DESIGN AND ANALYSIS FRAMWORK OF PATH LOSS BASED ON GENERIC WiMAX MODELS FOR MAHIDOL UNIVERSITY: SALAYA-PHAYATHAI LINK

PORNCHAI UBOL

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…………………………………………
Mr. Pornchai Ubol
Candidate

…………………………………………
Asst. Prof. Supaporn Kiattisin,
Ph.D. (Electrical and Computer Engineering)
Major advisor

…………………………………………
Asst. Prof. Adisorn Leelasantitham,
Ph.D. (Electrical Engineering)
Co- advisor

…………………………………………
Lect. Waranyu Wongseree,
Ph.D. (Electrical Engineering)
Co- advisor

…………………………………
Prof. Banchong Mahaisavariya,
M.D., Dip Thai Board of Orthopedics
Dean
Faculty of Graduate Studies
Mahidol University

…………………………………………
Asst. Prof. Supaporn Kiattisin, Ph.D.
Ph.D. (Electrical and Computer Engineering)
Program Director
Technology of Information System
Management
Faculty of Engineering
Mahidol University

Thesis
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on
November 27, 2013

………………………………...….
Mr. Pornchai Ubol
Candidate

………………………………...….
Asst. Prof. Kavee Krairavee,
Ph.D. (Sustainable Land Use and Natural Resource Management)
Chair

………………………………...….
Asst. Prof. Supaporn Kiattisin,
Ph.D. (Electrical and Computer Engineering)
Member

………………………………...….
Asst. Prof. Adisorn Leelasantitham,
Ph.D. (Electrical Engineering)
Member

………………………………...….
Lect. Waranyu Wongseree,
Ph.D. (Electrical Engineering)
Member

………………………………...….
Lect. Surapong Pongyupinpanich,
Ph.D. (Electronic and Information)
Member

………………………………...….
Prof. Banchong Mahaisavariya,
M.D., Dip Thai Board of Orthopedics
Dean
Faculty of Graduate Studies
Mahidol University

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

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Pornchai Ubol

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PORNCHAI UBOL 5336475 EGTI/M

M.Sc. (TECHNOLOGY OF INFORMATION SYSTEM MANAGEMENT)

THESIS ADVISORY COMMITTEE: SUPAPORN KIATTISIN, Ph.D., WARANYU WONGSAREE, Ph.D., ADISORN LEELASANTITHAM, Ph.D.

ABSTRACT

Broadband data communication systems have grown tremendously with the increasing high-speed for data transfers and demand for data communications in the berried areas to provide in the network infrastructure. Therefore WiMAX network can have an important role for the service of transmitting the high-speed data and covering more areas. WiMAX network will use radio frequency range 2 - 11 GHz and the signal path loss that important for the design of WiMAX network.

This paper presents a propagation path loss model to study the WiMAX network design between Mahidol University Salaya campus to Phayathai campus,by selecting the most suitable model to calculate the different radio frequency and the information height of the antenna. Therefore, it made calculation at 2.5GHz, 3.5GHz and 5GHz to determine the path loss of signal is based on distance for predicted the WiMAX network design.

KEY WORDS: PATH LOSS / PROPAGATION MODEL / WiMAX / FREQUENCY

74 pages

กรอบการออกแบบและวิเคราะห์การสูญเสียกำลังสัญญาณด้วยแบบจำลองไวแมกซ์สำหรับการเชื่อมต่อวิทยาเขตศาลายากับวิทยาเขตพญาไท มหาวิทยาลัยมหิดล

Design and analysis framework of path loss based on generic wimax models for Mahidol University: salaya- phayathai link

พรชัย อุบล 5336475 EGTI/M

วท.ม. (เทคโนโลยีการจัดการระบบสารสนเทศ)

คณะกรรมการที่ปรึกษาวิทยานิพนธ์: สุภาภรณ์ เกียรติสิน,Ph.D.,วรัญญู วงษ์เสรี,Ph.D., อดิศร ลีลาสันติธรรม,Ph.D.

บทคัดย่อ

ระบบการสื่อสารข้อมูลแบบบรอดแบนด์ (Broadband) มีการเติบโตอย่างมากพร้อมกับความต้องการความเร็วในการรับส่งข้อมูลที่เพิ่มขึ้นและความต้องการระบบสื่อสารข้อมูลในพื้นที่ที่มีอุปสรรคในการวางโครงสร้างพื้นฐานที่เป็นแบบสายฉะนั้นระบบเครือข่ายไวแมกซ์ (WiMAX) จึงมีบทบาทในการลดข้อจำกัดเหล่านี้เพราะสามารถสนองตอบต่อการให้บริการในการรับส่งข้อมูลที่ความเร็วสูงและให้การบริการครอบคลุมพื้นที่มากขึ้นซึ่งระบบไวแมกซ์ (WiMAX) นั้นจะใช้งานที่ความถี่ของคลื่นวิทยุย่านความถี่ 2- 11 GHz และการหาค่าการสูญเสียกำลัง (path loss)ของสัญญาณนั้นจะเป็นค่าที่แสดงให้เห็นถึงประสิทธิภาพและความสามารถในการให้บริการของเครือข่ายซึ่งเป็นข้อมูลสำคัญสำหรับการออกแบบระบบเครือข่ายไวแมกซ์

งานวิจัยนี้ได้นำเสนอการใช้แบบจำลองการสูญเสียกำลังสัญญาณ(Path loss model) เพื่อวิเคราะห์และการออกแบบระบบเครือข่ายไวแมกซ์ระหว่างมหาวิทยาลัยมหิดลวิทยาเขตศาลายากับวิทยาเขตพญาไทโดยจะเลือกใช้แบบจำลองที่เหมาะสมกับพื้นที่มากที่สุดการคำนวณนี้จะใช้ค่าความถี่ที่แตกต่างกันในการคำนวณคือ ความถี่ที่ 2.5 GHz, 3.5GHzและ 5GHz พร้อมทั้งข้อมูลความสูงของเสาอากาศเพื่อหาค่าการสูญเสียกำลังตามระยะทางจากลักษณะสภาพแวดล้อมเพื่อนำผลที่ได้มาเป็นข้อมูลสำหรับการออกแบบระบบเครือข่ายไวแมกซ์

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CHAPTER I

INTRODUCTION

1.1 General Introduction

The need for communication is vital to people in daily lives, whether on roads in big cities or other locations. For a long time, people have experienced communication problems with each other due to signals, in which the initial phase of the connection consists of the transmission of signals and information through cable lines. If the user is far from the service area, service-related problems will arise due to the need to install cable lines accordingly with the increased distance, which also require more costs and create signals’ transmission problem in which the signals will be weaken accordingly with the increased distance. Later on, technology development for communication was developed to solve the problem of complex cable installations and to reduce connection costs in connection. The developed system was wireless communication system.

Wireless communication is data communication between the source device and the end-point device through electromagnetic waves, which serves as a medium for data transmission. Wireless transmission offer services in many applications such as radio broadcasts, phones, wireless LAN, broadband wireless, and satellites [1] 3], as seen in Figure 1.1.

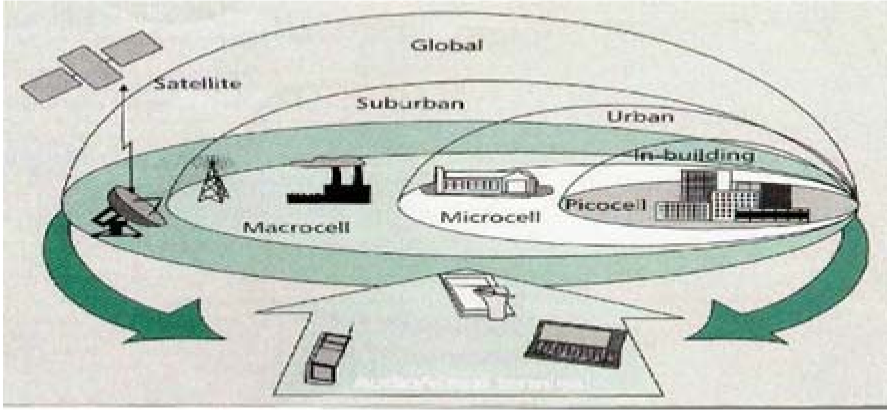

Figure 1.1 Wireless Communications. [1]

The wireless communication systems have developed technologies and standards that support their usability with respect to data transmission speed and forms of service, which include contacts of stationary users and contacts of mobile users, and can provide services at any time and place. Here, wireless communication systems have a role in reducing the inequality of information access and knowledge of the people in areas where service cannot be provided by wired networks. The technologies and standards of the systems are shown in Table 1.1.

Table 1.1 The comparison of wireless technologies in different models. [2] [5]

Standard / Performance	Wi-Fi 802.11	WiMAX 802.16	WCDMA 3G	UWB IEEE	Satellite C-Band, KU-Band
Frequency (GHz)	2 - 11	2 - 11	1.8 - 2.1	7.5	3.4 – 12
Speed (Mbps)	6 - 54	30-75	2-10	110-480	4
Coverage (Km)	0.03-0.1	1.6-10	1.6-8	0.01	Zone beam
Cost	High	High	small	High	High
Security	Middle	Good	Middle	Good	Good

From the table comparing wireless technologies, considerations of each technology found that the WiMAX system technology has more capabilities than other technologies as follows.

1.1.1 Speed

The speed of signal transmission can be as high as 75 Megabytes per second (Mbps) by using a mechanism to alter signals to have a higher efficiency.

Signals may be sent under a high frequency that functions efficiently and face no problems of reflected signals.

1.1.2 Comprehensive services

WiMAX is capable of spreading signals by Point-to-point and Multipoint communication, thus can work in Non-Line-of-Sight, meaning that it can function well even with obstacles blocking such as buildings and trees. Signals can be sent to distances as far as 30 miles or 48 kilometers under a high frequency. Apart from that, the Base Station can also consider the suitability between speed and distance.

1.1.3 The ability of system expansion

WiMAX is competent in supporting bandwidth usage, and signal channels for communication with flexibility, which can be adjusted accordingly with the installation plans and investment costs of the base station system.

1.1.4 Security systems

WiMAX has a secure standard that aids in increasing for the safety of communication with attributes to data confidentiality and data encryption. It also has systems that monitor usages and built-in encryption system as well.

Therefore, the considered capabilities of the WiMAX system that were previously mentioned are reasons in supporting WiMAX as the choice in system planning and in network system planning. However, WiMAX has one condition that is important to the initial design, which is the path loss accordingly to the distance. This can be calculated from the loss of the strength of the magnetic field that spreads in the air between the transmitting station and the receiving station by using the propagation model and considering the signal attenuation between the transmitting and receiving stations, as well as conditions of distance, carrier frequency, antenna height, and the environment of the area.

1.2 Problems

Mahidol University has established many campuses, in which this research chose to study the area between the Salaya and Phayathai campuses. The Salaya campus is located within the Phutthamonthon district in Nakhon Pathom province, while the Phayathai campus is located in the Phayathai district in Bangkok. The distance between the two campuses is approximately 25 kilometers. Currently, the university’s wireless broadband service cannot cover all areas of the campus. Instead, the services are made available for each faculty, and students may use within faculty areas only. Communication between the Phayathai campus and Salaya campus is a connection through the use of optical fiber cables in data transmission, which is a Point-to-Point communication. As a result, this makes the university’s personnel and students lose connection to the university’s network when traveling far from service area of the network system or when traveling between the campuses. Once combining this problem with WiMAX’s current technological abilities that can offer services in many forms, this research proposes an idea as a guide in designing a WiMAX network system by using a propagation model to calculate the path loss accordingly to the distance as referential information for designing the network systems further.

1.3 Objectives

1.3.1 Mention the principles of function and basic architecture of the WiMAX network system.

1.3.2 Find a propagation model that is suitable for the areas of Mahidol University’s Salaya campus and Phayathai campus.

1.3.3 Use the propagation model to calculate the path loss accordingly to the distance in the environment of campus areas as referential information for the designs of WiMAX network systems.

1.3.4 Calculate path loss accordingly to the distance, in which this study utilizes frequencies of 2.5 GHz, 3.5 GHz, and 5 GHz and antenna heights of 6 meters and 10 meters.

1.4 Scope

1.4.1 Determine the areas of the research, which are the areas of Mahidol University's Salaya campus, Phayathai campus, and the distance between the two campuses.

1.4.2 Calculate path loss by using a propagation model that is suitable with the area.

1.4.3 Determine conditions of the system that affect the calculations by the propagation model.

1.4.4 Find the value of path loss accordingly to the distance by using the MAT LAB program.

1.5 Expected Result

The results of this research are the values of path loss accordingly to the distance in 3 areas that have different environments. The values of path loss can be used as referential information for planning the designs WiMAX network systems in areas with environments that are similar to the areas used during the research, in order to serve as initial information for guiding the execution of design planning of the network systems further.

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CHAPTER II
LITERATURE REVIEW AND THEORY

In this chapter will discusses the development of the WiMAX technology, including standard and architecture of the system and the benefits of propagation model as well.

2.1 Wimax

WiMAX (World Wide interoperability for Microwave Access) is improved from the former radio frequency technology via microwave that is called the broadband wireless communication at the standard of IEEE 802.16 with Ling-of-Sight and Point-to-point. Later then, IEEE 802.16a standard has been developed in January 2004 by the license of IEEE (Institute of Electrical and Electronics Engineers) which is available for 30 miles range or 50 meters. Thus, WiMAX service extends wider than 3G phone connection for 10 times. Moreover, the speed limit is 75 Mbps, which is 30 times faster than 3G. The service is also available in point to multipoint system at the same time. The service supports Non-Line-of-Sight system and it works properly through objects such as trees or buildings. Therefore, WiMAX is considered benefitting people to extend connection and internet access widely. As shown in figure 2.1.

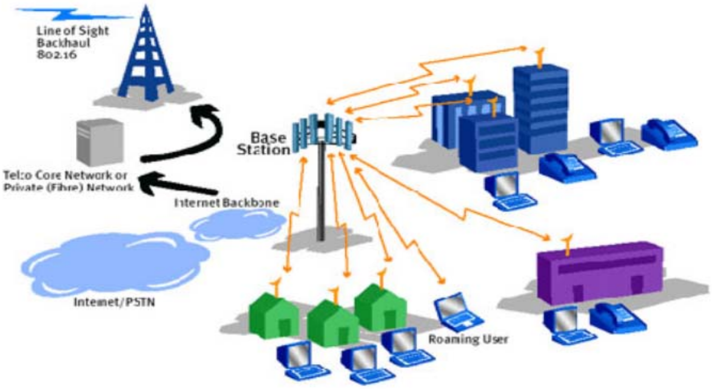

Figure 2.1 How WiMAX works. [4]

2.1.1 Standard WiMAX

In the past of wireless broadband connection service depended on the inventor and the service provider which there was no standardization and the cost was too high. Thus, The Institute of Electrical and Electronic Engineer Standard Association (IEEE-SA) in the USA has developed IEEE802.16 and also The European Telecommunication Standards Institute (ETSI) in Europe has developed HyperMan standard in order to provide wireless broadband service in June 2001. The structures provider and the process data provider have established WiMAX Forum cooperation. Therefore, WiMAX system development and specification can be improved. As shown in Table 2.1.

Table 2.1 Summary of IEEE 802.16 standards. [1] [5]

Standard	Comments
IEEE802.16	This is the basic 802.16 standard that was released in 2001. It provided for basic high data links at frequencies between 11 and 60 GHz.
IEEE802.16a	This amendment addressed certain spectrum issues and enabled the standard to be used at frequencies below the 11 GHz minimum of the original standard.
IEEE802.16b	It increased the spectrum that was specified to include frequencies between 5 and 6 GHz while also providing for Quality of Service aspects.
IEEE802.16c	This amendment to 802.16 provided a system profile for operating between 10 and 66 GHz and provided more details for operations within this range.
IEEE802.16d (802.16-2004)	This amendment was also known as 802.16-2004 in view of the fact that it was released in 2004. It was a major revision of the 802.16 standard and upon its release, all previous documents were withdrawn. The standard amendment provided a number of fixes and improvements to 802.16a including the use of 256

Table 2.1 Summary of IEEE 802.16 standards. [1] [5] (cont.)

Standard	Comments
	carrier OFDM. Profiles for compliance testing are also provided, and the standard was aligned with the ETSI HiperMAN standard to allow for global deployment. The standard only addressed fixed operation.
IEEE802.16e (802.16-2005)	This standard, also known as 802.16-2005 in view of its release date, provided for nomadic and mobile use. With lower data rates of 15 Mbps against to 70 Mbps of 802.16d, it enabled full nomadic and mobile use including handover.
IEEE802.16f	Management information base.
IEEE802.16g	Management plane procedures and service.
IEEE802.16h	Improved coexistence mechanisms for license-exempt opera.
IEEE802.16j	Multi-hop relay specification.
IEEE802.16k	802.16 bridging.
IEEE802.16m	Advanced air interface. This amendment is looking Toth e future and it is anticipated it will provide data rates of 100 Mbps for mobile applications and 1 Gbps for fixed applications. It will allow cellular, macro and micro cell coverage; with currently there are no restrictions on the RF bandwidth although it is expected to be 20 MHz or more.

2.1.2 WiMAX connection system

Structures of WiMAX connection system.

2.1.2.1Base Station: BSS to control data transferring of subscriber station in a service location of the base station and then connect with Wired Internet Backbone.

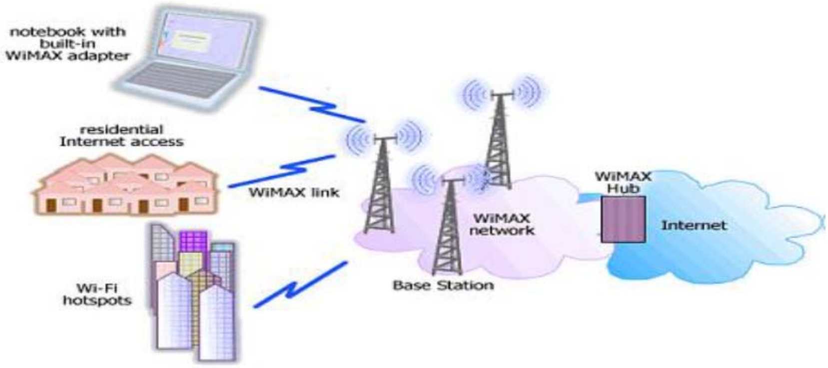

Figure 2.2 WiMAX network. [1]

2.1.2.2Subscriber Station: SS to communicate between users and the station via a subscriber device called CPE (Customer Premises Equipment) which is a Hub as if the central point of effective remote communication.

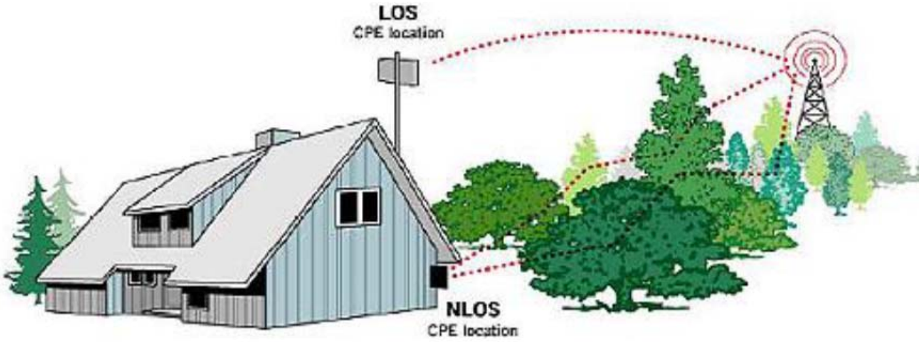

Figure 2.3 Subscriber Station. [6]

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The WiMAX structures network system is not a complicated as mobiles phone system, which WiMAX base station has an ability to process data and to control the subscriber stations system. Moreover, the base station is able to save up the user profile and to directly calculate the network connection as it is called Internet Protocol (IP). [5]

2.2 Basic Propagation Mechanism

Wireless communication which uses radio signal is composed with signal sending via the transmission antenna and receiving region via the receiving antenna as it is shown in figure 2.4 the electro-magnetic wave or the radio wave will be buffering from the transmission antenna and broadcasting through the intermediary to reach the receiving antenna. The properties of the antenna, the intermediary, and the other materials mostly affect energy reaching receiving antenna.

Path lose is the reduction in power density of an electromagnetic wave as it propagates through space. Path loss is a major component in the analysis and design of the link budget of a telecommunication system.

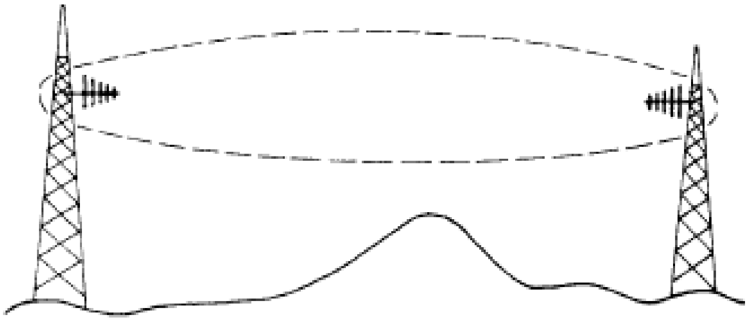

Figure 2.4 wireless communications. [16]

The radio wave which sends out the energy is composed of Electric and Magnetic Fields, which will assume that both of these powers are vertical. To analyze the radio wave polarization (Vertical or Horizontal), that use the Electric Field (shorten as “E” Filed). If “E” Filed is vertical to the earth, that wave would be Vertically Polarized; otherwise, the “E” Filed is horizontal to the earth, that wave would be horizontally polarized. As it is shown in figure 2.5.

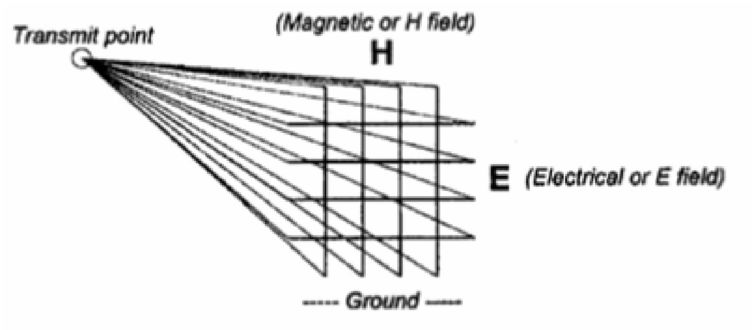

Figure 2.5 Electric and Magnetic Fields. [16]

The radio wave which is from the transmission antenna would bring reflected, Refraction, and Diffraction as light or heat, in terms of the wave has touched or got through various kinds of medium.

Reflection is the reflection of the wave from Medium that is resisting the wave. It will not reflect point by pointing, but it will reflect in a location. The range of the following location depends on Angle of Incidence.

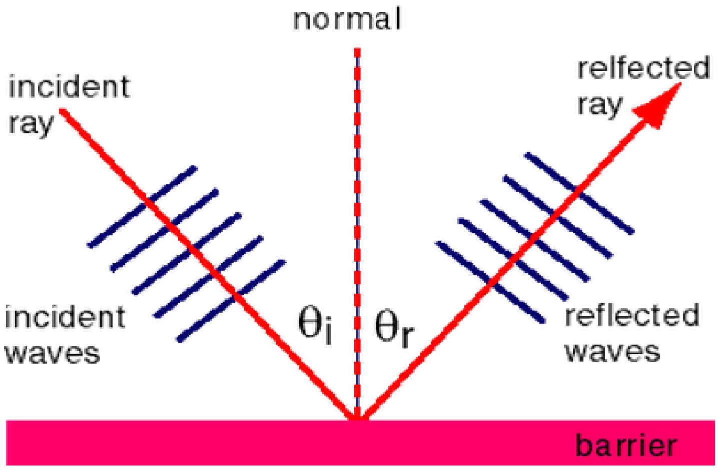

Figure 2.6 Wave Reflection. [9]

Refraction is the refraction of the radio wave when it passes through one Medium to another Medium. Because of the speed difference, Bending situation has been involved which depends on Refractive Index.

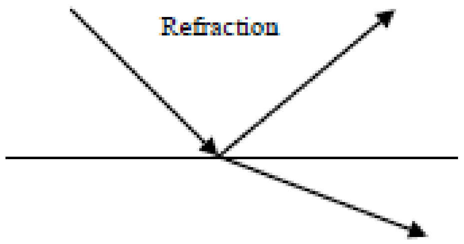

Figure 2.7 Wave refraction. [9]

Diffraction is the diffraction of the radio wave when passing by the border of obstacles. There would be deviation of the line of sight directly or indirectly towards the lower base station.

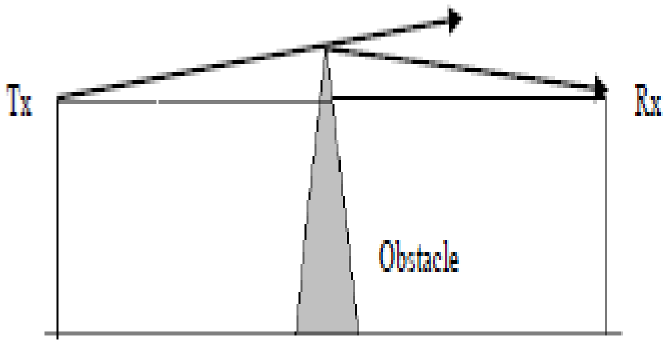

Figure 2.8 diffraction of radio wave. [9]

2.3 Propagation Model [14] [16]

To plan wireless connection system, the objective is too archive the efficient service by managing the level of signal connectivity. Thus, propagation model is the important tool to improve wireless connection system in order to calculate the path loss which might be occurred during the transmission of the signal between the base station and the subscriber station. Therefore, able to gain more information to design the wireless connection system. Here is common figure of the Isotropic antenna show in figure 2.9.

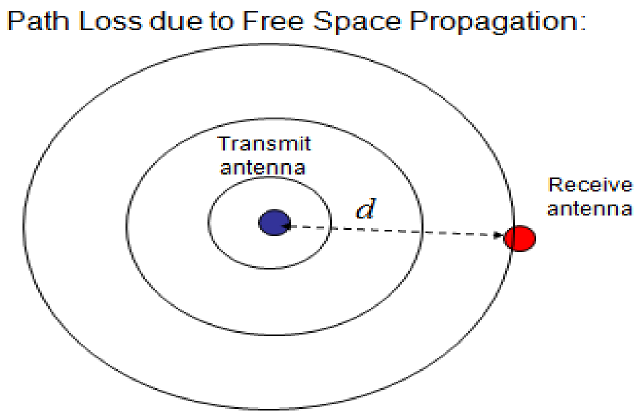

Figure 2.9 Free Space Propagation signal. [14]

Therefore, the equation of calculation would be;

$$P_{rec} = \left(\frac{\lambda}{4\pi d}\right)^2 P_{transm} \qquad (1)$$

When:

$$\lambda = \frac{c}{f}$$

And transfer to decibel formation as show in equation 2;

Path loss in dB:

$$L = 10 \log_{10}\left(\frac{P_{transm}}{P_{rec}}\right) = 20 \log_{10}(F\ (MHz)) + 20 \log_{10}(d\ (Km)) + 32.45 \qquad (2)$$

2.3.1 Free Space Path Loss Model (FSPL)

Free Space Path Loss between the base station and the subscriber station can be calculated by analyzing the frequency and the distance without any obstacles as seen in equation 3.

$$PL_{FSPL} = 32.4 + 20 \log_{10}(d) + 20 \log_{10}(f) \qquad (3)$$

When:

f: frequency	[MHz]
d: distance	[m]
Free Space Path Loss	[dBm]

2.3.2 Okumura Model

The Okumura model has been invented based on the experiment of path loss in Tokyo and then the average has been found to provide the graph figure for transmission model in other locations. The result has been specified as standard factor and in case of calculation path loss in different regions; country regions for instance, or the antenna height difference, correction factor can be used. To correct those factors, consider at equation 4.

$$PL\ (dB) = L_f + A_{mn}(f,d) - G(h_{te}) - G(h_{re}) - G_{AREA} \qquad (4)$$

When:

PL: Median path loss [dB]

L_f: Free space path loss [dB]

A_{mn} (f,d) : Median attenuation relative to free space [dB]

G (h_{te}) : Base station antenna height gain factor [dB]

G (h_{re}) : Mobile station antenna height gain factor [dB]

G_{AREA} : Gain due to the type of environment [dB]

And parameter:

f: Frequency [MHz]

h_{te} : Transmitter antenna height [m]

h_{re} : Receiver antenna height [m]

d: Distance between transmitter and receiver antenna [Km]

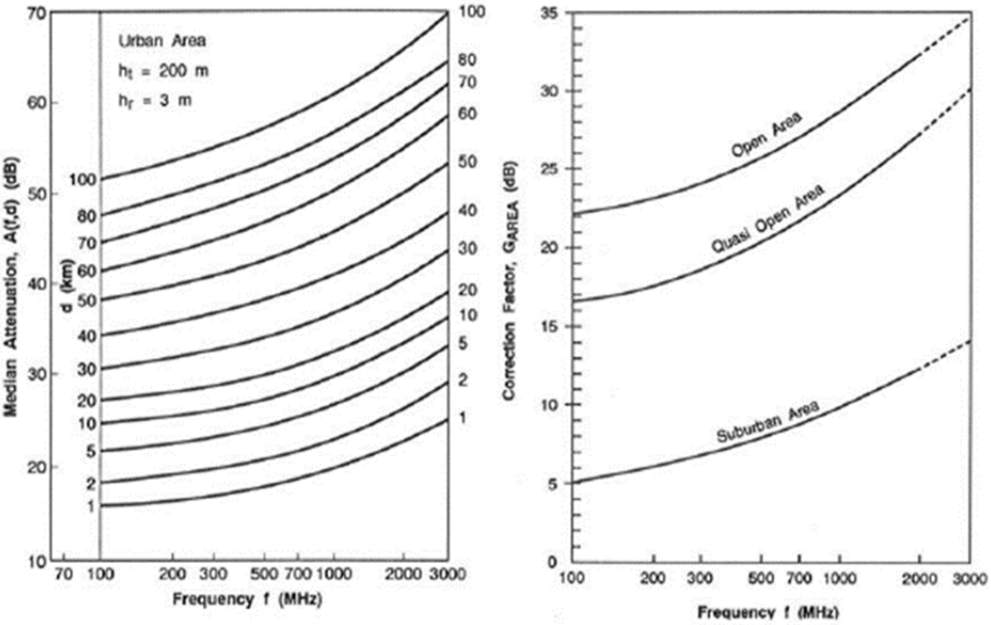

Figure 2.10 free space path loss and the factor. [8]

And if the antenna height has been changed, therefore; the solution would be as seen in equation 5.

$G(h_b) = 20 \log (h_b/200)$ $10 \text{ m} < h_b < 1000\text{m}$ (5)

$G(h_m) = 10 \log (h_m/3)$ $h_m < 3\text{m}$

$G(h_m) = 20 \log (h_m)$ $3 \text{ m} < h_m < 10\text{m}$

By:

h_b = base antenna

h_m = subscriber antenna

2.3.3 COST 231 Hata Model

The COST 231 model has been developed from Hata-Model which has the rate of frequency from150 MHz - 1500 MHz and the distance between base and subscriber is approximately 20 km. The base antenna height is between 30 – 200 meter and the subscriber antenna height is 1 – 10 meter. That can calculate the path loss by environmental difference and using equation 6.

$PL=46.3+33.9\log_{10}(f)-13.82\log_{10}(h_b)-ah_m+(44.9-6.55\log_{10}(h_b))\log_{10} d+C_m$ (6)

When:

d: distance between base and subscriber	[Km]
f: frequency	[MHz]
h_b: base antenna height	[m]

C_m = 0dB city environment

= 3 dB country environment

ah_m is city environment, therefore

$ah_m = 3.20(\log_{10}(11.75h_r))^2 - 4.79$ for > 400 MHz

Country environment:

$ah_m = (1.11\log_{10}f - 0.7)h_r-(1.5\log_{10} f-0.8)$

When:

h_r= subscriber antenna height [m]

2.3.4 Stanford University Interim (SUI) Model

SUI model has been developed by Stanford University and WiMAX cooperation. It is recommended to calculate the frequency which is lower than 11 GHz and base antenna height is between 10meter to 80 meter and subscriber antenna height is between 2 -10 meter. The distance is between 0.1- 8 km.

SUI model can be calculated path loss in two different environmental factors as shown in table 2.2 and equation 7.

$$PL = A+10\gamma\log_{10}\left(\frac{d}{d_0}\right) + x_f + x_h + S \qquad (7)$$

$$A=20\log_{10}\left(\frac{4ml_0}{\lambda}\right) \qquad (7.1)$$

$$\gamma = a - bh_b + c/h_b \qquad (7.2)$$

$$x_f = 6.0\log_{10}\left(\frac{f}{2000}\right) \qquad (7.3)$$

$$x_h = -10.8 \log_{10} \left(\frac{h_r}{2000}\right) \text{ for terrain type A, B} \quad (7.4)$$

$$x_h = -20.0 \log_{10} \left(\frac{h_r}{2000}\right) \text{ for terrain type C} \quad (7.5)$$

When:

A = path loss reference distance d_0

γ= path loss exponent

d= Distance (m) between the transmitter and the receiver	[m]
d_0= Reference distance (100)	[m]
λ= Wavelength	[m]
X_f= Correction for frequency above 2 GHz	[MHz]
X_h = Correction for receiving antenna height	[m]
S= Correction for shadowing	[dB]
h_b = base antenna height	[m]
h_m= subscriber antenna height	[m]

Table 2.2 parameter used in the SUI model.

Parameter	Terrain A	Terrain B	Terrain C
A	4.6	4	3.6
B	0.0075	0.0065	0.0050
C	12.6	17.1	20
S	10.6dB	9.6dB	8.2dB
S_{95}	17.4dB	15.8dB	13.5dB

2.3.5 COST 231 Walfish-lkegami (W-I) Model

This model is the combination between Walfish and F. lkegami. It is suitable for city or any regions which there are a lot of buildings and skyscrapers. The path loss factor would be more accurate as shown in equation 8.

For LOS condition:

$$PL_{los} = 42.6 + 26 \log (d) + 20 \log (f) \qquad (8)$$

For NLOS condition:

$$PL_{NLOS} = L_{fsl} + L_{rst} + L_{msd} \text{ for urban and suburban} \qquad (8.1)$$

$$PL_{NLOS} = L_{fs} \qquad \text{if } L_{rts} + L_{msd} > 0 \qquad (8.2)$$

When:

L_{FSL} = free space loss

L_{rst} = root top to street diffraction

L_{msd} = Multi-screen diffraction loss

Free space loss:

$$L_{FSL} = 32.4 + 20 \log (d) + 20 \log (f) \qquad (8.3)$$

Roof top to street diffraction:

$$L_{rts} = \begin{cases} - & 16.9 - 10\log(w) + 10\log(f) + 20\log(H_{mobile}) + L_{ori} \\ 0 & . \end{cases}$$

$h_{roof} > h_{mobile}$ (8.4)

When:

$$L_{ori} = \begin{cases} -10 + 0.354\varphi & for\ 0 \le \varphi \le 35 \\ 2.5 + 0.075(\varphi - 35) & for\ 35 \le \varphi \le 55 \\ 4 - 0.114(\varphi - 55) & for 55 \le \varphi \le 90 \end{cases}$$

(8.5)

When:

$$\Delta\,\mathrm{H}_{mobile} = h_{roof} - h_{mobile}$$

$$\Delta\,\mathrm{H}_{base} = h_{base} - h_{roof}$$

The multi-screen diffraction loss is:

$$L_{msd} = \begin{cases} L_{bsh} + k_a + k_d + k_f log_{10}(f) + 9log_{10}(f) - 9log_{10}(B) & for\ L_{msd} > 0 \\ 0 & for\ L_{msd} < 0 \end{cases} \quad (8.6)$$

When:

$$L_{bsh} = \begin{cases} -18log_{10}(1 + \Delta h_{base}) & for\ h_{base} > h_{roof} \\ 0 & for\ h_{base} \le h_{roof} \end{cases} \quad (8.7)$$

$$\mathrm{k}_a = \begin{cases} 54 & for\ h_{base} > h_{roof} \\ 54 - 0.8\Delta \mathrm{h}_{base} & for\ d \ge 0.5km\ and\ h_{base} \le h_{roof} \\ 54 - 0.8\mathrm{h}_{base}\left(\frac{d}{0.5}\right) & for\ d < 0.5km\ and\ h_{base} \le h_{roof} \end{cases} \quad (8.8)$$

$$\mathrm{k}_\mathrm{d} = \begin{cases} 18 & \text{for } h_{base} > h_{roof} \\ 18 - +15\left(\frac{\Delta h_{base}}{h_{roof}}\right) & \text{for } h_{base} \le h_{roof} \end{cases} \quad (8.9)$$

$$\mathrm{k}_\mathrm{f} = \begin{cases} -4 + 0.7\left(\frac{f}{925} - 1\right) & for\ suburban\ with\ moderate\ tree\ density \\ -4 + 1.5\left(\frac{f}{925} - 1\right) & for\ metropolitan/urban \end{cases} \quad (8.10)$$

When:

d: Distance between transmitter and receiver antenna [m]

f: Frequency [GHz]

B: Building to building distance [m]

w: Street width [m]

φ: Street orientation angel w.r.t. direct radio path [degree]

2.4 Related Works

The study and the plan of wireless connection system by propagation path loss Model is to calculate the path loss from the base station to the subscriber station based on the result of the path loss experiment in real environment and the equation of propagation path loss model in order to get the most accurate result. Moreover, there is also a research, which improves propagation path loss model with signal calculation.

V.S. Abhayawardhana, I.J. Wassell, D. Crosby,M.P.Sellars and M.G. Brown[7]will be presenting the research about developing propagation Path Loss Model to be used as path loss calculating solution and path loss difference of wireless connection mobile system in Cambridge, UK location with SUI ,COST-231 Hata, and ECC-33 model by changing subscriber antenna height and environment (country, urban, city) and also using frequency 3.5 GHz in order to find a model which provides the most accurate path loss result with different environments. As it is said in the research, ECC-33 model provides the best result in terms of city environment while SUI and COST-231 model provides the highest path loss in every environment.

Josip Milanovic, Snjezana Rimac-Drlje and Krunoslav Bejuk[10] that research has shown that the difference between signal factor receiving from the subscriber station and signal factor based on propagation Path Loss Model calculation by using SUI,COST-231Hata,Macro Model, Model 9999:which would be calculated under the circumstance NLOS and LOS and it would be operated in Osijek, Croatia and different urban regions in order to find the propagation Path Loss Model result between the base and the subscriber. As it is shown in the research, the result based on SUI model in terms of NLOS has provided the most accurate result to the path loss; however, it has provided the very different result in terms of LOS. Macro, Model 9999 has provided the best result in terms of LOS and the worst result in terms of NLOS. 231-Hata model has provided the highest result from both NLOS and LOS.

Mohammed Alshami,T.A.,J.T.and A.E.[21]’s research has shown that the path loss based onOkumura,Hata,Cost-231,Ericsson,Erceg,Walfish,Ecc-33,Leeif frequency 3.5 GHz and distance 1km to 50 km and compared with the path loss calculating in real situation in order to find link budget, power outage probability and the distance; it is shown that Erceg model provided the most accurate result with the other results in every environment.

Jalel Chebil, Ali K. Lawas, and Md. Rafiqul Islam [12] the research will be presenting the comparison between the Path Loss signal and the diffraction in real situation and there are 4 differences in urban regions in Kuala Lumpur and the path loss based on the calculation of propagation Path Loss Model which has been using 6 models; long-normal shadowing, Lee Model, Stanford University Interim model (SUI), COST 231 Hata model, Egli model and ECC-33 As it is shown in the experimental result, SUI model provided the most accurate path loss result.

As it is shown most of the research, propagation Path Loss Model would be used to calculate the path loss and to find the signal transmission which would be transferred from base station to subscriber station. Moreover, there is a comparison between the propagation Path Loss Model and the path loss calculating in experimental regions, which is based on city, urban, and country regions and also the subscriber antenna height difference. As we can analyze from the research, it is shown in table 2.3 in order to find the most suitable model for the experimental region.

Table 2.3 model comparison. [8] [9]

Model	Frequency Rang	Applicable	Different terrain
Okumura	200 MHz-1920MHz	LOS/NLOS	Ideal in the city.
Hata	150 MHz – 1500 MHz	LOS/NLOS	Support all Terrains.
Lee	900 MHz	LOS/NLOS	Use correction factors.
Longley Rice Model	20 MHz – 20GHz	LOS/NLOS	Suitable in VHF and UHF
SUI	>1900 MHz	LOS/NLOS	Support all Terrains
COST 231 W-I	>1900 MHz	LOS/NLOS	Flat suburban and urban have uniform building height.

As it is shown in table 2.3. It is seen that SUI (Stanford University Interim Model) and COST 231 W-I. That are suitable for analyzing Path loss signal because the region which can be used to improve the WiMAX connection system is full of the specific buildings and trees. Therefore, that the path loss has been invented. SUI and COST 231 W-can be used to calculate the path loss with the specific environment and the result would be more accurate.

CHAPTER III

PROPOSED MODELS

In this chapter to specify the propagation path loss model which has been mentioned in the previous chapter. As shown in research and the comparison in Table 2.3, that there is a model which is functional and the result is close to the real path loss and it is also suitable for the demo location which there are two places; Stanford University Interim (SUI) Model and COST 231 Walfish-lkegami(W-I) Model. To look over the model, path loss should be compared by free space path loss model which the environment is not involved and frequency 2.5 GHz, 3.5 GHz and 5GHz with the receiving antenna heights 6 meter and 10 meter. WiMAX connection system planning can be divided by three formats; First, the planning in Mahidol University (Salaya campus). Second, the planning in Mahidol University (Phayathai campus) and the third one is planning between two campuses without any obstacles. However, planning with obstacles will be mentioned in the next topic.

3.1 PlanningWiMAXconnection system in Mahidol University (Salaya campus)

As it is shown in figure 3.1, the point is represents Mahidol University (Salaya campus) locates and there are these following places in the campus; University council office, principle office, various departments office, Golden Jubilee Medical center, Risk Management center, Copyright Management center, Intellectual Property Management center, Wisdom Application center, Contemplative Education center, Internal Observer center, Center of Ethical Reinforcement for Human research, Faculty of Science, Faculty of Medicine Ramathibodi Hospital, Faculty of Associated Medical Science, Graduate school, Faculty of Social Science and Humanity, Faculty of Environment and Resource Study, Faculty of Engineering, Faculty of Veterinary Science, Faculty of Physical Therapy, Faculty of Arts, Faculty of Information and

Communication technology, Institute for Population and Social Research, Institution of Nutrition, research Institute for Languages and Culture of Asia, Institute of Molecular Bioscience, ASEAN Institute for Health Development, National Institute for Child and Family Development, Institute for Innovative Learning, Library and Knowledge center, National Laboratory Animal center, Ratchasuda College, College of Sport Science and Technology, International College, College of Music, and College of Religious Studies[23] Point B is where Office of president located and also Computer center which is the hub of all connection system of the campus. Considering from the necessary fundamental structure for base station, for example, electrical wiring from the connection system to antenna and convenience of the base station access in order to maintain and inspect the system, thus, the base station has been installed at point B. Line of Sight (LOS) has been used between Salaya and Phayathai campus while Non Line of Sight (NLOS) is for the region in Salaya campus.

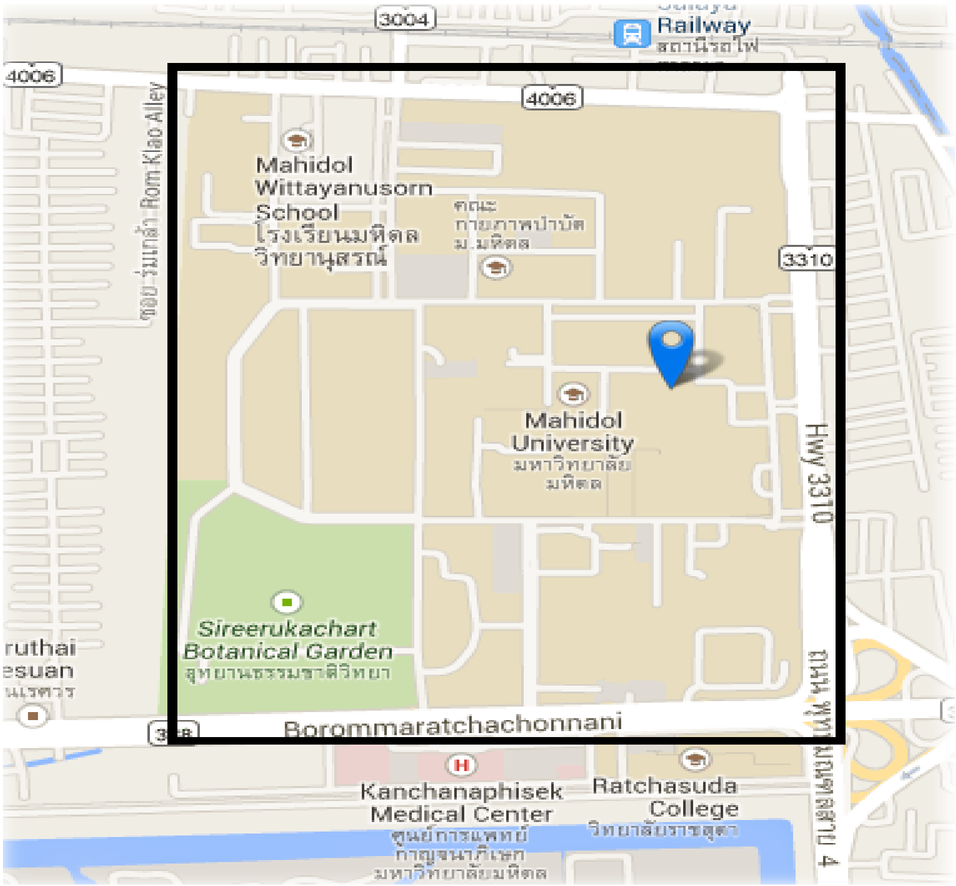

Figure 3.1 Mahidol University (Salaya campus) map. [22]

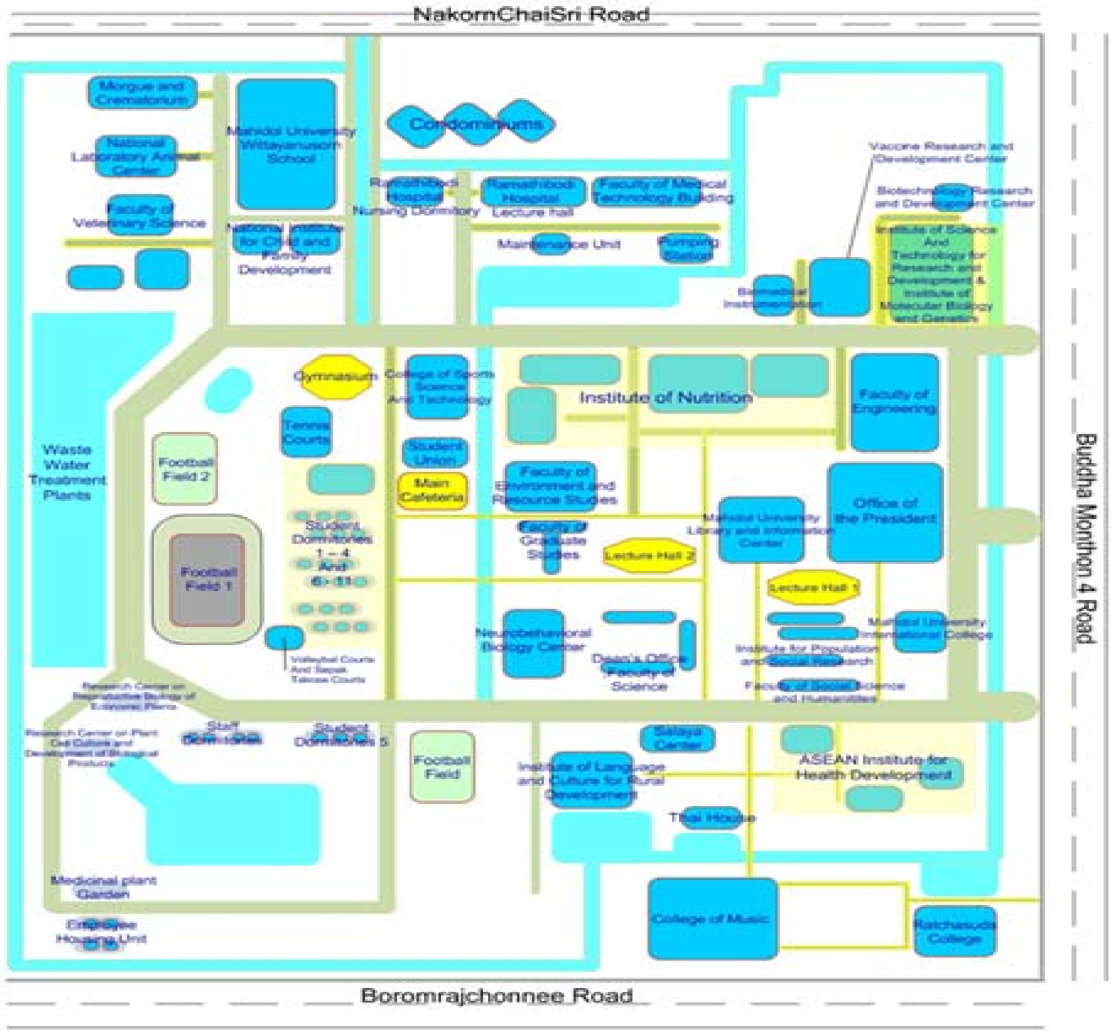

Figure 3.2 Locations. [24]

3.2 Planning WiMAX system in Mahidol University (Phayathai campus) [23]

The location of Mahidol University (Phayathai campus) is shown in point A and orange point as you can see in figure 3.3.

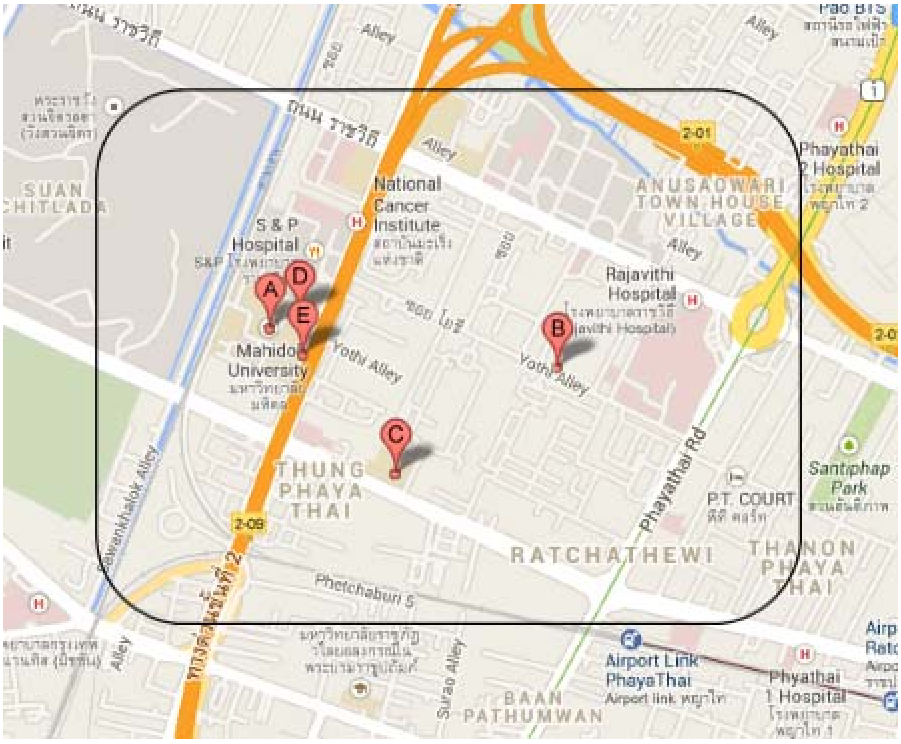

Figure 3.3 Mahidol University (Payathai campus). [22]

And these are the following departments as detailed show in figure 3.4.

1 Faculty of Public Health.

2 Faculty of Tropical Medicine.

3 Faculty of Dentistry.

4 Faculty of Pharmacy.

5 Faculty of Medicine, Ramathibodi Hospital.

6 Faculty of Science National Doping Control Center.

7 Mahidol University Computing Center.

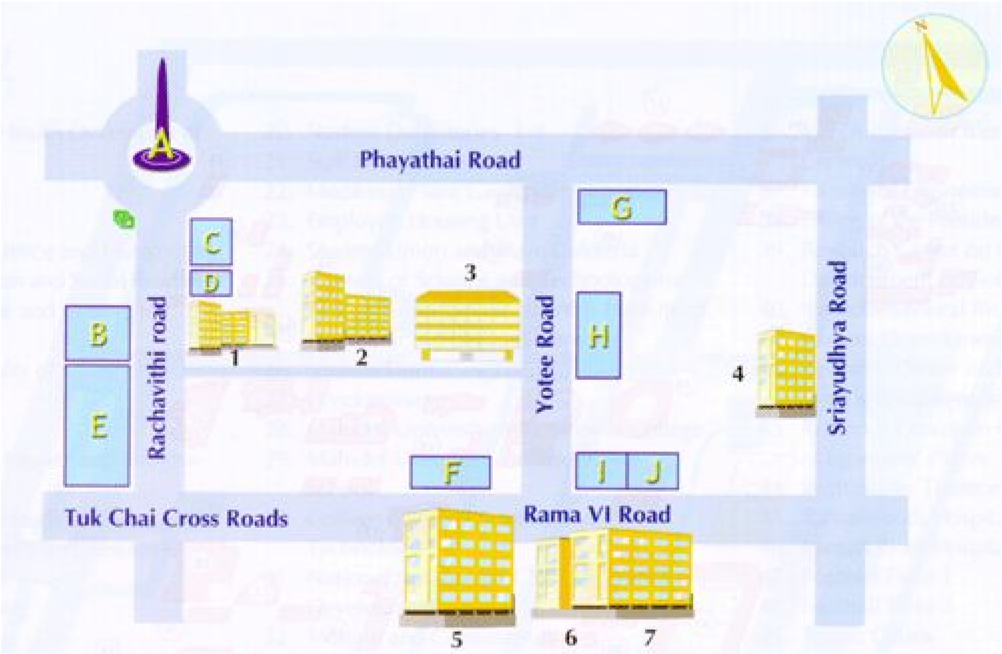

Figure 3.4 departments located.[24]

As shown in figure 3.4, number 7 represents Computing Center which is where to install the base station since the building is appropriate for connection service system and it is available for electrical wiring and air conditioning. Moreover, it is convenient to maintain the system. LOS will be activated between Salaya and Phayathai campus while NLOS is for Phayathai campus.

3.3 Planning WiMAX connection system between two campuses

In figure 3.5 represents the distance between Mahidol University Salaya campus and Mahidol University Phayathai campus which is approximately 25 km. Point A represents Salaya location and point B represents Phayathai location. To plan WiMAX connection system, free space path loss model must be analyzed in order to calculate the path loss with using LOS.

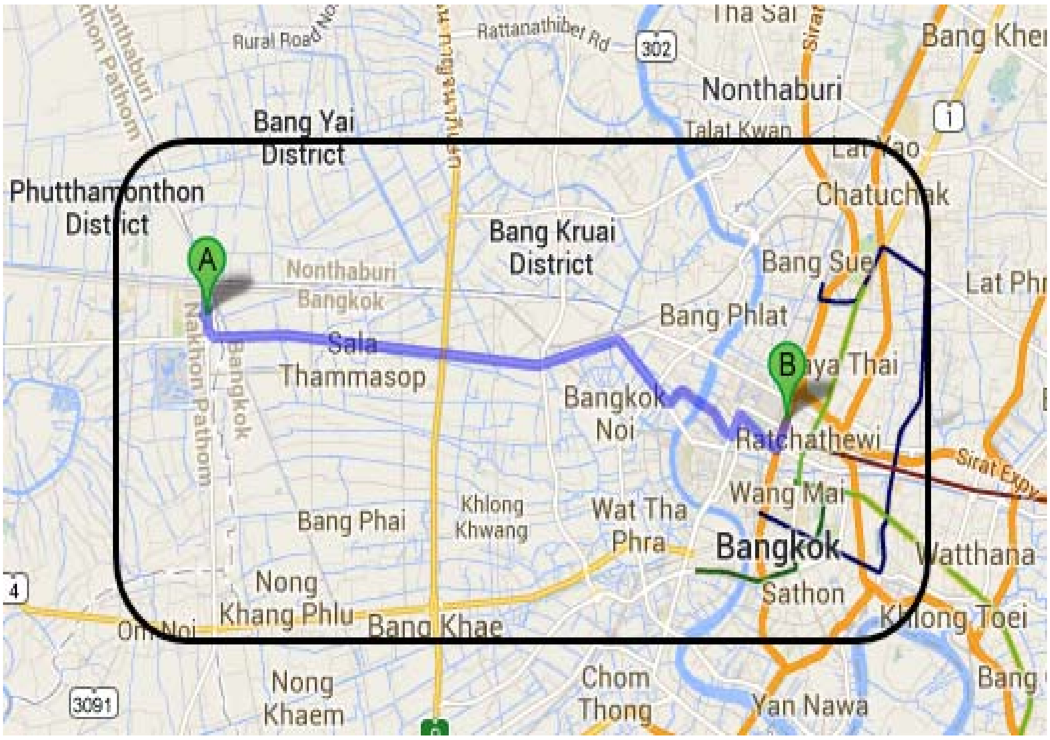

Figure 3.5 the distance between two campuses. [22]

CHAPTER IV
SIMULATION RESULTS AND DISCUSSION

This chapter involves the calculations to find path loss values along the routes in the area of Mahidol University Phayathai campus and in the area of the Salaya campus by examining the distance between the receiver antenna and the sender antenna at 5 kilometers, and the distance between the Phayathai campus and Salaya campus at 25 kilometers with the sender antenna height at 30 meters. Examinations under the conditions of Line-of-Sight signal propagation (LOS) and Non-Line-of-Sight propagation (NLOS) were made, in which the parameters that were used in the calculations are displayed in table 4.1.

Table 4.1 Simulations parameter.

Parameter	Values
Base station transmitter power	43dBm
Mobile transmitter power	30dBm
Transmitter antenna height	30 m
Receiver antenna height	6 m, 10 m,30 m
Operating frequency	2.5 GHz,3.5 GHz,5GHz
Correction for shadowing	10.6 dB
Street orientation angle	30°
Street width	25 m
Average building height	15 m
Building to building distance	50 m
Distance between Tx-Rx	5Km, 25Km

4.1 Simulation Result

4.1.1 Path loss in Mahidol University Salaya campus area

For the calculation to find the attenuation values in the Salaya campus, the Stanford University Interim (SUI) Model was used to calculate, in which the parameters were determined according to the values shown in table 4.1. In the calculation, 6 meters and 10 meters receiver antenna heights, and 30 meters sender antenna height were used, as well as using 2.5GHz, 3.5GHz and 5GHz frequencies. Once performing the simulation with the MAT Lab program, the following results were obtained as displayed in figure 4.1, 4.2, 4.3, 4.4, 4.5 and 4.6.

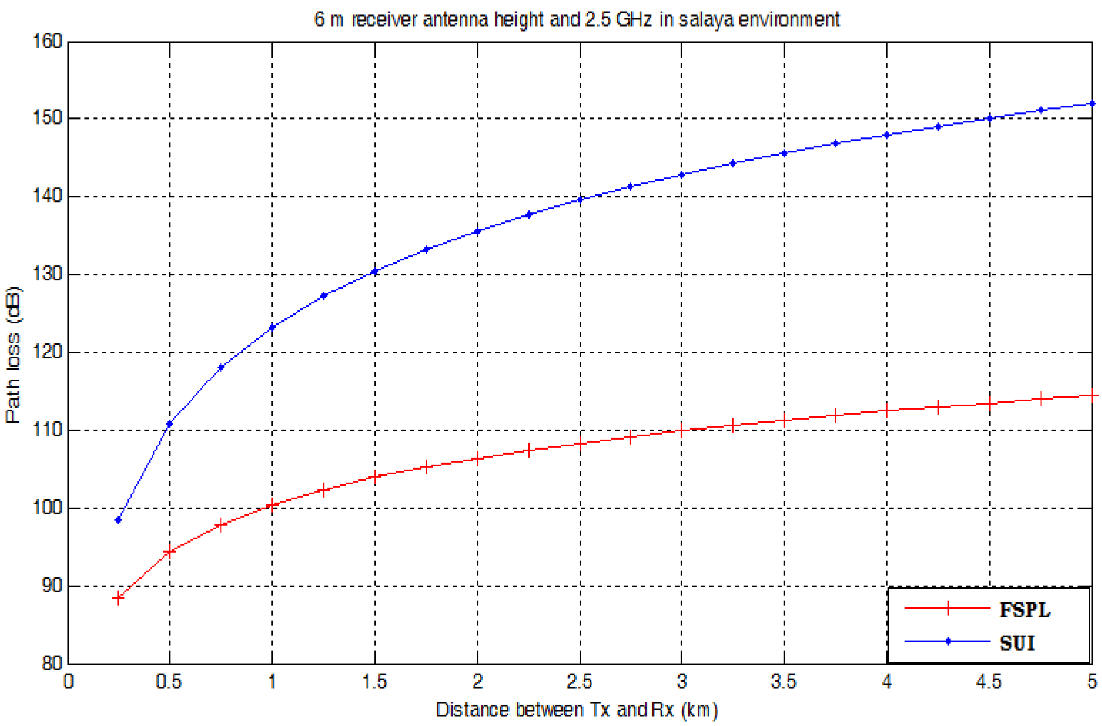

Figure 4.1 Path loss in Salaya campus at 6 m receiver antenna height and 2.5GHz frequency.

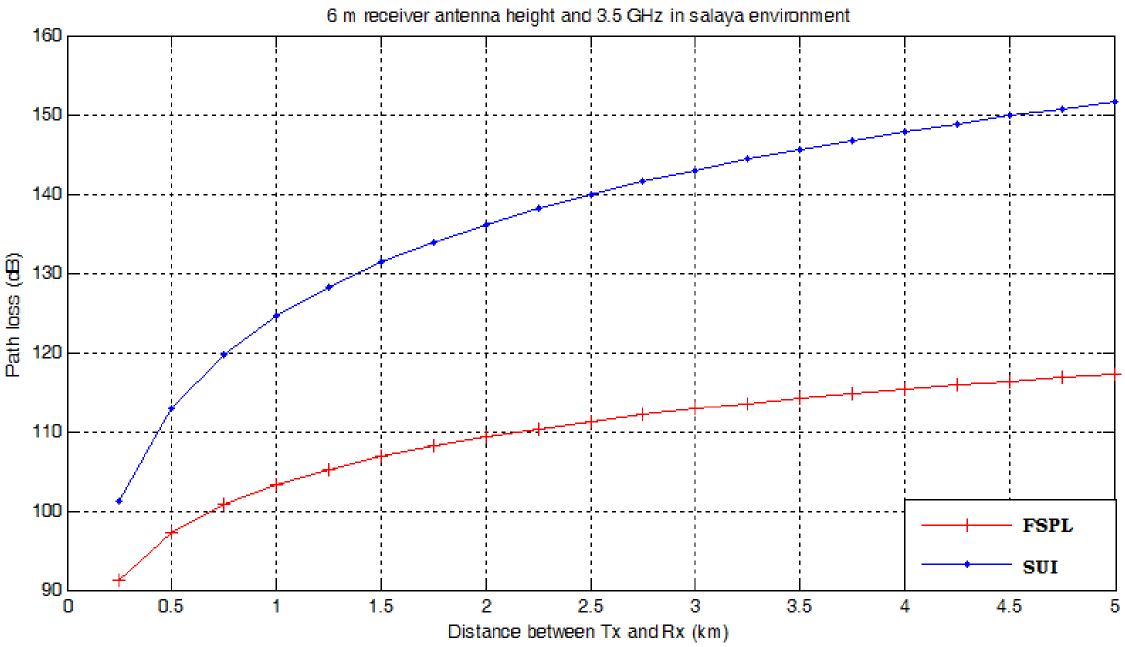

Figure 4.2 Path loss in Salaya campus at 6 m receiver antenna height and 3.5GHz frequency.

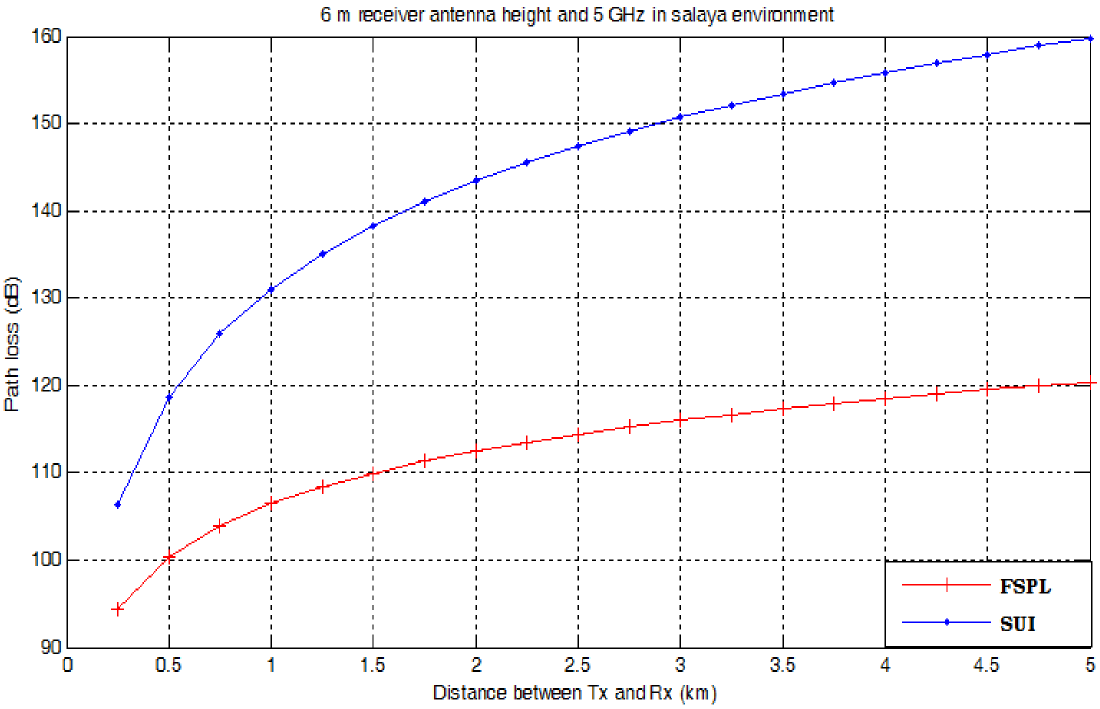

Figure 4.3 Path loss in Salaya campus at 6 m receiver antenna height and 5GHz frequency.

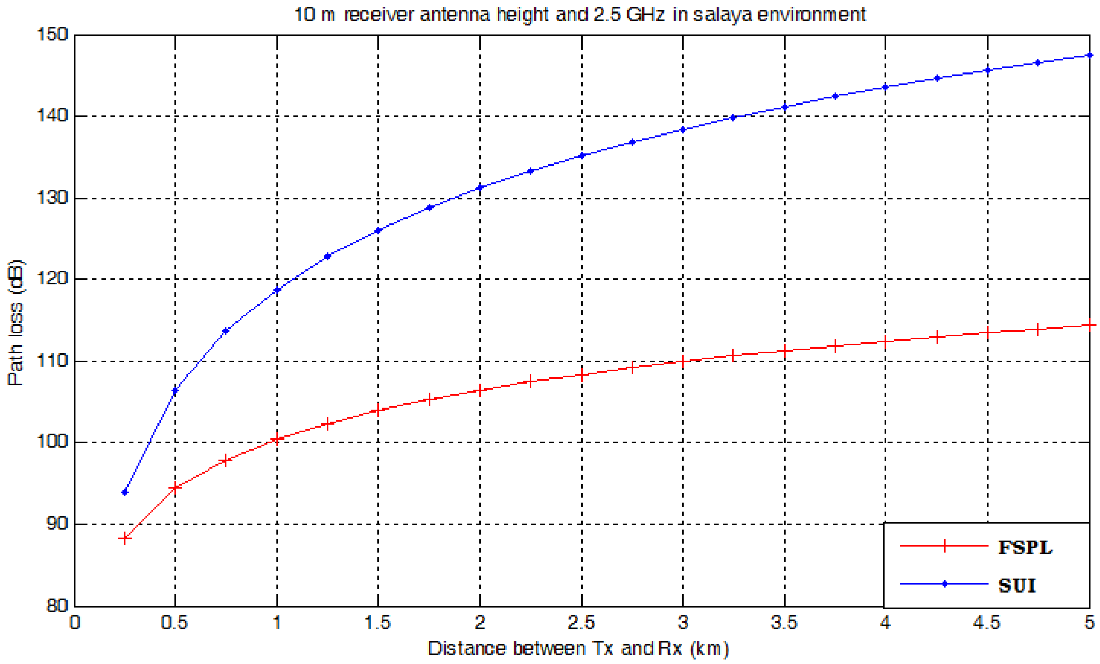

Figure 4.4 Path loss in Salaya campus at 10 m receiver antenna height and 2.5GHz frequency.

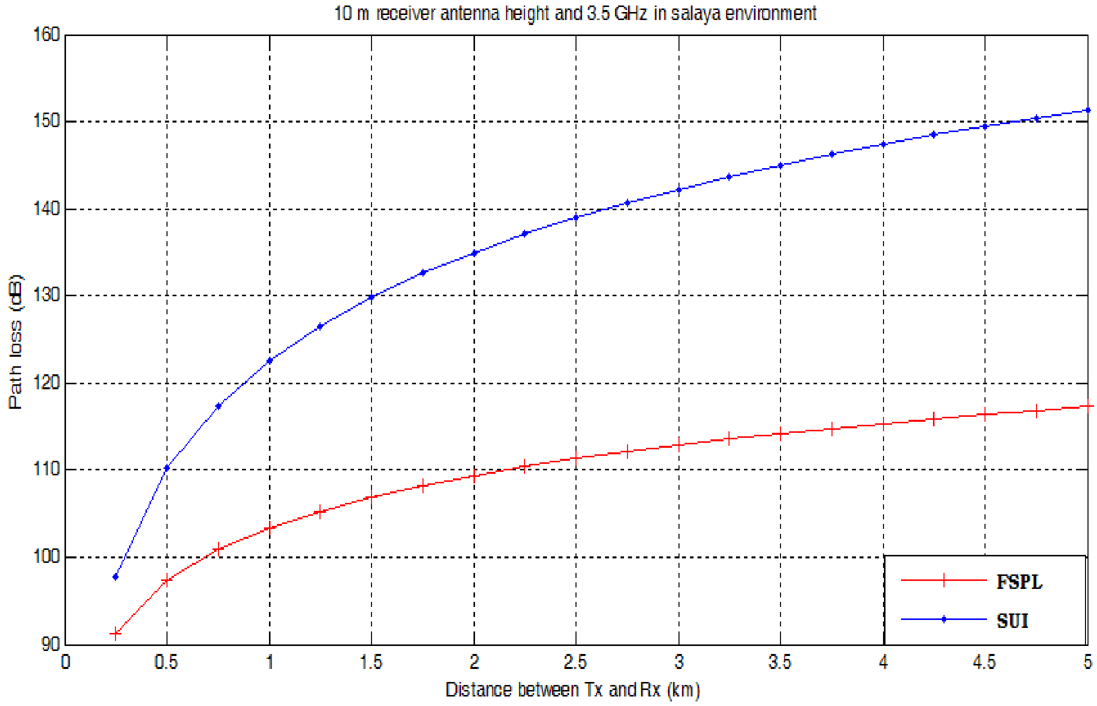

Figure 4.5 Path loss in Salaya campus at 10 m receiver antenna height and 3.5GHz frequency.

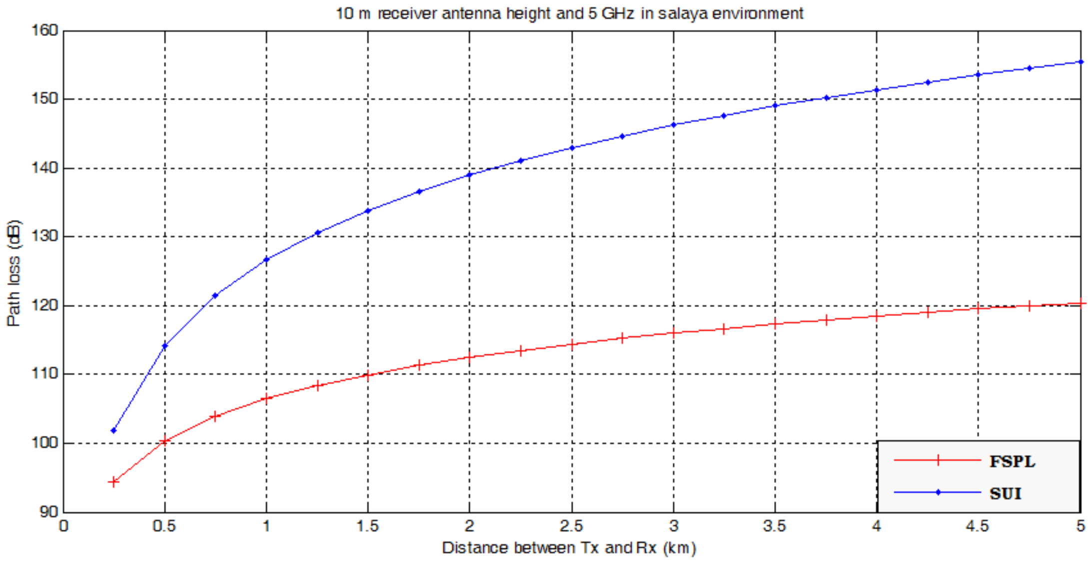

Figure 4.6 Path loss in Salaya campus at 10 m receiver antenna height and 5GHz frequency.

4.1.2 Path loss in Mahidol University Phayathai Campus area

For the calculation to find the attenuation values in the Phayathai campus, the COST 231 Walfish-lkegami (W-I) Model was used to calculate, in which the parameters were determined according to the values shown in table 4.1. In the calculation, 6 meters and 10 meters receiver antenna heights, and 30 meters sender antenna height were used, as well as using 2.5GHz, 3.5GHz and 5GHz frequencies. Moreover, the building’s height and the road’s width were used in the calculation as well. Once performing the simulation with the MAT Lab program, the following results were obtained as displayed in figure 4.7, 4.8, 4.19, 4.10, 4.11, and 4.12.

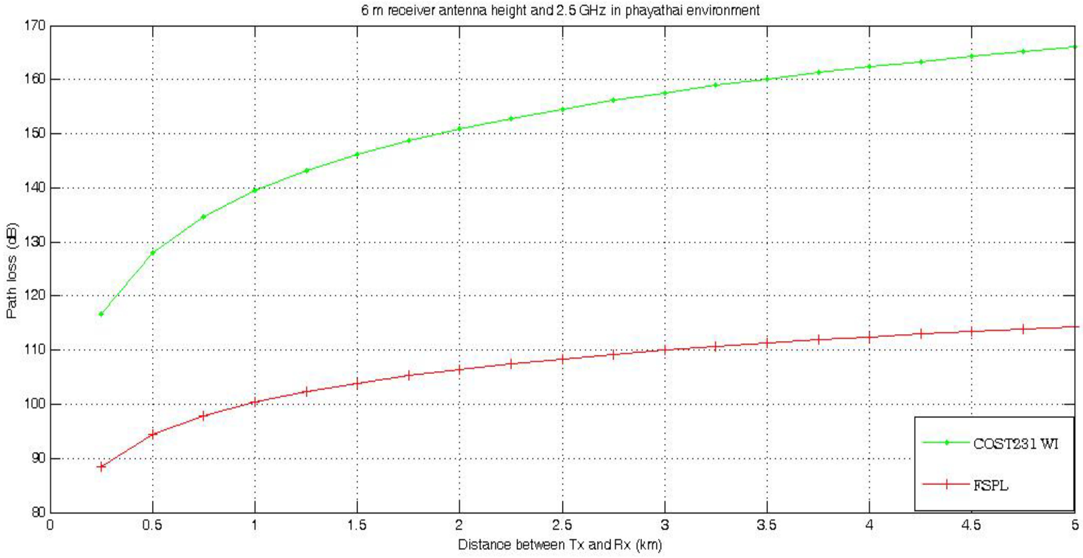

Figure 4.7 Path loss in Phayathai campus at 6 m receiver antenna height and 2.5GHz frequency.

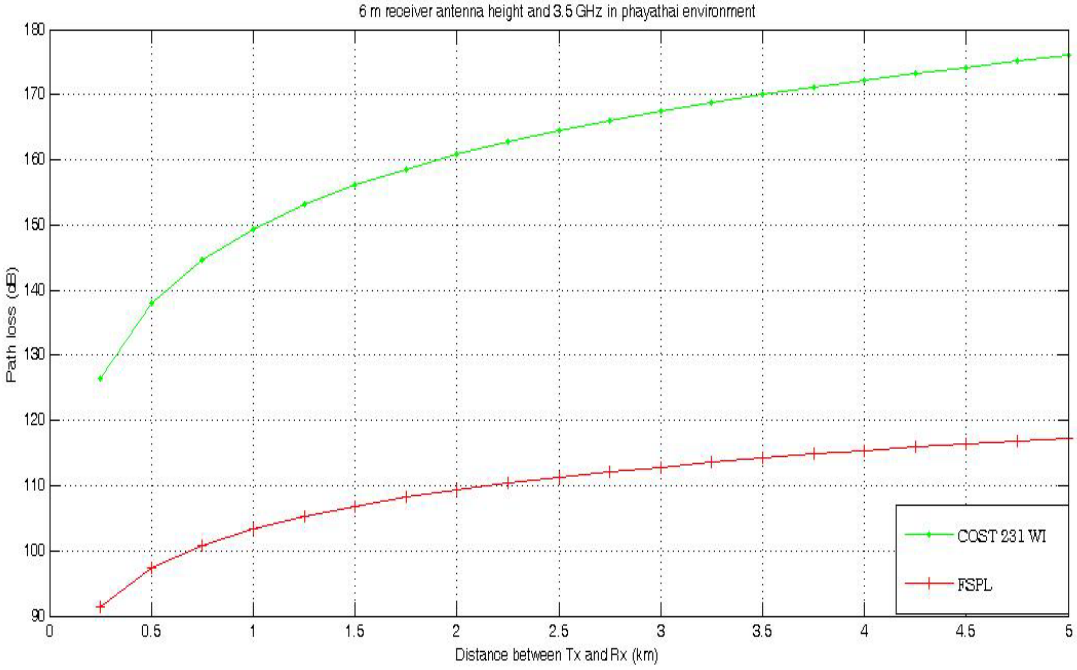

Figure 4.8 Path loss in Phayathai campus at 6 m receiver antenna height and 3.5GHz frequency.

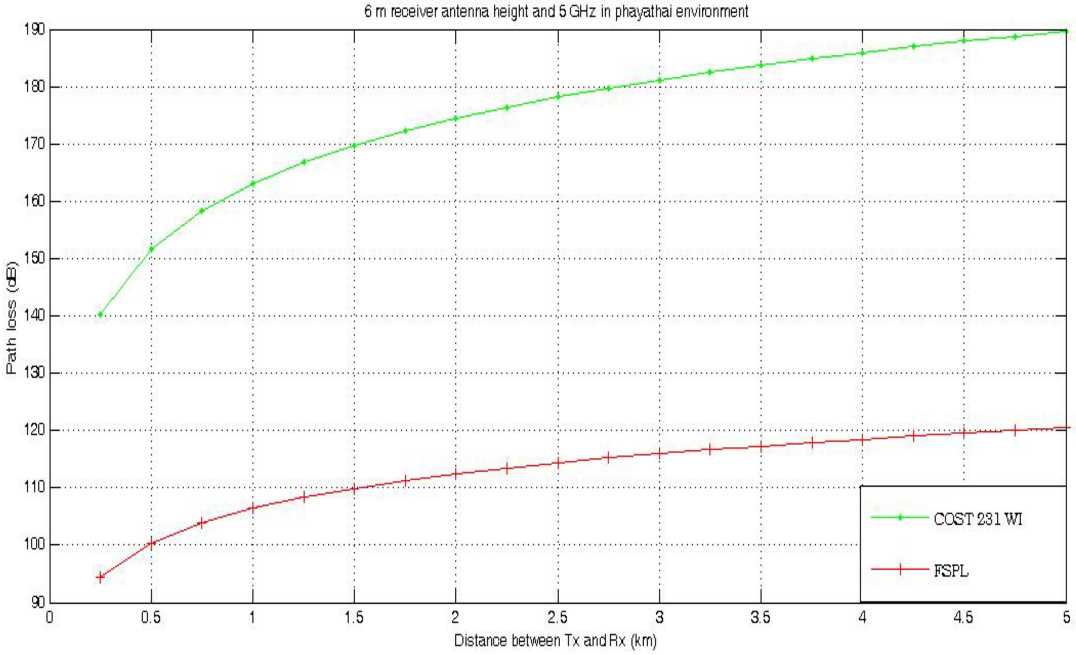

Figure 4.9 Path loss in Phayathai campus at 6 m receiver antenna height and 5GHz frequency.

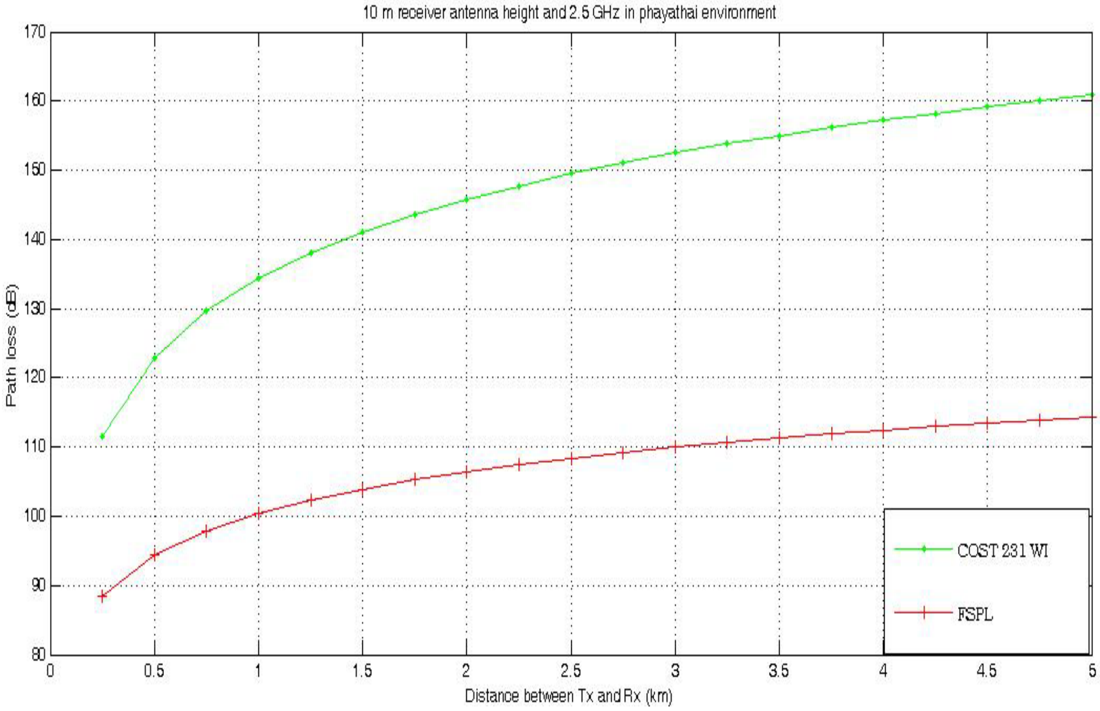

Figure 4.10 Path loss in Phayathai campus at 10 m receiver antenna height and 2.5GHz frequency.

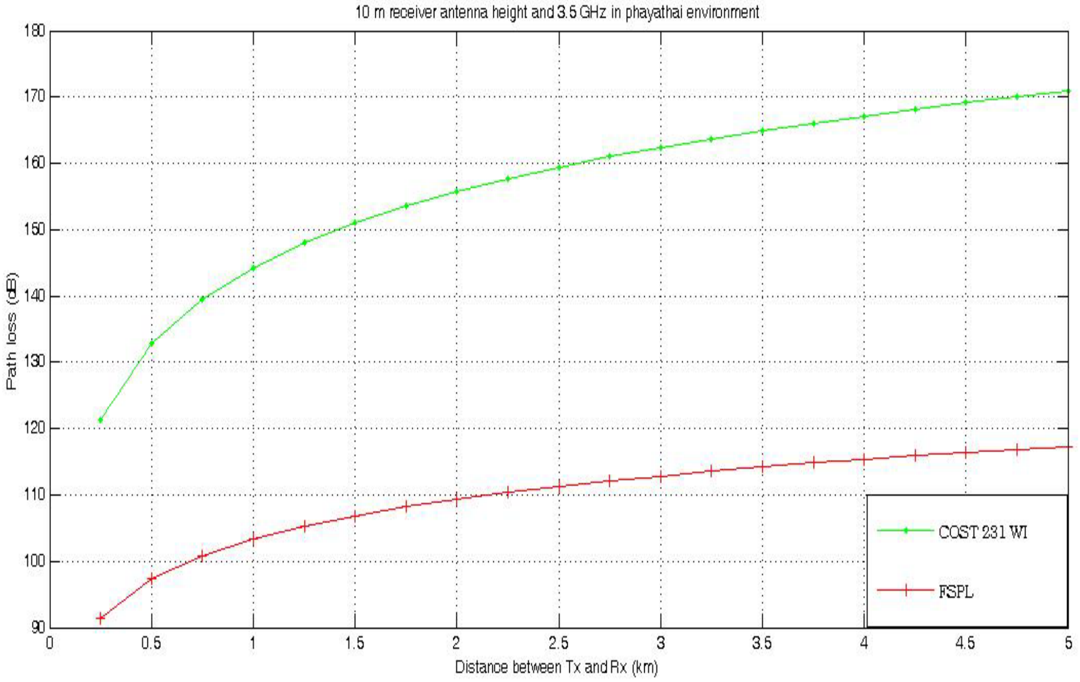

Figure 4.11 Path loss in Phayathai campus at 10 m receiver antenna height and 3.5GHz frequency.

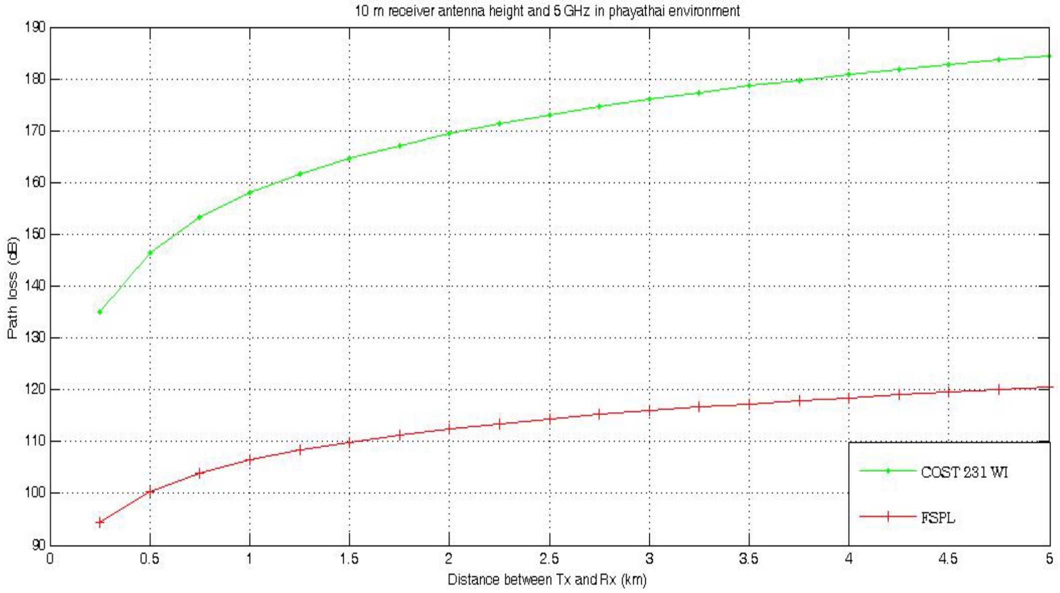

Figure 4.12 Path loss in Phayathai campus at 10 m receiver antenna height and 5GHz frequency.

4.1.3 Path loss between Mahidol University Salaya Campus and Phayathai Campus

For the calculation to find the attenuation values between the Salaya campus and Phayathai campus, the COST 231 Walfish-lkegami (W-I) Model was used to calculate, which is a signal transmission through cables by determining the parameters according to the values shown in table 4.1. In the calculation, 30 meters receiver antenna heights, and 30 meters sender antenna height were used, as well as using 2.5GHz, 3.5GHz and 5GHz frequencies. Once performing the simulation with the MAT Lab program, the following results were obtained as displayed in figure 4.13, 4.14 and 4.15.

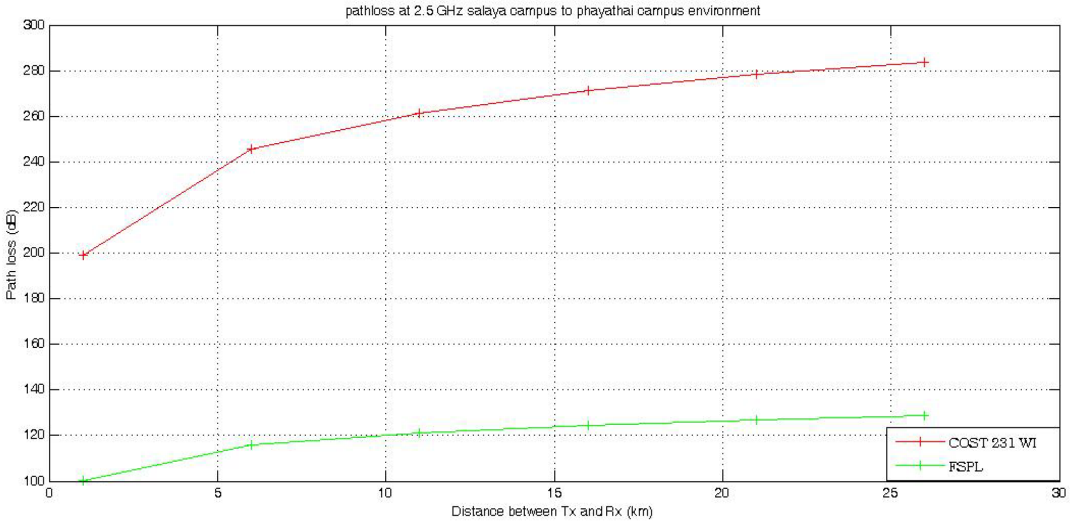

Figure 4.13 Path loss at 2.5GHz frequency.

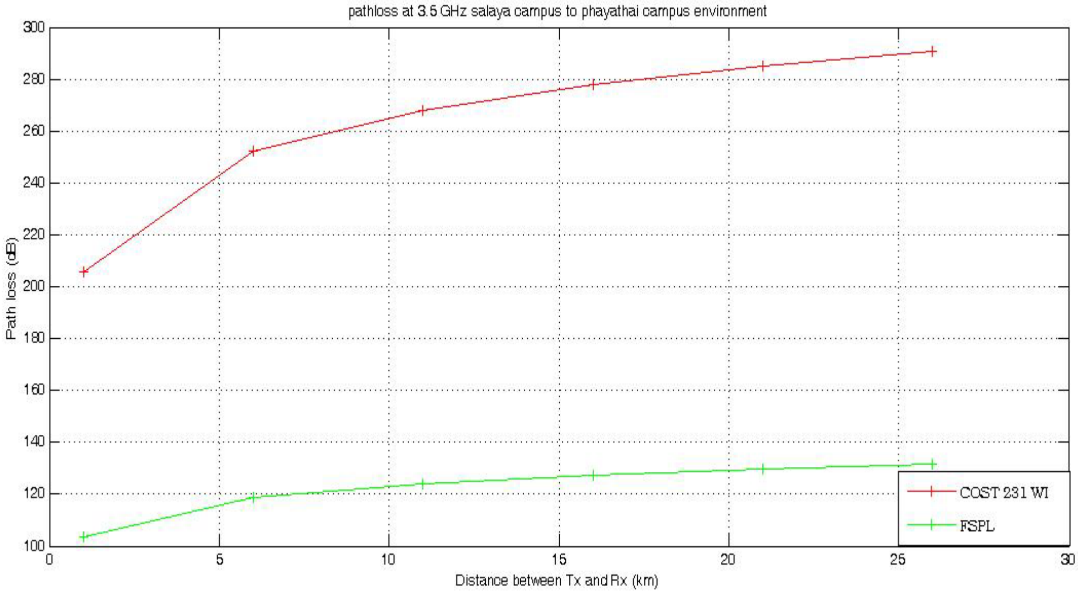

Figure 4.14 Path loss at 3.5GHz frequency.

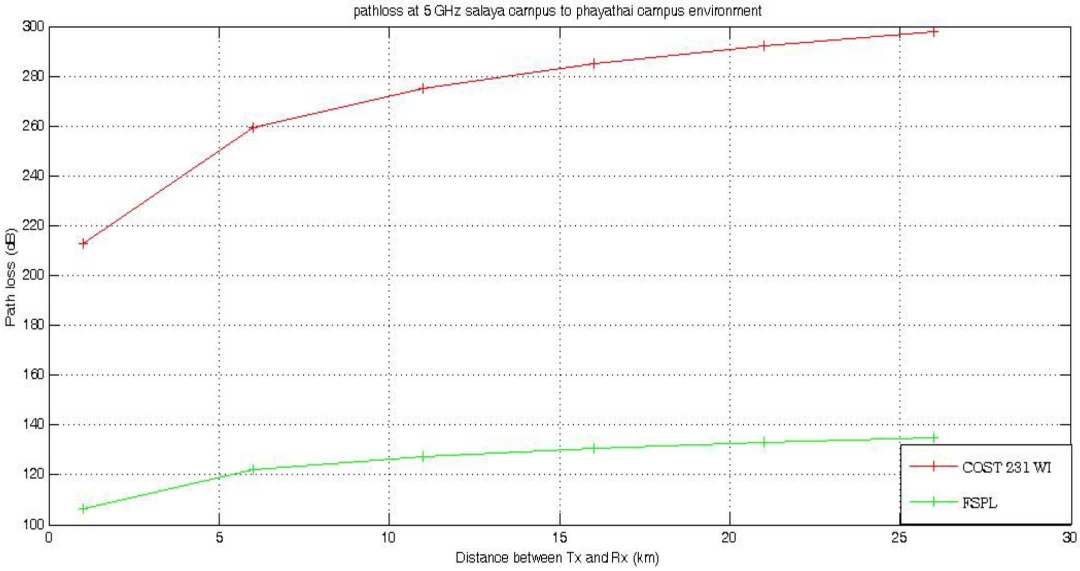

Figure 4.15 Path loss at 5GHz frequency.

4.2 Analysis of Simulation Results

In this research, the simulation results were examined to compare path losses that occurred from using 3 different frequencies and different adjustments of the receiver antenna height. The examinations were separated by each area as follows.

4.2.1 Analysis of simulation results in salaya campus area

From the simulation results in the environment of Mahidol University Salaya campus area, the obtained path loss values were compared by examining the antenna heights at 6 meters, 10 meters, and frequencies at 2.5GHz, 3.5GHz and 5GHz, as shown in images 4.16, 4.17 and 4.18.

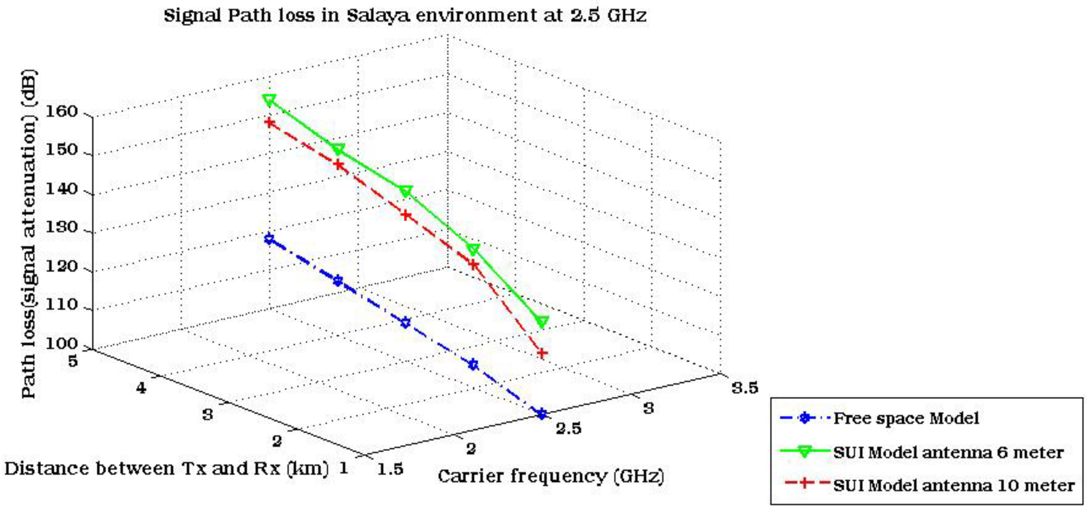

Figure 4.16 Path loss in Salaya campus at 2.5GHz frequency.

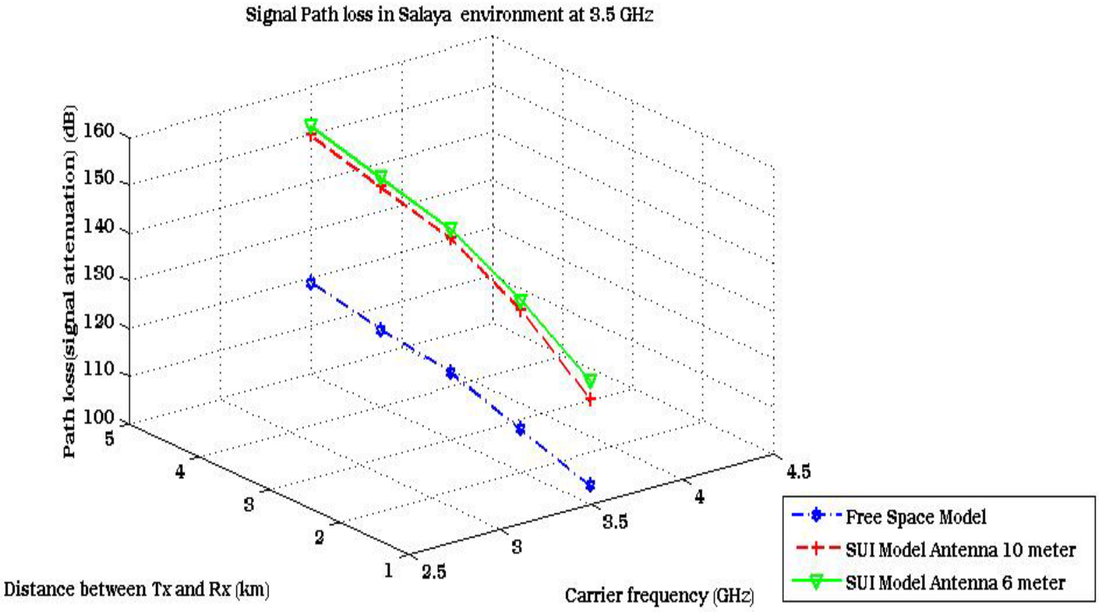

Figure 4.17 Path loss in Salaya campus at 3.5GHz frequency.

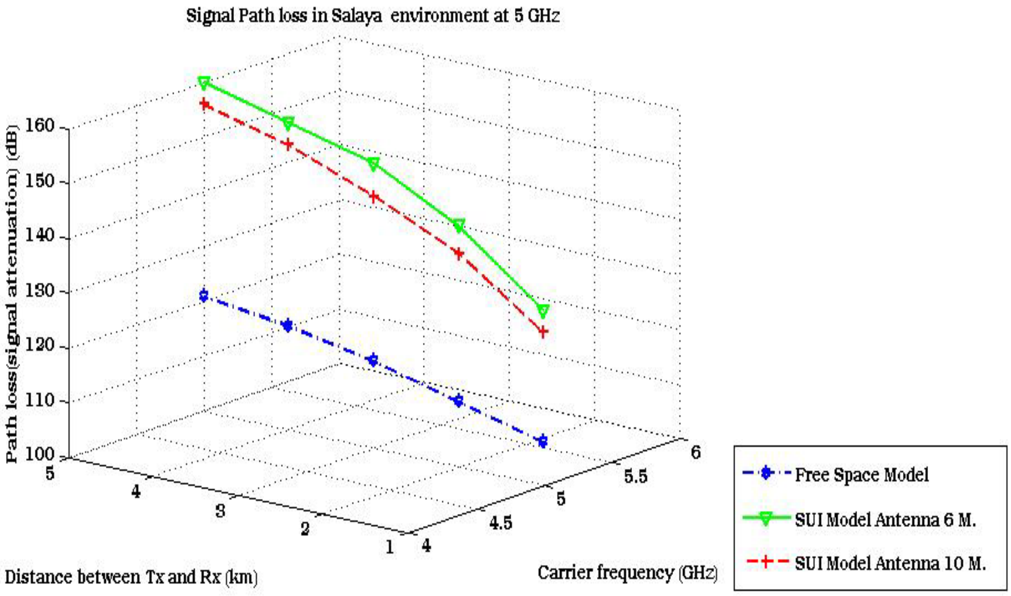

Figure 4.18 Path loss in Salaya campus at 3.5GHz frequency.

Once examining the comparisons of path loss values as shown in images 4.16, 4.17 and 4.18, an area within the Salaya campus that is a suburban surrounding composed of trees and buildings that are not very tall, it was discovered that, at the radius distance of 5 kilometers from the sender antenna to the receiver antenna and at 2.5GHz, 3.5GHz and 5GHz frequencies, the path loss values were 150 dB, 152 dB and 160 dB at 6 meters receiver antenna height. Moreover, once adjusting the receiver antenna height to be 10 meters, the path loss values were 148 dB, 150 dB and 156 dB. It can be seen that the higher path loss values have increased according to the distances and frequencies of usage that have escalated. Moreover, adjustments of the receiver antenna height have discovered that the path loss values will decrease.

4.2.2 Analysis of simulation results in Phayathai campus area

From the simulation results in the environment of Mahidol University Phayathai campus area, the obtained path loss values were compared by examining the antenna heights at 6 meters, 10 meters, and frequencies at 2.5GHz, 3.5GHz and 5GHz, as shown in images 4.19, 4.20 and 4.21.

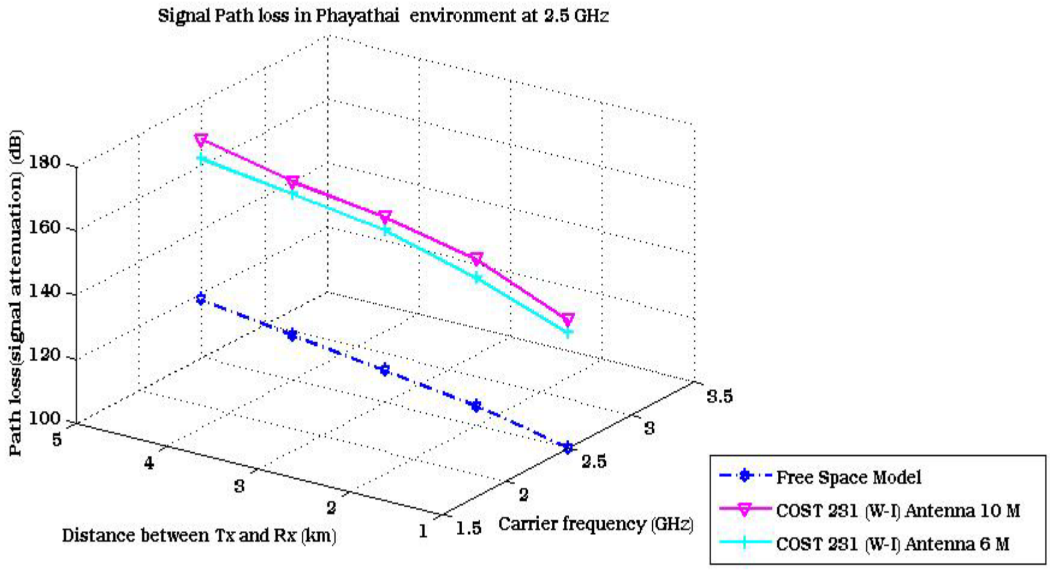

Figure 4.19 Path loss in Phayathai campus at 2.5GHz frequency.

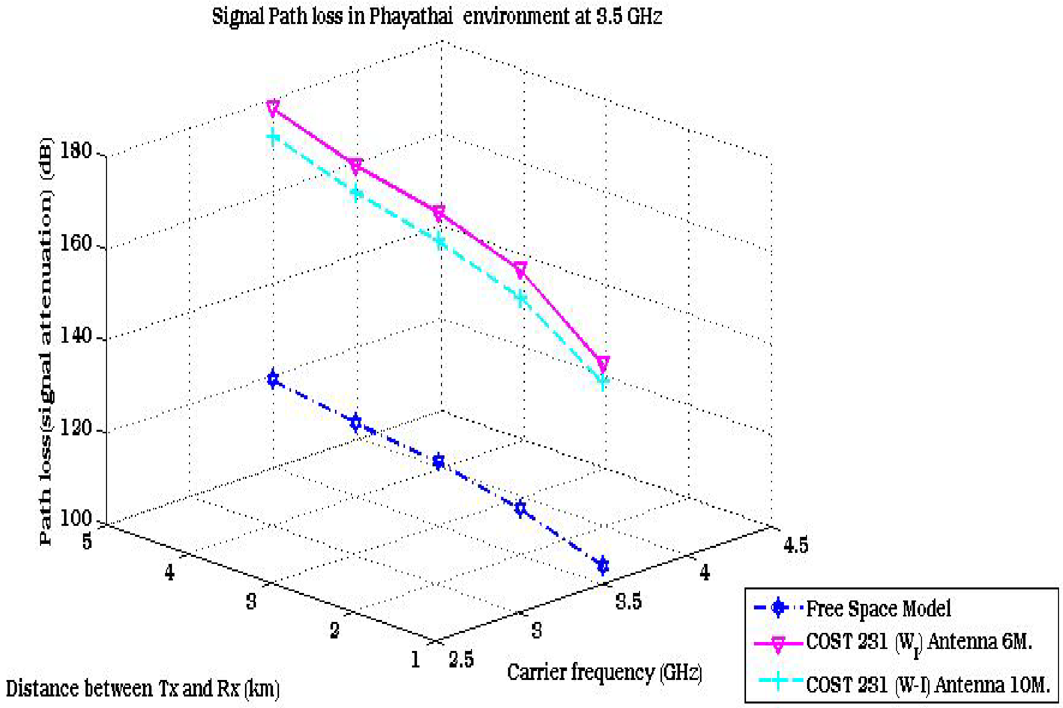

Figure 4.20 Path loss in Phayathai campus at 3.5GHz frequency.

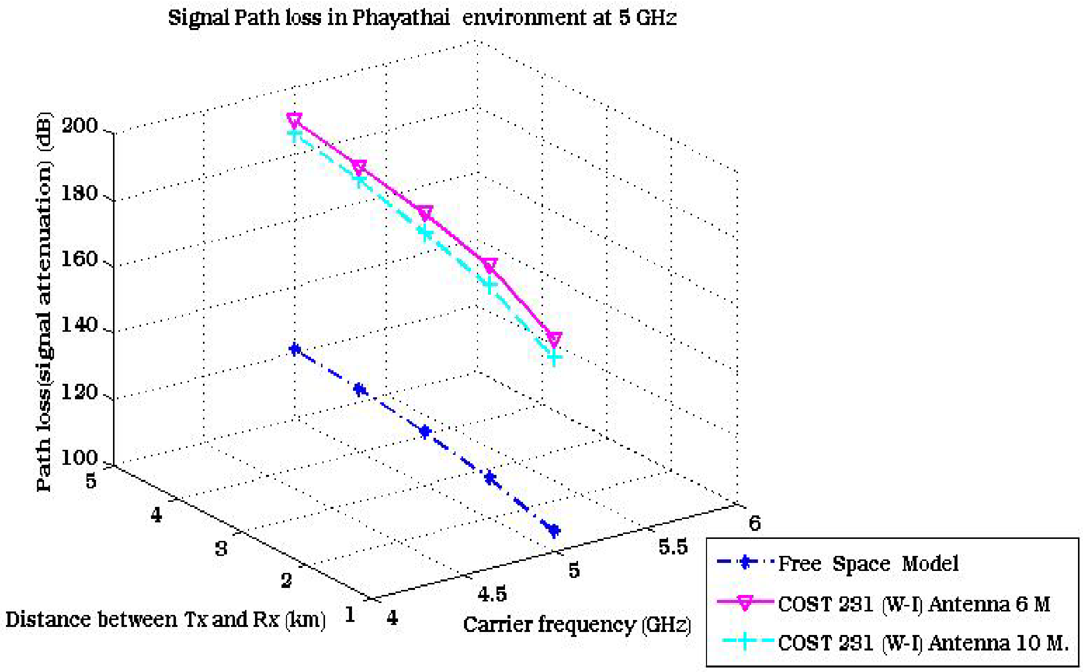

Figure 4.21 Path loss in Phayathai campus at 5GHz frequency.

Once examining the comparisons of path loss values as shown in images 4.19, 4.20 and 4.21, an area within the Phayathai campus that is a metropolitan surrounding composed of trees and buildings with similar heights, it was discovered that, at the radius distance of 5 kilometers from the sender antenna to the receiver antenna and at 2.5GHz, 3.5GHz and 5GHz frequencies, the path loss values were 168 dB, 178 dB and 190 dB at 6 meters receiver antenna height. Moreover, once adjusting the receiver antenna height to be 10 meters, the path loss values were 160 dB, 170 dB and 186 dB. It can be seen that the higher path loss values have increased according to the distances, frequencies of usage that have escalated, and the surroundings of the area with barriers that were obstacles for the signal transmission. Moreover, adjustments of the receiver antenna height have discovered that the path loss values will decrease.

4.2.3 Analysis of simulation results at salaya campus to phayathai campus area

From the simulation results in the surrounding between Mahidol University Salaya campus to Phayathai campus area, the obtained path loss values were compared by examining at 2.5GHz, 3.5GHz and 5GHz frequencies, as shown in image 4.22.

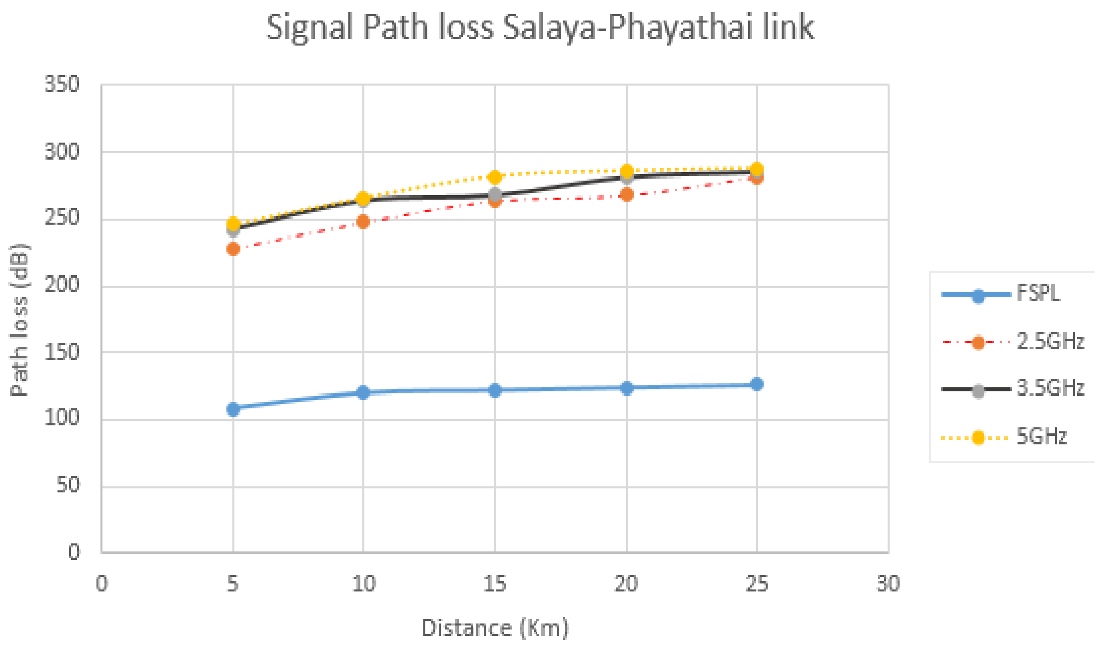

Figure 4.22 Comparison of path loss between Salaya campus and Phayathai campus

From image 4.22, it was an examination of path loss according to the route between using the COST 231 W I Model and the Free Space Model. For the COST 231 W I Model, the distance between the sender station and receiver station is around 25 kilometers and it is a Line-of-Sight signal propagation. A prototype estimated the path loss values that occured along the route. From here, it can be seen that the path loss values were 280 dB, 286 dB and 288 dB at 2.5GHz, 3.5GHz and 5GHz frequencies. Therefore, it was found that adjustments of frequencies and increased distances have affected the path loss to increase. Nevertheless, the high values of path loss will impact the service areas and the usage speed will decrease as well.

4.3 Cell cover planning

This topic will mention about finding the number of cells and the base station that can provide services covering the areas of Salaya campus, Phayathai campus, and between both campuses. Properties of the base station that added special technical abilities were selected, such as increasing the transmission strength of the base station and other special features. Comparisons with the base station according to the standard regulations were displayed in table 4.2.

Table 4.2 Full featured base station versus Standard base station comparison. [5] [21]

Assumption	Frequency : 3.5 GHz Bandwidth: 3.5 GHz Per 60° Sector	Full featured		Standard	
		From	To	From	To
Cell radius (Km)	LOS	30	50	10	60
	NLOS	4	9	1	2
	Indoor CPE	1	2	0.3	0.5
Maximum throughput Per sector (Mbps)	Downlink	11.3	8	11.3	8
	Uplink	11.3	8	11.3	8
Maximum throughput Per CPE at cell Edge (Mbps)	Downlink	11.3	8	11.3	2.8
	Uplink	0.7	0.175	11.3	2.8
Maximum number of Subscribers		More		Less	

From the table, it can be said that each WiMAX base station can provide NLOS services in the service radius of 4-9 kilometers, and support communication with the highest speed of 8-11.3 Mbps, including transmitting signals from the base station to clients and from clients back to the base station. Moreover, the signal transmission can be sent to longer distances when sending in LOS. The design in this research will calculate to find a base station that can provide services in each area by using the equation 4.1 and the cell footprint values, as displayed in table 4.3.

$$\text{Number of required base station} = \frac{Service\ Area(Km^2)}{Cell\ Footprint(Km^2)} \tag{4.1}$$

Table 4.3 Cell Footprint. [5] [21]

Operating Range (Km)	Square Cell Footprint (km^2)	Hexagonal Cell Footprint (Km^2)
0.7	0.98	1.27
0.8	1.28	1.66
1.0	2.00	2.60
1.4	3.92	5.09
2.0	8.00	10.39
2.8	15.68	20.37
4.0	32.00	41.57

4.3.1 Service area of Mahidol University Salaya campus

Mahidol University Salaya campus has the area of approximately 2 square kilometers, which will consist of faculties and numbers of users as shown in table 4.4.

Table 4.4 Faculties and Numbers of Users at Salaya. [24]

Faculty	Number of User
Science	1720
Environment and Resource	1020
Engineering	2320
Veterinary Science	1080
Information and Communication technology	1980
Social Science and Humanity	1460
International College	3450
Total	13030

In designing for the Mahidol University Salaya campus area according to the information from tables 4.2 and 4.3, this area uses an operating range at 1 km and the cell format is a hexagonal cell, which will cover services for stationary and mobile users. From the information, it can be estimated that 1 cell will cover an area of approximately 2.60 km2 and in the cell, there will be only 1 base station. For this case, the base station will be designed to use Advanced Antenna Systems antenna tower that is composed with 6 antenna sectors and installed at angles that are 60° different. In addition, it can provide services to approximately 200 users per sector. As for the indoor network, there will be an installation of the Subscriber Unit at the department buildings in order to provide services, as displayed in figure 4.23.

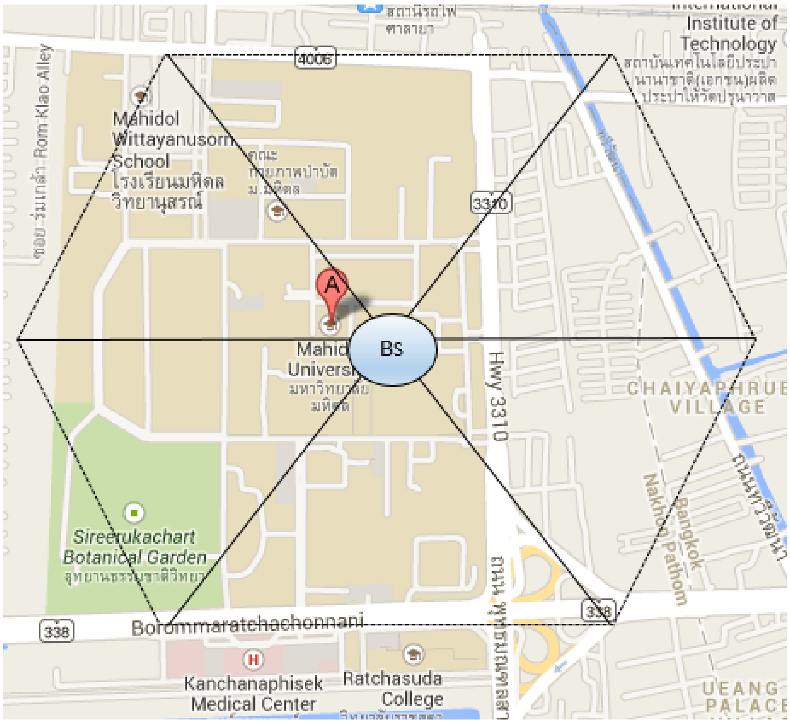

Figure 4.23 Salaya Base Station Signal Cover.

4.3.2 Service area of Mahidol University Phayathai campus

Mahidol University Phayathai campus has the area of approximately 0.32 square kilometers, which will consist of faculties and numbers of users as shown in table 4.5.

Table 4.5 Faculties and Numbers of Users at Phayathai. [24]

Faculty	Number of User
Science	2373
Public Health	1475
Tropical Medicine	1018
Pharmacy	1270
Ramathibodi Hospital	2078
Dentistry	1460
Total	7596

In designing for the Mahidol University Phayathai campus area according to the information from tables 4.2 and 4.3, this area uses an operating range at 0.8 km and the cell format is a hexagonal cell, which will cover services for stationary and mobile users. From the information, it can be estimated that 1 cell will cover an area of approximately 1.66 km2 and in the cell, there will be only 1 base station. For this case, the base station will be designed to use Advanced Antenna Systems antenna tower that is composed with 6 antenna sectors and installed at angles that are 60° different. In addition, it can provide services to approximately 200 users per sector. As for the indoor network, there will be an installation of the Subscriber Unit at the department buildings in order to provide services, as displayed in image 4.24.

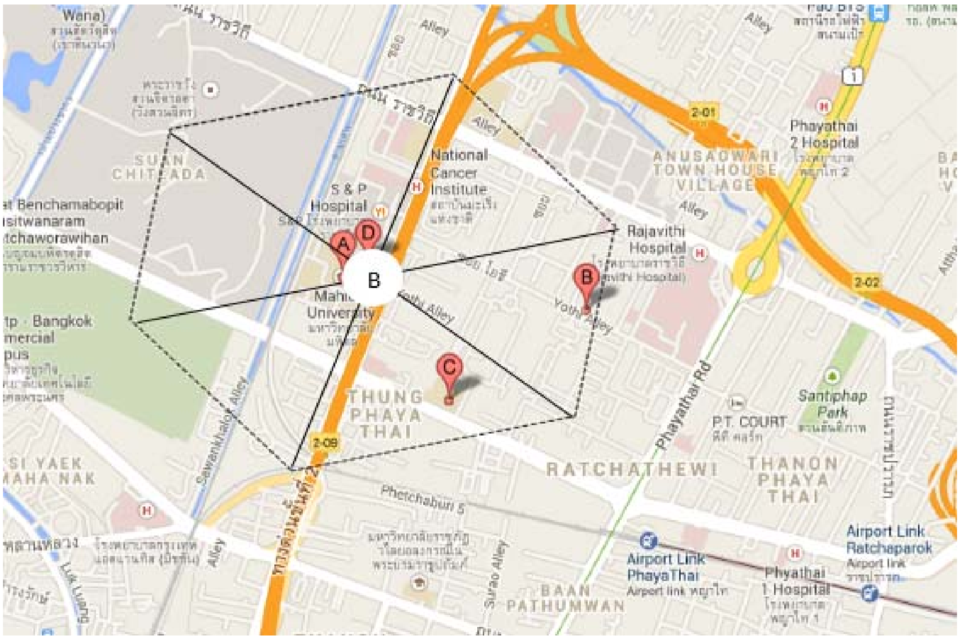

Figure 4.24 Phayathai Base Station Signal Cover.

4.3.3 Service area between Mahidol University Phayathai campus and Salaya campus

The distance between Salaya campus and Phayathai campus is approximately 25 kilometers. From the data in table 4.2, this area uses the hexagonal cell format, which will cover services for stationary and mobile users. From the information, it can be estimated that 1 cell will cover an area of approximately 5 km and in the cell, there will be only 1 base station. For this case, the base station will be designed to use Advanced Antenna Systems antenna tower that is composed with 6 antenna sectors and installed at angles that are 60° different. In addition, it can provide services to approximately 200 users per sector. For this area, the design will add 3 more cells, and each cell will transmit continuous signal of LOS, which is designed to allow users to contact with the base station throughout the entire travel, as displayed in image 4.25.

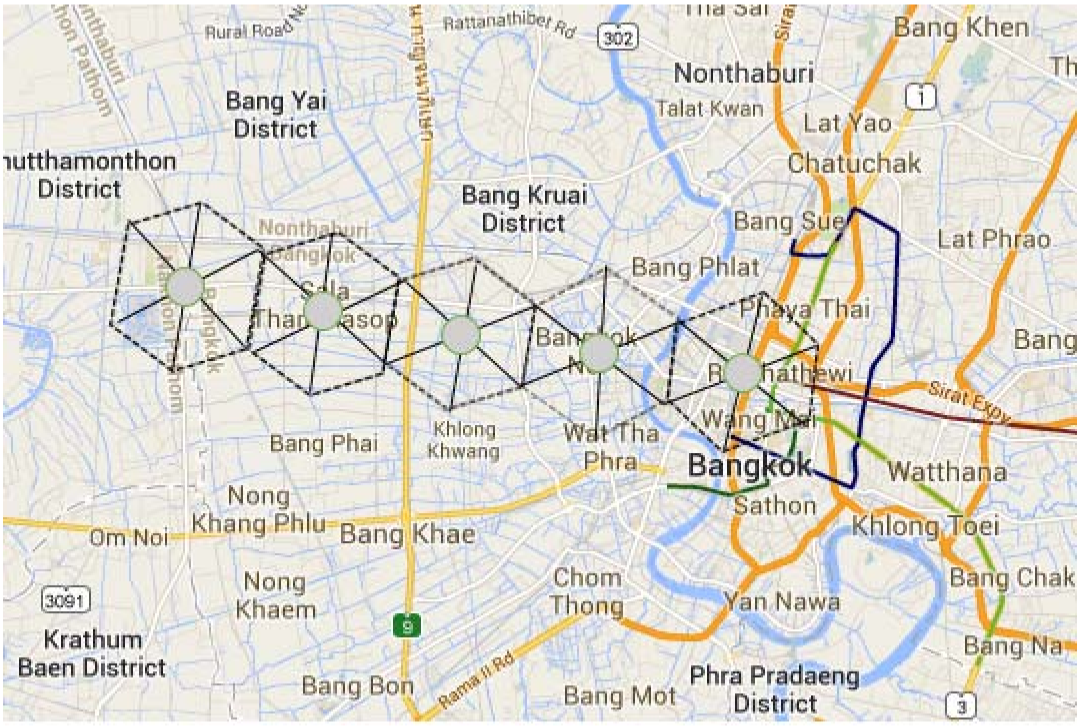

Figure 4.25 Salaya to Phayathai WiMAX Signal Cover.

CHAPTER V
CONCLUSION AND FUTURE WORK

5.1 Conclusion

This research portrays the results of path loss values to serve as referential information in the WiMAX network system design, which adjusted the frequencies at 2.5GHz, 3.5GHz and 5GHz, and receiver antenna heights at 6 meters and 10 meters. The calculated path loss values were similar with the measured path loss values, which occurred from selecting to use the path loss prototype that was tested by a research. It can be seen that the SUI Path Loss Model gave path loss values in the suburban surrounding composed of trees and buildings that are not very tall, which is suitable to the Salaya campus area. On the contrary, the COST 231 W I Path Loss Model gave path loss values in the metropolitan surrounding composed of buildings with similar heights and road widths, which is suitable to the Phayathai campus area. Moreover, once examining the path loss values according to the routes, it was discovered that the changing frequencies and antenna heights have impacts on the path loss values. When adding higher frequencies and maintaining the distance between the sender antenna and receiver antenna as it was, the path loss values increased. When adjusting the receiver antenna heights, the path loss values decreased. This obtained data will assist in becoming referential information for the considerations of the WiMAX network system design. Once there are information on path loss values according to the routes, values can be chosen by specifying the service duration of the network and calculating them. Hence, the Received Power value will be obtained at the end station, and once examining it with the S/N value at the end station, it can still remain in condition to work and the data is able to tell the amount of cells and the amount of base stations that are appropriate to the area. Therefore, data on path loss values that were simulated are the values used for reference in the WiMAX network system design according to the surroundings and areas that are similar to the areas conducted in this research.

5.2 Future Work

The study pathways and researches in the future, by using this research as referential information, have the following boundaries.

5.2.1 Test measurements of path loss in the practical areas

From the simulation results, the attenuation values will be received according to the radius distances that provide services at the distances of 1 km, 2 km, 3 km, 4 km and 5 km from the base station. Moreover, the base station is to be set up, and the parameter values are to be determined, as well as the signal measurement points according to the distances from the base station. The adjustments of the frequencies are at 2.5GHz, 3.5GHz and 5GHz, and the heights of the receiver antenna are at 6 meters and 10 meters. These are in order to analyze the results that are measured and the results that are calculated.

5.2.2 Signal test to find the areas that cover the services

The signal testing point is determined according to the distances in the area that is used to conduct the research. The attenuation values are measured according to the distance that is the radius around the base station, and the distances from the base station are to be increased in order to find the longest distance in which the clients are still able to connect to the base station. In addition, adjustments of the frequencies and receiver antenna heights can be similar to the above research.

5.2.3 Test to find number of clients in the areas that can provide services

A research about finding the highest number of clients in which the base station is still able to provide services, by setting up the base station and 60 client stations, and determining the distance between the base station and clients according to the past research in order to test. This will be done by transmitting data of equal sizes and increasing the number of clients in order to find the highest number of clients. Moreover, the number of clients will be reduced to find the number of clients that allows the base station to work the most efficiently in the area conducting the research and in the adjustments of frequencies and receiver antenna heights. The obtained differences will be compared.

5.2.4 Analysis of the probability of building the WiMAX network system

When analyzing to find the probability, one must study the costs of the wireless network system first, which are:

5.2.4.1. Costs of the base station construction area
5.2.4.2. Material costs for antenna installation
5.2.4.3. The service area of the system
5.2.4.4. System maintenance costs
5.2.4.5. Equipment costs of the network system

The analysis to find the costs of planning the network system with cables include:

5.2.4.6 Signal cables costs
5.2.4.7 Installation costs
5.2.4.8 Maintenance costs
5.2.4.9 Service areas
5.2.4.105. Equipment costs of the network system

In addition, analysis to compare between the two systems in their abilities to provide services of each system and their cost-effectivenesses for further constructions can be done.

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APPENDICES

APPENDIX A

SIMULATION PROCESS FLOW CHART

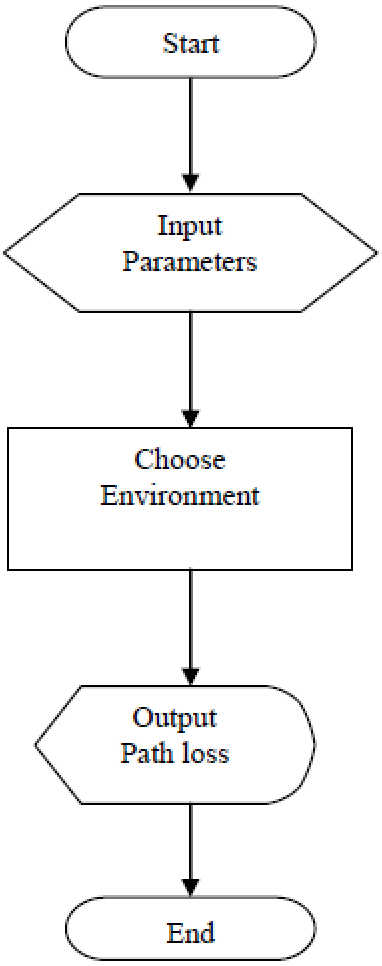

Figure 1 Simulation flow chart.

APPENDIX B

MATLAB Code for Salaya campus environment in different frequency and antenna height.

Frequency 2.5 GHz and antenna height 6 meter.

```
%%%% models for salaya area in 6 m receiver antenna height%%%%%
close all;
clear all;
clc
%Distance in Kilometer
N=5;
d=0.0:0.25:N;
%frequency in MHz
f=2500;
%transmitter antenna heights 30 m
hb=30;
%receiver antenna heights 6 m
hr=6;
%%%%%%%%%%%%%%%%Free Space Loss%%%%%%%%%%%%%%%%%%
fsmodel=32.45+20.*log10(d)+20.*log10(f);
%%%%%%%%%%%%%%%%SUI model%%%%%%%%%%%
%100 m is used as a reference in SUI model
d1= 0.1;
%receiver hight
lambda=((3*10^8)/( 2500*10^6));
% frequency in MHz
f=2500;
%fading standard deviation s is 10.6 dB in urban
s=10.6;
% Suburban is consider as a terrain a
a=3.6;
b=0.005;
c=20;
gamma=a-b*hb+c/hb;
PLsui=20.*log10((4*pi*d1)/lambda)+10*gamma.*log10(d/d1)+6.*log1
0(f/2000)-20.*log10(hr/2000)+s;
%%%%%%%%%%%%%%%Plotting%%%%%%%%%%%%%%%%%%%%%
plot(d,fsmodel,'r+-',d,PLsui,'b.-');
grid on;
%%%%%%%%%%%%%%%%%Axis and Title%%%%%%%%%%%%%%%%%%
xlabel('Distance between Tx and Rx (km)');
ylabel('Path loss (dB)');
title('6 m receiver antenna height and 2.5 GHz in salaya
environment');
```

Frequency 3.5 GHz and antenna height 6 meter**.**

```
%%% models for salaya area in 6 m receiver antenna height%%%%
close all;
clear all;
clc
%Distance in Kilometer
N=5;
d=0.0:0.25:N;
%frequency in MHz
f=3500;
%transmitter antenna heights 30 m
hb=30;
%receiver antenna heights 6 m
hr=6;
%%%%%%%%%%%%%%%%Free Space Loss%%%%%%%%%%%%%%%%%%%
fsmodel=32.45+20.*log10(d)+20.*log10(f);
%%%%%%%%%%%%%%%%SUI model%%%%%%%%%%%
%100 m is used as a reference in SUI model
d1= 0.1;
%receiver hight
lambda=((3*10^8)/( 3500*10^6));
% frequency in MHz
f=3500;
%fading standard deviation s is 10.6 dB in urban
s=10.6;
% Suburban is consider as a terrain a
a=3.6;
b=0.005;
c=20;
gamma=a-b*hb+c/hb;
PLsui=20.*log10((4*pi*d1)/lambda)+10*gamma.*log10(d/d1)+6.*log1
0(f/2000)-20.*log10(hr/2000)+s;
%%%%%%%%%%%%%%%%Plotting%%%%%%%%%%%%%%%%%%%%%%
plot(d,fsmodel,'r+-',d,PLsui,'b.-');
grid on;
%%%%%%%%%%%%%%%%%Axis and Title%%%%%%%%%%%%%%%%%%%
xlabel('Distance between Tx and Rx (km)');
ylabel('Path loss (dB)');
title('6 m receiver antenna height and 3.5 GHz in salaya
environment');
```

Frequency 5 GHz and antenna height 6 meter.

```
%%%%%%%%%%%%% models for salaya area in 6 m receiver antenna
height%%%%%
close all;
clear all;
clc
%Distance in Kilometer
N=5;
d=0.0:0.25:N;
%frequency in MHz
f=5000;
%transmitter antenna heights 30 m
hb=30;
%receiver antenna heights 6 m
hr=6;
%%%%%%%%%%%%%%%%Free Space Loss%%%%%%%%%%%%%%%%%%%
fsmodel=32.45+20.*log10(d)+20.*log10(f);
%%%%%%%%%%%%%%%%SUI model%%%%%%%%%%%
%100 m is used as a reference in SUI model
d1= 0.1;
%receiver hight
lambda=((3*10^8)/( 5000*10^6));
% frequency in MHz
f=5000;
%fading standard deviation s is 10.6 dB in urban
s=10.6;
% Suburban is consider as a terrain a
a=3.6;
b=0.005;
c=12.6;
gamma=a-b*hb+c/hb;
PLsui=20.*log10((4*pi*d1)/lambda)+10*gamma.*log10(d/d1)+6.*log1
0(f/2000)-20.*log10(hr/2000)+s;
%%%%%%%%%%%%%%%%Plotting%%%%%%%%%%%%%%%%%%%%%%
plot(d,fsmodel,'r+-',d,PLsui,'b.-');
grid on;
%%%%%%%%%%%%%%%%%Axis and Title%%%%%%%%%%%%%%%%%%%
xlabel('Distance between Tx and Rx (km)');
ylabel('Path loss (dB)');
title('6 m receiver antenna height and 5 GHz in salaya
environment');
```

Frequency 2.5 GHz and antenna height 10 meter.

```
%%%%%%%%% models for salaya area in 10 m receiver antenna
height%%%%
close all;
clear all;
clc
%Distance in Kilometer
N=5;
d=0.0:0.25:N;
%frequency in MHz
f=2500;
%transmitter antenna heights 30 m
hb=30;
%receiver antenna heights 10 m
hr=10;
%%%%%%%%%%%%%%%%Free Space Loss%%%%%%%%%%%%%%%%%%
fsmodel=32.45+20.*log10(d)+20.*log10(f);

%%%%%%%%%%%%%%%%SUI model%%%%%%%%%%
%100 m is used as a reference in SUI model
d1= 0.1;
%receiver hight
lambda=((3*10^8)/( 2500*10^6));
% frequency in MHz
f=2500;
%fading standard deviation s is 10.6 dB in urban
s=10.6;
% Suburban is consider as a terrain a
a=3.6;
b=0.005;
c=20;
gamma=a-b*hb+c/hb;
PLsui=20.*log10((4*pi*d1)/lambda)+10*gamma.*log10(d/d1)+6.*log1
0(f/2000)-20.*log10(hr/2000)+s;
%%%%%%%%%%%%%%%%Plotting%%%%%%%%%%%%%%%%%%%%%%
plot(d,fsmodel,'r+-',d,PLsui,'b.-');
grid on;

%%%%%%%%%%%%%%%%%Axis and Title%%%%%%%%%%%%%%%%%%
xlabel('Distance between Tx and Rx (km)');
ylabel('Path loss (dB)');
title('10 m receiver antenna height and 2.5 GHz in salaya
environment');
```

Frequency 3.5 GHz and antenna height 10 meter.

```
%%%%%%%%%%%%% models for salaya area in 10 m receiver antenna
height%%%%%
close all;
clear all;
clc
%Distance in Kilometer
N=5;
d=0.0:0.25:N;
%frequency in MHz
f=3500;
%transmitter antenna heights 30 m
hb=30;
%receiver antenna heights 10 m
hr=10;
%%%%%%%%%%%%%%%%Free Space Loss%%%%%%%%%%%%%%%%%%
fsmodel=32.45+20.*log10(d)+20.*log10(f);
%%%%%%%%%%%%%%%%SUI model%%%%%%%%%%%
%100 m is used as a reference in SUI model
d1= 0.1;
%receiver hight
lambda=((3*10^8)/( 3500*10^6));
% frequency in MHz
f=3500;
%fading standard deviation s is 10.6 dB in urban
s=10.6;
% Suburban is consider as a terrain a
a=3.6;
b=0.005;
c=20;
gamma=a-b*hb+c/hb;
PLsui=20.*log10((4*pi*d1)/lambda)+10*gamma.*log10(d/d1)+6.*log1
0(f/2000)-20.*log10(hr/2000)+s;
%%%%%%%%%%%%%%%%Plotting%%%%%%%%%%%%%%%%%%%%%%
plot(d,fsmodel,'r+-',d,PLsui,'b.-');
grid on;
%%%%%%%%%%%%%%%%%Axis and Title%%%%%%%%%%%%%%%%%%
xlabel('Distance between Tx and Rx (km)');
ylabel('Path loss (dB)');
title('10 m receiver antenna height and 3.5 GHz in salaya
environment');
```

Frequency 5 GHz and antenna height 10 meter.

```
%%%%%%%%%%%%% models for salaya area in 10 m receiver antenna
height%%%%%
close all;
clear all;
clc
%Distance in Kilometer
N=5;
d=0.0:0.25:N;
%frequency in MHz
f=5000;
%transmitter antenna heights 30 m
hb=30;
%receiver antenna heights 10 m
hr=10;
%%%%%%%%%%%%%%%%Free Space Loss%%%%%%%%%%%%%%%%%%%
fsmodel=32.45+20.*log10(d)+20.*log10(f);
%%%%%%%%%%%%%%%%SUI model%%%%%%%%%%%
%100 m is used as a reference in SUI model
d1= 0.1;
%receiver hight
lambda=((3*10^8)/( 5000*10^6));
% frequency in MHz
f=5000;
%fading standard deviation s is 10.6 dB in urban
s=10.6;
% Suburban is consider as a terrain a
a=3.6;
b=0.005;
c=20;
gamma=a-b*hb+c/hb;
PLsui=20.*log10((4*pi*d1)/lambda)+10*gamma.*log10(d/d1)+6.*log1
0(f/2000)-20.*log10(hr/2000)+s;
%%%%%%%%%%%%%%%%Plotting%%%%%%%%%%%%%%%%%%%%%%
plot(d,fsmodel,'r+-',d,PLsui,'b.-');
grid on;
%%%%%%%%%%%%%%%%%Axis and Title%%%%%%%%%%%%%%%%%%%
xlabel('Distance between Tx and Rx (km)');
ylabel('Path loss (dB)');
title('10 m receiver antenna height and 5 GHz in salaya
environment');
```

APPENDIX C

MATLAB Code for Phayathai campus environment in different frequency and antenna height.

Frequency 2.5 GHz and antenna height 6 meter.

```
%%%%%%%%%%%%% models for phayathai area in 6 m receiver antenna
height%%%%%
close all;
clear all;
clc
%Distance in Kilometer
N=5;
d=0.0:0.25:N;
%frequency in MHz
f=2500;
%transmitter antenna heights 30 m
hb=30;
%receiver antenna heights 6 m
hr=6;
%%%%%%%%%%%%%%%%Free Space Loss%%%%%%%%%%%%%%%%%%%
fsmodel=32.45+20.*log10(d)+20.*log10(f);
%%%%%%%%%%%%%%% COST 231 W I model%%%%%%%%%%%%%%
%distance between buildings
B=50;
%street width B/2
w=25;
%Hmobile=h roof-h mobile(15-6)m we consider h roof is 15 m
Hmobile=9;
%street orientation angel 30 degree
theta=30;
Lori=2.5+0.075*theta;
Lrts=-16.9-10.*log10(w)+10.*log10(f)+20.*log10(Hmobile)+Lori;
Lfs=32.45+20.*log10(d)+20.*log10(f);
%Hbase=h base-h roof(30-15)we cosider transmitter height is 30
m
Hbase=15;
%in suburban kf is (-4+1.5((f/925)-1))
Lmsd=-18.*log10(1+Hbase)+54+18.*log10(d)+(-4+1.5*((f/925)-
1)).*log10(f)-9.*log10(B);
PLcwi=Lfs+Lrts+Lmsd;
 %%%%%%%%%%%%%%%%Plotting%%%%%%%%%%%%%%%%%%%%%%
plot(d,PLcwi, 'g.-',d,fsmodel,'r+-');
grid on;
%%%%%%%%%%%%%%%%%Axis and Title%%%%%%%%%%%%%%%%%%%
xlabel('Distance between Tx and Rx (km)');
ylabel('Path loss (dB)');
```

```
title('6 m receiver antenna height and 2.5 GHz in phayathai
environment');
```

Frequency 3.5 GHz and antenna height 6 meter.

```
%%%%%%%%%%%%% models for phayathai area in 6 m receiver antenna
height%%%%%
close all;
clear all;
clc
%Distance in Kilometer
N=5;
d=0.0:0.25:N;
%frequency in MHz
f=3500;
%transmitter antenna heights 30 m
hb=30;
%receiver antenna heights 6 m
hr=6;
%%%%%%%%%%%%%%%%Free Space Loss%%%%%%%%%%%%%%%%%%%
fsmodel=32.45+20.*log10(d)+20.*log10(f);
%%%%%%%%%%%%%%% COST 231 W I model%%%%%%%%%%%%%%
%distance between buildings
B=50;
%street width B/2
w=25;
%Hmobile=h roof-h mobile(15-6)m we consider h roof is 15 m
Hmobile=9;
%street orientation angel 30 degree
theta=30;
Lori=2.5+0.075*theta;
Lrts=-16.9-10.*log10(w)+10.*log10(f)+20.*log10(Hmobile)+Lori;
Lfs=32.45+20.*log10(d)+20.*log10(f);
%Hbase=h base-h roof(30-15)we cosider transmitter height is 30
m
Hbase=15;
%in suburban kf is (-4+1.5((f/925)-1))
Lmsd=-18.*log10(1+Hbase)+54+18.*log10(d)+(-4+1.5*((f/925)-
1)).*log10(f)-9.*log10(B);
PLcwi=Lfs+Lrts+Lmsd;

%%%%%%%%%%%%%%%%Plotting%%%%%%%%%%%%%%%%%%%%%%
plot(d,PLcwi, 'g.-',d,fsmodel,'r+-');
grid on;
%%%%%%%%%%%%%%%%%Axis and Title%%%%%%%%%%%%%%%%%%%
xlabel('Distance between Tx and Rx (km)');
ylabel('Path loss (dB)');
title('6 m receiver antenna height and 3.5 GHz in phayathai
environment');
```

Frequency 5 GHz and antenna height 6 meter.

```
%%%%%%%%%%%%% models for phayathai area in 6 m receiver antenna
height%%%%
close all;
clear all;
clc
%Distance in Kilometer
N=5;
d=0.0:0.25:N;
%frequency in MHz
f=5000;
%transmitter antenna heights 30 m
hb=30;
%receiver antenna heights 6 m
hr=6;
%%%%%%%%%%%%%%%%Free Space Loss%%%%%%%%%%%%%%%%%%
fsmodel=32.45+20.*log10(d)+20.*log10(f);
%%%%%%%%%%%%%%% COST 231 W I model%%%%%%%%%%%%%
%distance between buildings
B=50;
%street width B/2
w=25;
%Hmobile=h roof-h mobile(15-6)m we consider h roof is 15 m
Hmobile=9;
%street orientation angel 30 degree
theta=30;
Lori=2.5+0.075*theta;
Lrts=-16.9-10.*log10(w)+10.*log10(f)+20.*log10(Hmobile)+Lori;
Lfs=32.45+20.*log10(d)+20.*log10(f);
%Hbase=h base-h roof(30-15)we cosider transmitter height is 30
m
Hbase=15;
%in suburban kf is (-4+1.5((f/925)-1))
Lmsd=-18.*log10(1+Hbase)+54+18.*log10(d)+(-4+1.5*((f/925)-
1)).*log10(f)-9.*log10(B);
PLcwi=Lfs+Lrts+Lmsd;

%%%%%%%%%%%%%%%%Plotting%%%%%%%%%%%%%%%%%%%%%%
plot(d,PLcwi, 'g.-',d,fsmodel,'r+-');
grid on;
%%%%%%%%%%%%%%%%%Axis and Title%%%%%%%%%%%%%%%%%%%
xlabel('Distance between Tx and Rx (km)');
ylabel('Path loss (dB)');
title('6 m receiver antenna height and 5 GHz in phayathai
environment');
```

Frequency 2.5 GHz and antenna height 10 meter.

```
%%%%%%%%%%%%% models for phayathai area in 10 m receiver
antenna height%%%%
close all;
clear all;
clc
%Distance in Kilometer
N=5;
d=0.0:0.25:N;
%frequency in MHz
f=2500;
%transmitter antenna heights 30 m
hb=30;
%receiver antenna heights 10 m
hr=10;
%%%%%%%%%%%%%%%Free Space Loss%%%%%%%%%%%%%%%%%%
fsmodel=32.45+20.*log10(d)+20.*log10(f);
%%%%%%%%%%%%%% COST 231 W I model%%%%%%%%%%%%%
%distance between buildings
B=50;
%street width B/2
w=25;
%Hmobile=h roof-h mobile(15-10)m we consider h roof is 15 m
Hmobile=5;
%street orientation angel 30 degree
theta=30;
Lori=2.5+0.075*theta;
Lrts=-16.9-10.*log10(w)+10.*log10(f)+20.*log10(Hmobile)+Lori;
Lfs=32.45+20.*log10(d)+20.*log10(f);
%Hbase=h base-h roof(30-15)we cosider transmitter height is 30
m
Hbase=15;
%in suburban kf is (-4+1.5((f/925)-1))
Lmsd=-18.*log10(1+Hbase)+54+18.*log10(d)+(-4+1.5*((f/925)-
1)).*log10(f)-9.*log10(B);
PLcwi=Lfs+Lrts+Lmsd;

%%%%%%%%%%%%%%%Plotting%%%%%%%%%%%%%%%%%%%%%
plot(d,PLcwi, 'g.-',d,fsmodel,'r+-');
grid on;
%%%%%%%%%%%%%%%%Axis and Title%%%%%%%%%%%%%%%%%%
xlabel('Distance between Tx and Rx (km)');
ylabel('Path loss (dB)');
title('10 m receiver antenna height and 2.5 GHz in phayathai
environment');
```

Frequency 3.5 GHz and antenna height 10 meter.

```
%%%%%%%%%%%% models for phayathai area in 10 m receiver
antenna height%%%%
close all;
clear all;
clc
%Distance in Kilometer
N=5;
d=0.0:0.25:N;
%frequency in MHz
f=3500;
%transmitter antenna heights 30 m
hb=30;
%receiver antenna heights 10 m
hr=10;
%%%%%%%%%%%%%%%%Free Space Loss%%%%%%%%%%%%%%%%%%
fsmodel=32.45+20.*log10(d)+20.*log10(f);
%%%%%%%%%%%%%% COST 231 W I model%%%%%%%%%%%%
%distance between buildings
B=50;
%street width B/2
w=25;
%Hmobile=h roof-h mobile(15-10)m we consider h roof is 15 m
Hmobile=5;
%street orientation angel 30 degree
theta=30;
Lori=2.5+0.075*theta;
Lrts=-16.9-10.*log10(w)+10.*log10(f)+20.*log10(Hmobile)+Lori;
Lfs=32.45+20.*log10(d)+20.*log10(f);
%Hbase=h base-h roof(30-15)we cosider transmitter height is 30
m
Hbase=15;
%in suburban kf is (-4+1.5((f/925)-1))
Lmsd=-18.*log10(1+Hbase)+54+18.*log10(d)+(-4+1.5*((f/925)-
1)).*log10(f)-9.*log10(B);
PLcwi=Lfs+Lrts+Lmsd;

%%%%%%%%%%%%%%%%Plotting%%%%%%%%%%%%%%%%%%%%%%
plot(d,PLcwi, 'g.-',d,fsmodel,'r+-');
grid on;
%%%%%%%%%%%%%%%%%%Axis and Title%%%%%%%%%%%%%%%%%%
xlabel('Distance between Tx and Rx (km)');
ylabel('Path loss (dB)');
title('10 m receiver antenna height and 3.5 GHz in phayathai
environment');
```

Frequency 5 GHz and antenna height 10 meter.

```
%%%%%%%%%%%%% models for phayathai area in 10 m receiver
antenna height%%%%%
close all;
clear all;
clc
%Distance in Kilometer
N=5;
d=0.0:0.25:N;
%frequency in MHz
f=5000;
%transmitter antenna heights 30 m
hb=30;
%receiver antenna heights 6 m
hr=10;
%%%%%%%%%%%%%%%%Free Space Loss%%%%%%%%%%%%%%%%%%%
fsmodel=32.45+20.*log10(d)+20.*log10(f);
%%%%%%%%%%%%%%% COST 231 W I model%%%%%%%%%%%%%%
%distance between buildings
B=50;
%street width B/2
w=25;
%Hmobile=h roof-h mobile(15-10)m we consider h roof is 15 m
Hmobile=5;
%street orientation angel 30 degree
theta=30;
Lori=2.5+0.075*theta;
Lrts=-16.9-10.*log10(w)+10.*log10(f)+20.*log10(Hmobile)+Lori;
Lfs=32.45+20.*log10(d)+20.*log10(f);
%Hbase=h base-h roof(30-15)we cosider transmitter height is 30
m
Hbase=15;
%in suburban kf is (-4+1.5((f/925)-1))
Lmsd=-18.*log10(1+Hbase)+54+18.*log10(d)+(-4+1.5*((f/925)-
1)).*log10(f)-9.*log10(B);
PLcwi=Lfs+Lrts+Lmsd;

%%%%%%%%%%%%%%%%Plotting%%%%%%%%%%%%%%%%%%%%%%
plot(d,PLcwi, 'g.-',d,fsmodel,'r+-');
grid on;
%%%%%%%%%%%%%%%%%Axis and Title%%%%%%%%%%%%%%%%%%%
xlabel('Distance between Tx and Rx (km)');
ylabel('Path loss (dB)');
title('10 m receiver antenna height and 5 GHz in phayathai
environment');
```

APPENDIX D

MATLAB Code for Salaya campus environment to phayathai campus in different frequency.

Frequency 2.5 GHz

```
%%%%%%%%%%%%%% models for salaya to phayahtai 30 m receiver
antenna height%%%%%
close all;
clear all;
clc
%Distance in Kilometer
N=30;
d=1.0:5.00:N;
%frequency in MHz
f=2500;
%transmitter antenna heights 30 m
hb=30;
%receiver antenna heights 30 m
hr=30;
%%%%%%%%%%%%%%%%Free Space Loss%%%%%%%%%%%%%%%%%%
fsmodel=32.45+20.*log10(d)+20.*log10(f);
%%%%%%%%%%%%%%%% COST 231 W I model%%%%%%%%%%%%%%
PLcwi=42.6+26.*log(d)+20.*log(f);
%%%%%%%%%%%%%%%%Plotting%%%%%%%%%%%%%%%%%%%%%%
plot(d,PLcwi, 'r+-',d,fsmodel,'g+-');
grid on;
%%%%%%%%%%%%%%%%%%Axis and Title%%%%%%%%%%%%%%%%%%
xlabel('Distance between Tx and Rx (km)');
ylabel('Path loss (dB)');
title('pathloss at 2.5 GHz salaya campus to phayathai campus
environment');
```

Frequency 3.5 GHz

```
%%%%%%%%%%%%% models for salaya to phayahtai 30 m receiver
antenna height%%%%%
close all;
clear all;
clc
%Distance in Kilometer
N=30;
d=1.0:5.00:N;
%frequency in MHz
f=3500;
%transmitter antenna heights 30 m
hb=30;
%receiver antenna heights 30 m
hr=30;
%%%%%%%%%%%%%%%%Free Space Loss%%%%%%%%%%%%%%%%%%%
fsmodel=32.45+20.*log10(d)+20.*log10(f);
%%%%%%%%%%%%%%% COST 231 W I model%%%%%%%%%%%%%%
PLcwi=42.6+26.*log(d)+20.*log(f);
%%%%%%%%%%%%%%%%Plotting%%%%%%%%%%%%%%%%%%%%%%
plot(d,PLcwi, 'r+-',d,fsmodel,'g+-');
grid on;
%%%%%%%%%%%%%%%%%Axis and Title%%%%%%%%%%%%%%%%%%%
xlabel('Distance between Tx and Rx (km)');
ylabel('Path loss (dB)');
title('pathloss at 3.5 GHz salaya campus to phayathai campus
environment');
```

Frequency 5 GHz

```
%%%%%%%%%%%%%% models for salaya to phayahtai 30 m receiver
antenna height%%%%%
close all;
clear all;
clc
%Distance in Kilometer
N=30;
d=1.0:5.00:N;
%frequency in MHz
f=5000;
%transmitter antenna heights 30 m
hb=30;
%receiver antenna heights 30 m
hr=30;
%%%%%%%%%%%%%%%%Free Space Loss%%%%%%%%%%%%%%%%%%%%
fsmodel=32.45+20.*log10(d)+20.*log10(f);
%%%%%%%%%%%%%%% COST 231 W I model%%%%%%%%%%%%%%
PLcwi=42.6+26.*log(d)+20.*log(f);
%%%%%%%%%%%%%%%%Plotting%%%%%%%%%%%%%%%%%%%%%%%%
plot(d,PLcwi, 'r+-',d,fsmodel,'g+-');
grid on;
%%%%%%%%%%%%%%%%%Axis and Title%%%%%%%%%%%%%%%%%%%
xlabel('Distance between Tx and Rx (km)');
ylabel('Path loss (dB)');
title('pathloss at 5 GHz salaya campus to phayathai campus
environment');
```

APPENDIX E

ABBREVIATION AND ACRONYMS

LAN	Local Area Network
WMAN	Wireless Metropolitan Area Network
MANs	Metropolitan Area Network
FWA	Fixed Wireless Access
UMTS	Universal Mobile Telecommunication System
BS	Base Station
SS	Subscriber Station
CPE	Customer Premises Equipment
IP	Internet Protocol
PL	Path Loss
FSPL	Free Space Path Loss
SUI	Stanford University Interim
WI	Walfish-Ikegami
LOS	Line-of-Sight
NLOS	Non-Line-of-Sight
SNR	Signal to Noise Ratio
VHF	Very High Frequency
Km	Kilometer

APPENDIX F
CONFERENCE

U.Pornchai, K.Supaporn, L, Adisorn, W.Waranyu. “Study on Designing and Measuring Performance of WiMAX Network Link Connected between Mahidol University Phayathai campus to Salaya Campus at 2.5 GHz, 3.5 GHz, 5GHz”.National Conference on Computer Information Technologies: CIT 2013 and Uninet Network Operation and Management Workshop: UniNOMS2013, pp 228-233, January 2013.

BIOGRAPHY

NAME	Mr. Pornchai Ubol
DATE OF BIRTH	19 September 1968
PLACE OF BIRTH	Nakornpathom, Thailand
INSTITUTIONS ATTENDED	Mahanakorn University of Technology, 1992-1995 B.Ind.Tech(Telecommunication Engineering)
HOME ADDRESS	2/17 Kokphajadee,Nakornchaisri Nakornpathom. 73120 Tel. 0852968525 E-mail: patvole@hotmail.com,
EMPLOYMENT ADDRESS	2/17 Kokphajadee,Nakornchaisri Nakornpathom. 73120 Tel. 034206075