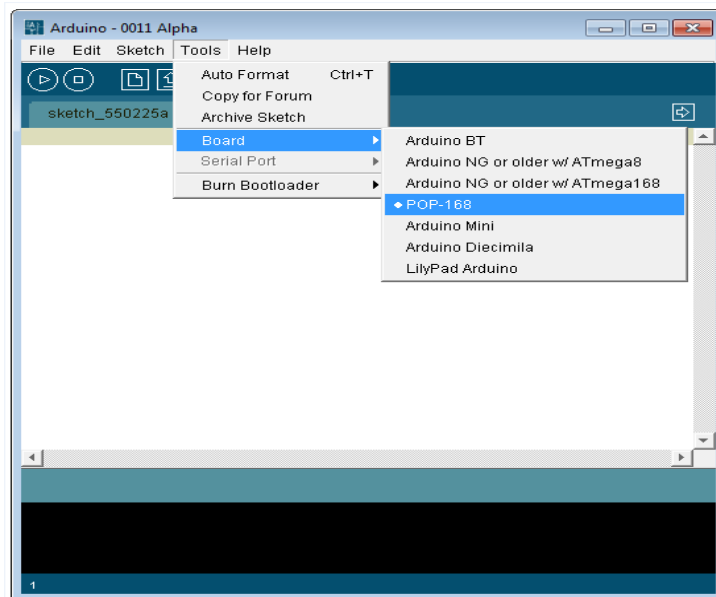


Figure 3.28 How to choose a microphone control of Arduino

When uploading a program from Arduino to POP-168 it is done through a sequential port that needs to be set as follows. Click on the tap, 'Tools', then click 'Serial Port', then it will show available ports; choose the desired port as shown in Figure 3.28. Sequential ports used with POP-168 can be both a normal port that already comes with the computer, which is usually COM1 port, or COM2 port and a virtual COM port that is additionally installed via a USB port. This is a sequential port RS-232, which is usually COM port that is signified with a number greater than 2, but in this case, COM6 is chosen because it is a USB port as shown in Figure 3.29.

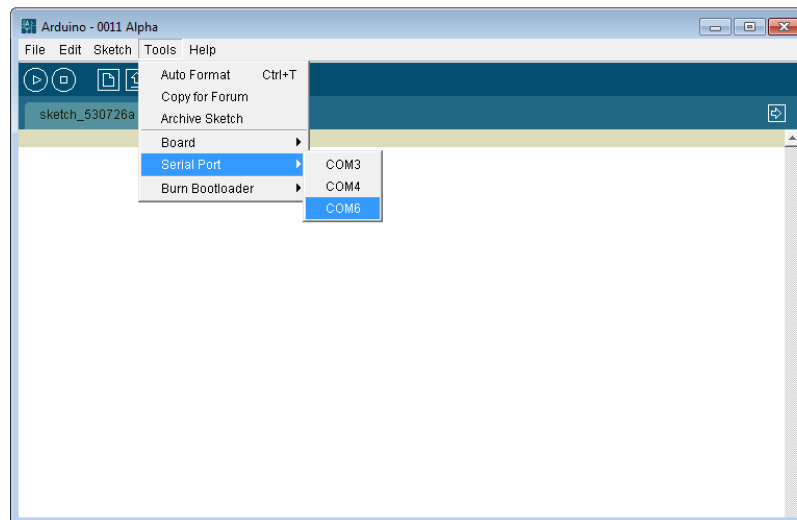


Figure 3.29 How to select a port to connect to POP-168 Module

Click on the drop down menu, 'File', then click 'New' to set up a program for the microphone control POP-168, which is done by using Arduino programming language. This programming language follows C/C++ with functions and library of digital input and output, analog input and output, communication via sequential ports, and mathematics as shown in Figure 3.30.

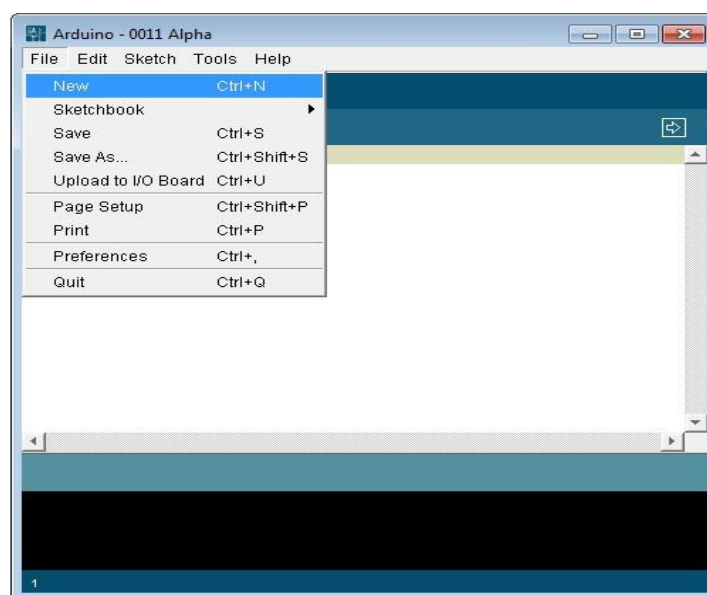
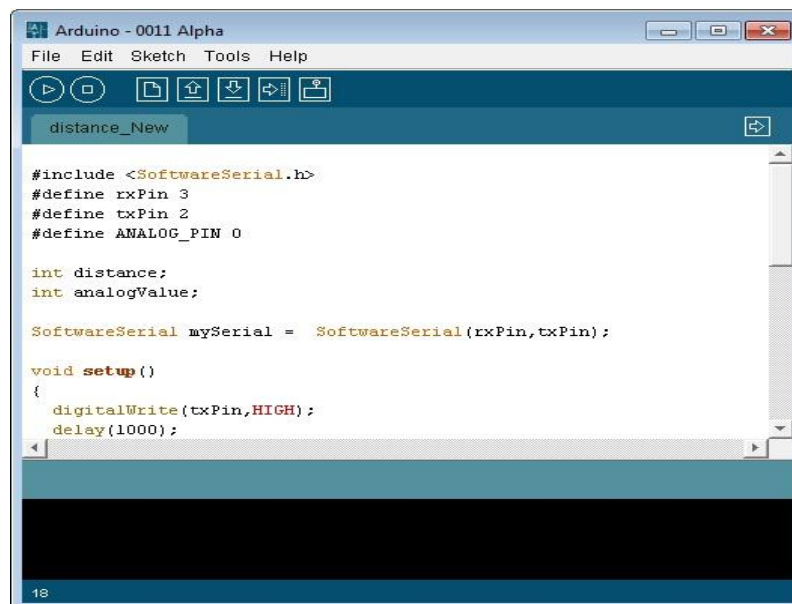


Figure 3.30 How to construct a program for POP-168 Module

The C programming language of Arduino for data receiver and display are divided into two parts including a void set up function for when the program runs it will execute the function once that is used at the beginning of the operation such as variables, etc. As for the void loop, the program will run this command continuously, for instance, reading in input values, processing output values, etc.

The image shows a screenshot of the Arduino IDE interface. The window title is "Arduino - 0011 Alpha". The menu bar includes "File", "Edit", "Sketch", "Tools", and "Help". Below the menu bar is a toolbar with icons for running, stopping, saving, and other functions. The main text area contains the following C code:

```
#include <SoftwareSerial.h>
#define rxPin 3
#define txPin 2
#define ANALOG_PIN 0

int distance;
int analogValue;

SoftwareSerial mySerial = SoftwareSerial(rxPin,txPin);

void setup()
{
  digitalWrite(txPin,HIGH);
  delay(1000);
}
```

The status bar at the bottom left shows the line number "18".

Figure 3.31 C programming language of Arduino for receiving and displaying data

After having finished writing the program, the program is compiled by choosing from the drop-down menu, 'Sketch', and then chooses, 'Verify/Compile' as shown in Figure 3.32.

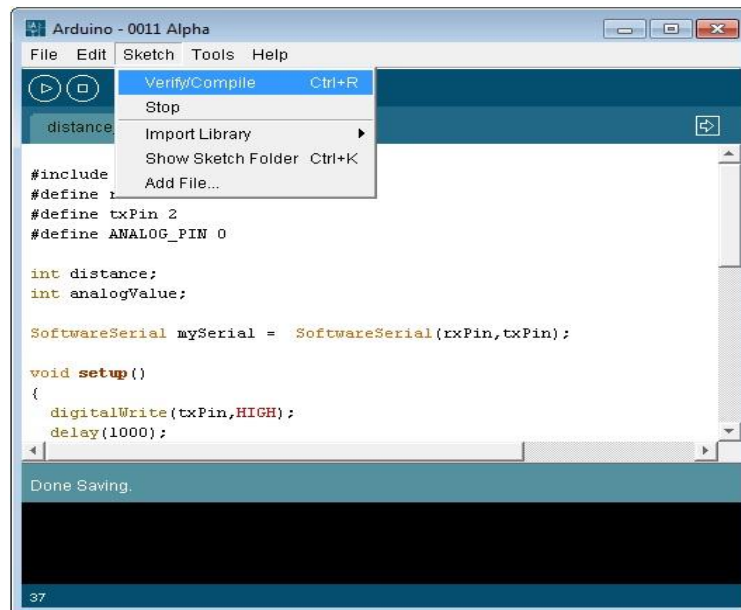


Figure 3.32 Choosing from the command menu as to compile the program

After compiling the program, it can be checked from the compile display window and at the very bottom of the screen the compiling status should say, 'Done compiling', and a message saying 'Binary sketch size: 2758 bytes (of a 14336 byte maximum)' as shown in Figure 3.32 that shows the compiled program's size is 2758 bytes from a flash memory size of 14336 bytes of the entire micro control as shown in Figure 3.33.

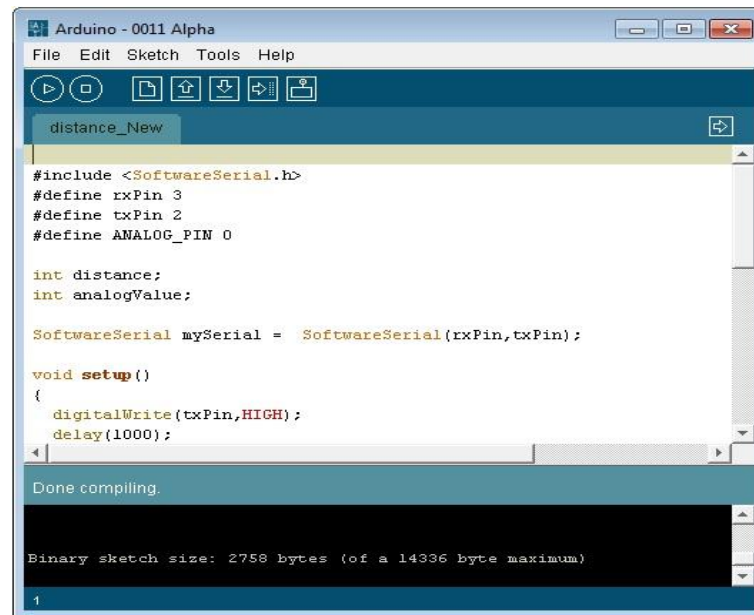


Figure 3.33 Done compiling to notify a successful compilation and also tells the size of the compiled file

After the compilation is complete, the next step is to upload the computer language program onto POP-168 Module as follows:

- (1) Press the BL switch on POP-168 Module (Press the white switch located on POP-168 Module as shown in Figure 3.33).
- (2) After that press hold the RESET switch (Press the black switch on the POP-INTERFACE board as shown in Figure 3.33).
- (3) Release the RESET switch and then let go of the BL switch.
- (4) Observe the blue LED on the POP-168, if it stays on it means the POP-168 Module is in operation ready for uploading follow in Figure 3.34.

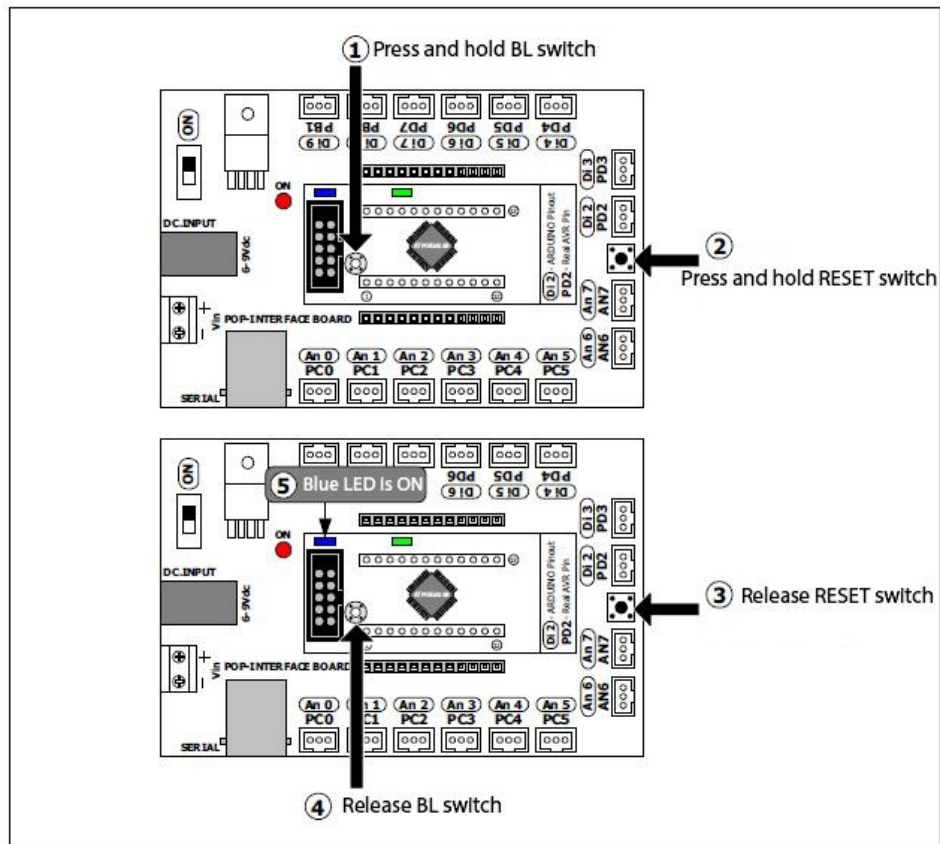


Figure 3.34 Shows the program mode of the POP-168 when using the POP-Interface board

(5) On Arduino select from the dropdown menu, 'File', then click 'Upload to I/O Board' as shown in Figure 3.35.

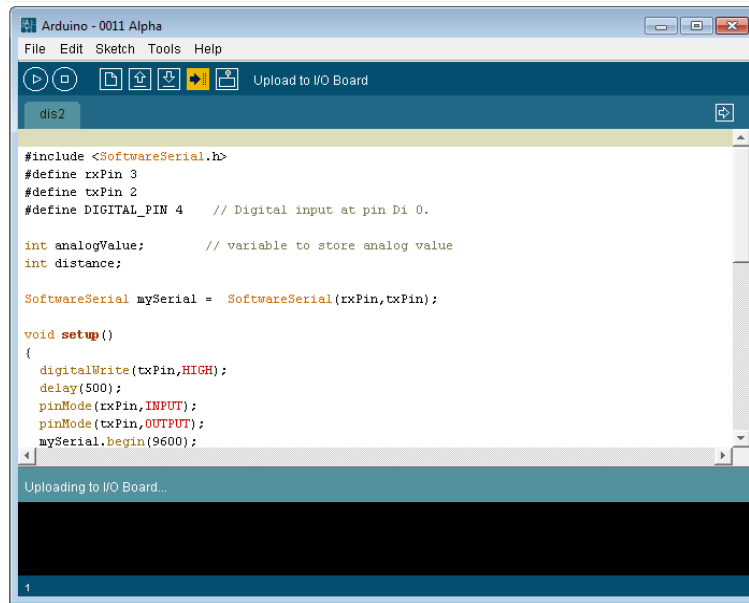


Figure 3.35 The Arduino window that is uploading the program

(6) When the upload is complete, a message saying ‘Done Uploading’ will appear as shown in Figure 3.36.

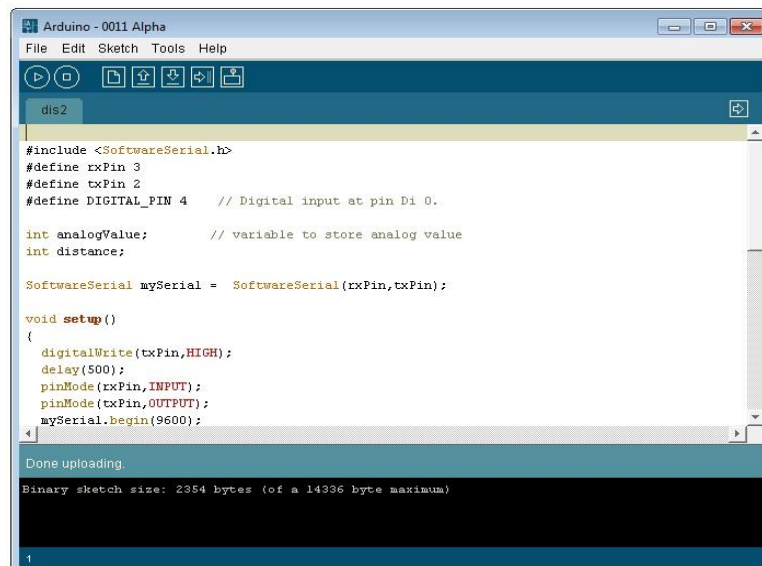


Figure 3.36 The window of Arduino after the program is successfully completed

(7) After the program is completely uploaded, press the RESET button again to start the program.

3.2.3 The Data Sending Procedure

3.2.3.1 When configuring the XBee-Pro of the data sender, the values are set by using X-CTU that is connected between the computer and the data receiver board, ZX-XBee232 via a serial port (RS232) where the data sender is the end device (CE=0) and MY =1 while the set baud rate on both XBees is 9600 bps (BD=3) as shown in Figure 3.20. In part of the microcontroller, the POP-168 will receive the data from a distance sensor and will send the data of the height of the ocean waves through the XBee-Pro that runs as the data sender as shown in Figure 3.2.

3.2.3.2 To test the path loss when sending data of the sea waves in an unobstructed environment (Line of Sight) and in an obstructed environment such as a pine forest by the sea shore. A signal generator, used as a signal sender through the pine forest, sent a frequency of 2.4 GHz (same frequency as of XBee-Pro Module) as shown in Figures 3.3, 3.4, and 3.5.

3.2.4 Environment (Pine Forest)

The signal measurements were done on a seaside at the Sirindhorn international environmental park of Thailand during the winter season see in Figure 3.37. The foliage chosen for this study is a pine forest on the beach near the sea wave generator as shown in Figure 3.5.

The forest consists mainly of soil and sand, with some parts covered with grass. The pine trees are evergreen and have an average height of approximately 60 m and are nearly equally spaced with a distance of 4 m. The average tree trunk diameter is around 0.25 m. The leaf is straight line with a diameter of 0.8 mm. There are several groups of leaf in a sub-branch. A group of leaf consists of about 60 leaves. The foliage depth is more than 500 m. This foliage depth is observed from the ground survey. During the measurement, the foliage is dry with strong wind.

The Sirindhorn International Environmental Park is located in Pharam 6 Barrack, Haynes Sub district, Cha-am District, Phetchaburi Province, on the kilometer mark of 216, near to the gulf of Thailand. This national park is established to

commemorate the 48th birthday anniversary of Royal Princess Maha Chakri Sirindhorn's Princess in 2005 and to restore the environment along the mangrove forest, beach forest, and the habitat for animals to its original condition in order to promote ecotourism in the Sirindhorn International Environmental Park as to stimulate public awareness and appreciation of energy conservation and the environment where along the seaside are pine forest.



Figure 3.37 The Sirindhorn International Environmental Park in Phetchaburi Province

There are many kinds of pine trees in Thailand, the ones found along the coastlines of the environmental park are sea pines with a scientific name of *Casuarina equisetifolia* J. R. & C. Forst with a co-scientific name of *Casuarina littoralis* Salist. Sea pines are perennial plants sizing between medium to large with an average height of 10 – 25 meters, but some trees may reach up to 50 meters and 80 centimeters in diameter, with erect trunk and branches sloping up to the tree's peak. The shape of the tree's peak is similar to a capsized cone with branches making obtuse or right angles to the tree trunk disorderly. Small branches are green, small, and round like arrayed needles. The trunk is grey-brown mixed in color with shallow-cracked outer barks. The inner skin is brown-red mixed and light brown sapwood separated from it.

Sea pines usually grow in groups and are located along beaches in sandy soils with a general water resource. They grow quite well in a warm to hot climate and very adaptive to tropical climate change. They do not thrive well in cold weather especially in frost. They grow well in areas at sea level and high up to 1,500 meters from sea level.

In Thailand, sea pines are a local wood, which are found naturally along beaches such as along the beach of Prachuap Khiri Khan, Ranong, Phang Nga, Phuket, Trang, Songkhla, Krabi, and along various islands. Sea pines grow along the beach as to prevent the sea waves scouring, and are good as a wind break and are used to replenish the bad soils see in Figure 3.38.



Figure 3.38 The pine trees along the sea shore

3.2.5 Data Receiving

3.2.5.1 The XBee-Pro configuration of the data receiver is done by setting values by the X-CTU program that connects between the computer and the data receiving board, ZX-XBee232, via the serial port RS232 where the data receiving end's coordinator (CE=1) and the value of MY=2. The baud rates on X-Bee are set at 9600 bps (BD=3) as shown in Figure 3.20. POP-168 Module controller will receive data from a distance sensor and send the data of the ocean wave heights via the XBee-Pro see in Figure 3.2.

3.2.5.2 To test for path loss of the ocean wave data in unobstructed environment (Line of sight) and in obstructed environment by beach pine trees, a standard equipment was used as a signal receiver that was connected to a low noise amplifier (LNA) that was aimed to amplify radio or micro waves transmitted from air wires that sent the data to the Spectrum Analyzer and the data was then sent to a computer to be restored. The important variables for finding path loss was the distance (in meters) where the distance was divided into 100 meters, 200 meters, 300 meters, and 400 meters for data reception and the received data were analyzed as in Figures 3.3, 3.4, and 3.5.

3.2.6 Analyzing data

After the desired data had been collected from various conditions, they will be analyzed to find the value of the path loss from the data transmission and then they were compared to well-known models.

For the radio wave propagation, the original free space path loss model is shown in Equation 3.1.

$$PL_{fs} \text{ (dB)} = 32.4 + 20\log_{10}d_{KM} + 20\log_{10}f_{MHz} \quad (3.1)$$

By f the frequency in MHz

d is the distance between the transmitting and receiving antennas in km.

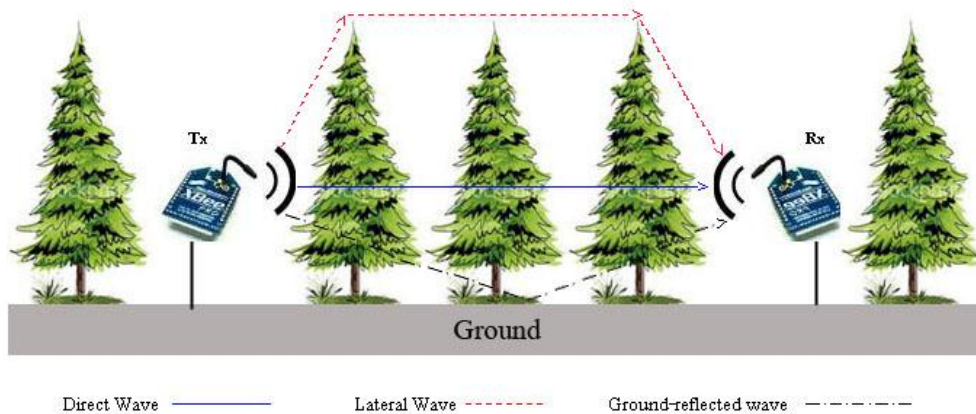


Figure 3.39 Geometry of radio wave propagation in a forest

When the radio wave propagates near the ground with a line of sight (LOS) condition, the effect of reflection from the ground is considered by the plane earth path loss model [6-10]. The plane earth path loss model is given as

$$PL_{pe} \text{ (dB)} = 40\log_{10}d + 20\log_{10}h_T - 20\log_{10}h_R, d \gg h_T, h_R \quad (3.2)$$

Where d is the distance between the transmitting and receiving antenna in meters. h_T , and h_R are the transmitting and receiving antenna heights, respectively, also in meters.

Since the radio wave propagation near ground through a large foliage depth, the dominant parts of the received signal strength consist of direct wave, ground reflected wave and the lateral wave, as shown in Figure 3.39. However in case of pine forest, the lateral wave may be neglected since its propagation path is very long comparing with the other parts. Additionally the ground is mainly sand more than soil. This make the ground reflected wave significantly change because of ground properties. Therefore the path loss models in the general forest are not suitable for the pine forest. However in order to compare the path loss characteristics between the pine and general forest, their model have to be carried out. The UHF propagation models for the large foliage depth are as follows;

A. Weissberger model

This model is applicable where a ray path is blocked by dense, dry, in-leaf trees

$$L_W(\text{dB}) = \begin{cases} 1.33 \times f^{0.284} d^{0.588} & 14 \text{ m} < d \leq 400 \text{ m} \\ 0.45 \times f^{0.284} d & 0 \text{ m} \leq d < 14 \text{ m} \end{cases} \quad (3.3)$$

Where f is the frequency in GHz and d is the depth of the trees in meters. The frequency range over which this model is valid is from 230 MHz to 95 GHz.

B. ITU Recommendation (ITU-R)

This empirical model is used in cases of distance between the transmitter and the receiver is within 400 m and the antennas are near the trees so that the dominant path of the signal propagates through the trees. This model is generally used for frequencies between 200 MHz to 95 GHz.

$$L_{\text{ITU-R}}(\text{dB}) = 0.2f^{0.3}d^{0.6} \quad (3.4)$$

Where f the frequency in GHz and d is is the depth of the trees in meters.

C. COST 235 model.

The COST 235 model [5] which was proposed based on measurements made in the frequencies of 9.6–57.6 GHz. While FITU-R model was derived from the ITU-R fitting at the frequencies of 11.2 and 20 GHz. These models are out of UHF band and the 2.4 GHz WSN. The COST 235 model which was proposed based on measurements made in the frequencies of 9.6–57.6 GHz for vegetation in leaf is as follows:

$$L(\text{dB})_{\text{COST235,in-leaf}} = 26.6f^{-0.2}d^{0.5} \quad (3.5)$$

And for vegetation out of leaf.

$$L(\text{dB})_{\text{COST235,out-leaf}} = 15.6f^{-0.009}d^{0.26} \quad (3.6)$$

Where f is also the frequency in GHz and the depth of the trees in meters. The seasonal difference is of the order of 4-6 dB.

3.2.7 Output

To study the results and conclude of the research. After that be represented the results in graphs.

CHAPTER IV

RESULT AND DISCUSSION

This chapter discusses the results obtained from the research on an empirical path loss model for measuring sea wave energy using wireless sensor network (WSN). The measurement system consists of displacement transducer, 2.4 GHz ZigBee module, a fixed CW transmitter and a portable spectrum analyzer, which was performed via the pine forests around the beach. During the research, a data was collected on the sea side at the Sirindhorn International Environmental Park of Thailand in winter. The measurements were carried out at a frequency of 2.4 GHz for the comparison between the approach and the Weissberger's model including the COST 235 model. The yielded results were displayed in graphs, and the six verification of path loss were defined as followed:

- The scatter plot of path loss (LOS)
- The scatter plot of path loss (Non-LOS)
- The verification of path loss with all models at a frequency of 2.4 GHz
- The verification of path loss with COST 235 models at a frequency of 1.8 GHz
- The verification of path loss with COST 235 models at a frequency of 2.4 GHz
- The verification of path loss with COST 235 models at a frequency of 3.5 GHz

The conclusive results from the research are displayed, described and summarized in graphs of different frequencies shown below:

4.1. The scatter plot of path loss (LOS)

- The original free space path loss model (PL_{fs}) graph.

$$PL_{fs}(\text{dB}) = 32.4 + 20\log_{10}d_{KM} + 20\log_{10}f_{MHz} \quad (4.1)$$

This is a basic model for find free space values where $f = 2.4$ GHz (2400 MHz), $d = 1$ -500 m displaying in the Table 4.1

Table 4.1 The relationship between distance (meter) and PL_{fs} (dB) at $f = 2.4$ GHz.

Distance (m)	$PL_{fs}(\text{dB})$
1	40.00
10	60.00
20	66.02
30	69.55
40	72.05
50	73.98
100	80.00
150	83.53
200	86.02
250	87.96
300	89.55
400	92.05
500	93.98

After that the values were used to plot on the graph as shown in Table 4.1 demonstrating a tendency in a form of logarithm according to the equation, $y = 8.6859\ln(x) + 40.004$ with a slope equal to 21.71 dB/decade.

- The plane earth path loss model (PL_{pe}) graph.

$$PL_{pe}(dB) = 40\log_{10}d + 20\log_{10}h_T - 20\log_{10}h_R, d \gg h_T, h \tag{4.2}$$

This is a model for data transmission in LOS form; when the radio wave propagates near the ground with a line of sight (LOS) condition, the effect of reflection from the ground is considered by the plane earth path loss model where $d = 50 - 500$ meters and $h_T, h_R = 1$ meter as shown in Table 4.2.

Table 4.2 The relationship between distance (m) and PL_{pe} (dB).

Distance (m)	PL_{pe} (dB)
50	67.96
100	80.00
150	87.04
200	92.04
250	95.92
300	99.08
400	104.08
500	107.96

After that the values were plotted on a graph as displayed in Table 4.2 showing a logarithm line of trend as in the equation, ' $y = 17.372\ln(x)$ ', with a slope of 43.43 dB/decade.

- The graph shows a path loss from the data LOS measurement.

$$Path\ loss\ LOS\ (dB) = P_t + LNA + G_t + G_r - signal \tag{4.3}$$

- Where
- P_t : Transmitting Power = 18 dBm
 - LNA: Low Noise Amplifier gain = 30 dB
 - G_t : Transmitting Antenna gain = 2.2 dB
 - G_r : Receiving Antenna gain = 2.2 dB
 - Signal: Receiving Signal (dBm)

A model for finding path loss from the measured data as shown in Table 4.3.

Table 4.3 Displays the relationship between distance (meter) and Path loss LOS (dB).

Distance (m)	Signal (dBm)	Path loss LOS(dB)
50	-39.25	91.65
100	-46.51	98.91
150	-49.32	101.72
200	-55.82	108.22
250	-58.79	111.19
300	-61.11	113.51
400	-65.56	117.96
500	-77.64	130.04

Then the values were plotted on a graph as shown in Figure 4.1 showing a logarithm trend as in equation, ' $y = 15.176\ln(x) + 28.985$ ', with a slope of 37.94 dB/decade.

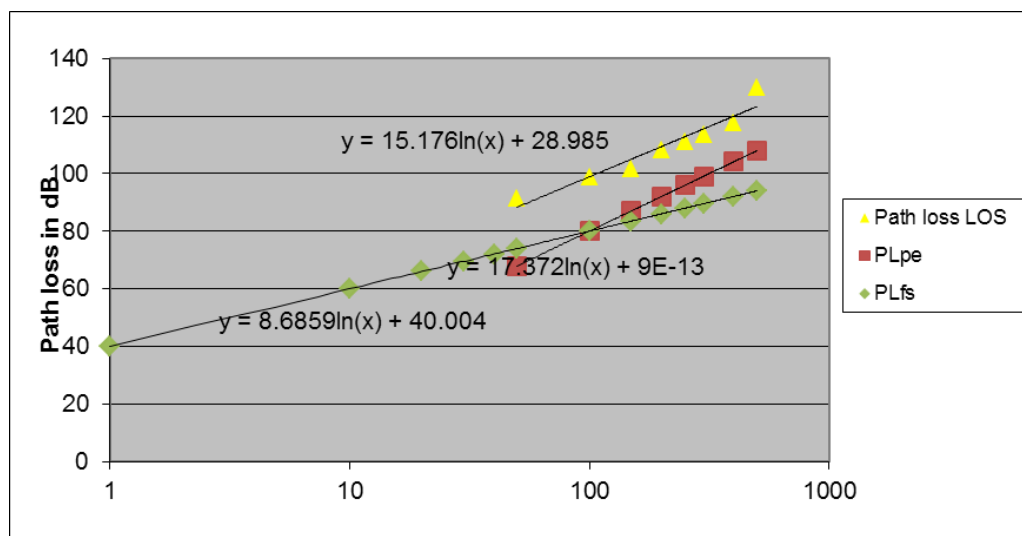


Figure 4.1 The scatter plot of path loss (LOS) in y-axis and distance (m) in x-axis

Table 4.4 The difference between slope value of Path loss LOS, PL_{pe} and PL_{fs}

Model	Slope (dB/decade)	Slope Different (dB/decade)
<i>Path loss LOS</i>	37.94	5.49
PL_{pe}	43.43	
<i>Path loss LOS</i>	37.94	16.23
PL_{fs}	21.71	
PL_{pe}	43.43	21.72
PL_{fs}	21.71	

Table 4.5 The values and percent's of difference between Path loss LOS (dB).

Distance (m)	Path loss LOS (dB)	PL_{pe} (dB)	Different	Error (%)
50	91.65	67.96	23.69	14.84
100	98.91	80.00	18.91	10.57
150	101.72	87.04	14.68	7.77
200	108.22	92.04	16.18	8.08
250	111.19	95.92	15.27	7.37
300	113.51	99.08	14.43	6.79
400	117.96	104.08	13.88	6.25
500	130.04	107.96	22.08	9.28
Average (%)				8.87

From the graph in Figure 4.1, when comparing between Path loss LOS graph and PL_{fs} graph, it was found that the slopes differed 16.23 dB/decade, and when comparing Path loss LOS graph and PL_{pe} graph, which was found that the slopes differed 5.49 dB/decade as shown in Table 4.4 displaying the Path loss LOS graph and PL_{pe} graph to be more correlated and with a steady trend due to the effect of the earth and the pine trees on the data transmission resulting in the Path loss LOS graph to

have a higher path loss value than PL_{pe} graph and a path loss average percent of 8.87% as demonstrated in Table 4.5.

4.2. The scatter plot of path loss (Non-LOS)

- A graph displaying a path loss of real data measured via pine trees. (Path loss)

A model in finding a path loss from a real measured data via pine trees showing the values based on Table 4.6.

Table 4.6 Demonstrates the relationship between distance (meter) and Path loss (dB).

Distance (m)	Signal (dBm)	Path loss (dB)
50	-46.48	98.88
100	-47.11	99.51
150	-58.87	111.27
200	-77.53	129.93
250	-77.61	130.01

Then the values were plotted on a graph as shown in Figure 4.2 displaying a logarithm trend as in equation, ' $y = 21.783\ln(x) + 7.8452$ ' with a slope equal to 54.46 dB/decade.

- The graph showing a new log-distance model is a newly built model and its path loss value was close to the real data value of the path loss measured via pine trees.

$$PL_{PINE}(\text{dB}) = 7.86 + 54.46\log(d) \quad (4.5)$$

Where the y-intercept was $y = 7.86$, the measured slope = 54.46 and $d = 50 - 250$ meters showing values in Table 4.7.

Table 4.7 Displays the relationship between distance (meter) and PL_{PINE} (dB).

Distance (m)	PL_{PINE} (dB)
50	100.39
100	116.78
150	126.37
200	133.17
250	138.45

The obtained values were then plotted on a graph shown in Figure 4.2 displaying a logarithm trend as in equation, $y = 23.652\ln(x) + 7.86$, with a slope equal to 59.13 dB/decade.

A model for a finding path loss from the real measured data without the pine tree obstacles is showing values in Table 4.8.

Table 4.8 The relationship between distance (meter) and Path loss LOS (dB).

Distance (m)	Signal (dBm)	Path loss LOS (dB)
50	-39.25	91.65
100	-46.51	98.91
150	-49.32	101.72
200	-55.82	108.22
250	-58.79	111.19

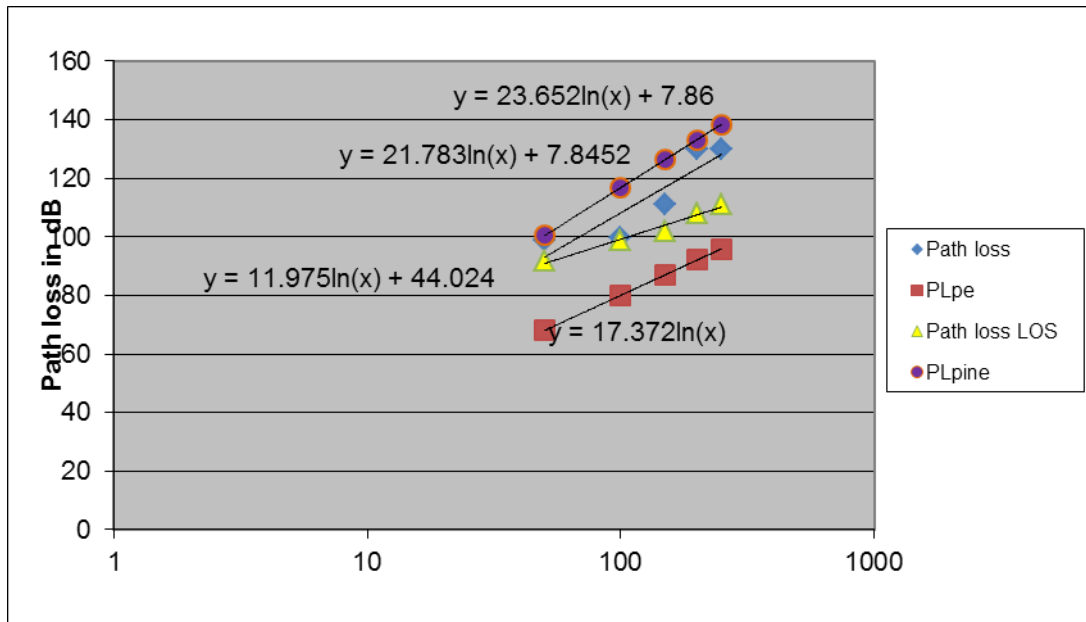


Figure 4.2 The scatter plot of path loss (Non-LOS) and log-distance model in y-axis and distance (m) in x-axis

Then the values obtained were plotted on a graph shown in Figure 4.2 displaying a logarithm trend as in equation, $y = 11.975\ln(x) + 44.024$ with a slope of 29.94 dB/decade.

- The plane earth path loss model (PL_{pe}) graph shows the values in Table 4.2. After that the values received were plotted on a graph as shown in Figure 4.2 demonstrating a logarithm trend as in equation, $y = 17.372\ln(x)$ with a slope of 43.43 dB/decade.

Table 4.9 Displays the difference in the slope values of PL_{PINE} , PL_{pe} and Path loss LOS.

Model	Slope (dB/decade)	Slope Different (dB/decade)
PL_{PINE}	59.13	15.70
PL_{pe}	43.43	
PL_{PINE}	59.13	29.19
Path loss LOS	29.94	

Table 4.10 The different values and percent's between PL_{PINE} (dB) and PL_{pe} (dB).

Distance (m)	PL_{PINE} (dB)	PL_{pe} (dB)	Different	Error (%)
50	100.39	67.96	32.43	19.26
100	116.78	80.00	36.78	18.69
150	126.37	87.04	39.33	18.43
200	133.17	92.04	41.13	18.26
250	138.45	95.92	42.53	18.15
Average path loss (%)				18.56

From the graph in Figure 4.2, when comparing the PL_{PINE} and PL_{pe} graphs, it was found that the slopes difference 15.70 dB/decade. And when comparing the PL_{PINE} and Path loss LOS graphs, it was found that the slopes differed 29.19 dB/decade as shown in Table 4.9. This showed that PL_{PINE} and PL_{pe} graphs were more correlated than Path loss LOS graph and a steady trend due to the earth and the pine trees that had effect on the data transmission. This resulted in the PL_{PINE} graph having the path loss value greater than the PL_{pe} graph with an average value of path loss equal to 18.56% as shown in Table 4.10.

4.3. The verification of path loss with all models at a frequency of 2.4 GHz

- A graph showing a path loss of real data measured via pine trees is a model for finding path loss from the real data showing values in Table 4.6. Then the values obtained were plotted on a graph as in Figure 4.3 displaying a linear trend as in equation, $y = 0.1092x + 39.102$ with a slope of 0.28 dB/decade.

- A graph showing a new model called ' $Af^b d^c$ model' is a newly built model with a path loss closest to the real data of the graph showing the path loss measured via pine trees as in equation.

$$L_{PINE} \text{ (dB)} = 16.5f^{0.5}d^{0.3} \quad (4.6)$$

Where $f = 2.4$ GHz, $d = 50 - 250$ m and $A, B, C = 16.5, 0.5, 0.3$ respectively showing values according to Table 4.11

Table 4.11 The relationship between distance (meter) and L_{PINE} (dB).

Distance (m)	L_{PINE} (dB)
50	73.14
100	90.04
150	101.69
200	110.86
250	118.53

Then the values obtained were plotted on a graph as shown in Figure 4.3 displaying a linear trend as in equation, $y = 0.2232x + 65.373$ with a slope equal to 0.56 dB/decade.

- Weissberger's model (L_w) graph

$$L_w(dB) = \begin{cases} 1.33xf^{0.284}d^{0.588} & 14m < d \leq 400m \\ 0.45xf^{0.284}d & 0m \leq d < 14m \end{cases} \quad (4.7)$$

This model is applicable where a ray path is blocked by dense, dry, in-leaf trees. Where $f = 2.4$ GHz, $d = 50 - 250$ meters as shown in Table 4.12.

Table 4.12 Displays the relationship between distance (meter) and L_w (dB)

Distance (m)	L_w (dB)
50	17.01
100	25.58
150	32.46
200	38.44
250	43.83

After that the values received were plotted on a graph as shown in Figure 4.3 demonstrating a linear trend as in equation, $y = 0.133x + 11.514$ with a slope of 0.33 dB/decade.

- ITU Recommendation (ITU-R) graph

$$L_{ITU-R} (dB) = 0.2f^{0.3}d^{0.6} \quad (4.8)$$

Where $f = 2.4$ GHz and $d = 50 - 250$ meters shown in Table 4.13.

Table 4.13 Displays the relationship between distance (meter) and L_{ITU-R} (dB).

Distance (m)	L_{ITU-R} (dB)
50	2.72
100	4.12
150	5.26
200	6.25
250	7.14

Then the values obtained were plotted on a graph as in Figure 4.3 showing a linear trend as in equation, $y = 0.0219x + 1.8061$, with a slope of 0.05 dB/decade.

- COST 235 model graph

For vegetation in leaf is as follows:

$$L \text{ (dB)}_{\text{COST235, in-leaf}} = 26.6f^{-0.2}d^{0.5} \quad (4.9)$$

And for vegetation out of leaf

$$L \text{ (dB)}_{\text{COST235, out-leaf}} = 15.6f^{-0.009}d^{0.26} \quad (4.10)$$

Where $f = 2.4$ GHz and $d = 50 - 250$ meters shown in Table 4.14

Table 4.14 The relationship between distance (meter), $L_{COST235,in-leaf}$ (dB) and $L_{COST235,out-leaf}$ (dB).

Distance (m)	$L_{COST235,out-leaf}$ (dB)	$L_{COST235,in-leaf}$ (dB)
50	157.88	42.80
100	223.27	51.25
150	273.45	56.95
200	315.76	61.37
250	353.03	65.04

Then the values obtained were plotted on a graph as in Figure 4.3 showing a linear trend as in equation for vegetation in leaf, which obtained an equation, $y = 120.05\ln(x) - 319.92$, $y = 13.757\ln(x) - 11.51$ with a slope of 2.4, 265.76 dB/decade.

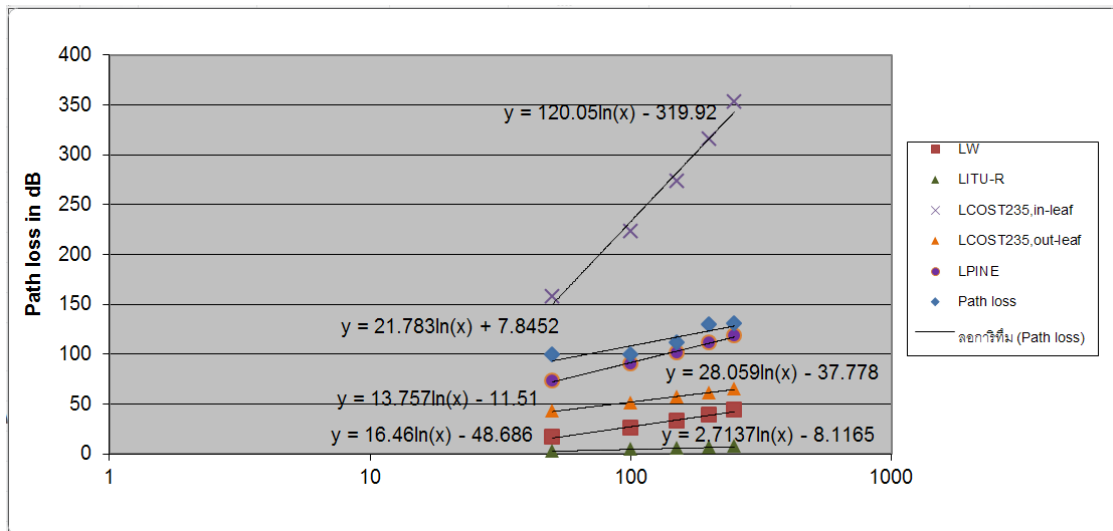


Figure 4.3 The verification of path loss with all models at a frequency of 2.4 GHz

Table 4.15 The difference in the values of the slopes of L_{PINE} , L_W , L_{ITU-R} , $L_{COST235,in-leaf}$ and $L_{COST235,out-leaf}$.

Model	Slope (dB/decade)	Slope Different (dB/decade)
L_{PINE}	70.15	29
L_W	41.15	
L_{PINE}	70.15	63.37
L_{ITU-R}	6.78	
L_{PINE}	70.15	229.98
$L_{COST235,in-leaf}$	300.13	
L_{PINE}	70.15	35.76
$L_{COST235,out-leaf}$	34.39	

Table 4.16 Displays the values and percent's of the difference between L_{PINE} and L_W .

Distance (m)	L_{PINE} (dB)	L_W (dB)	Different	Error (%)
50	73.14	17.01	56.12	62.25
100	90.04	25.58	64.47	55.76
150	101.69	32.46	69.23	51.60
200	110.86	38.44	72.41	48.50
250	118.53	43.83	74.70	46.01
Average (%)				52.82

Table 4.17 The values and percent's of the difference between L_{PINE} and L_{ITU-R} .

Distance (m)	L_{PINE} (dB)	L_{ITU-R} (dB)	Different	Error (%)
50	73.14	2.72	70.42	92.83
100	90.04	4.12	85.92	91.25
150	101.69	5.26	96.43	90.17
200	110.86	6.25	104.61	89.33
250	118.53	7.14	111.39	88.63
Average (%)				90.44

Table 4.18 The values and percent's of the difference between L_{PINE} and $L_{COST235,in-leaf}$.

Distance (m)	L_{PINE} (dB)	$L_{COST235,in-leaf}$ (dB)	Different	Error (%)
50	73.14	157.88	84.74	36.68
100	90.04	223.27	133.23	42.52
150	101.69	273.45	171.76	45.79
200	110.86	315.76	204.90	48.03
250	118.53	353.03	234.49	49.73
Average (%)				44.55

Table 4.19 The values and percent's of the difference between L_{PINE} and $L_{COST235,in-leaf}$

Distance (m)	L_{PINE} (dB)	$L_{COST235,in-leaf}$ (dB)	Different	Error (%)
50	73.14	42.80	30.34	26.17
100	90.04	51.25	38.79	27.46
150	101.69	56.95	44.74	28.20
200	110.86	61.37	49.49	28.73
250	118.53	65.04	53.50	29.14
Average (%)				27.94

Table 4.20 The values and percent's of difference between L_{PINE} , L_W , L_{ITU-R} , $L_{COST235,in-leaf}$ and $L_{COST235,out-leaf}$

Models Compare (dB)		Average (%)
L_{PINE}	L_W	52.82
L_{PINE}	L_{ITU-R}	90.44
L_{PINE}	$L_{COST235,in-leaf}$	44.55
L_{PINE}	$L_{COST235,out-leaf}$	27.94

From the graph in Figure 4.3, when comparing the L_{PINE} graph and L_W , $L_{COST235,in-leaf}$ and $L_{COST235,out-leaf}$ graphs, it was found that the slopes differed as shown in Table 4.15 and L_{PINE} graph was correlated with L_W and $L_{COST235,out-leaf}$ graph with slopes of 0.23 and 0.28 dB/decade respectively. From the comparison of the average percentage of path loss between L_{PINE} and L_W and $L_{COST235,out-leaf}$ graphs, it was found that L_W graph had an average percentage of path loss equal to 52.82% while $L_{COST235,out-leaf}$ graph with an average percent of path loss equal to 27.94% as shown in Table 4.16 – 4.20. This showed that $L_{COST235,out-leaf}$ graph had a steady trend and was close to L_{PINE} graph the most due to the leaves of the pine having straight line with a diameter of 0.8 mm. There are several groups of leaf in a sub-branch. A group of leaf consists of about 60 leaves. As a result of the pine leaves being round and small, the

experiment yielded a path loss and a slope close to COST 235 model for vegetation out of leaf the most.

4.4. The verification of path loss with COST 235 models at a frequency of 1.8 GHz

From COST 235 models at a frequency of 1.8 GHz, a graph in Figure 4.4 was obtained as in Table 4.21, and when comparing the difference of the slope and L_{PINE} graph, the values were yielded as in Table 4.24.

Table 4.21 Equations and slopes of L_{PINE} , Path loss, L_W , L_{ITU-R} , $L_{COST235,in-leaf}$ and $L_{COST235,out-leaf}$ at frequency 1.8 GHz.

Model	Equation	Slope (dB/decade)
L_{PINE}	$y = 25.964\ln(x) - 34.958$	64.91
Path loss	$y = 21.783\ln(x) + 7.8452$	54.46
L_W	$y = 15.169\ln(x) - 44.866$	37.92
L_{ITU-R}	$y = 2.4893\ln(x) - 7.4454$	6.22
$L_{COST235,in-leaf}$	$y = 127.16\ln(x) - 338.87$	317.9
$L_{COST235,out-leaf}$	$y = 13.793\ln(x) - 11.54$	34.48

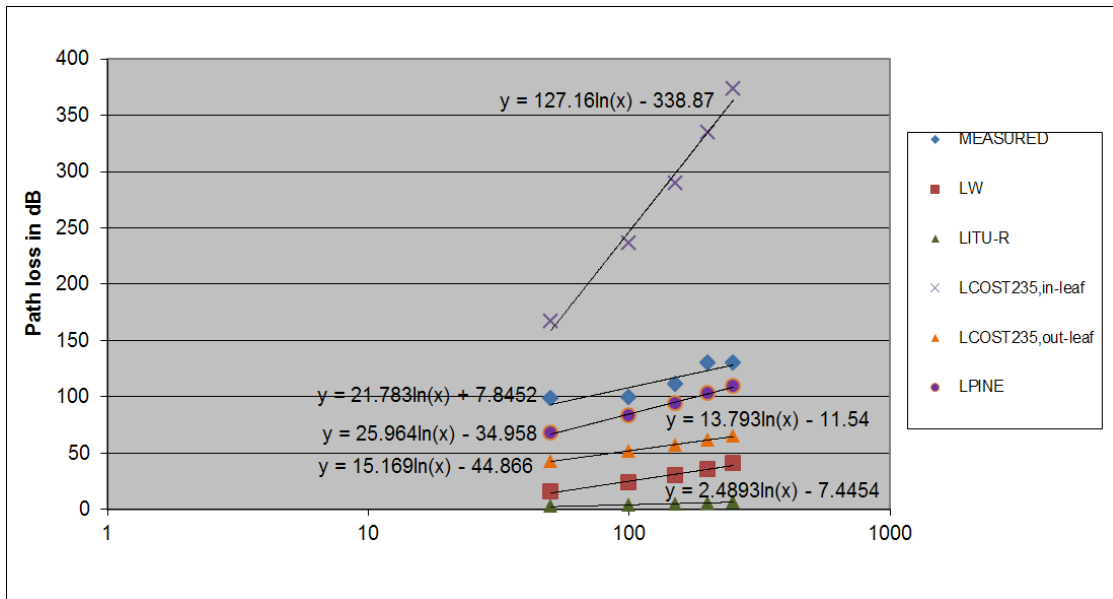


Figure 4.4 The verification of path loss (dB) in y-axis and distance (m) in x-axis with COST 235 models at a frequency of 1.8 GHz

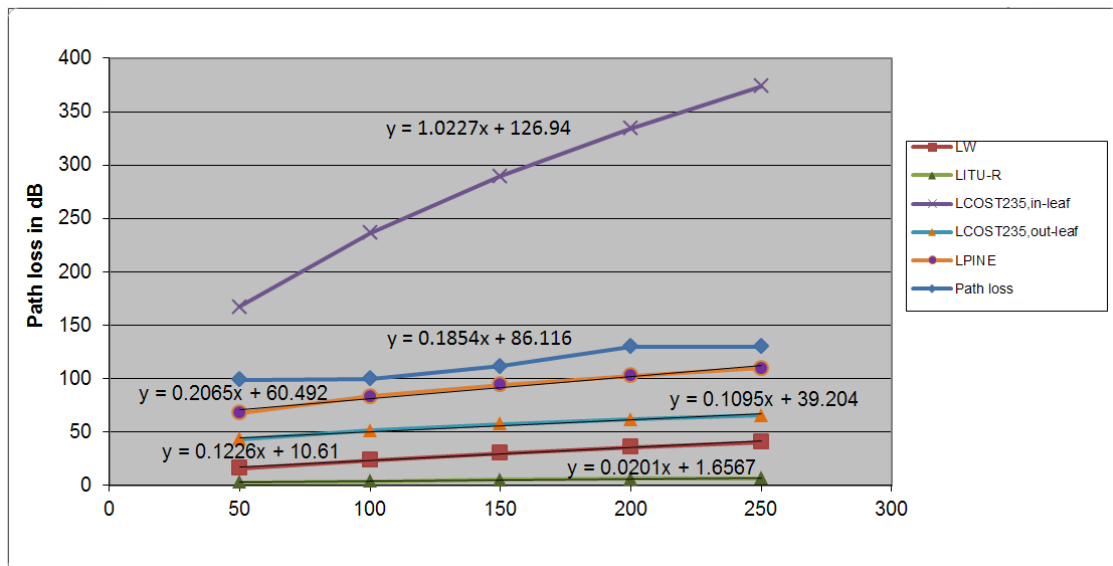


Figure 4.5 The verification of path loss (dB) in y-axis and distance (m) in x-axis with COST 235 models at a frequency of 1.8 GHz (Linear Graph)

From graph in Figure 4.4-4.5, when comparing L_{PINE} and $L_{COST235,out-leaf}$ graphs at a frequency of 1.8 GHz, it was found that the slopes differed by 0.24 dB/decade as shown in Table 4.21. From comparing the average percentage of path

loss of L_{PINE} and $L_{COST235,out-leaf}$ graphs, it was found that the average path loss was equal to 24.21 %. This resulted in $L_{COST235,out-leaf}$ graph to be similar to L_{PINE} graph the most.

4.5. The verification of path loss with COST 235 models at a frequency of 2.4 GHz

From COST 235 models at a frequency of 2.4 GHz, a graph in Figure 4.6 was yielded as shown in Table 4.22 and when comparing the slope to L_{PINE} graph, the values were obtained as in Table 4.24.

Table 4.22 Equations and slopes of L_{PINE} , Path loss, L_W , L_{ITU-R} , $L_{COST235,in-leaf}$ and $L_{COST235,out-leaf}$ at frequency 2.4 GHz

Model	Equation	Slope (dB/decade)
L_{PINE}	$y = 28.059\ln(x) - 37.778$	70.15
Path loss	$y = 21.783\ln(x) + 7.8452$	54.46
L_W	$y = 16.46\ln(x) - 48.686$	41.15
L_{ITU-R}	$y = 2.7137\ln(x) - 8.1165$	6.78
$L_{COST235,in-leaf}$	$y = 120.05\ln(x) - 319.92$	300.13
$L_{COST235,out-leaf}$	$y = 13.757\ln(x) - 11.51$	34.39

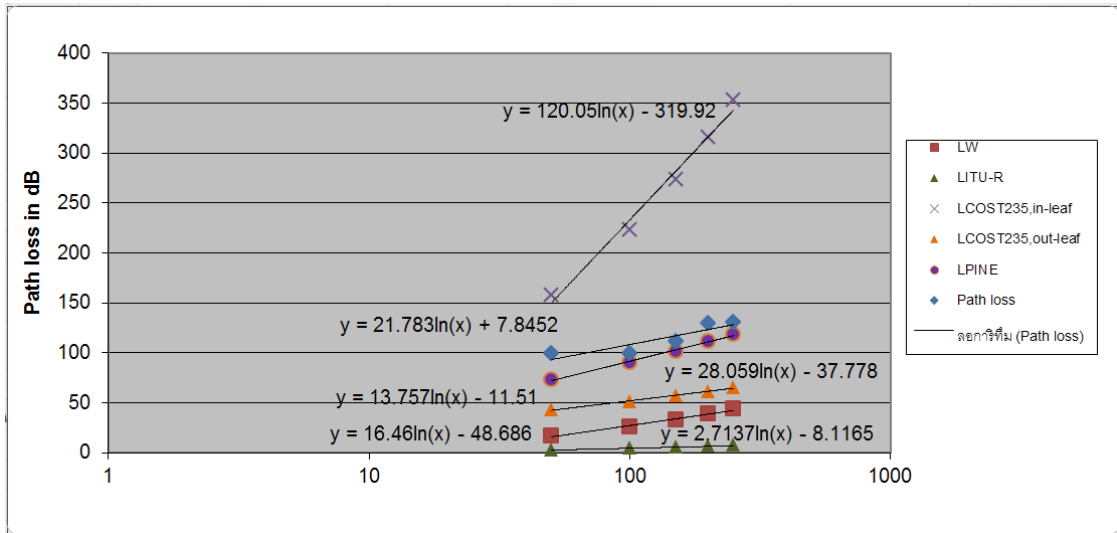


Figure 4.6 The verification of path loss (dB) in y-axis and distance (m) in x-axis with COST 235 models at a frequency of 2.4 GHz

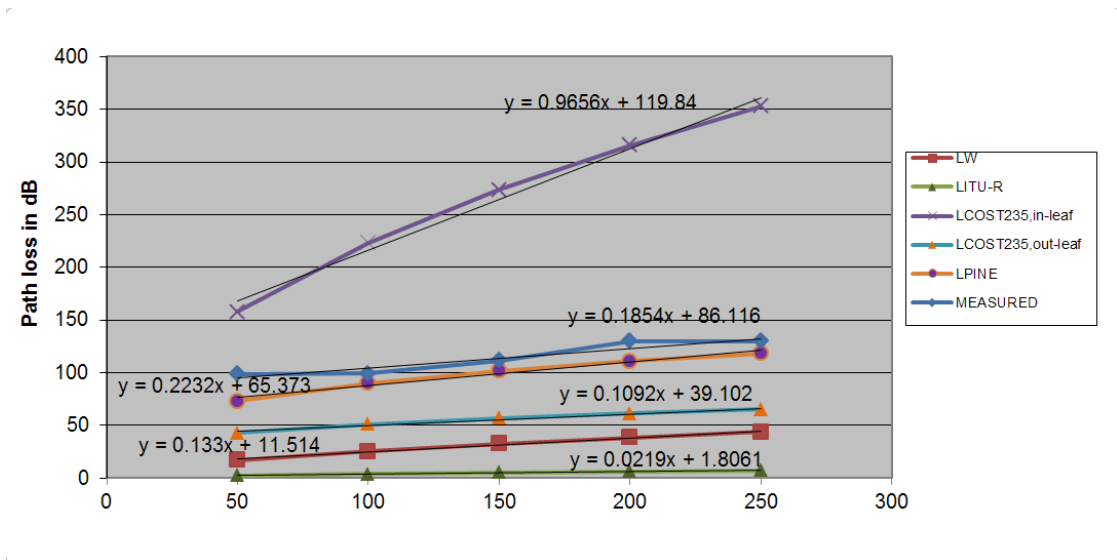


Figure 4.7 The verification of path loss (dB) in y-axis and distance (m) in x-axis with COST 235 models at a frequency of 2.4 GHz (Linear Graph)

From graph in Figure 4.6-4.7, when comparing L_{PINE} graph to $L_{COST235,out-leaf}$ graph at a frequency of 2.4 GHz, it was found that the slopes differed by 0.29 dB/decade as shown in Table 4.22. In a comparison between the average path loss of L_{PINE} and $L_{COST235,out-leaf}$ graphs, it was found that the path loss was equal to 27.94 %, which means $L_{COST235,out-leaf}$ graph had a similar trend closest to the L_{PINE} graph.

4.6. The verification of path loss with COST 235 models at a frequency of 3.5 GHz

From COST 235 models at a frequency of 3.5 GHz, a graph was obtained as in Figure 4.8 as shown in Table 4.23. And when comparing the difference of the slopes with the L_{PINE} graph, the values were obtained as in Table 4.24.

Table 4.23 Equations and slopes of L_{PINE} , Path loss, L_W , L_{ITU-R} , $L_{COST235,in-leaf}$ and $L_{COST235,out-leaf}$ at frequency 3.5 GHz

Model	Equation	Slope (dB/decade)
L_{PINE}	$y = 36.205\ln(x) - 48.746$	90.51
Path loss	$y = 21.783\ln(x) + 7.8452$	54.46
L_W	$y = 18.322\ln(x) - 54.192$	45.81
L_{ITU-R}	$y = 3.0389\ln(x) - 90.892$	7.60
$L_{COST235,in-leaf}$	$y = 111.33\ln(x) - 296.67$	278.33
$L_{COST235,out-leaf}$	$y = 13.711\ln(x) - 11.471$	34.28

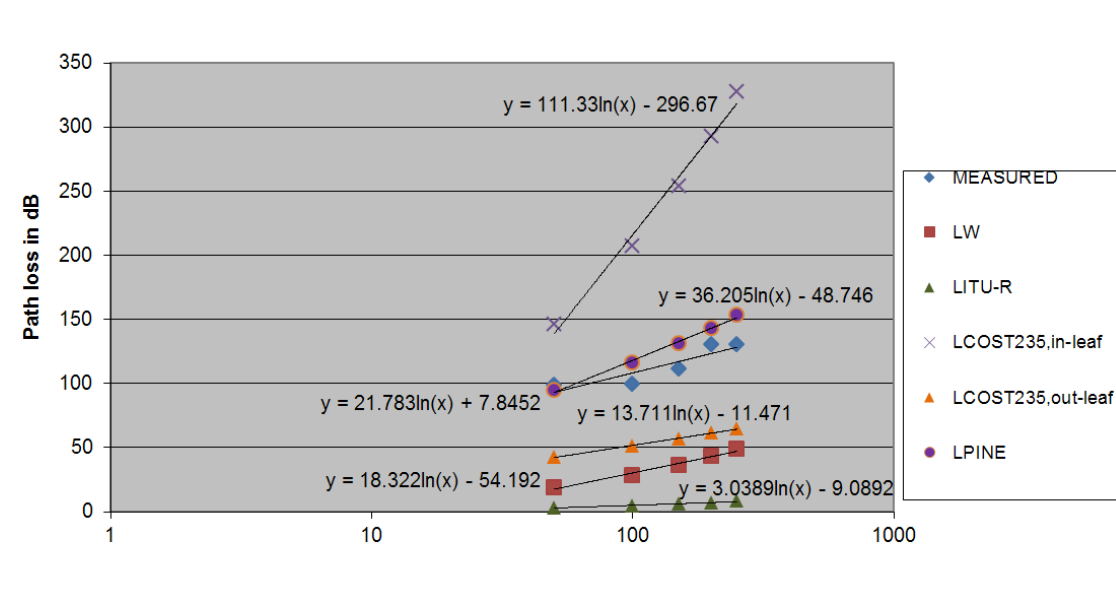


Figure 4.8 The verification of path loss (dB) in y-axis and distance (m) in x-axis with COST 235 models at a frequency of 3.5 GHz

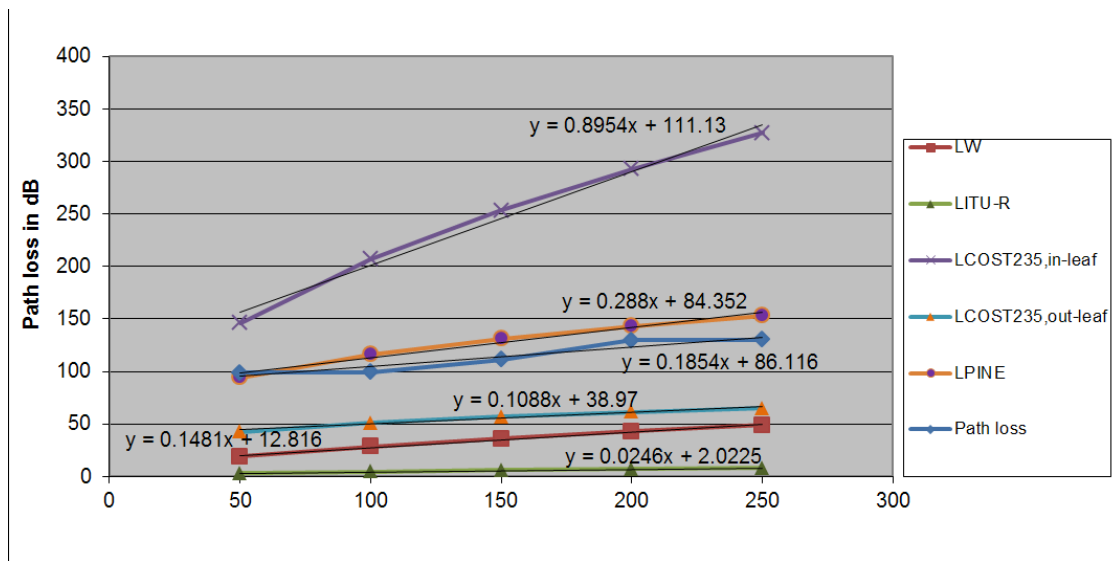


Figure 4.9 The verification of path loss (dB) in y-axis and distance (m) in x-axis with COST 235 models at a frequency of 3.5 GHz (Linear Graph)

From graph in Figure 4.8-4.9, when comparing L_{PINE} graph to $L_{COST235,out-leaf}$ graph at a frequency of 2.4 GHz, it was found that the slopes differed by 0.45 dB/decade as shown in Table 4.24. And when the average path loss was compared between L_{PINE} and graph $L_{COST235,out-leaf}$ graphs, it showed the path loss to be equal to 39.37%, which means that $L_{COST235,out-leaf}$ had a similar trend as L_{PINE} graph the most.

Table 4.24 Displays the different slope values between L_{PINE} , L_W , L_{ITU-R} , $L_{COST235,in-leaf}$ and $L_{COST235,out-leaf}$ at a frequency of 1.8, 2.4 and 3.5 GHz

Model		Slope Different (dB/decade)		
		f = 1.8 GHz	f = 2.4 GHz	f = 3.5 GHz
L_{PINE}	L_W	0.21	0.23	0.35
L_{PINE}	L_{ITU-R}	0.47	0.51	0.66
L_{PINE}	$L_{COST235,in-leaf}$	2.04	1.85	1.52
L_{PINE}	$L_{COST235,out-leaf}$	0.25	0.29	0.45

Table 4.25 Demonstrates the different percentages between L_{PINE} , L_W , L_{ITU-R} , $L_{COST235,in-leaf}$ and $L_{COST235,out-leaf}$ at a frequency of 1.8, 2.4 and 3.5 GHz

Models		Average (%)		
		f = 1.8 GHz	f = 2.4 GHz	f = 3.5 GHz
L_{PINE}	L_W	52.97	52.82	57.92
L_{PINE}	L_{ITU-R}	90.52	90.44	91.65
L_{PINE}	$L_{COST235,in-leaf}$	49.79	44.55	30.44
L_{PINE}	$L_{COST235,out-leaf}$	24.21	27.94	39.37

From Table 4.21 – 4.25 and from Figure 4.4 – 4.9, it can be concluded that in comparison between L_{PINE} and $L_{COST235,out-leaf}$ graphs at various frequencies of 1.8, 2.4 and 3.5 GHz, the frequencies had effect on the data transmission as the frequency increased the percentage of error also increased. Because when the frequency went up, its quality was diminished by obstacles more than the lower frequency. In the study, the experiment was designed for the frequency at 2.4 GHz and from the table of L_{PINE} and $L_{COST235,out-leaf}$ models, when comparing the percentages of error at frequencies between 2.4 GHz, 1.8 GHz and 3.5 GHz, it was found that the percentage of error at 3.5 GHz was greater than of 1.8 GHz. Therefore, it can be concluded that the frequency at 1.8 GHz can be used in the experiment in place of 2.4 GHz for data transmission, but at 3.5 GHz, it would not be applicable because the percentage of error would be too high.

CHAPTER V

CONCLUSION

5.1 Conclusion

We have proposed the empirical path loss models for sea wave energy sensor via WSN. We performed measurements at a frequency of 2.4 GHz via pine forest around the beach at the Sirindhorn International Environmental Park. We proposed the path loss for pine forest in from of both the log-distance and $Af^b d^c$ model. From the results it is found that the path loss slope of the log-distance from and the three numerical values A, B , and C of the $Af^b d^c$ from are 54.46 dB/decade, 16.5, 0.5, and 0.3 respectively. The proposed model provides a good agreement at the distance of 50 to 250 m. comparing with the well-known models confirm the verification of the proposed model.

When comparing the two newly built models with the well-known models, it was found that the newly built typed one model, log-distance type, is the closest to the plane earth path loss model due to the soil and pines being the major factors that had an effect on the data communication. The newly built typed two model, $L = Af^b d^c$ model, is the most similar to COST 235 for vegetation out of leaf because the pine leaves have a characteristic of a straight line with a diameter of 0.8 mm. There are several groups of leaf in a sub-branch. A group of leaf consists of about 60 leaves while the other models consist of trees that have thick leaves and grow in groups.

5.2 Recommendation

The range of the transmission depends on the wind speed. It is an important factor has effect directly to range in during different periods the wind speed changes. If the wind speed changes, the three numerical values A, B, and C will be changed as well.

In addition, during this research a data along the beach line in winter had been collected, which had the strongest winds resulting in the increase of error for the model. Therefore, the data transmission would be more effective and the error reading decreases, if the wind factor could be controlled.

5.3 Future work

The result from the system can be applied to data for make a decision to build electricity generator from sea waves and it is a data for who want to survey sea waves in this area.

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BIOGRAPHY

NAME	Supanuch Seesaiprai
DATE OF BIRTH	16 November 1985
PLACE OF BIRTH	Roiet, Thailand
INSTITUTIONS ATTENDED	Kasetsart University, 2004-2007 Bachelor of Liberal Arts and Science (Computer Science) Mahidol University, 2009-2013 Master of Science (Technology Information System Management)
RESEARCH GRANTS	Electricity Generating Authority of Thailand (EGAT), Contact number 53-B104000-051-IO.SS03A3008088-MU
HOME ADDRESS	72/11 M.2 Arpagorn Village Salaya Phutthamonthon Nakhonpathom 73170 Tel. +662-249-6596 E-mail: yoyosung555@hotmail.com
PUBLICATION / PRESENTATION	Path Loss Model for Wirelless Sea Wave Energy Sensor Network via Pine Forest around Beach, The 3rd International Conference on Knowledge and Smart Technologies (KST-2011), Burapha University, Chonburi, Thailand