بسم الله الرحمن الرحيم

Palestine polytechnic University

College of Engineering & Technology

Electrical and Computer Engineering Department

Communication and Electronic Engineering

Graduation Project

Generalization of the PPU Building-C indoor radio propagation model (modified ITU model) at frequencies 900 MHz and 2.4 GHz

Project Supervisor

Dr. Osama Ata

Prepared by:

Ala'Eddin Mohammad Shahateet

Mutaz Ibrahim Jawadeh

Adnan Ibrahim Amro

May 23, 2011

ABSTRACT

Wireless systems pose the biggest design challenges particularly in indoor propagation environment. This project attempts to model the propagation of the RF wave travelling inside a building, and seeks to set some boundaries for useful design of a wireless system inside typically commercial buildings, such as university building structures schools and hospitals at 900 MHz and 2.4GHz.

Suggested buildings will be surveyed in Hebron for modeling and measurement purposes. These are the faculty of applied science, they faculty of administrative sciences and informatics, Al-Ahli hospital, Palestine Graduate Union in addition to Building C in Wady Hariya Investigation of the five buildings offers a good sample to generalize the model over the one which was previously developed for building C alone, as a more representative model for indoor radio propagation.

Our motivation for this work is based upon a previous work carried out by a group of students at the PPU which received a great support by Jawwal. Our goal is to come up with a more general model that would be both a reliable and representative model to a wider sample of multi-floor commercial type buildings in Palestine. The improved model lends itself to its generalization for the GSM and wireless LAN frequencies as well as the multiwall effective attenuation fourth power nonlinear equation that solely relies on the number of wall separations within the floor, which clearly improved the standard deviation of the indoor ITU path loss model. Furthermore we modeled the floor separation effect in wireless LAN. Our model can be applied with a highly satisfactory confidence level to buildings similar to the 5 building sample we conducted measurements upon.

DEDICATIONS

To our family, who have always been there for us, and have never doubted our dreams, no matter how crazy they might be.

Also to anyone who finds himself at a place in life where the question of why seems unanswerable, you are not alone.
To our mothers

To those who taught us the science of life
Our Brothers

To whom we've gotten from them the most beautiful moments
To students of the Department of Communications and Electronics Engineering

To the Department of Electrical and Computer Engineering

ACKNOWLEDGEMENTS

We would like to acknowledge the encouragement, advice and guidance of Dr. Osama Ata, our supervisor.

We also thank the members of our graduate committee for their guidance and suggestions.

We also thank Dr. Khaled Hijjeh on behalf of JAWWAL for his help in using equipment and resources.

We acknowledge the guidance and assistance of Dr. Fadel Batran, Director of Al-Ahli Hospital and staff for their great support.

We would like to thank our family members, especially our parents for supporting and encouraging us to carry out this project.

Without our parents' and professors' encouragement, we would not have finished the project

Chapter Three

Chapter Six

List of Tables

List of Figures

Chapter One

INTRODUCTION

1.1 Introduction

1.2 Indoor Propagation Modeling

1.3 Empirical Models

1.4 Deterministic Models

1.5 Difference between the Indoor and Outdoor Propagation

1.6 Classifications of Project

1.1 Introduction

Modeling of indoor propagation is crucial to the operation of wireless LAN, GSM, and other indoor communications systems. The outdoor environment is different from the indoor environment in many ways. The outdoor environment is more hostile, in terms of the various physical mechanisms that affect the signal.

Modeling indoor propagation is complicated because of the large variability in building layouts and construction materials. In addition, the environment can change radically by the simple movement of people, closing of doors, for example. For these reasons, deterministic models are not often used. In this project, an empirical model is presented. An empirical model can provide a reasonable representation of the indoor environment.

In this project we propose to develop indoor propagation model, based on a former project done by a group of students. Their work focused on a single building " PPU Building-C " , the group took the ITU model as a reference to their research. To make a valid and reliable generalization of the former model we propose to consider several buildings with various properties e.g. crowded places, commercial buildings and technology centers that vary in size , building structure, internal design and number of separation walls.

1.2 Indoor Propagation Modeling

The initial understanding of radio wave propagation goes back to the pioneering work of James Clerk Maxwell, who in 1864 formulated the theory of electromagnetic propagation which predicted the existence of radio waves. In 1887, the physical existence of these waves was demonstrated by Heinrich Hertz. However, Hertz saw no practical use for radio waves; reasoning that since audio frequencies were low, where propagation was poor, and radio waves could never carry voice. The work of Maxwell and Hertz initiated the field of radio communications: in 1894 Oliver Lodge used these principles to build the first wireless communication system, however its transmission distance was limited to 150 meters. By 1897 the entrepreneur Guglielmo Marconi had managed to send a radio signal from the Isle of Wight to a tugboat 18 miles away, and in 1901 Marconi’s wireless system could traverse the Atlantic Ocean. These early systems used telegraph signals for communicating information. The first transmission of voice and music was done by Reginald Fessenden in 1906 using a form of amplitude modulation, which got around the propagation limitations at low frequencies observed by Hertz by translating signals to a higher frequency, as is done in all wireless systems today. [1] So by any measure, wireless communication is the fastest growing segment in the communication industry. Example of the wireless communication is the global system for mobile communication (GSM). GSM faced many changes and growing over the last century. One of the biggest challenges for the wireless communication mainly for the GSM and WLAN networks is the indoor radio propagation.

Modeling in various environments provides a better understanding of wave propagation mechanisms. As mentioned before, indoor environment modeling is a great challenge in the absence of a specific way to design and execute all buildings in the same exact way and control factors affecting the wireless environment.

There are two different approaches to model a wireless environment: empirical and deterministic. Another approach can be generated from these two approaches which is semi_ deterministic. A brief explanation of these two approaches necessary is to understand the difference between them.

1.3 Empirical Models

The empirical models are site-specific models. They are based on very simple and straightforward formulas with dependence on distance. The formulas depend on the measurements that describe the environment. We can say that empirical models are very simple and may be adequate for some indoor environments. Simple input data are needed so empirical models can be easily calculated. On the other hand in very internally complicated buildings designs, empirical models show poor accuracy. Improving the empirical model with additional conditions could well provide an acceptable solution. [1]

1.4 Deterministic Models

Deterministic models are based on the principles of electromagnetic wave propagation. A well known example is ray tracing which is based on the geometrical optics principles. In ray tracing all rays are found between transmitter and receiver and their contributions added together. Rays' reflection and diffraction and the penetration for each ray can be calculated using electromagnetic theory. We can say that these models are accurate and they can also predict many parameters like time delay, angle spread and so on . Unfortunately, they are slow, need a huge input data and the code implementation is very complicated.[1]

1.5 Difference Between the Indoor and Outdoor Propagation

The indoor wireless channel differs from the outdoor channel in two main aspects. The environment in the former is relatively much variable in terms of the path length, and coverage is smaller. The distance between transmitter and receiver is shorter due to high attenuation caused by the internal walls and furniture and often also because of the lower transmitter power. The short distance implies shorter delay of echoes and consequently a lower delay spread. The temporal variations of the channel are slower compared to the conditions where the mobile antenna is mounted on a car. In the case in outdoor systems, there are several important propagation parameters to be predicted. The path loss and the statistical characteristics of the received signal envelope are most important for coverage planning applications. The wide-band and time variation characteristics are essential for evaluation of the system performance by using either hardware or software simulation.[1]

1.6 Classifications of Project

This Project is classified into 6 chapters as follows:

Chapter (1):"Introduction"

The chapter is an introductory chapter, which also describes what is 'the indoor propagation model'

Chapter (2):" Radio Propagation"

The chapter there is an extensive study on the propagation phenomena, and propagation models for indoor models.

Chapter (3):"Multi Wall Attenuation Loss"

The chapter explains the effective of multi wall attenuation loss for all selected buildings on the GSM and WLAN signal.

Chapter (4)**:**" GSM Analysis"

The chapters discuss the analysis of the measurements of GSM that is done for all selected building in our project.

Chapter (5)**:**" WLAN Analysis"

The chapter discusses the analysis of the measurements of WLAN that is done for all selected building in our project.

Chapter (6)**:**" Conclusion"

This chapter presents the main results that we have reached during the measurement process.

Chapter Two

INDOOR PROPAGATION

2.1 Buildings

2.1.1 Propagation of signals Inside of Buildings

2.1.2 Type of Losses in Different Buildings

2.1.2.1 The Losses for the (same floor)

2.1.2.2 The Losses between floors

2.2 Selected Buildings

2.2.1 Patient's Friends Society

2.2.1.1 Services Building

2.2.1.2 College of Nursing

2.2.1.3 Al-Ahli Hospital

2.2.2 Palestine Polytechnic University

2.2.2.1 Building (A)

2.2.2.2 Building (B)

2.2.2.3 Abu Roman Building

2.3 Propagation Mechanisms

2.3.1 Reflection

2.3.2 Diffraction

2.3.3 Scattering

2.3.4 Refraction

2.5 Free Space Propagation

2.6 Path Loss and Shadowing

2.7 Multipath and fading

2.1 Buildings

Buildings vary in terms of composition and cutting. Such difference leads often to a change in the nature of the behavior of electromagnetic signal inside buildings. In this part we will discuss the impact of change in the behavior of electromagnetic signal on the type of building and the number of walls.

2.1.1 Propagation of signals Inside of Buildings

The indoor wireless systems can provide a huge design challenge. This chapter will shed some light on this mysterious subject and will seek to set boundaries for the use of wireless systems inside typical buildings at 900 MHz and 2.4 GHz.

RF propagation obstacles can be classified into hard partitions if they are part of the physical/structural components of a building. On the other hand, obstacles formed by the office furniture and fixed or movable/portable structures that do not extend to a buildings ceiling are considered soft partitions. Radio signals effectively penetrate both kinds of obstacles or partitions in ways that are very hard to predict.

In the design of UHF radio systems for mobile and personal Communications the characteristics of the RF channel present problems to the system designer. Scattering, diffraction, refraction and reflection by the structure of building lead to multipath propagation. For indoor propagation the signal is reflected, scattered and diffracted by the walls and the steel structure of the building.

The multipath propagation (Figure 2.1) in turn leads to distortion and fading of the signals transmitted over the radio channel. When a radio wave at UHF is transmitted either outside or inside it often travels by multiple paths before reaching the receiver. The multipath components may consist of a direct wave, a line- of-sight component, and other wave components **.**At any position in an inside and outside environment, one should not expect to receive signals in one direction only, but other directions would be possible depending on the surroundings.[2]

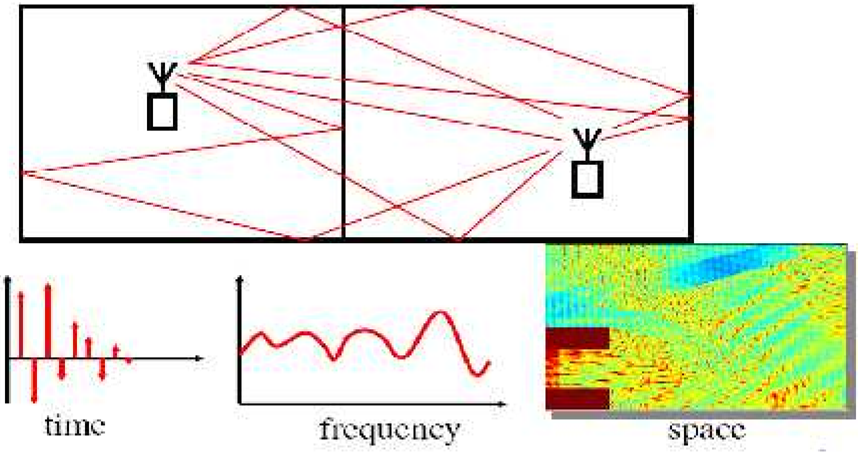


Figure 2.1 : Wave propagation inside of Building

2.1.2 Type of Losses in Different Buildings

The development of an efficient indoor Wireless system requires consideration of the attenuation of radio signals inside natural and Industrial structures. The indoor channel experiences multipath dispersions due to presence of a large number of reflectors and scatters . Unfortunately little can be done to eliminate multipath disturbances. The indoor channel experiences higher path losses which are very severe most of the time with sharper changes in mean signal level.[3]

The losses of different buildings can be divided into two types:

2.1.2.1 The Losses for the (same floor)

Buildings have a wide variety of partitions and obstacles which form the internal and external structure. Houses typically use a wood frame separation with plaster boards to form internal walls and have wood or no reinforced concrete between floors. Office buildings, on the other hand, often have large open areas (open plan) which are constructed by using movable office partitions so that the space may be reconfigured easily, and use metal reinforced concrete between floors. Partitions losses that are formed as part of the building structure are called hard partitions, and partitions that may be moved and which do not span to the ceiling are called soft partitions. Partitions vary widely in their physical and electrical characteristics, making it difficult to apply general models to specific indoor installations. Nonetheless, researchers have formed extensive databases of losses for a great number of partitions.

2.1.2.2 The Losses between floors

The losses between floors of a building are determined by the external dimensions and materials of the building, as well as the type of construction used to create the floors and the external surroundings. Even the number of windows in a building and the presence of tinting can cause the losses in floors, which attenuates the radio signal.

2.2 Selected Buildings

2.2.1 Patient's Friends Society

Patient's Friends Society divided to three sections :

1- Services building

2- College of Nursing

3- Al-Ahli Hospital

2.2.1.1 Services Building

The services building is composed of three floors and has large halls and this gives the test area to study the behavior of signal propagation in spacious rooms the presence of many metal barriers, such as kitchenware and laundry equipment are expected cause signal propagation problems.

2.2.1.2 College of Nursing

The College of Nursing is located at the basement of the hospital which is a one-story and contains many of the wood and glass walls and allows us to test the losses of the penetration of signal in such types of building structure .

2.2.1.3 Al-Ahli Hospital

Al Ahli Hospital is the most important section in the building, which is a large three-storey building contains the rooms of patients and doctors in addition to, four large skylights (as in Figure 2.2**)** building allows us to take a very large number of measurements that lead to accurate analysis in order to find the appropriate model for the behavior of the signal inside the building.

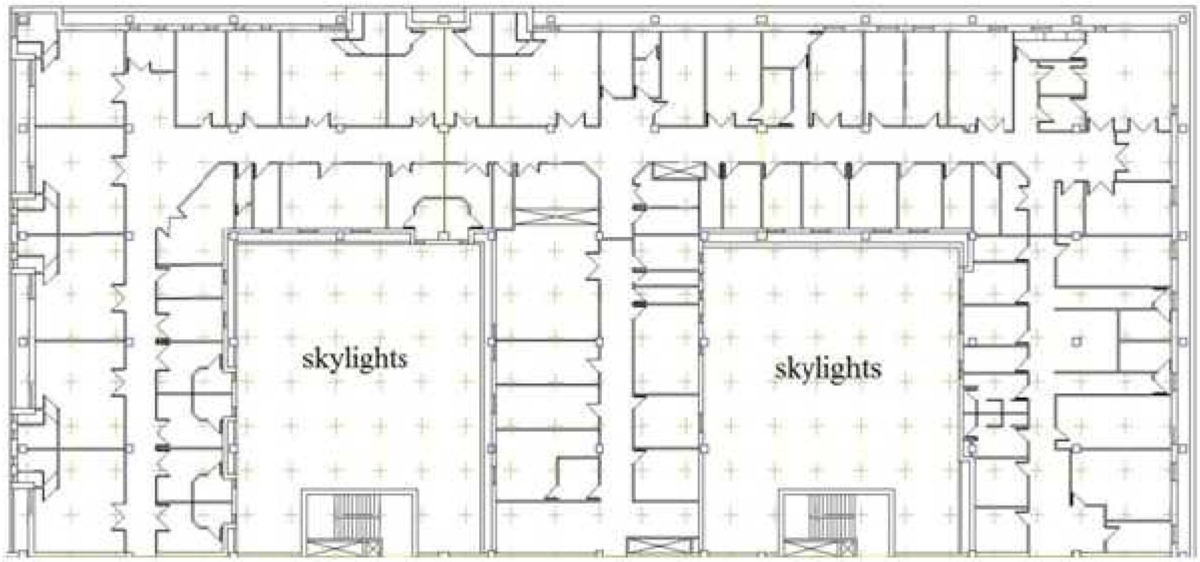


Figure 2.2 : Al-Ahli Hospital with Skylights

2.2.2 Palestine Polytechnic University

2.2.2.1 Building (A)

Building A is a four-storey building structure containing a large number of classrooms and narrow corridors. It represents a typical type of educational building used in universities or college institutes.

2.2.2.2 Building (B)

Building B is a five-storey building structure containing a large number of classrooms, corridors and labs. It represents a type of educational building used in universities or college institutes.

2.2.2.3 Abu Rumman Building

Abu Rumman building is a three-storey building structure that contains large glass windows. This is expected to change the nature of the losses of the signal inside the building, compared to other buildings.

2.3 Propagation Mechanisms

Reflection, Diffraction, Refraction and Scattering are the propagation mechanisms which impact signal propagation on a mobile communication system. These mechanisms and the propagation models which describe these mechanisms are discussed subsequently in this section.

2.3.1 Reflection

Reflection occurs when a propagating electromagnetic wave impinges upon an object which has very large dimensions when compared to the wavelength of the propagating wave. Reflections occur from the surface of the earth and from buildings and walls. Figure 2.3 and figure 2.4

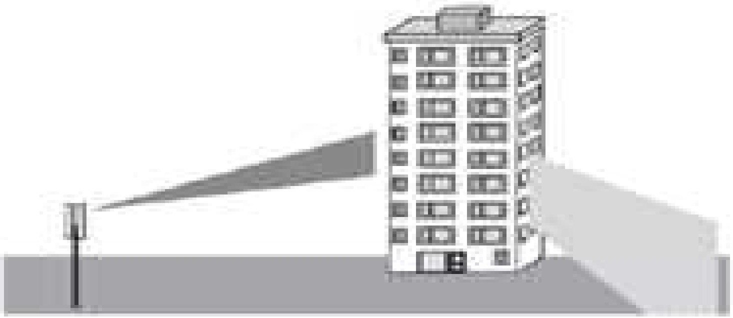


Figure 2.3: **Signal strength reduced by reflection from walls and other objects.**

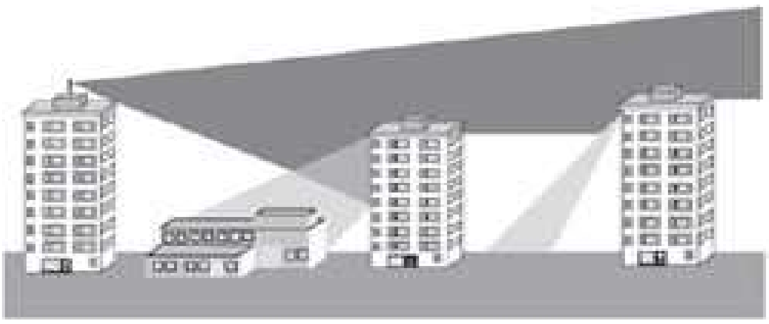


Figure 2.4 : **Reflection can be used to achieve radio coverage in urban areas.**

2.3.2 Diffraction

Diffraction occurs when the radio path between the transmitter and receiver is obstructed by a surface that has sharp irregularities (edges). The secondary waves resulting from the obstructing surface are present throughout the space and even behind the obstacle, giving rise to a bending of waves around the obstacle, even when a line-of-sight path does not exist between transmitter and receiver. At high frequencies, diffraction, like reflection depends on the geometry of the receiver and the size of the object, as well as the amplitude, phase, and polarization of the incident Jar to the plane of incidence. Figure 2.5

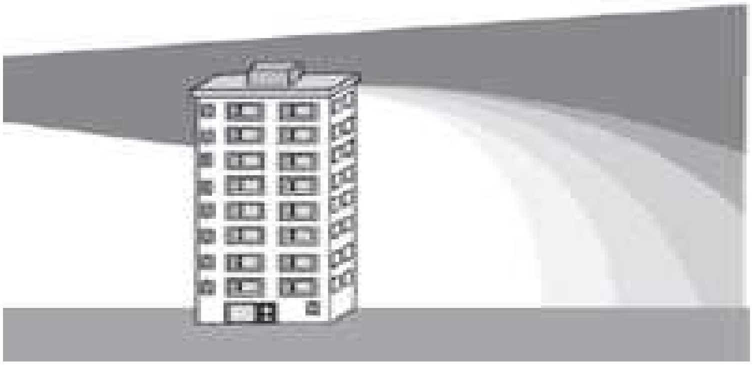


Figure 2.5 **: Signals can 'bend' round obstructions to some extent (diffraction).**

2.3.3 Scattering

Scattering occurs when the medium through which the wave travels consists of objects with dimensions that are small compared to the wavelength, and where the number of obstacles per unit volume is large. Scattered waves are produced by rough surfaces, small objects, or by other irregularities in the channel. In practice, foliage, street signs, and lamp posts induce scattering in a mobile communications system. Figure 2.6

Figure 2.6 :Scattering of Electromagnetic wave.

2.3.4 Refraction

Refraction occurs when the direction of an electromagnetic wave changes as it moves from an area of one refractive index to another. occurs when the direction of an electromagnetic wave changes as it moves from an area of one refractive index to another. Figure 2.7

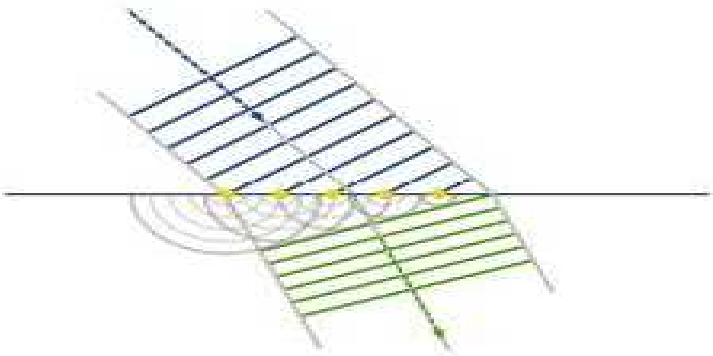


Figure 2.7 :Refraction of Electromagnetic wave.

2.5 Free Space Propagation

The free space propagation model is used to predict received signal strength when the transmitter and receiver have a clear, Line Of Sight (LOS) path between them. In large-scale radio wave propagation models, the free space model predicts that received power decays as a function of the T-R separation distance raised to some power. The free space power received by the receiver antenna is separated from a radiating transmitter antenna by a distance d.

2.6 Path Loss and Shadowing

Path loss is a variation in the received signal power over distance. Path loss is caused by dissipation of the power radiated by the transmitter as well as effects of the propagation channel. Shadowing is caused by obstacles between the transmitter and receiver that attenuate signal power through absorption, refraction, reflection, scattering and diffraction. Figure 2.7 [4] shows path loss, shadowing and multipath affect over distance. When the attenuation is very strong, the signal is blocked.

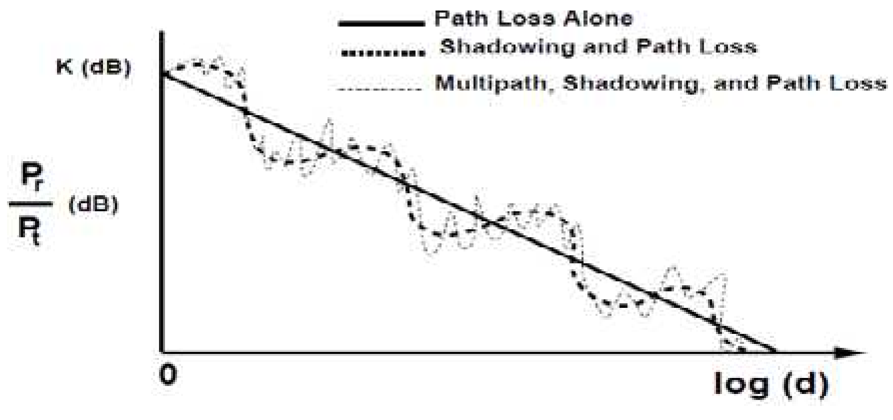


Figure 2.8 : Path loss, Shadowing and Multipath over distance.

2.7 Multipath and fading

Signal multipath fading occurs when the transmitted signal arrives at the receiver via multiple propagation paths. Each of these paths may have a separate phase, attenuation, delay and Doppler frequency associated with it. The phenomenon of reflection, diffraction and scattering all give rise to additional radio propagation paths beyond the direct optical “line of sight” path between the radio transmitter and receiver. These paths add up constructively or destructively, resulting in a phenomenon called fading. Signal fading refers to the rapid change in received signal strength over a small travel distance or time interval. This occurs because in a multipath propagation environment, the signal received by the mobile at any point in space may consist of a large number of plane waves having randomly distributed amplitudes, phases, delays and angles of arrival. These In other words, when multiple signal propagation paths exist, caused by whatever phenomenon, the actual received signal level is vector sum of all the signals incident from any direction or angle of arrival. Some signals will aid the direct path, while other signals will subtract (or tend to vector cancel) from the direct signal path. The total composite phenomenon is thus called multipath. If the objects in a radio channel are stationary, and channel variations are considered to be only due to the motion of the mobile, then signal fading is a purely spatial phenomenon. A receiver moving at high speed may traverse through several fades in a short period of time. If the mobile moves at low speed, or is stationary, then the receiver may experience a deep fade for an extended period of time. Reliable communication can then be very difficult because of the very low signal-to-noise ratio (SNR) at points of deep fades. Fading is divided into two types the small scale fading and large scale fading Figure 2.9, Figure 2.10. The indoor radio propagation at some areas may be very bad causing phenomena called “Dead Spots” [5] where the signal is virtually non-existent. The dead spot region may increase depending on the inside building structure which increase the number of available multipath that caused by the propagation mechanisms (reflection, scattering and diffraction). The dead spot is three dimensional spot and a small movement of the mobile station may change the signal strength from no signal to full signal.

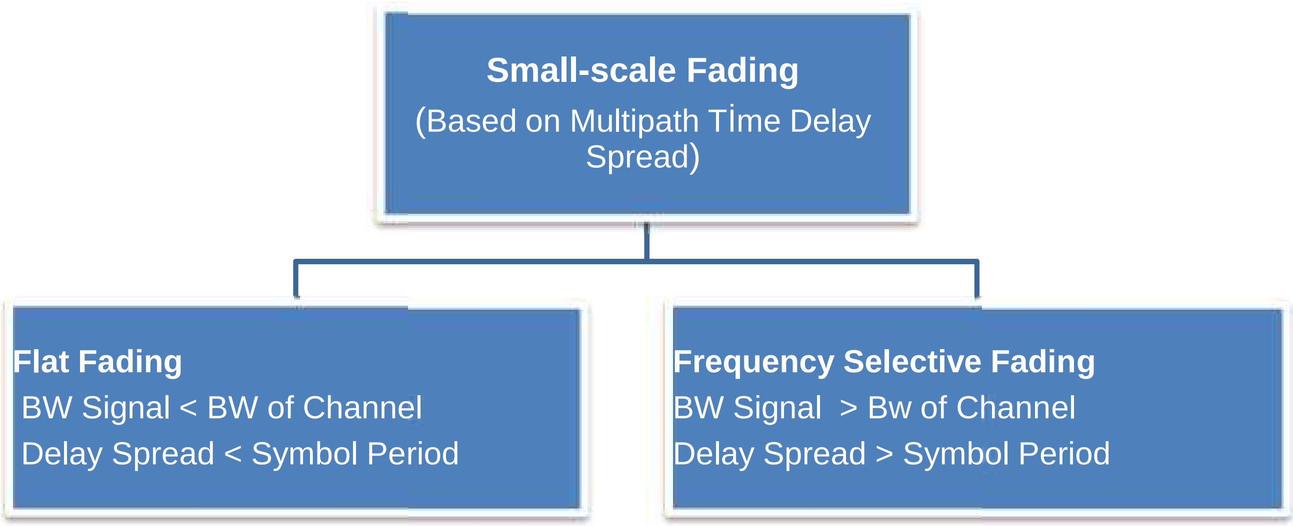


Figure 2.9 : Types of small scale fading (based on multipath time delay spread)

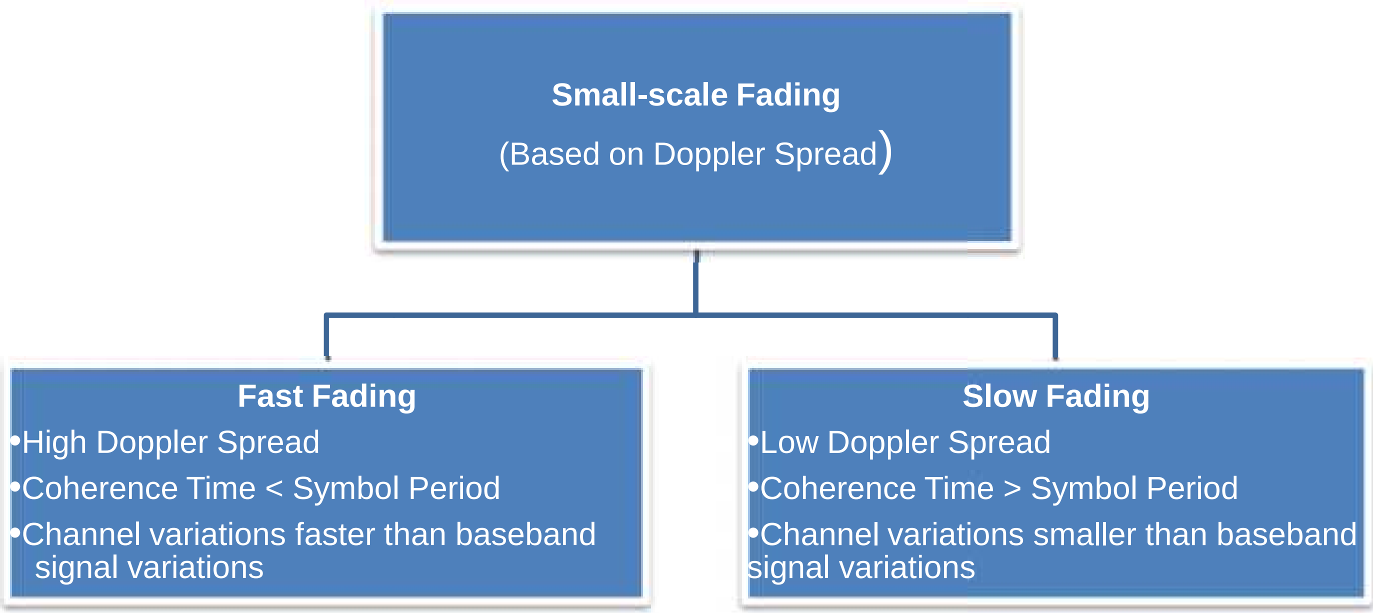


Figure 2.10 : Type of small scale fading (based on Doppler spread)

2.8 Doppler spread and Doppler shifts

Relative motion between the transmitter and receiver imparts a Doppler shift on the signal, where the entire signal spectrum is shifted in frequency. When multipath is combined with relative motion, the electromagnetic wave may experience both positive and negative Doppler shifts, smearing and spreading the signal in frequency. This effect is called Doppler spread. Doppler spread takes into account the relative motion between mobile and base station, or by movements of objects in the channel. It describes the time varying nature of the channel in a small scale region [6].

2.9 Wave Polarization

The polarization of an electromagnetic wave (Figure 2.11)is defined by the trajectory of the time-domain electric field as viewed in the direction of propagation. the polarization of a uniform plane wave propagating in the z direction given as

$$E = E_x\, a_x + E_y\, a_y \qquad 2.1$$

where

$$E_x = a \cos(\omega t - kz + \phi_a) \qquad 2.2$$

$$E_y = b \cos(\omega t - kz + \phi_b) \qquad 2.3$$

The plane of polarization of a radio wave is the plane in which the E-field propagates with respect to the Earth.

- If the E-field component of the radiated wave travels in a plane perpendicular to the Earth’s surface (vertical), the radiation is said to be vertically polarized.
- If the E-field propagates in a plane parallel to the Earth’s surface (horizontal), the radiation is said to be horizontally polarized.
- Circular polarization produces an electric field that rotates as it travels. Circular polarization falls into two categories, depending on the direction of rotation, right-hand circular’ and ‘left-hand circular’. The polarization of a radio wave can rotate as it propagates.
- One advantage of Circular polarization is that rotation does not affect it: it remains circular. For this reason, circular polarization is commonly used in links to geostationary satellites at frequencies below 10 GHz.

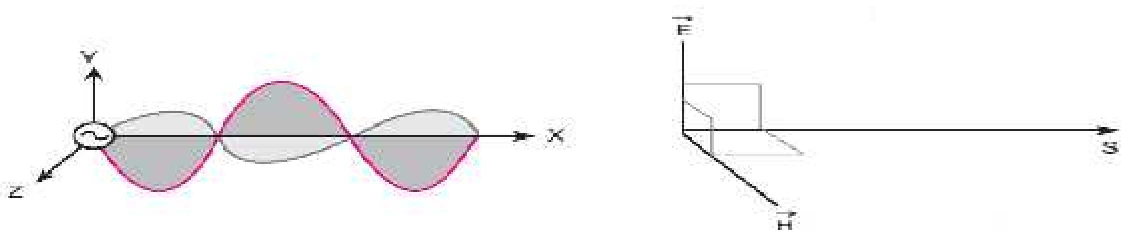


Figure 2.11: Vertical and Horizontal polarization.

2.10 Previous studies

2.10.1 Empirical Narrow Band Models

These models describe the path loss of the signal. they mainly depend on two parameters that specify these models one is the frequency and the other is the distance. Another parameter which appears in these models describes the characteristics of the wireless environment.

The main advantage of these models is that they have the flexibility to make them a site specific models. They are very practical rather than deterministic models that have many parameters and need a very large input data.

2.10.1.1 Simplified Path Loss Model [7]

SPLM is a simple formula that describes the path loss value. The model is useful for both indoor and outdoor environment and it's like the following:

$$P_r=P_t K(d_0/d)^n \qquad (2.4)$$

Where:

P_r is the average received power.
P_t is the average transmitted power.
d_0 is a reference distance for the antenna far-field.
d is distance between the transmitter and the receiver.
n is the path loss exponent.
K is a unitless constant value determined by the following equation:
$K=\lambda/ 4\pi d_0$. λ is the wave length of the transmitted signal.

If we want the dB value of the received power we have the following formula :

$$P_r\,dBm = P_t\,dBm + K\,dB - 10n\log_{10} d/d_0 \qquad (2.5)$$

n describes the wireless environment characteristic . in indoor sceneries n is a important parameter it is maybe the most important parameter because the model does not specify the penetration loss of walls or the other factors that affect the signal strength. We have the following table that has typical values of n for different indoor and outdoor scenarios:

Environment	N range
Urban macro cells	3.7-6.5
Urban microcells	2.7-3.5
Office Building (same floor)	1.6-3.5
Office Building (multiple floors)	2-6
Store	1.8-2.2
Factory	1.6-3.3
Home	3

Table2.1: A typical value of n [9]

There is a simple way to calculate n based on measurement this way works for many other models like ITU-Model. This way is explained in the following example.

Example 2.1: Consider the set of empirical measurements of Pr/Pt given in the table below for an indoor system at 900 MHz. Find the path loss exponent n that minimizes the MSE between the simplified model and the empirical dB power measurements, assuming that d0 = 1 m and K is determined from the free space path gain formula at this d0. Find the received power at 150 m for the simplified path loss model with this path loss exponent and a transmit power of 1 mW (0 dBm).[7]

Distance from Transmitter	M = Pr/Pt
10 m	-70 dB
20 m	-75 dB
50 m	-90 dB
100 m	-110 dB
300 m	-125 dB

Table2.2: Example 2.1.

We first set up the MMSE error equation for the dB power measurements as

$$\sigma_{\varphi dB}^{2} = \frac{1}{K}\sum_{i=1}^{K}[\Pr_{measured}(d_i) - \Pr_{model}\ (d_i)]^2 \qquad (2.6)$$

Where $P_{r\ measured}$ (di) is the path loss measurement in Table 2.2 at distance d_i and

$P_{r\ model}(d_i)$ = K−10n $\log_{10}$(d)

Using the free space path loss formula, K = $20\log_{10}(.3333/(4\pi))$ = −31.54dB.

Thus

F(n) = (−70 + 31.54 + 10n)2 + (−75 + 31.54 + 13.01n)2 + (−90 + 31.54 + 16.99n)2

+ (−110 + 31.54 + 20n)2 + (−125 + 31.54 + 24.77n)2

= 21676.3 − 11654.9n + 1571.47n2.

Differentiating F(n) relative to n and setting it to zero yields

∂F(n)/∂n = −11654.9 + 3142.94n = 0 → n = 3.71.

To find the received power at 150 m under the simplified path loss model with

K = −31.54, n = 3.71, and P_t = 0 dBm, we have

Pr = Pt + K – 10n log10(d/d0) = 0 − 31.54 − 10 * 3.71 log10(150) = −112.27 dBm.

2.10.1.2 Multi-Wall Model

Another empirical model is the Multi-Wall Model which indicates the path loss as a free space loss together with the losses introduced by walls and floors penetrated by the direct ray between the transmitter and receiver. It was proven that the total floor loss is a non-linear function of the number of penetrated floors. This characteristic is taken into account with an introduction of an empirical factor b. The multi-wall path loss is given by

$$L = L_{FS} + L_C + \sum_{i=1}^{I} K_{Wi} L_{Wi} + K_f^{\frac{K_f+2}{K_f+1} - b}\ Lf \qquad (2.7)$$

Where:

L_{FS} the free space loss between the transmitter and the receiver.

L_C constant loss. Derived from the measured value.

$K_{Wi}$the number of separated walls of type I.

L_{Wi}loss of wall of type I.

K_f number of floors.

Lf loss between adjacent floors.

b constant determined by fitting.

I indicate the number of wall types.

The term Constant loss factor is applied in case where wall losses are determined on the basis of measurements and is usually near to zero. The third term in the equation expresses the total wall loss as a sum of the walls between transmitter and receiver. For practical reasons the number of different types of walls should be kept low. Otherwise, the difference between the wall types is small and their significance becomes negligible. It is also important to mention that the loss factors are not physical wall losses , but model coefficients ,optimized along the measured path. Besides, the loss factors implicitly include the effect of furniture and the effects of signal paths guided through corridors.[8]

2.10.1.3 ITU model for indoor attenuation [9]

The reason of select ITU model is a site-general model which means compatibility. Another reason is that the model has flexible parameters which can be easily tampered giving us wide range of freedom, and dealing with internal content of the building. ITU model is a simple model and easy to deal with, and it is able to be numerically tuned.

ITU Model for Indoor Attenuation, it can estimate the path loss inside a room or a closed area inside a building delimited by walls of any form. Suitable for appliances designed for indoor use, this model approximates the total path loss an indoor link may experience.

ITU model Commensurate with the indoor environment, it can use the lower microwave bands around 2.4 GHZ.

$$L_{total} = 20 \log10(f) + N \log10(d) + Lf(n) - 28 \text{ dB} \quad (2.8)$$

Where:

N is the distance power loss coefficient
f is the frequency in MHz
d is the distance in meters (d > 1m)
Lf(n) is the floor penetration loss factor
n is the number of floors between the transmitter and the receiver.

For wireless LANs

The general form the ITU model , last equation above (2.8). The floor loss coefficient Lf(n) can be obtained by numerical tuning for the model with respect to the measured values. The floor penetration loss factor equal zero in same floor case that is mean if the ITU model formula becomes :

$$L_{total} = 20 \log_{10}(f) + N \log_{10}(d) - 28 \text{ dB} \quad (2.9)$$

Frequency in WLAN is equal 2.4GHz, then:

L total = 20 log10 (2400MHz)+ N log10 (d)- 28 dB

= 67.6+Nlog10 (d)-28

=39.6+Nlog10 (d)

For GSM

Frequency in GSM is equal 900MHz, then:

L total = 20 log10 (900MHz)+ N log10 (d)- 28 dB

= 59+Nlog10 (d)-28

=31+Nlog10 (d)

2.10.2 Deterministic Models

The deterministic models are a very complex models that is used to simulate the propagation of the radio waves. Therefore the effect of the environment on the propagation parameters can be taken into account more accurately than in empirical models. Another advantage is that deterministic models make it possible to predict several propagation parameters. Like impulse response and angle-of-arrival can be predicted at the same time. There are two main approaches the ray launching approach and the image approach.

2.10.2.1 Two-Ray Model [10]

Simple reflection and refraction causes the scattering of electromagnetic waves called the ray-tracing. The complex permittivity of the obstacle related to the degree of transmission and reflection of a signal through and off an obstacle. Two-Ray model is one of the propagation models based on ray-optic theory. i.e. modeling of Line of Sight radio channel as shown in Figure 2.12

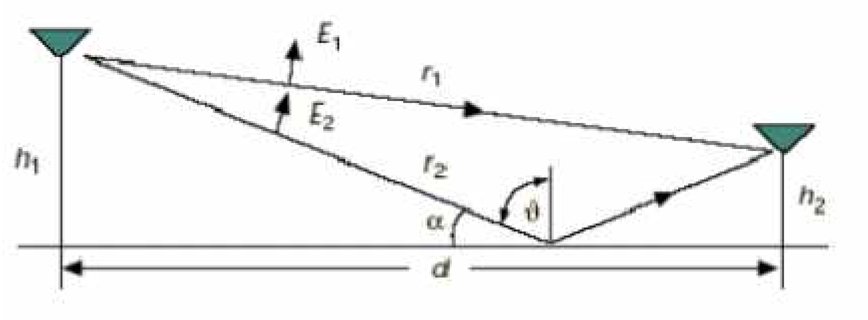


Figure 2.12 : Two-Ray

Use a direct path and reflected path. The distance d is the separation distance between transmitting antenna of height h1 and the receiving antenna of height h2. Summing the contribution from each ray obtain the received signal Pr for isotropic antennas, can be expressed as:

$$P_r = P_t \ \frac{\lambda}{4\pi} \ [\frac{1}{r_1} e^{-jkr_1} + \Gamma \ \alpha \ \frac{1}{r_2} e^{-jkr_2}]^2 \qquad (2.10)$$

P_t : is the transmitted power.

r_1: is the direct distance from the transmitter to the receiver.

r_2: is the distance through reflection on the ground.

T(α): is the reflection coefficient depending on the angle of incidence α and the polarization.

The reflection coefficient is given by polarization by :

$$\Gamma(\Theta)=\frac{\cos - a\ \ \overline{\varepsilon_r - \sin^2\theta}}{\cos + a\ \ \overline{\varepsilon_r - \sin^2\theta}} \qquad (2.11)$$

θ = 90-α .

a = 1/ ε or 1 for vertical or horizontal polarization, respectively.

ε r :is a relative dielectric constant of the reflected surface.

2.11 Previous study about WLAN& GSM

A numerical adjustment to the ITU model at 2.4GHz for wireless LAN's in Chrysikos et al[11] based on measurement made in two buildings . Chrysikos said that the path loss exponent increase after a certain distance. Another adjustment that they made was the value of the floor penetration loss (lf)from 15+4(n-1) where n is the number of floors to 7.5(n+1). But Chrysikos didn't take enough samples and he took one sample only to calculate lf accurately for different building designs.

Tarneveik et al[12] did an amendment to the KM model(Lm= 20log (2πd/λ) + kF + pW) where kF,pW is the floor and wall attenuation factors. They took a large sample and in various countries. Tarneveik validate that the path loss decay after certain distance inside the building with a linear accumulating value which determined by a fitting in the model. The main shortage of his work is that calculating the path loss requires gathering a lot of input data.

Pavel Pechač et al[13] investigated the indoor propagating waves at 900 MHz to characterize the behavior of the signal strength values. They studied two forms of the simplified free space model. The difference between them is the value of the floor attenuation factor one is constant whereas the other is variable depending on the number of penetrated floors. In their study , they took two different buildings with wide corridors. And measured the path loss in the corridors for all floors then calculated the path loss exponent for the two models. For calculation inside the rooms ,they added the wall attenuation factors. But , they end up with a vague model since the performance of the two where close. Another thing was that they didn't make any numerical adjustment to the models. Also due to the corridor effect, the value of the loss exponent was very small in one building it was .9 which is very small compared with the free space path loss exponent which is 2.

Chrysikos et al [14] featured a site-specific validation of indoor RF models for a commercial topology with an installed Wi-Fi system operating at 2.4 GHz (802.11g protocol). They deployed a three access points in various places in an international airport then they collected the data. In the study , they tested three models the free; space model the one slope model and the ITU model. In each case the calculated the path loss exponent that achieves the minimum square error. Afterwards ,they compared the measured data with the calculated. The ITU model supplied the worst performance for the three access points. So they made a numerical adjustment to improve the ITU model. a single floor measurements made so they didn't tested the ITU for multi- story buildings. Although they compared the three models for three different access point but it is for almost the same indoor environment.

Bartolomc and Vallejo [15] presented the path loss results and channel characterization at 1.9 GHz obtained in indoor environments. They studied three building and they model the propagating wave for various situation for the location of the transmitter in the building. and different indoor scenarios. They came up with models to describe the corridors area and the cases of multi-wall and the presence of diffraction of the propagated wave. But the models in two cases require the gathering of many information about the building constriction which makes the model many times accurate but complex.

Jyotshna Cherukuriin [16] thesis is aimed at contributing to the development of improved propagation prediction models for in-building wireless communications and, at the same time, providing a better physical understanding of radio wave propagation in areas such as classrooms, laboratories, corridors, offices. Extensive measurements were recorded with transmitter at three different locations within Smith building, at 2.4GHz band for WLAN and WPAN applications. Three stochastic models reported. By comparing results of all the 3 models with measurements, he concludes that none of the techniques truly works well for both LOS and NLOS environments. A possible method for overcoming the limitations of the individual models would be to integrate multiple techniques. This may improve estimation results and in addition reduce number of required RF measurements.

Lucio Ferreirant Martijn Kuipersnt Carlos Rodriguest, Luis M. CorreiaL in [17], presented characterizations of signal penetration into buildings for GSM and UMTS. The extra attenuation follows a Log-Normal Distribution, hence, the average and the standard deviation values can be used for a good Characterization. An average attenuation of 5.7 dB for GSM900 is observed. It is concluded that attenuation of penetration into buildings increases as one goes "deeper into the building" (5 dB to indoor light, 6 dB to indoor, and 9 dB to deep indoor, on average), and decreases as one moves "up in the building" (0.8 dB with each floor level). Results for GSM1800 and UMTS can be obtained by shifting GSM900 CDFs by 1.9 dB.

PPU Building C Model [20]

In "Indoor Radio Propagation at 900 MHz & 2400 MHz Frequencies" a site-specific validation of the ITU indoor path loss model at 2.4 GHz and 900MHz was done, based on measurements acquired in an experiment for a WLAN and GSM indoor office environment, the authors did a numerical adjustment of the site-general ITU model to the specific measured data that reflect the intrinsic characteristics of the complex indoor topology.

Wireless LAN

The authors did analysis on PPU building B and came up with the following formulas for wireless LAN:

$$P_r\,(\text{dBm}) = -23 - 10n\log_{10}(d) \quad \textbf{for the same floor} \quad (2.12)$$

$$P_r\,(\text{dBm}) = -23 - 10n\log_{10}(d) + Lf(n) \quad \textbf{for multi floors} \quad (2.13)$$

Where Lf **(n):**

Number of Floor separation	$Lf(n)$
1	5n
2	18(n+1)

Table 2.3: multi floor separation penetrated loss

And the values of standard deviation were as follow:

Floor separation	Standard deviation (σ)
2^{nd} to 1^{st}	8.61
2^{nd} to 2^{nd}	9.75
2^{nd} to 3^{rd}	5.50
2^{nd} to 4^{th}	5.06

Table 2.4: Standard deviation WLAN

GSM

The authors did analysis on PPU building C and come up with the following formula for GSM:

$$P_{r\,(dBm)} = 5 - 10n \log_{10}(d) - \sigma \qquad (2.14)$$

And the value of standard deviation where as follow:

Floor number	Standard deviation (σ)
1^{st} floor	8.04
2^{nd} floor	9.07
3^{rd} floor	9.4

Table 2.5: Standard deviation GSM

CHAPTER THREE

MULTI WALL ATTENUATION LOSS

3.1 Introduction

All radio waves propagated undergo signal losses before arriving at the receiving site as we discussed earlier in chapter two. These losses are losses due to propagation mechanisms and frees pace loss. Normally, the major loss of signal is because of the spreading out of the wavefront as it travels from the transmitter. As distance increases, the area of the wavefront spreads out. This means the amount of power contained within any unit of area on the wavefront decreases as distance increases.

For the indoor environment, there are other types of losses that also significantly affect propagation. These losses are signals attenuation due to multi wall penetration, so it is normal to take into account the effective wall attenuation factor as a main factor in calculating the path loss. This section will investigate the attenuation effect of internal walls on the GSM and wireless LAN signals.

3.2 Methodology

The ITU model, described in equation 3.1, contains the primary component “n” which is the path loss exponent that accounts for the effect of the environment on the signal strength of the external source. For free space n equals 2.

$$P_r = P_t - 20Log_{10} f \ MHz \ - 10nLog_{10} d - L_{out} + 28 \qquad (3.1)$$

In order to isolate the effect of the internals walls, we processed the data in a way by first eliminating the effect of free space distance by simply adding ($20\log_{10}$ (d)) to the measured power of the signal ($Pr_{(TEMS)}$ + $20Log_{10}$(d)). We progressively separated the measured points, according to the number of internal walls separation between the transmitter and the receiver, then averaged the values of ($Pr_{(TEMS)}$ + $20Log_{10}$(d)) over the number of considered internals walls. Subtracting then the first value “at wall zero” we discarded the effect of environment because the effect of zero walls on the signal is zero, hence just the effect of internal walls was accountant for. After the wall effect is known the effect of environment is easily obtained by separating the effect of walls from the measured signal and the path loss, n_0, can then be calculated.[18]

3.3 Multi Wall Attenuation Losses Analysis for 900 (MHz)

3.3.1 Al-Ahli Hospital

Al-Ahli hospital is a large three-storey building with a maximum of 11 considered internal walls , in the 2nd and 3rd floors.. Table 3.1 shows the analyzed data, describing the averaged accumulated attenuation loss, over the total number of internal walls per each floor. The analysis reveals that , as the number of walls increase , the attenuation loss of internal walls increases in a nonlinear trend. We can graphically show such trend and mathematically model it, as would be shown in the next sections. As the locations of the measured points were predetermined from the AutoCAD ™ map of the multi floor building, a few points, shown as blank cells, in Table (3.1) were not recorded, for not having access to those pertaining walls.

Number of walls	0	1	2	3	4	5	6
Al-Ahli-First Floor	0		11.1331	15.1723		25.8201	25.8306
Al-Ahli-Second Floor	0	5.496268		17.0032	22.8536	27.2495	28.4313
Al-Ahli-Third Floor	0	4.862881	9.15360	12.5354	19.1326		24.3743

Number of walls	7	8	9	10	11
Al-Ahli-First Floor	29.6980	30.0578	30.7691	No wall	No wall
Al-Ahli-Second Floor	29.5228	29.7636	30.4212	30.7345	30.7347
Al-Ahli-Third Floor	28.032	28.5130	28.9930	27.9580	28.8995

Table3.1: Multiwall attenuation loss analysis at Al-Ahli Hospital in Hebron.

Figures 3.1 to 3.3 show the attenuation loss effect with the number of internal walls related to the 1st, 2nd, 3rd floor in Al-Ahli hospital respectively:

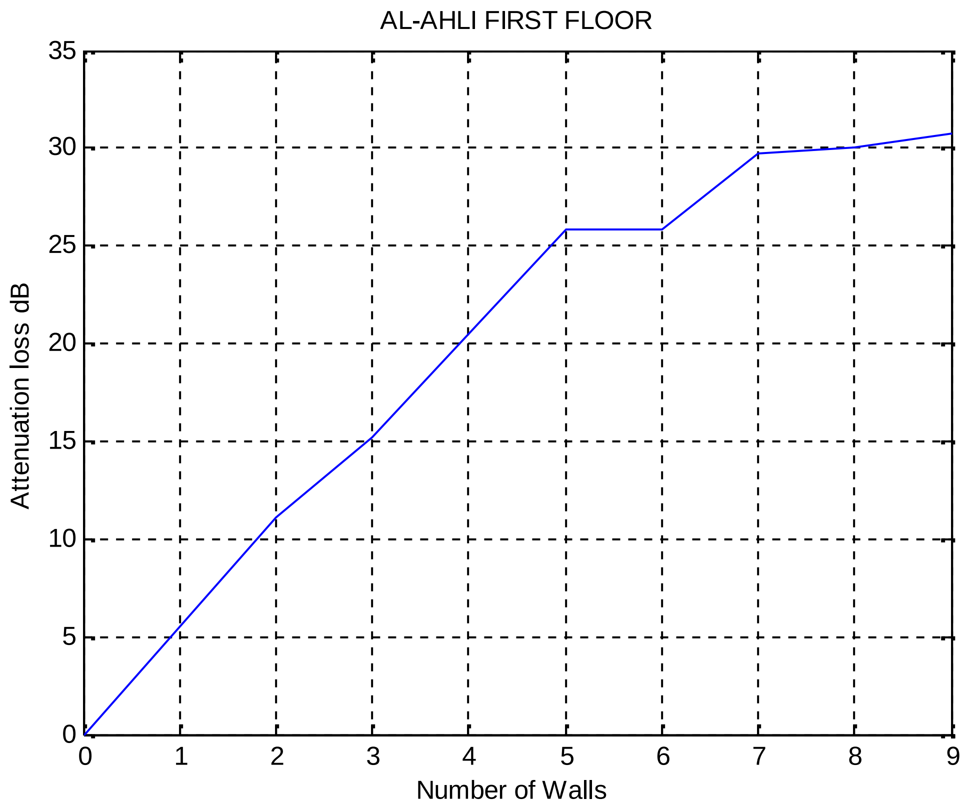


Figure 3.1: Attenuation loss versus number of walls inside first floor of Al-Ahli hospital.

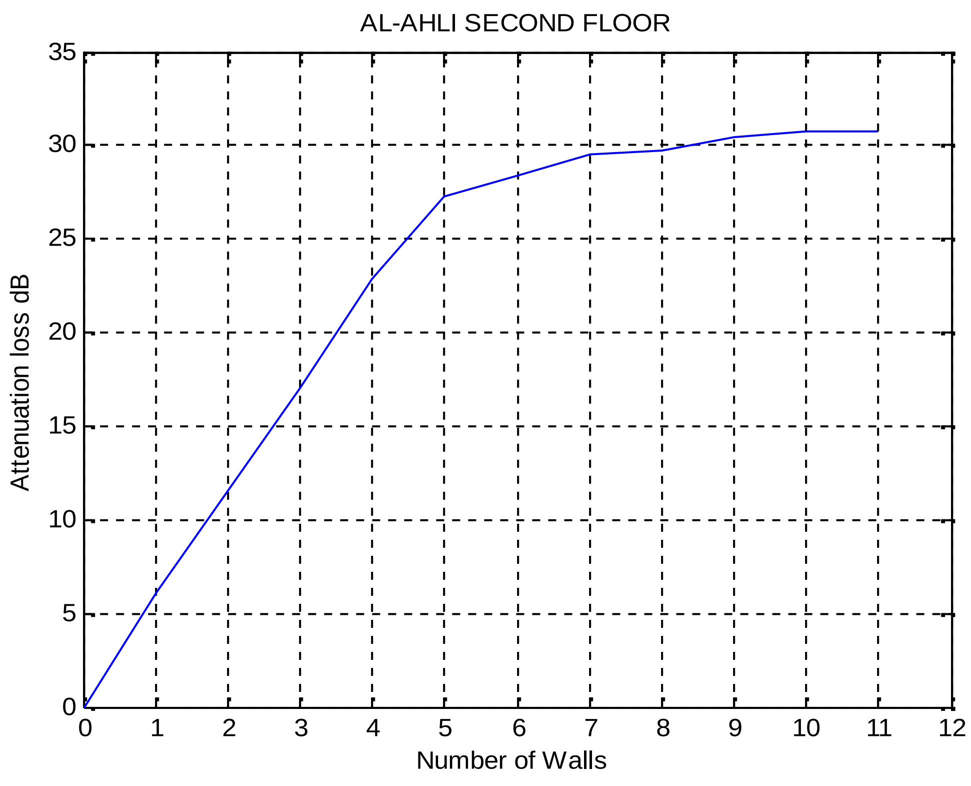


Figure 3.2: Attenuation loss versus number of walls inside second floor of Al-Ahli hospital.

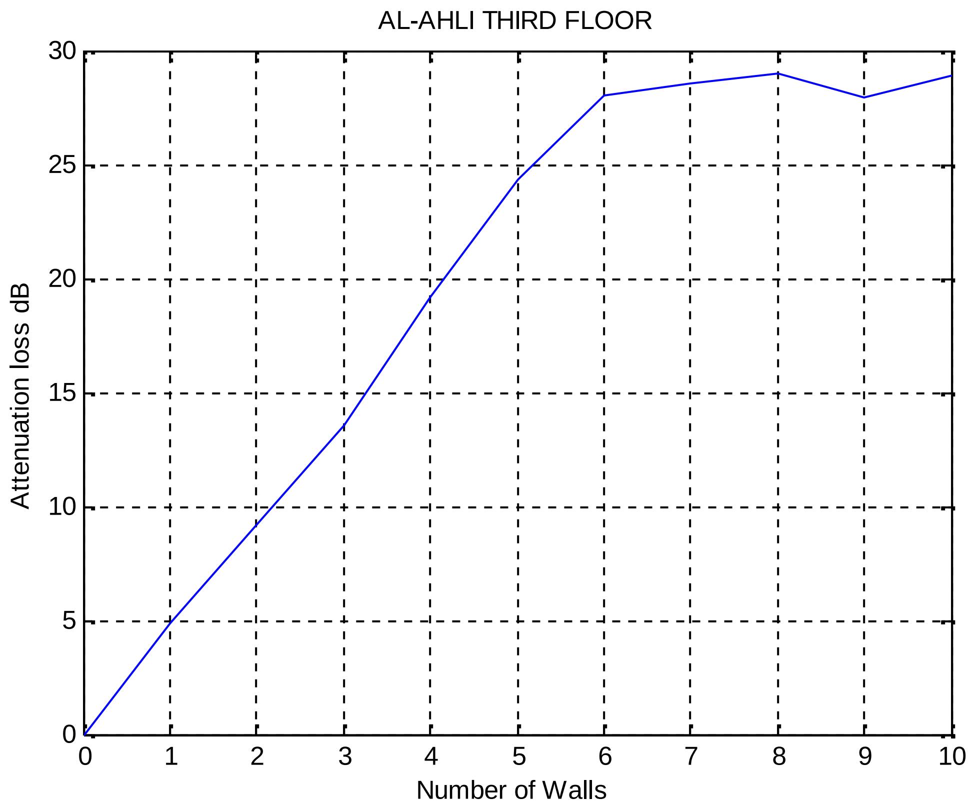


Figure 3.3: Attenuation loss versus number of walls inside third floor of Al-Ahli hospital.

From figures 3.1 to 3.3, the wall attenuation per single wall ranged from (4.9 - 5.5 dB) and that was consistent over the first seven walls, between the source and the point received . After the eighth wall the attenuation loss factor tended towards saturation, as the received power becomes relatively very low.

3.3.2 Abu Rumman Building

Abu Rumman is a three-storey building with 5 internal walls as a maximum. The average of the attenuation loss with regard to the number of internal walls in the table (3.2) for the three floors:

Number of walls	0	1	2	3	4	5
aburumman-1	0	5.53417057	(single	internal	wall	only)
aburumman-2	0	4.07663903			16.4959778	19.5685031
aburumman-3	0	5.88979695	8.96726933	12.3288973	No wall	No wall

Table 3.2: Multiwall attenuation loss analysis at Abu Rumman building.

We note from the Table 3.2, similar to Al-Ahli floors, that when the number of internal walls increased the attenuation loss factor nonlinearly increased. In fact, he difference amount of the increase in the attenuation loss decreased per each additional wall. Figures 3.4 to 3.6 show the attenuation loss factor with the number of internal walls related to the 1st, 2nd, 3rd floor in Abu Rumman building respectively.

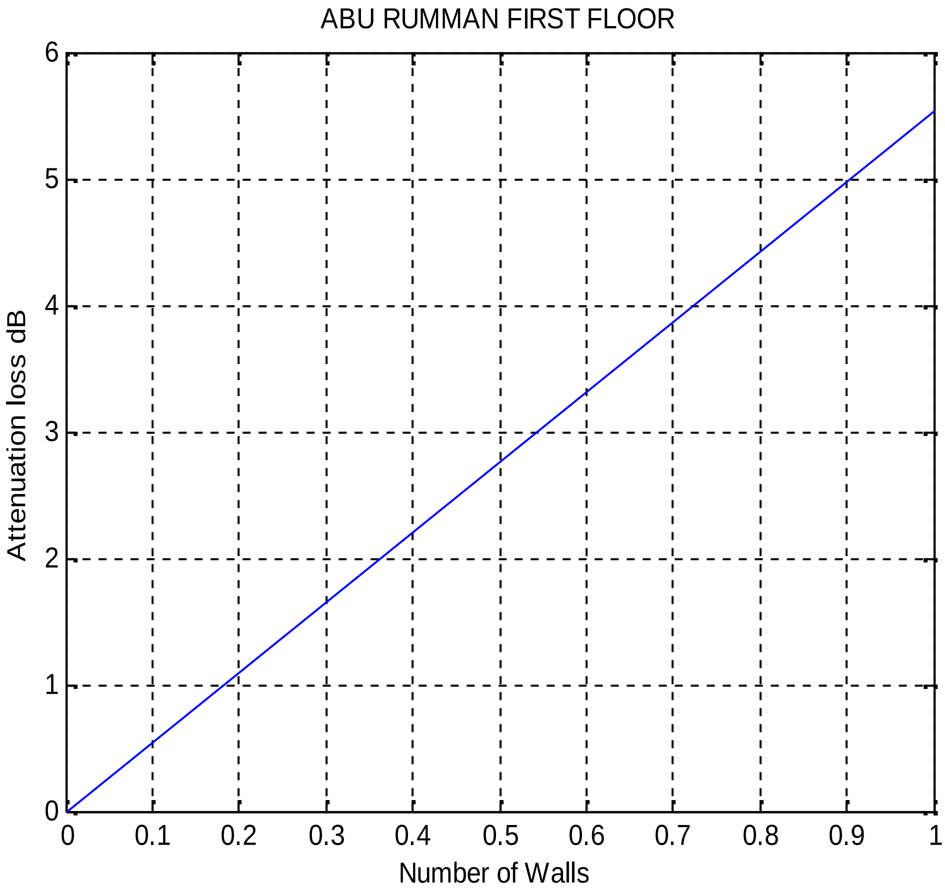


Figure 3.4: Attenuation loss versus number of walls inside first floor of Abu Rumman building.

Inside Abu Rumman first floor there was a single internal wall (Figure3.4) and the attenuation loss factor was (5.5 dB) which is approximately similar to Al-Ahli hospital.

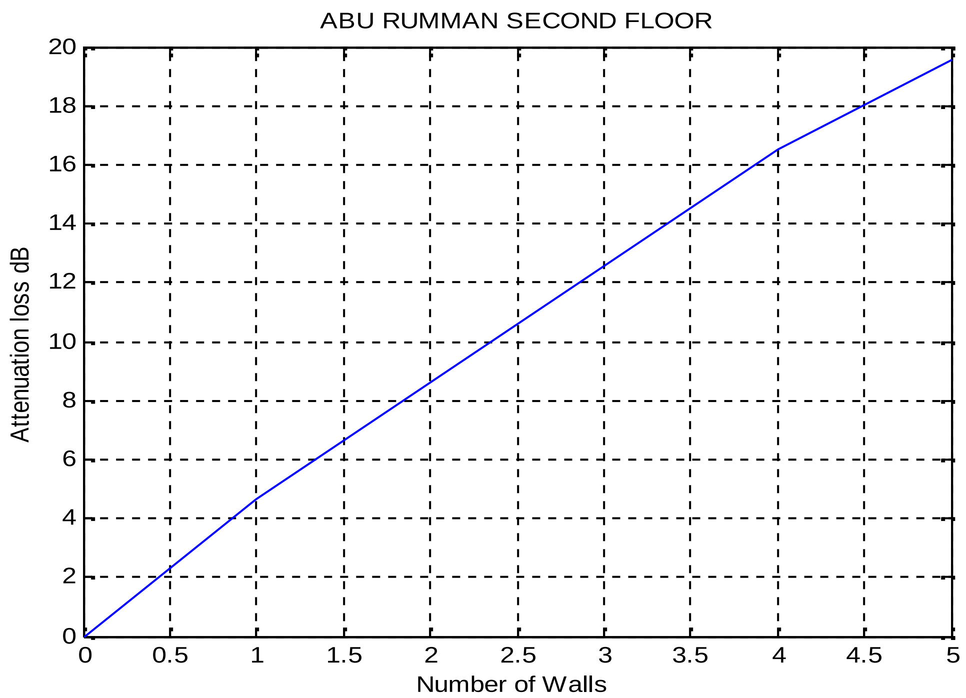


Figure3.5: Attenuation loss versus number of walls inside second floor of Abu Rumman building.

Figure 3.5 reveals that the attenuation loss factor per wall ranged between (4-4.5 dB) for each of the first 4 internal walls and 3.5 dB for the fifth one.

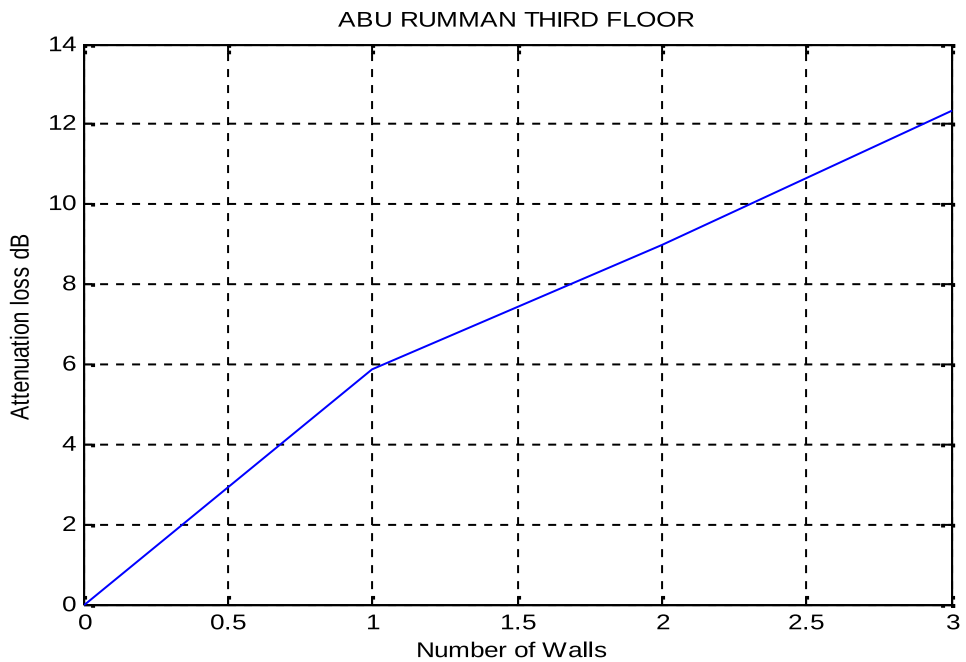


Figure 3.6: Attenuation loss versus number of walls inside third floor of Abu Rumman building.

In Abu Rumman third floor there were three internal floors. , Figure 3.6 reveals that the attenuation loss factor ranged from (4.5-5.7 dB) per wall.

3.3.3 PPU Building A

PPU Building A is a four-storey building with up to 3 internal walls in the fourth floor.. The accumulative averages of the attenuation loss versus the number of internal walls are shown in Table 3.3 for the four floors.

Number of walls	0	1	2	3
buildingA-1	0	5.86002028	No wall	No wall
buildingA-2	0		9.32404098	No wall
buildingA-3	0		8.45948909	14.0378681
buildingA-4	0	5.03328315		13.6471003

Table3.3: Multiwall attenuation loss analysis at PPU Building A.

From the table (3.3) the attenuation loss factor increased when the number of internal wall increased. Figures 3.7 to 3.10 show the attenuation loss factor versus the number of internal walls for the 1st, 2nd, 3rd and 4th floor of PPU Building A respectively:

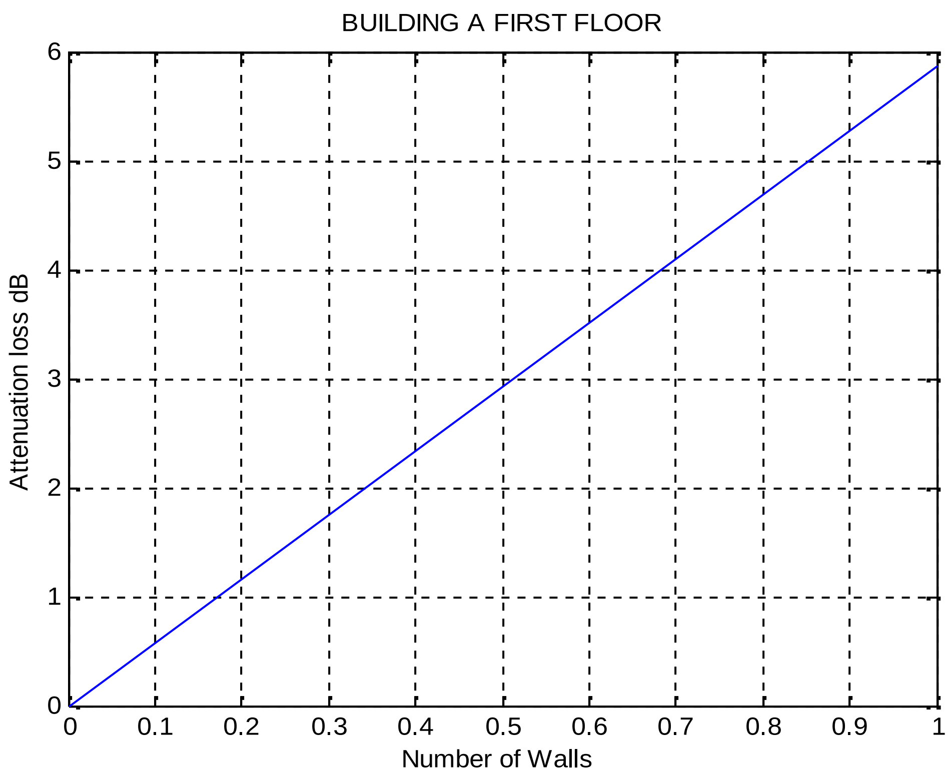


Figure 3.7: Attenuation loss versus number of wall inside 1st floor pf PPU Building A.

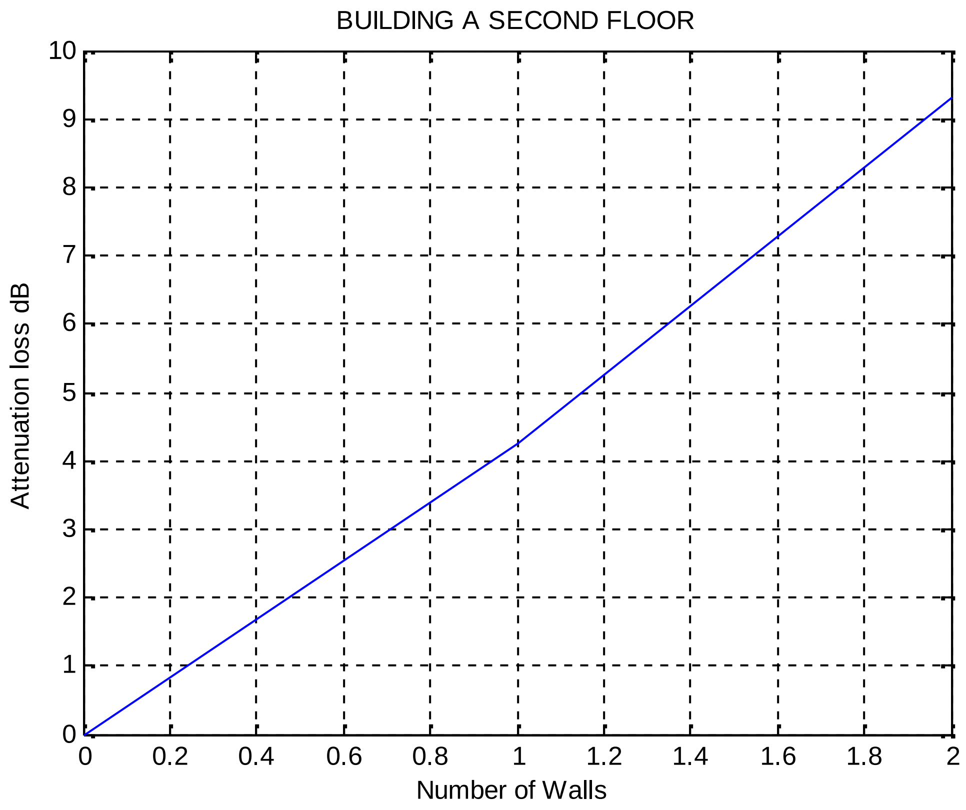


Figure 3.8: Attenuation loss versus number of walls inside 2nd floor of PPU Building A.

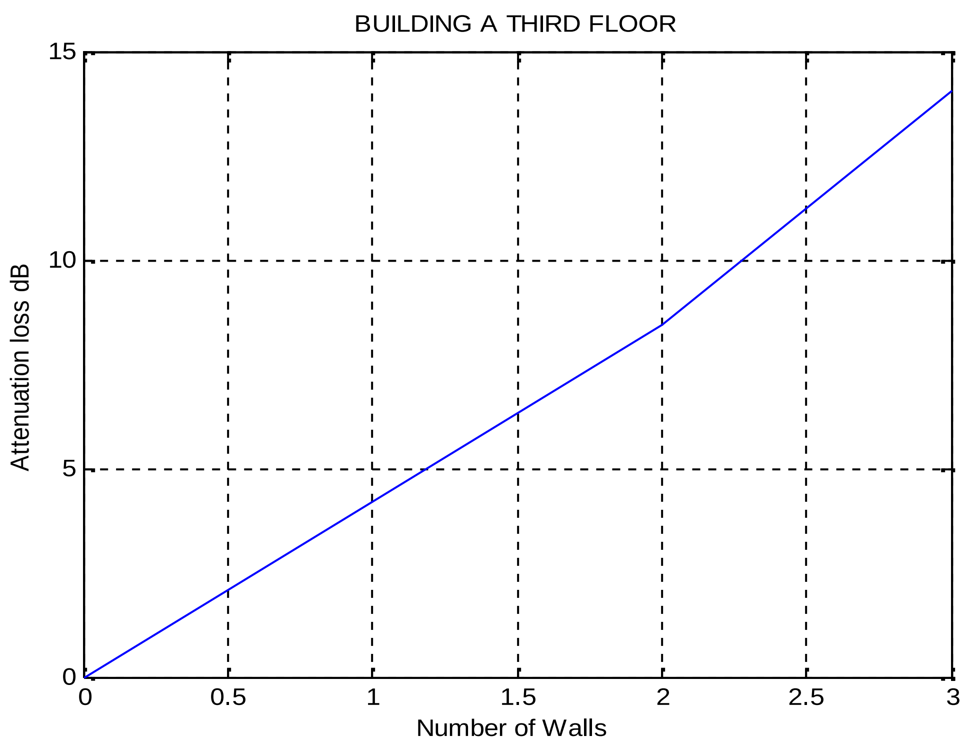


Figure 3.9: Attenuation loss versus number of walls inside 3rd floor of PPU Building A.

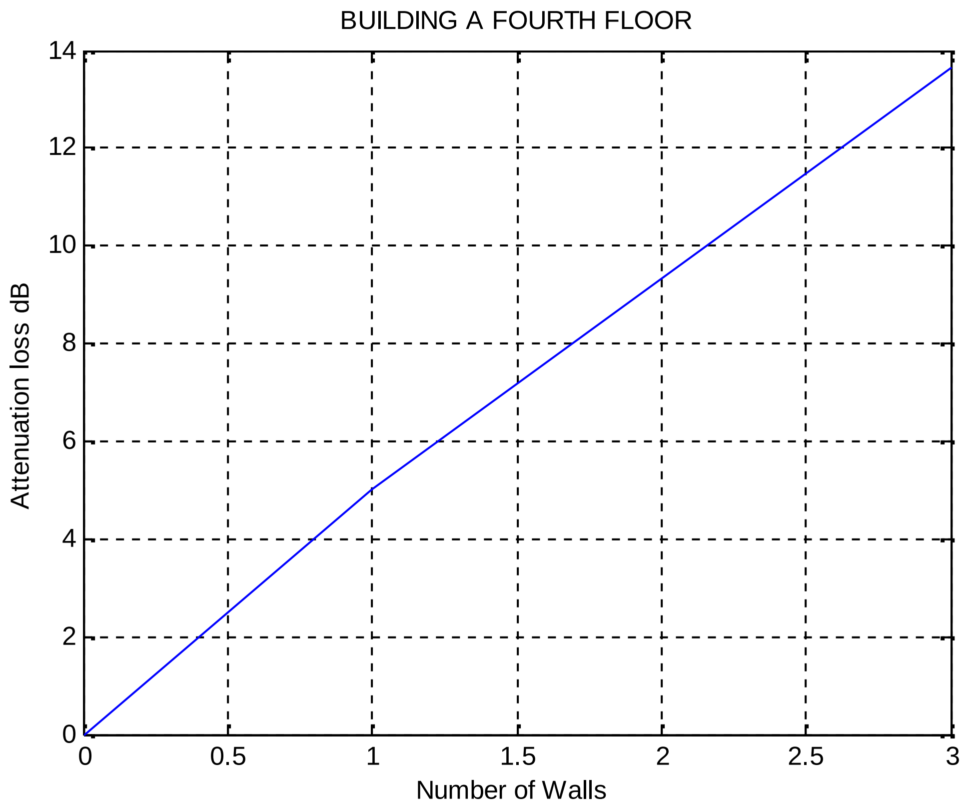


Figure 3.10: Attenuation loss versus number of walls inside 4th floor of PPU Building A.

Figures 3.7 to 3.10 reveal that, for PPU Building A, the wall attenuation factor per single wall ranged from (4.9 - 5.5 dB).

3.3.4 Services Building

Services Building is a three-storey building with up to 4 internal walls in the G-floor. The accumulative average of the attenuation loss versus the number of internal walls are shown in the Table 3.4 for the three floors.

Number of walls	0	1	2	3	4
services building-G	0		10.0958201		21.0452486
services building-1	0	5.30199262	7.82598266	No wall	No wall
services building-2	0	6.55493966	No wall	No wall	No wall

Table 3.4: Attenuation loss analysis at the Services Building.

Table 3.4 illustrates when the number of internal walls increased the attenuation loss factor increased. Figures 3.11 to 3.13 show the attenuation loss factor versus the number of internal walls for the 1st, 2nd and 3rd floor, in the Services Building respectively.

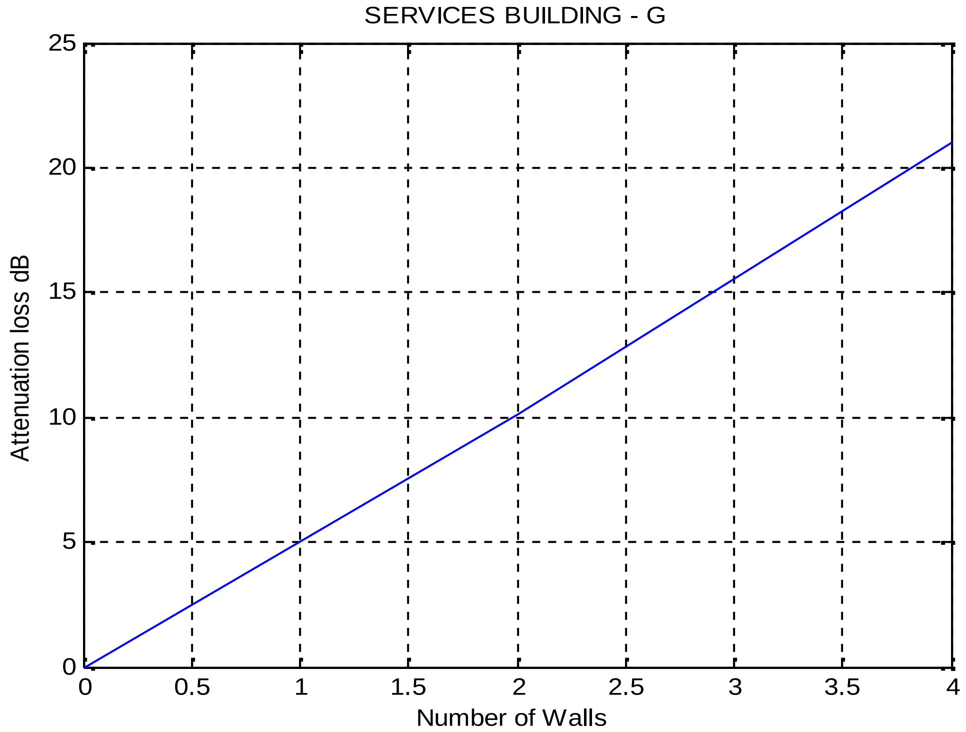


Figure 3.11: Attenuation loss versus number of walls inside G-floor of the Services Building.

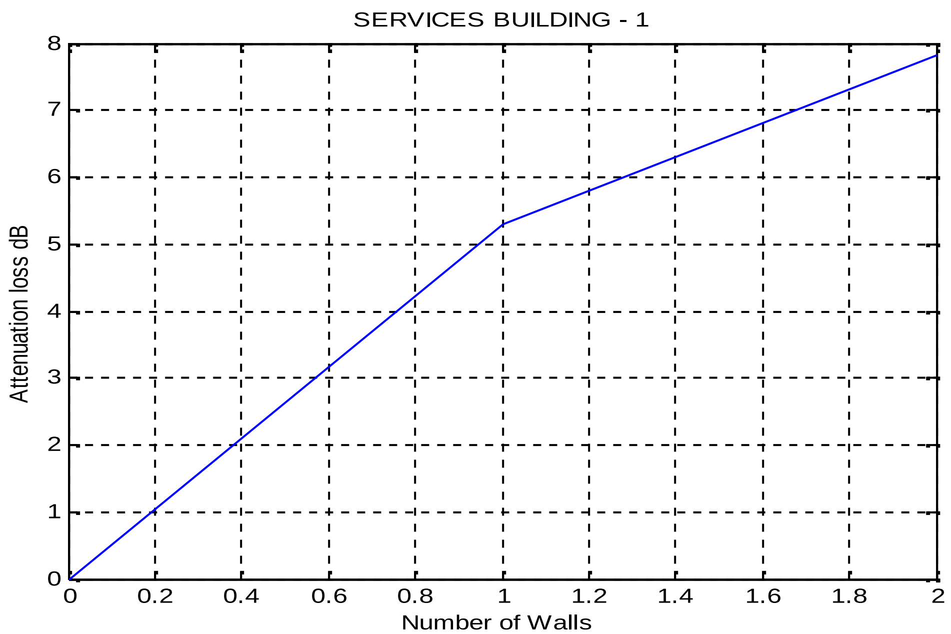


Figure 3.12: Attenuation loss versus number of walls inside 1st floor of the Services Building.

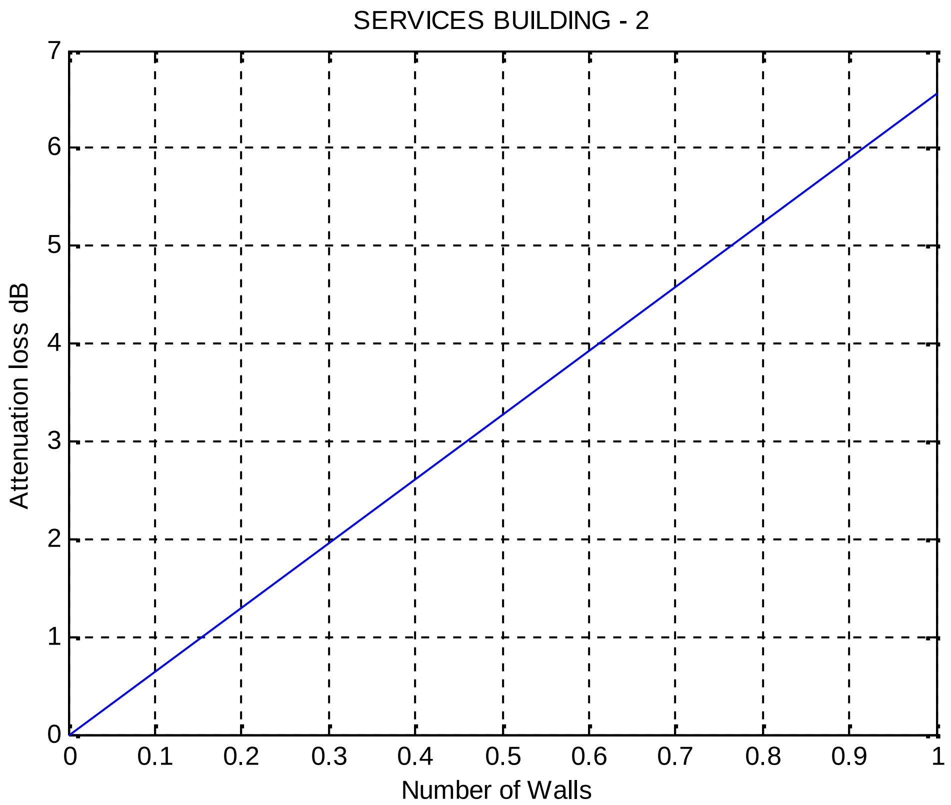


Figure 3.13: Attenuation loss versus number of walls inside 2nd floor of the Services Building.

The average wall attenuation per internal wall for all floors in the Services Building ranged from (5 - 6 dB).

3.3.5 PPU Building B

PPU Building B is a five-storey building with up to 3 internal walls in the 3rd to 5th floors. The average values of the attenuation loss versus the number of internal walls are shown in Table 3.5 for the five floors.

Number of walls	0	1	2	3
1st Floor	0	5.852677	No wall	No wall
2nd Floor	0	4.25225417	No wall	No wall
3rd Floor	0	3.42397227	9.57945436	15.6500051
4th Floor	0	4.55068153	9.86386598	11.4252211
5th Floor	0	4.56199001	7.67017473	16.9572567

Table 3.5: Attenuation loss analysis at the PPU Building B.

Figures 3.14 to 3.3.18 show the attenuation loss factor versus the number of internal walls of the 1st, 2nd, 3rd, 4th and 5th floor in the PPU building B respectively.

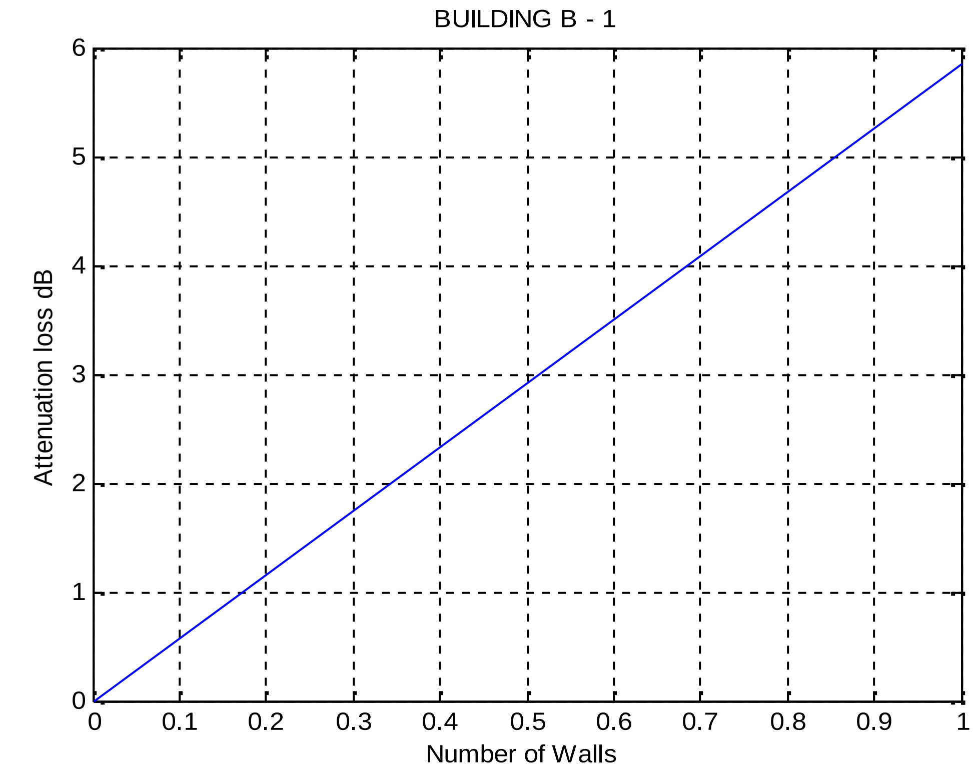


Figure 3.14: Attenuation loss versus number of walls inside1st floor of PPU Building B.

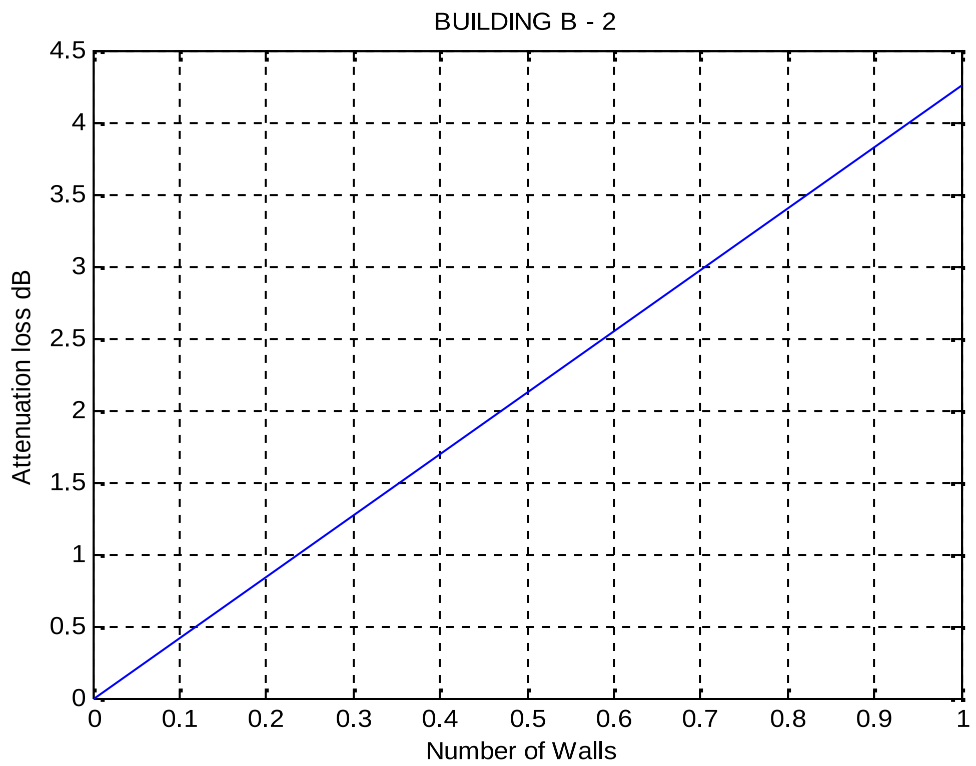


Figure 3.15: Attenuation loss versus number of walls inside 2nd floor of PPU Building B.

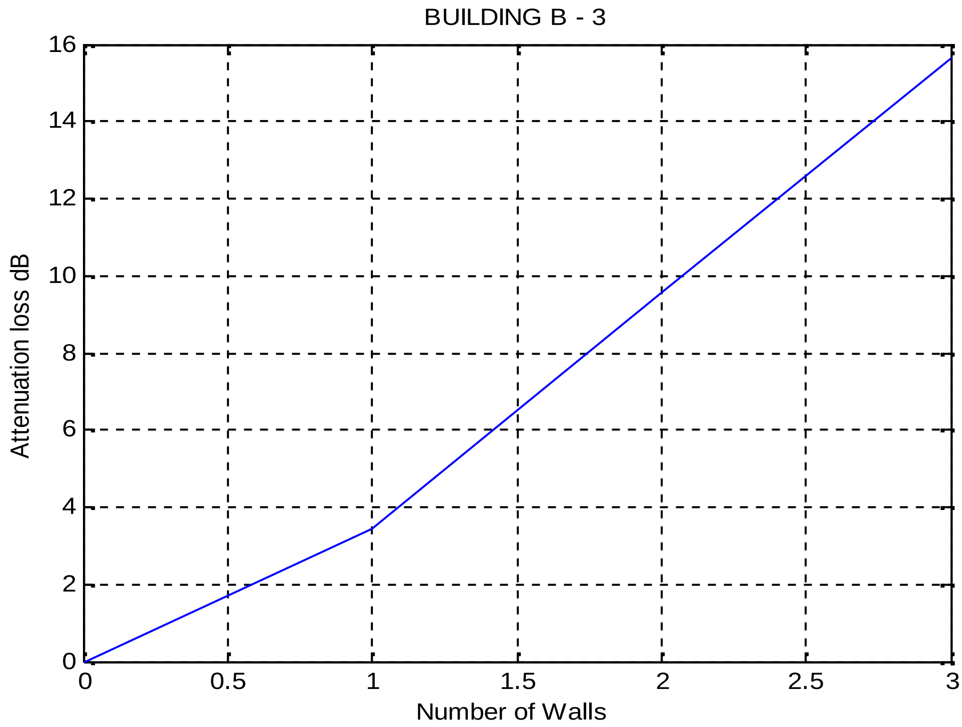


Figure 3.16: Attenuation loss versus number of walls inside 3rd floor of PPU Building B.

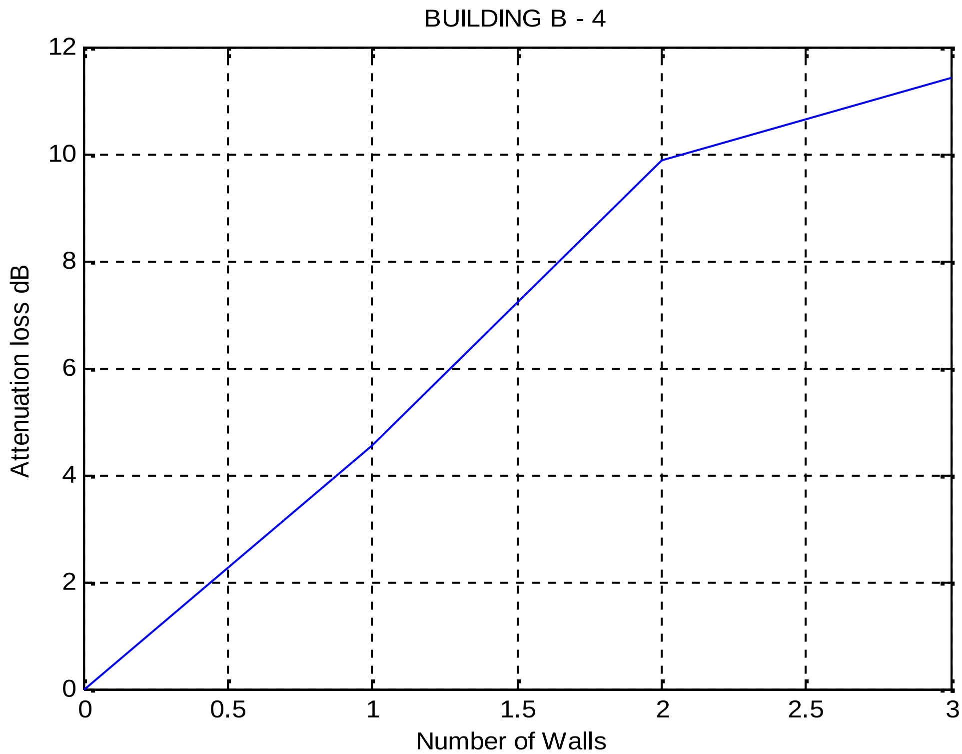


Figure 3.17: Attenuation loss versus number of walls inside 4th floor of PPU Building B.

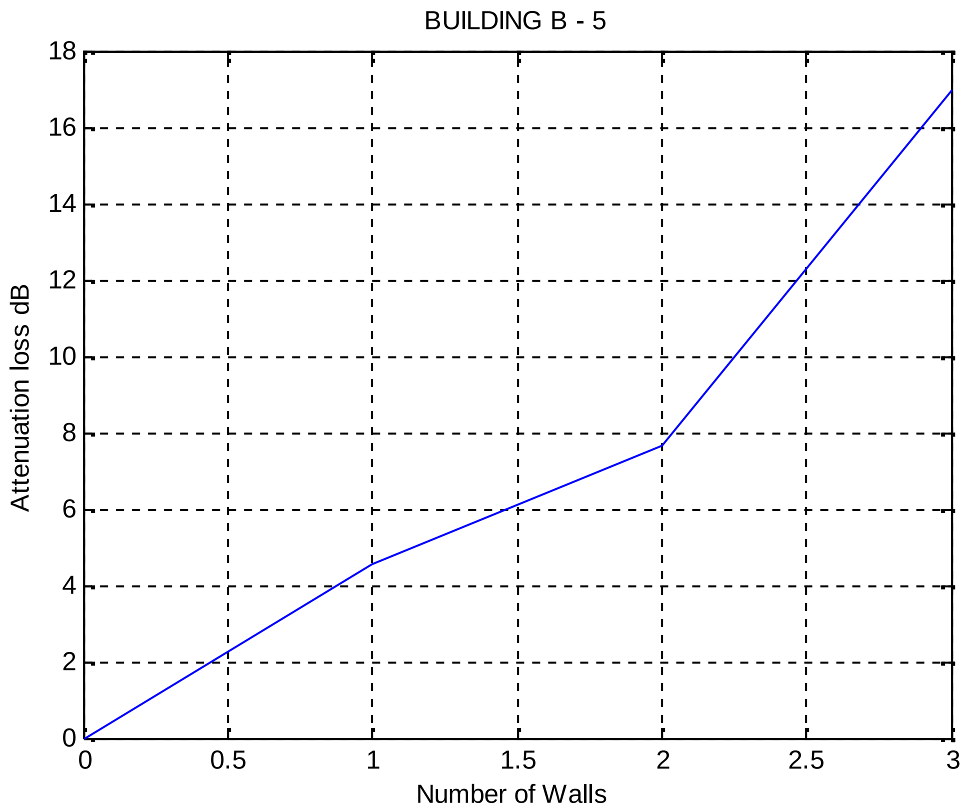


Figure 3.18: Attenuation loss versus number of walls inside 5th floor of PPU Building B.

Figures 3.14 to 3.18 , for PPU building B, reveal that the wall attenuation factor per single wall ranged from (4 - 5.5 dB) and that is approximately the same for internal walls in other buildings.

If a comparison is done between the figures of all floors for all selected buildings, it is noted that the attenuation loss factor is almost similar for the same number of internal walls as shown in Figure 3.19. The variance between the curves for all floors ranges from (1- 2.5 dB). The average is taken for all floors.

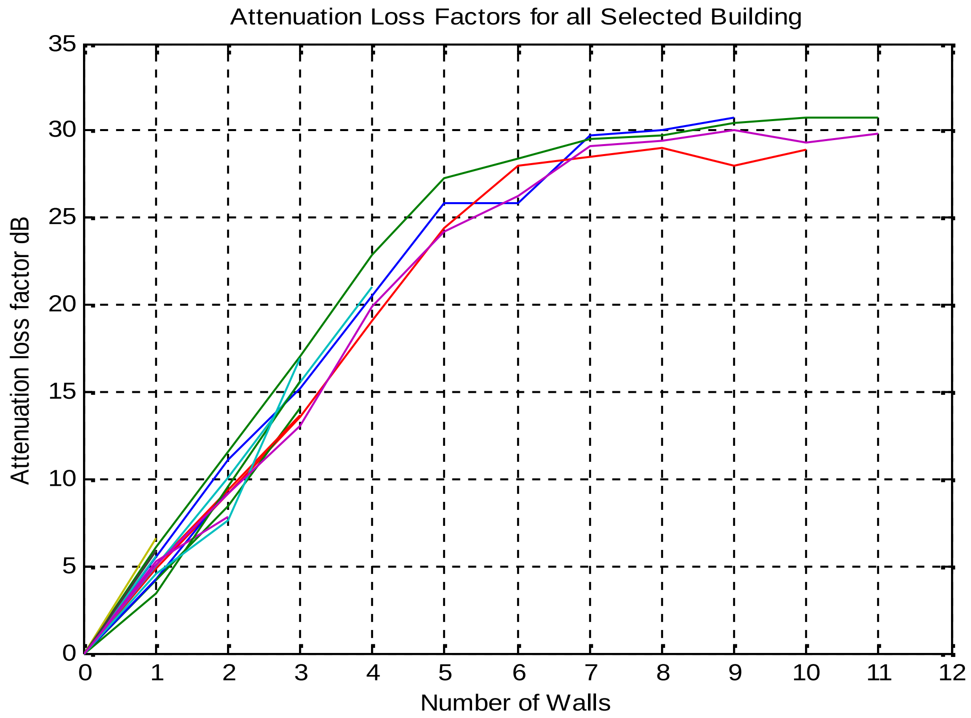


Figure 3.19: Attenuation Loss Factor for All selected buildings for (900MHz)

3.3.6 Averaging of the Attenuation Loss Factors for all Floors

From the above analysis of the floors and noticing similarities in the attenuation loss factors for the internal walls, the average for all floors can be worked out Results are shown in Table 3.6.

Number of walls	0	1	2	3	4	5	6
Average of effective attenuation factor(dB)	0	5.0608	9.2072	13.00	19.881	24.212	26.212

7	8	9	10	11	12	13	14	15
29.084	29.44	30.061	29.346	29.817	32.983	35.0693	36.93	36.980

Table: 3.6. Averaging of the Attenuation Loss Factors for all Floors for (900MHz)

We note that the variance of curves for all floors, as shown in Figure 3.19 vary from

(1- 2.5 dB). The effective average attenuation loss for all floors is shown in Figure 3.20.

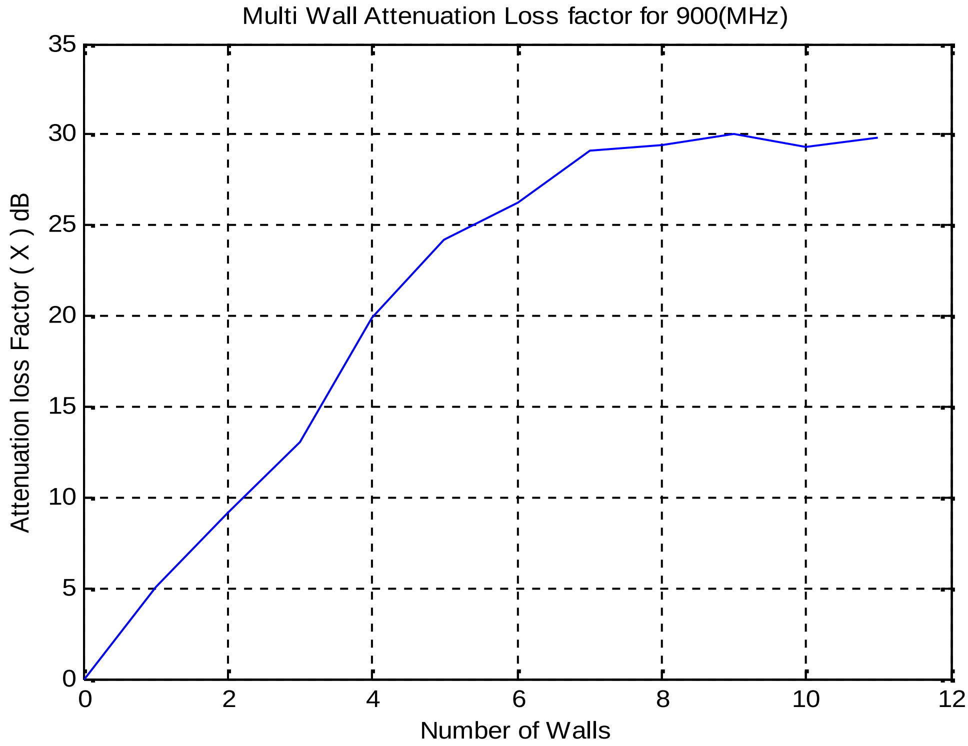


Figure: 3.20. Attenuation loss versus number of walls

Figure (3.20) illustrate the average of the attenuation loss factors for all floors of selected buildings verses the number of internal walls and the figure (3.21) represent to the best fit curve for the average curve with variance about the average curve less than (0.5 dB).

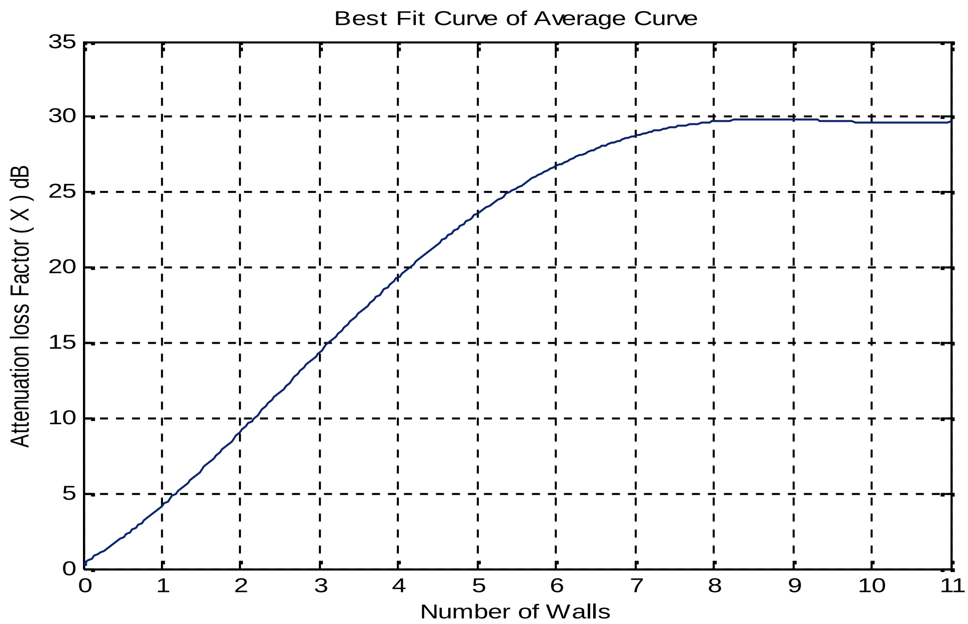


Figure: (3.21) Attenuation loss versus number of walls

From the figure 3.21, we can express the value of the attenuation loss factor (X_{α}) by the equation (3.2).

$$X_{\alpha}\,(dB) = 0.0075\,K^4 - .018\,K^3 + 1.1\,K^2 + 2.9\,K \quad (3.2)$$

Where

K **:** The number of separated walls of brick type

Equation (3.2) applying for up to 11 indoor wall separations in the measurement process. It is worth mentioning that these was only a single floor accommodate 15 walls, we only considered up to 11 walls after while the received signal become too weak.

3.4 Multi Wall Attenuation Losses Analysis for 2.4 (GHz)

3.4.1 AL-Ahli Hospital

In the Al-Ahli hospital we did the same floor measurements for two floors the ground floor and the second floor. During this we noticed that the maximum wall separation for all measured points is five for the two floors.

After we analyzed the wall attenuation factors we ended up with the following tables for the two floors:

No. walls(L)	0	1	2	3	4	5
Effective attenuation factor(dB) for the second floor	0	10.86	18.28	24.97	30.15	33.85
Effective attenuation factor(dB) for the ground floor	0	9.2	17.35	24.30	30.01	32.98

Table 3.7: Multiwall attenuation loss analysis at Al-Ahli Hospital in Hebron

From the table (3.7), the wall attenuation factor for a single wall approached from 9-10 dB, and for the last wall was (33) dB which is considered a significant value. The other observation is that when increase of the number of the walls the value of the wall attenuation is increasing with a variable decreasing values.

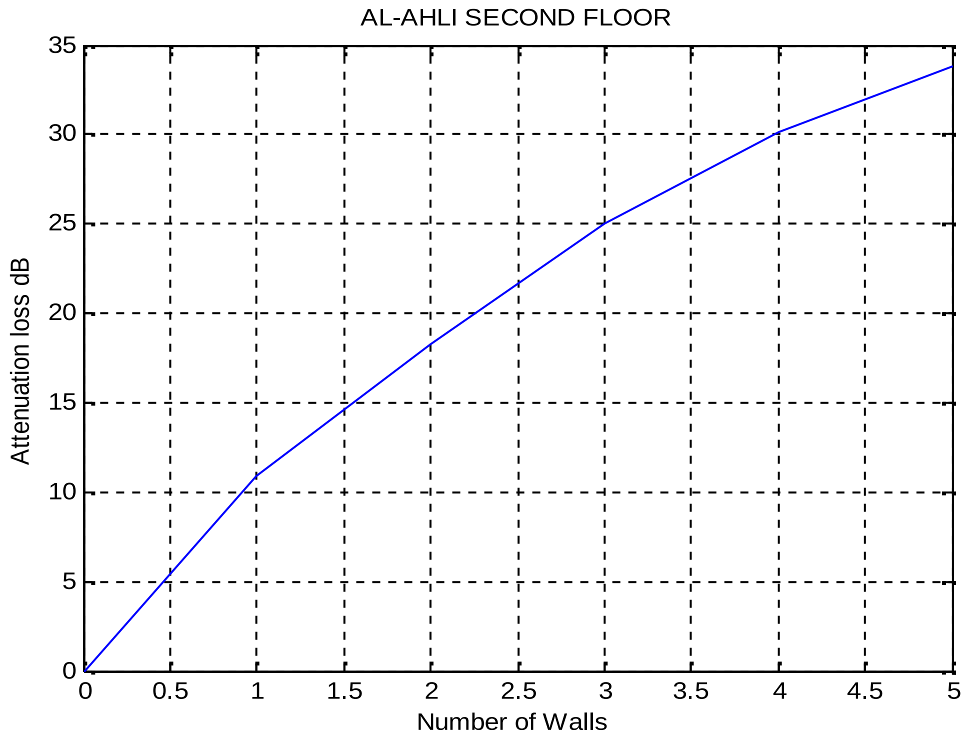


Figure: (3.22) Attenuation loss versus number of wall inside 2nd floor of Al-Ahli Hospital.

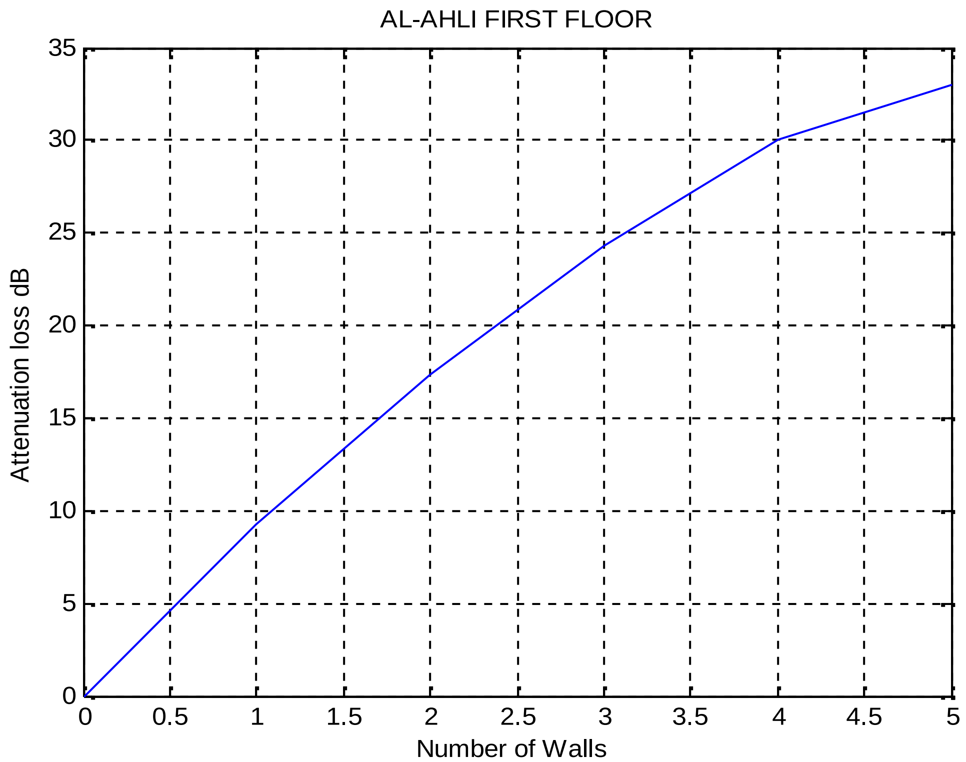


Figure: (3.23) Attenuation loss versus number of wall inside 1st floor of Al-Ahli hospital.

Figure (3.22) represents the wall attenuation factor verses the number of walls for the second floor in Al-Ahli hospital. And figure (3.23) represent the wall attenuation factor verses the number of walls for the ground floor in Al-Ahli hospital. From the two figures we notice that the wall attenuation is increases in a nonlinear fashion with the number of walls.

3.4.2 Abu Rumman Building

Measurements were taken in the 1st, 2nd and 3rd floors in Abu Rumman building and the average of five walls separation and six walls separation at maximum which were approximately similar to those at Al- Ahli hospital.

Tables of wall attenuation factors for the three floors:

No. walls(L)	0	1	2	3	4	5	6
Effective attenuation factor(dB) for the 1st floor	0	8.97	17.14	23.81	30.74	33.74	--
Effective attenuation factor(dB) for the 2nd floor	0	9.7	17.75	23.29	30.74	33.13	35.38
Effective attenuation factor(dB) for the 3rd floor	0	9.07	17.32	24.53	30.32	--	--

Table 3.8: Multiwall attenuation loss analysis at Abu Rumman Building in Hebron.

The wall attenuation factor for the first wall was about 9 dB and for the accumulative six walls as 35dB , For the first three floors, The variation with the number of walls was almost linear.

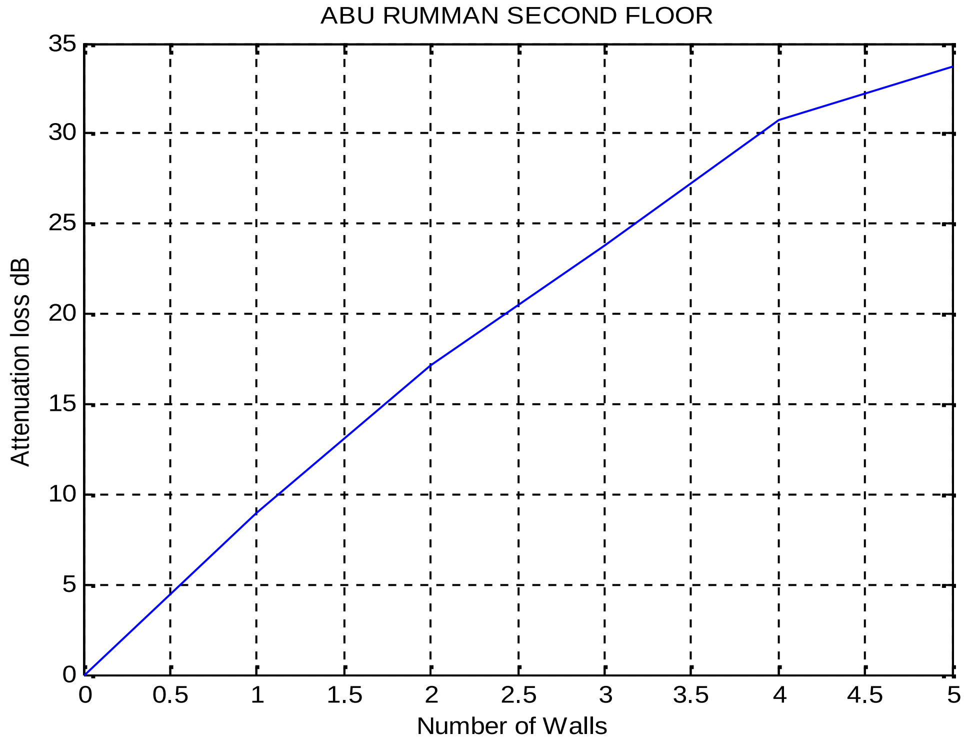


Figure: (3.24) Attenuation loss versus number of wall inside 2nd floor of Abu Rumman building.

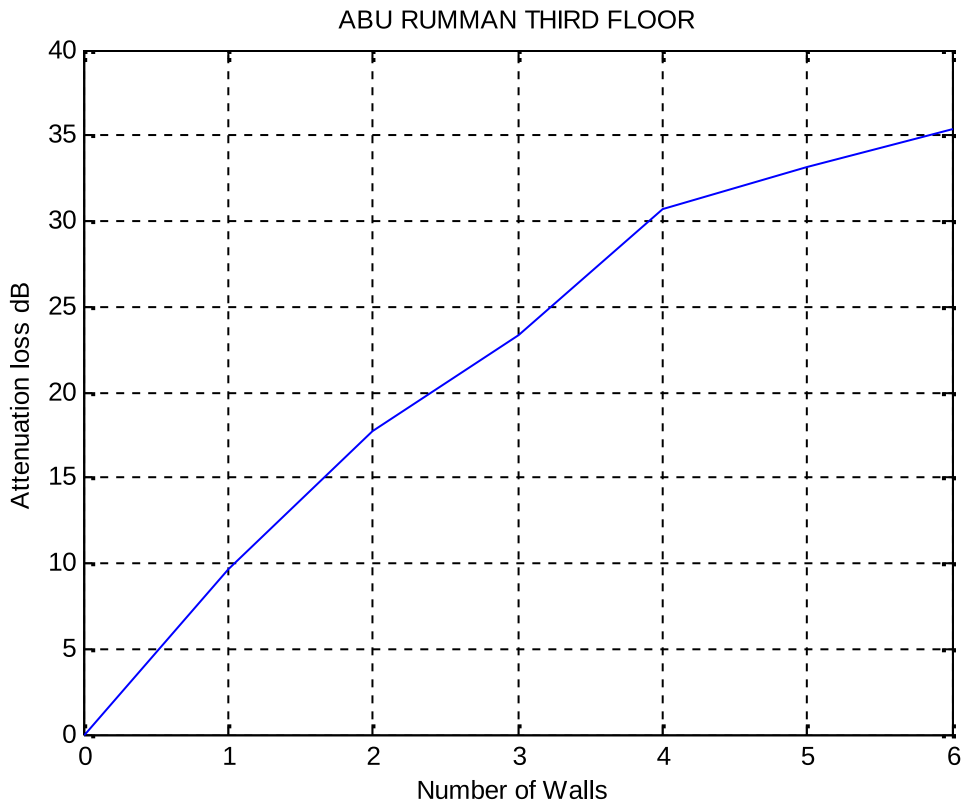


Figure: (3.25) Attenuation loss versus number of wall inside 3rd floor of Abu Rumman building.

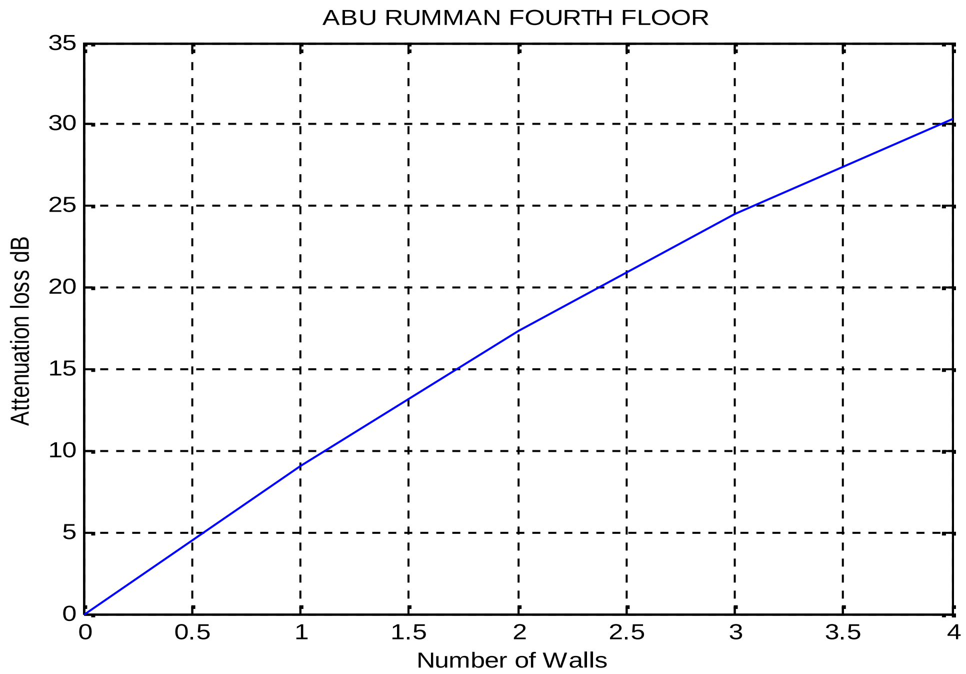


Figure: (3.26) Attenuation loss versus number of wall inside 4th floor of Abu Rumman building.

Figure (3.24) represents the wall attenuation factor verses the number of walls for the 1st floor in. And figure (3.25) represent the wall attenuation factor verses the number of walls for the 2nd floor. And figure (3.26) represent the wall attenuation factor verses the number of walls for the 3rd floor. From the three figures we can notice that the wall attenuation is increasing in a nonlinear fashion with the number of walls similar as before.

3.4.3 PPU Building A:

In the A building same floor measurements where at the 1st floors 3rd and the 4th floor. With an average of four wall separation between the points except the first floor which was only three walls only, Which is less than the previous two building but not by much.

The multi wall attenuation factors were like the following in table (3.9):

No. walls(L)	0	1	2	3	4
Effective attenuation factor(dB) for the 1st floor	0	9.05	16.66	24.60	--
Effective attenuation factor(dB) for the 3rd floor	0	9.06	16.55	24.39	30.12
Effective attenuation factor(dB) for the 4th floor	0	9.18	17.32	24.13	28.14

Table 3.9: Multiwall attenuation loss analysis at PPU Building A in Hebron

From Table (3.9) The wall attenuation factor for a single wall is about 9 dB and nearly the same for all floors. And it was from 28 to 30 dB when the signal traveled in four consecutive walls .The effective wall attenuation factor was approximately equal for the three floors at similar wall number e.g. it was 16.6 in the 1st floor and 16.6 in the 3rd and 17.3 in the 4th when the signal traveled in two consecutive walls, Which is justified by the similarity of the internal wall construction in the building.

Figure (3.27) represent the wall attenuation factor verses the number of walls for the 1st floor in. And figure (3.28) represent the wall attenuation factor verses the number of walls for the 3rd floor. And figure (3.29) represent the wall attenuation factor verses the number of walls for the 4th floor. We can notice that for the three walls there is a semi linear behavior but the deference between them is 9dB 8db and above 7dB which is anon constant value for more walls we can notice the nonlinearity.

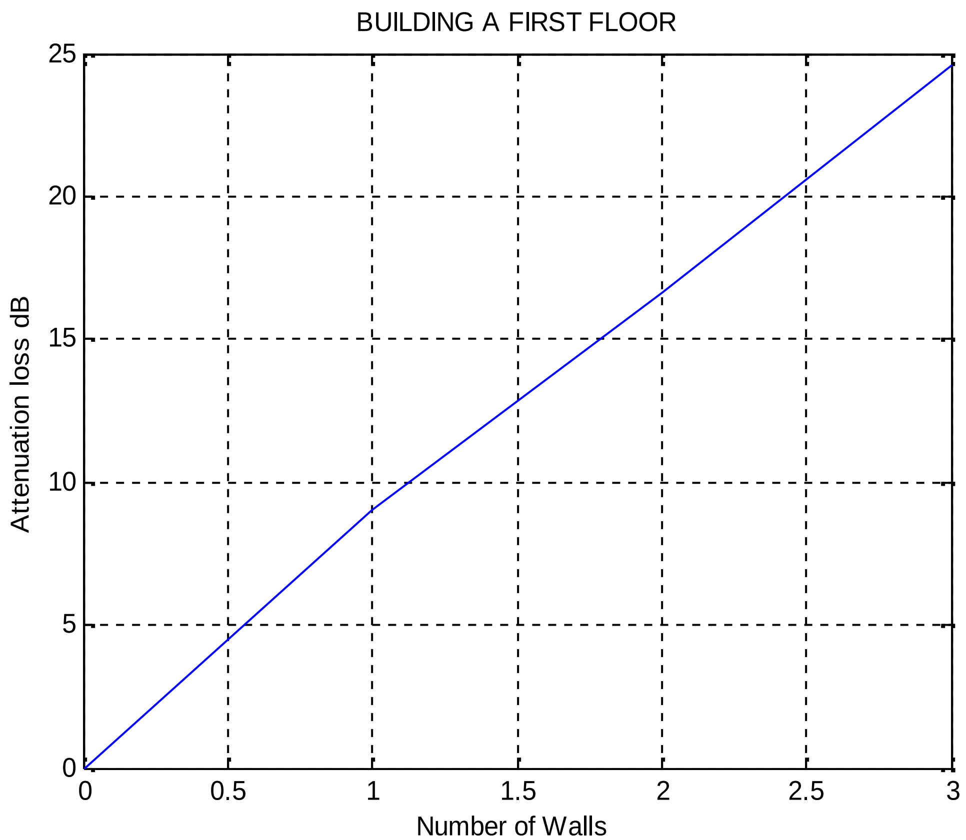


Figure: 3.27. Attenuation loss versus number of wall inside 1st floor of PPU Building A.

Figure: (3.28) Attenuation loss versus number of wall inside 3rd floor of PPU Building A.

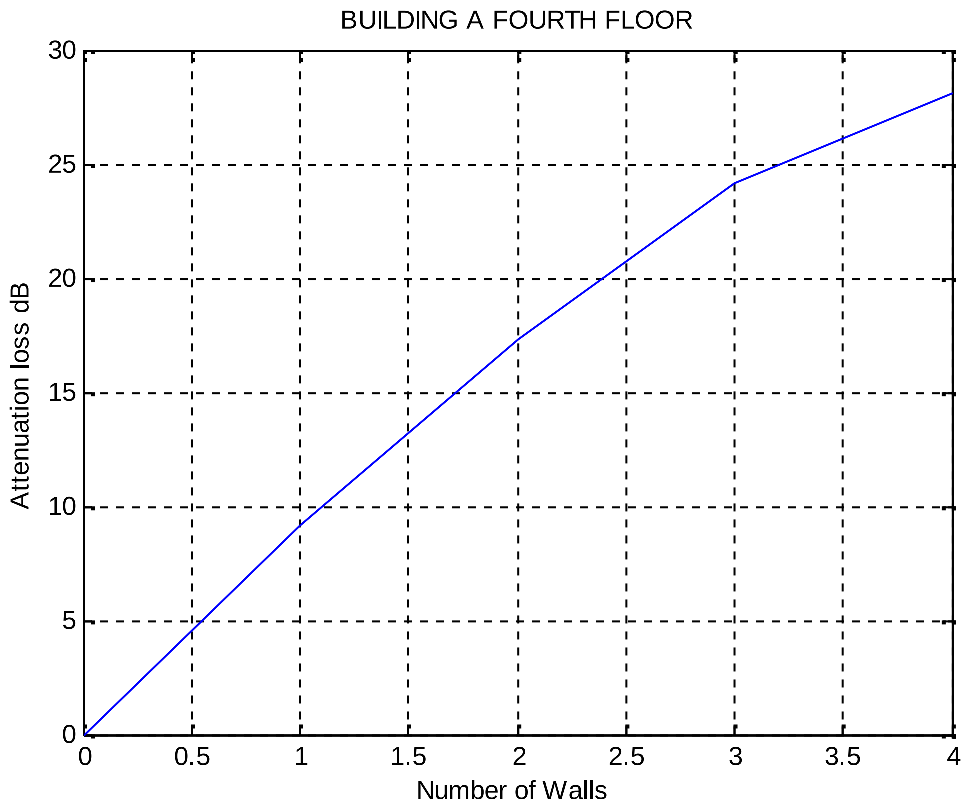


Figure: (3.29) Attenuation loss versus number of wall inside 4tht floor of PPU Building A.

3.4.4 PPU Building C

In the C building same floor measurements where at the 1st , 2nd and 3rd floor with an average of four wall separation between the points except the first floor which was only two walls only.

The multi wall attenuation factors were like the following in table (3.10):

No. walls(L)	0	1	2	3	4	5
Effective attenuation factor(dB) for the 1st floor	0	8.08	15.77	--	--	--
Effective attenuation factor(dB) for the 2nd floor	0	8.72	15.91	24.87	29.6	--
Effective attenuation factor(dB) for the 3rd floor	0	9.14	17.91	24.83	30.39	33.41

Table 3.10: Multiwall attenuation loss analysis at PPU Building C in Hebron.

The wall attenuation factor for a single wall was about 9 dB and nearly the same for all floors and for the last floor the wall attenuation factor was 33dB for the fifth wall and the effective wall attenuation factor were approximately equal for the three floors, Which is justified by the similarity of the internal wall constriction in the building.

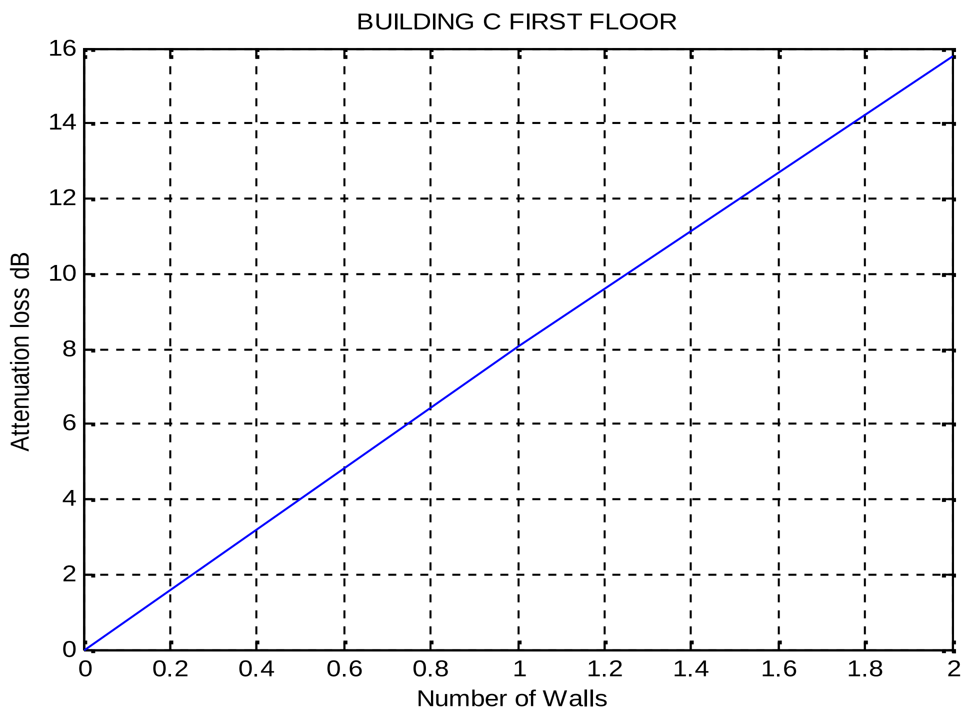


Figure: 3.30. Attenuation loss versus number of wall inside 1st floor of PPU Building C.

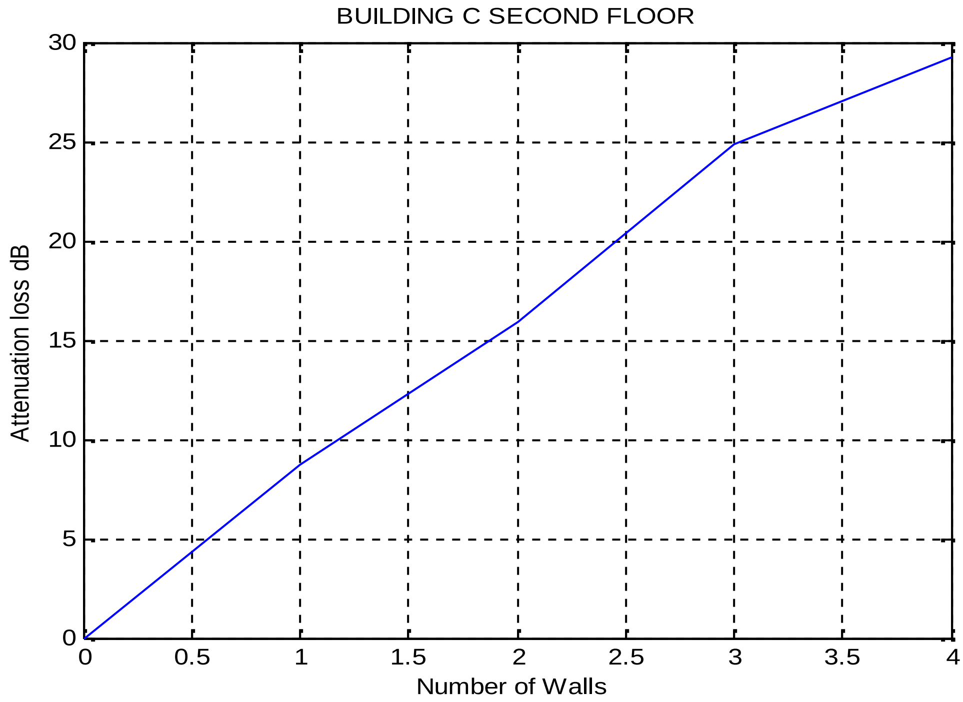


Figure: 3.31. Attenuation loss versus number of wall inside 2nd floor of PPU Building C.

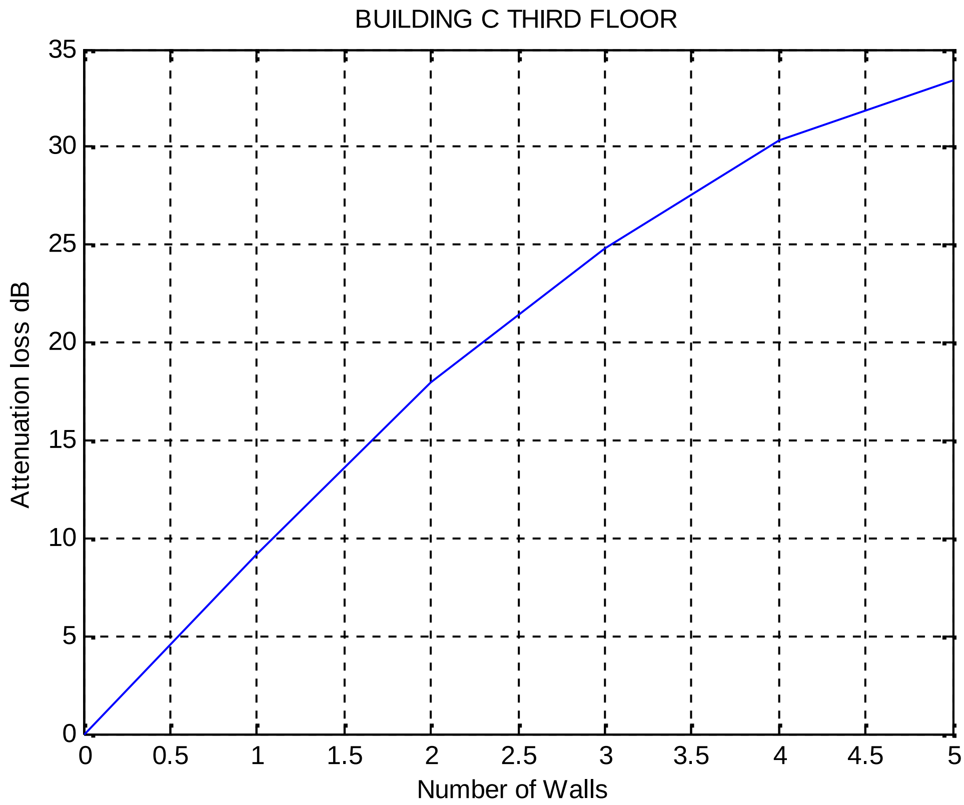


Figure: 3.32. Attenuation loss versus number of wall inside 3rd floor of PPU Building C.

Figure (3.30) represents the wall attenuation factor verses the number of walls for the 1st floor in. And figure (3.31) represent the wall attenuation factor verses the number of walls for the 2nd floor and figure (3.32) represent the wall attenuation factor verses the number of walls for the 3rd floor. We can notice that for the two walls there is a semi linear behavior but the deference between them is 8dB 7db which is anon constant value for more walls we can notice the nonlinearity.

3.4.5 Averaging of the Attenuation Loss Factors for all Floors

When comparing the effect of wall attenuation factors for different floor in the same building we noticed a great similarity of this effect which is justified by simply state that the walls construction is the same for all the floors.

The other thing that we noticed is for all building the walls affect the signal strength with similar values for example, wall one in Al-Ahli hospital is about 9dB which is similar to the affect of wall one in Abu Rumman, C and A building and the same for the rest. The reason for this is that all walls in the four building and in most building in Hebron is made from the same material a difference of one to two at maximum can occur if the width of the wall changes or the marital percentages is not the same, because of the difference is very little we can state that any wall will have the same attenuation factor as the rest even in a deferent building.

In the following table (3.11) we averaged the values of the wall attenuation factors in all building:

No. walls(L)	0	1	2	3	4	5	6
Average effective attenuation factor(dB)	0	9.23	17.09	24.37	29.99	33.42	35.38

Table3.11: Averaging of the Attenuation Loss Factors for all Floors for (2.4 GHz)

The wall attenuation factor for a single wall was about 9 dB and for the last floor the wall attenuation factor was about 35dB for the sixth floor. If we calculated the difference between any consecutive walls which is 9dB, 8dB, 7dB, 5db, 4dB, 2 dB from the zero to six we can notice that the difference decreases as the number of walls increases e.g. the effect increases as the number of walls increase in a non constant decreasing value.

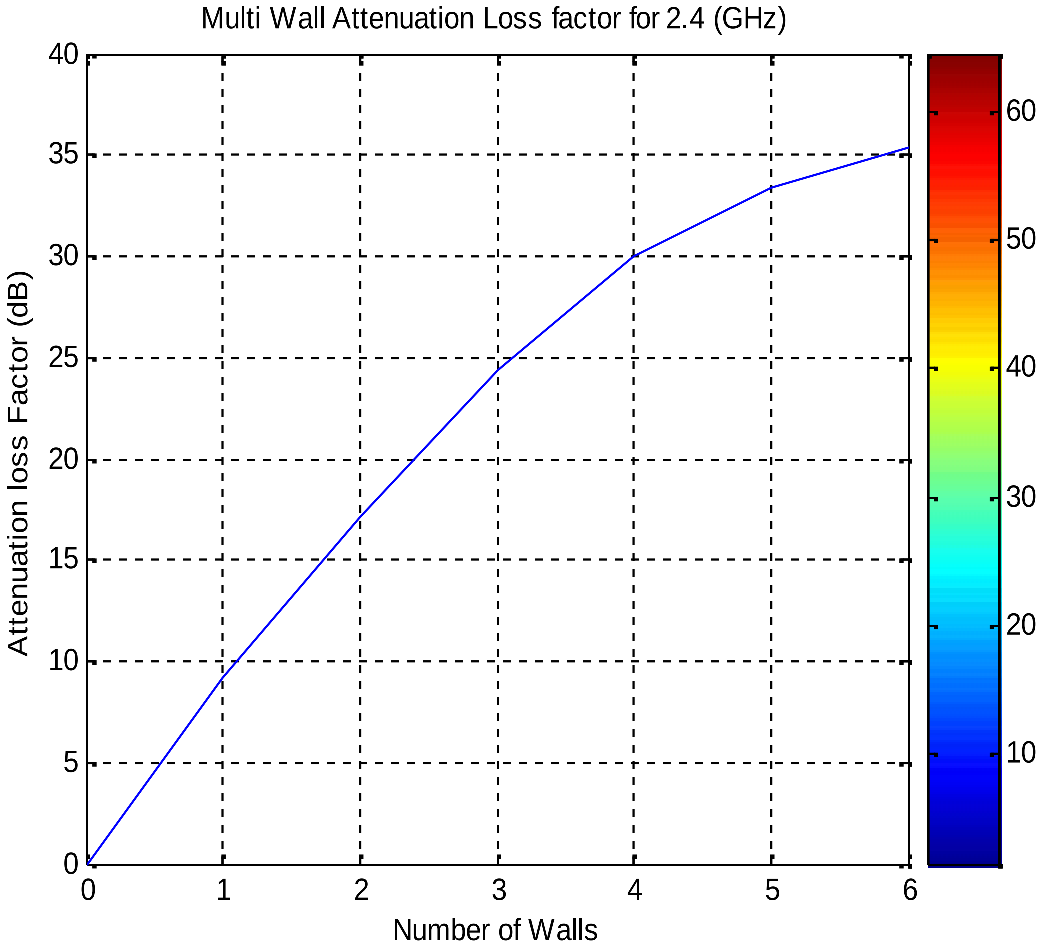


Figure: .3.33. Attenuation loss versus number of wall.

Figure (3.33) shows the relation between number of wall separations between the transmitter and the receiver and the attenuation loss caused by the walls.

Equation (3.3), represent a closed for of the best fit line that represent the measured avarage show in figure (3.33).

$$X_{\alpha}\ (dB) = 0.0032\ K^4 - 0.086\ K^3 - 0.17\ K^2 + 9.3\ K \quad (3.3)$$

Where

K **:** The number of separated walls of type bricks.

The individual curves in all floors of all buildings and the best fit line curve can be shown in figure (E1) and figure (E2) of Appendix (E).

To verify the similarity we calculated the variance between all floors and the average in table (3.12):

Floor name	σ (dB)	Floor name	σ (dB)	Floor name	σ (dB)
Al- Ahli 2nd floor	0.88	Al- Ahli G floor	0.21	Abu Rumman 1st floor	0.42
Abu Rumman 2nd floor	0.59	Abu Rumman 1st floor	0.21	A 1st floor	0.26
A 3rd floor	0.26	A 4th floor	0.84	C 1st floor	1.008
C 2nd floor	0.7	C 3rd floor	0.42	Average σ (dB)	0.479

Table3.12: Standard deviation between attenuation losses factors in all floors and the average attenuation factor for (2.4GHz)

From the table we notice this:

1- The overall standard deviation between the average attenuation wall factor and the actual value of the wall attenuation factor for all floors is less than 0.5 dB which is very small. For the same building almost the same variance in each floor.

2- The biggest value of the variance was in building C 1st floor and it was close to one dB which is relatively small.

3.5 Conclusion

In conclusion the average wall attenuation factor can be used for all selected buildings in the GSM and wireless LAN analysis with relatively high confidence since most buildings in Palestine have relatively similar construction as the selected buildings, we measured, the same derived best fit model equation could be used for similar multi floor building constructions with similar internal walls at GSM and 2.4 GHz frequencies.

.

Chapter Four

GSM ANALYSIS

4.1 Introduction

The outdoor propagated electromagnetic signal is considered as LOS (line of site) if it doesn’t face any obstacles during its transmission to the proper receiver. In the absence of a LOS path, diffraction, refraction, scattering, and/or multipath reflections are the dominant propagation modes. These modes produce a NLOS path (non-line of site). The LOS signal will have only one path to propagate, so it will not be affected to multipath problems. The total path loss due to the increasing distance between the transmitter and the receiver is the most effecting factor for this case. Comparing it to the NLOS the situation is so different; the propagated signal here faces many extra propagation factors more than the transceiver distance which causes path loss. The multipath, fading, reflection, refraction, scattering and diffraction modes attenuates, phase shifts and polarizes electromagnetic signal. Indoor the situation is even worse; most of signal propagation inside the building is a NLOS due to the common structure of the buildings. The NLOS signal will face more obstacles during its journey; ceilings, furniture, people and walls etc. [17]

This chapter presents a validation of the ITU indoor path loss model at 900 MHz .Based on measurements for a GSM indoor environment. Our main modification on the ITU-Model was on the multi wall attenuation losses. It also provides an analysis of the measurements taken for the selected buildings and create a new model by modified the ITU model, it is called AMA model take into account the most important obstacles facing the signal inside buildings which was a multi wall attenuation loss.

4.2 Building Structure and Location

First of all a study of the building location and structure was done. Those included the Palestine Polytechnic University (Building A, B and Abu-Rumman) and the Patient's Friends Society (Al-Ahli hospital and Services building) All buildings are located at Hebron city Sketches of all buildings and pertaining floors are shown in Appendix A.

4.3 Procedure of GSM Measurements

Contrary to WLAN measurements where access points are located indoors, internal GSM measurement sources were not available. Hence all indoor GSM measurements had to rely on outdoor GSM base stations each of which would provide strongest and greatest coverage for the building under test. Extra precautions had to be taken, therefore for GSM indoor measurements and consequent analysis.

Our strategy in measurement was based on the technique of grid plan. Depending on the open floor area in a building each floor was divided into (5X5 m) or (3X3) grid units, which was done by AutoCAD™ software. The GSM measurement was done vi by TEMS handsets and TEMS customized software.

TEMS handset was held at a point, 160 cm high from the floor and was held at 45 degree angle, in order to receive the vertical and horizontal polarizations.

The measurement process involved waiting for 5 seconds till the signal remains stabilizes, then recording the measurements logfile afterwards. This process takes 30 seconds since 5 measurements are recoded per second,, a logfile contains 150 readings per location point. The measurements of all buildings are shown in the appendix B

TEMS Investigation Software Procedures:

1- Preparation of the TEMS-MOBILE and selection of the best base station that cover Building.
2- Distribution of the measurement points by AutoCAD™.
3- Assignment the distance for the reference to all points of measurement by the meter.
4- Measurement of the signal strength at all points in all building.

4.4 Modified ITU Model Calculation (The AMA-Model)

Our new modified ITU model includes parameters that account for the multi wall and free space losses

The free space losses are:

$$L = 20\text{Log}_{10}\frac{4\pi d}{\lambda} \quad (4.1)$$

Where

d: The distance in meters

λ: The wavelength in meters

Equation 4.1 can be rewritten as:

$$L = 20Log_{10}4\pi + 20Log_{10}d - 20Log_{10}\lambda$$

where $\lambda\ (m) = \frac{c\ (m/s)}{f(MHz)} = \frac{3\ X\ 10^8}{f\ \ MHz\ \ X\ 10^6}$

Hence

$$L = 20Log_{10}4\pi + 20Log_{10}d - 20Log_{10}\frac{3\ X\ 10^8}{f\ \ MHz\ \ X\ 10^6}$$

$$= 20Log_{10}4\pi + 20Log_{10}d - \{20Log_{10}\ 3\ X\ 10^8\ - 20Log_{10}(f\ \ MHz\ \ X\ 10^6)\}$$

$$= 20Log_{10}4\pi - 20Log_{10}\ 3\ X\ 10^8\ + 20Log_{10}10^6 + 20Log_{10}d + 20Log_{10}f\ \ MHz$$

$$=\ 20Log_{10}(f\ \ MHz\ \ +\ 20Log_{10}d - 27.55$$

With the wall obstructions in the way, the slope of the indoor model increases and the model equation can be described :

$$L =\ 20Log_{10}(f\ \ MHz\ \ +\ NLog_{10}d - 28 \qquad (4.2)$$

Where N is the slope of measured data and equals 10n (n is an Exponent Path Loss). In reference to equation number (4.2) the ITU-Model didn't include the obstruction losses., the effect of internal walls constitutes and their penetration losses , despite of their consequent paramount importance , were not accounted for .

The new ITU modified model (AMA Model) is described for:

$$L =\ 20Log_{10}f\ \ MHz\ \ +\ 10nLog_{10}d + L_{outer} + \chi_{\alpha} - 28 \qquad (4.3)$$

L : Path loss in dB units
f : The frequency in MHz
d : The distance in meters
$\boldsymbol{L_{outer}}$: Penetration loss of outer wall

The multi wall signal attenuation χ_{α} can be described as:

$$X_{\alpha}\ (dB) = 0.0075\ K^4 - .018\ K^3 + 1.1\ K^2 + 2.9\ K \qquad (4.4)$$

K = number of separated walls.

For the selected buildings, the internal walls were composed of bricks and we also can determine χ_{α} by the figure (4.1).

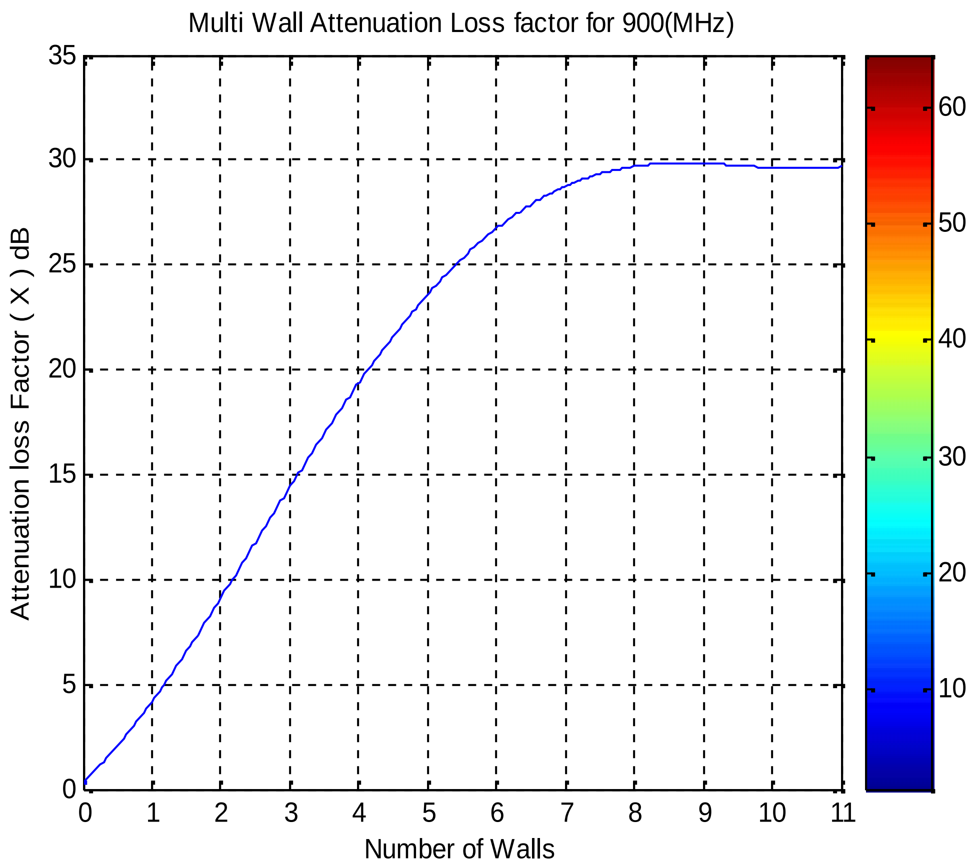


Figure 4.1:mulit wall attenuation loss factor for 900(MHz).

4.5 Selected Building Analysis

4.5.1 Services Building

The services building is composed of three floors figure 4.2. From Figure 4.2 we noted a valid observation that the coverage of signal on the first and second floor contained an entry point through the glass windows which reduced the amount of loss in the signal, so the model for this floors should not include penetration loss of outer wall, but should include penetration loss of glass. On the contrary, the coverage of signal on the third floor didn't contain the entry point through the glass windows, so the model for those floors would include penetration loss of outer wall.

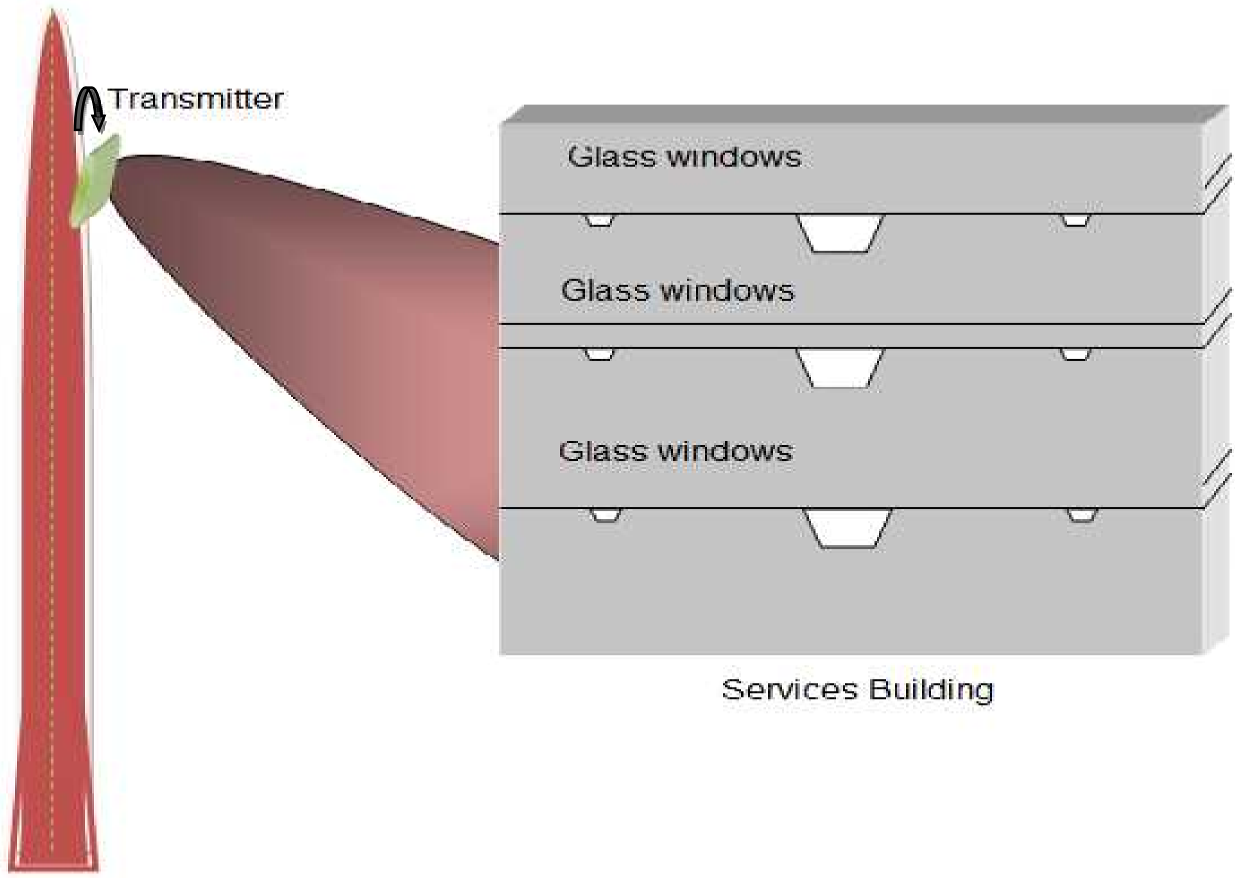


Figure 4.2: Services building and the transmitting antenna sketch.

From Figure 4.2 we noted a valid observation that the coverage of signal on the first and second floor contained an entry point through the glass windows which reduced the amount of loss in the signal, so the model for this floors should not include penetration loss of outer wall, but should include penetration loss of glass. On the contrary, the coverage of signal on the third floor didn't contain the entry point through the glass windows, so the model for those floors would include penetration loss of outer wall.

The difference between the unmodified ITU model mean and the measured mean worked out 13 dB With the modified the ITU-Model which involved the penetration losses of all internal walls, the difference reduced to (3 to 4 dB), The figures bellow show the measured, and modeled values related to the 1^{st} ,2^{nd},3^{rd} floor respectively :

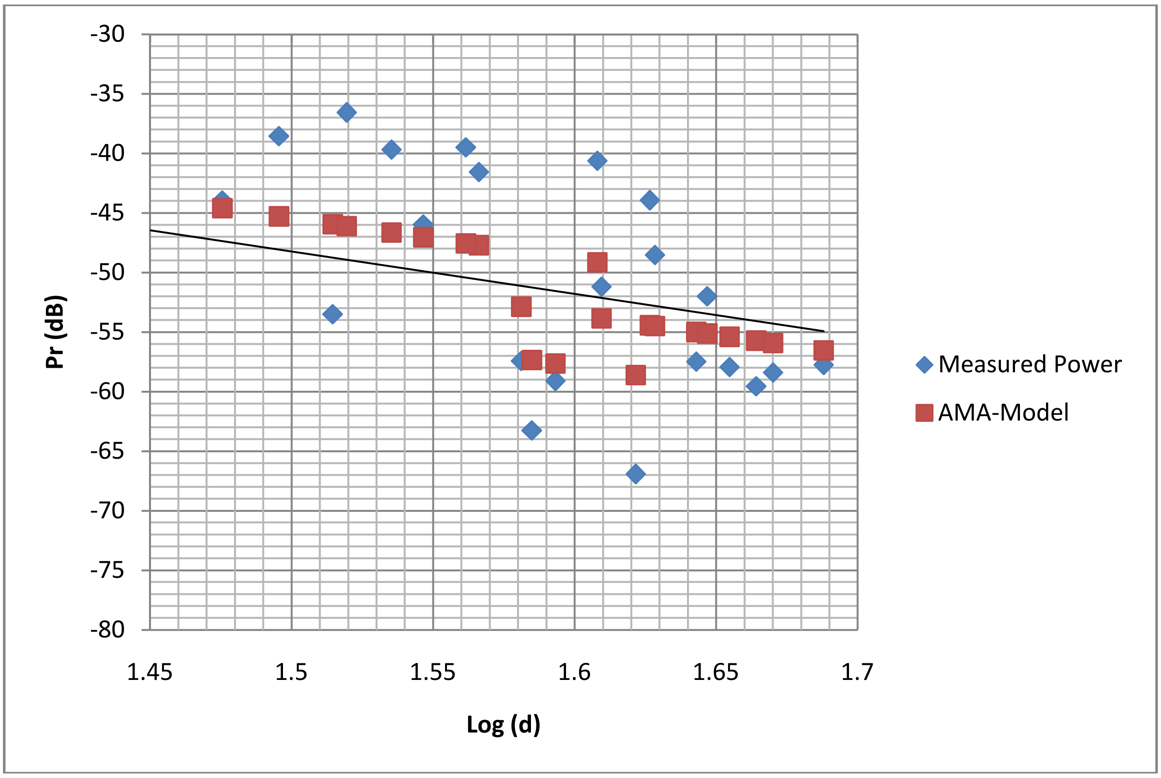


Figure 4.3: Measuerd and calculated data for services building 1st floor

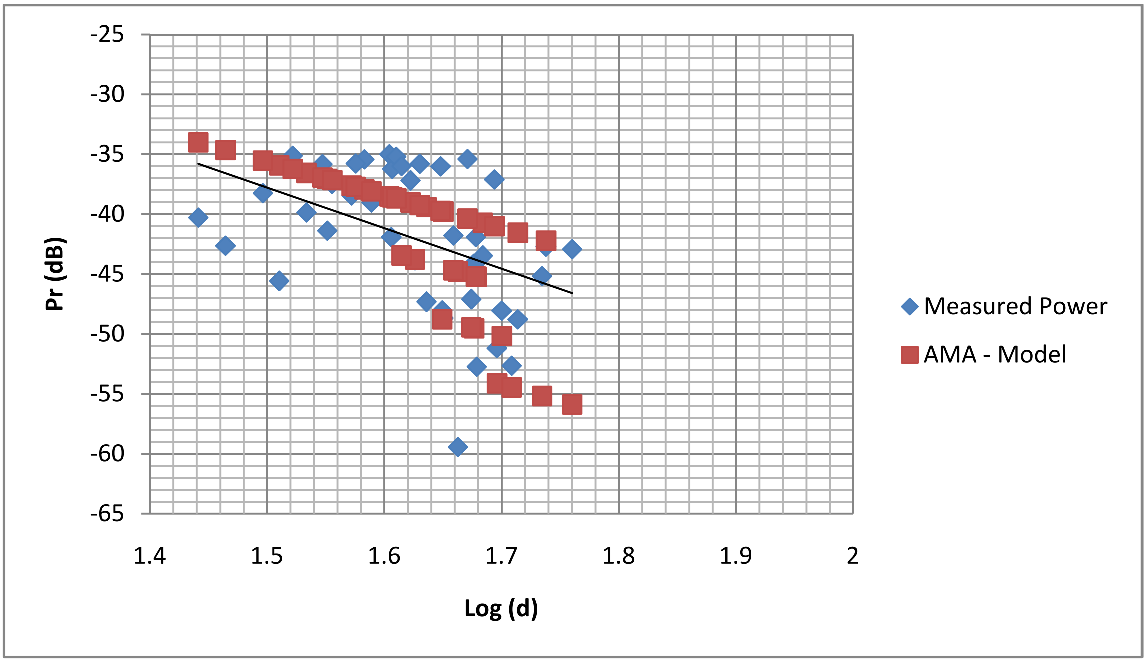


Figure 4.4:Measuerd and calculated data for services building 2nd floor.

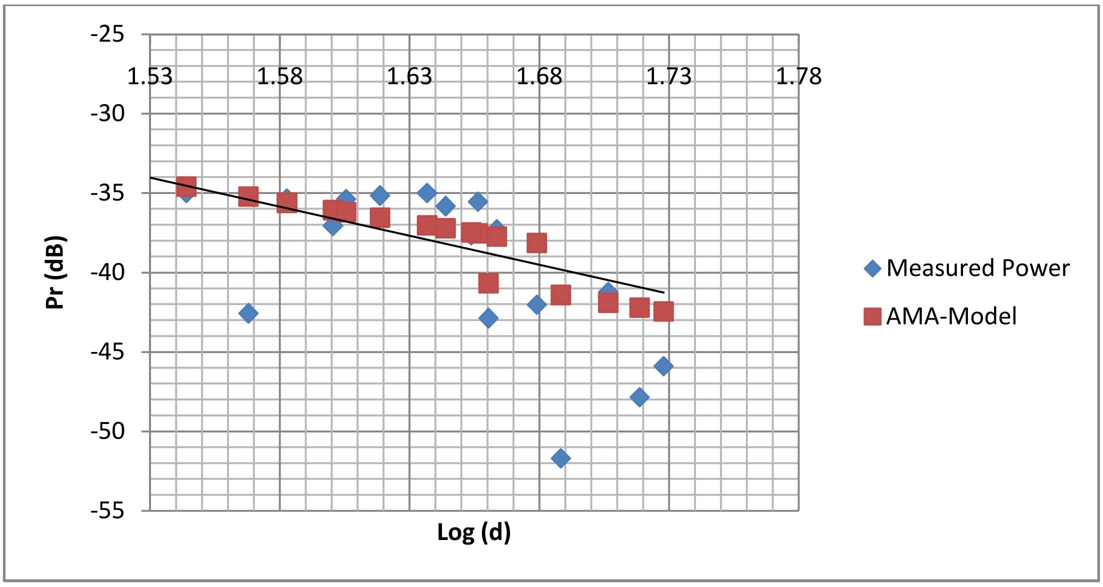


Figure 4.5: Measured and calculated data for services building 1st floor.

The exponent path loss at the zero walls and the standard deviation of measured data for all floors of the services building in the table (4.1)

Number of floor	n_0	σ ITU (dB)	σ AMA (dB)	% of Improvement
Floor One	3.424015	9.24905733	6.41990842	30.588
Floor Two	2.769697	6.10182571	5.63897905	7.585
Floor Three	2.623826	5.53814093	4.58972126	17.125

Table 4.1:comparison between the ITU and the AMA model for the service building.

Table (4.1) shows the standard deviation of measurements made on the services building. It illustrates the improvement that occurred after the modification on the ITU model, where the percentage of improvement works out as:

$$\%\ of\ improvment = \frac{\sigma_{ITU}-\sigma_{AMA}}{\sigma_{ITU}} \times 100\% \qquad (4.5)$$

4.5.2 Al-Ahli Hospital

Al Ahli Hospital is the most important building, which is a large three-storey building contains the rooms of patients and doctors in addition to, four large skylights. When we modified the ITU – Model and applied the AMA – Model the gap between the measured mean and the AMA mean was reduced to (4-5 dB). The figures bellow show the measured, and modeled values related to the 1^{st} ,2^{nd},3^{rd} floor respectively :

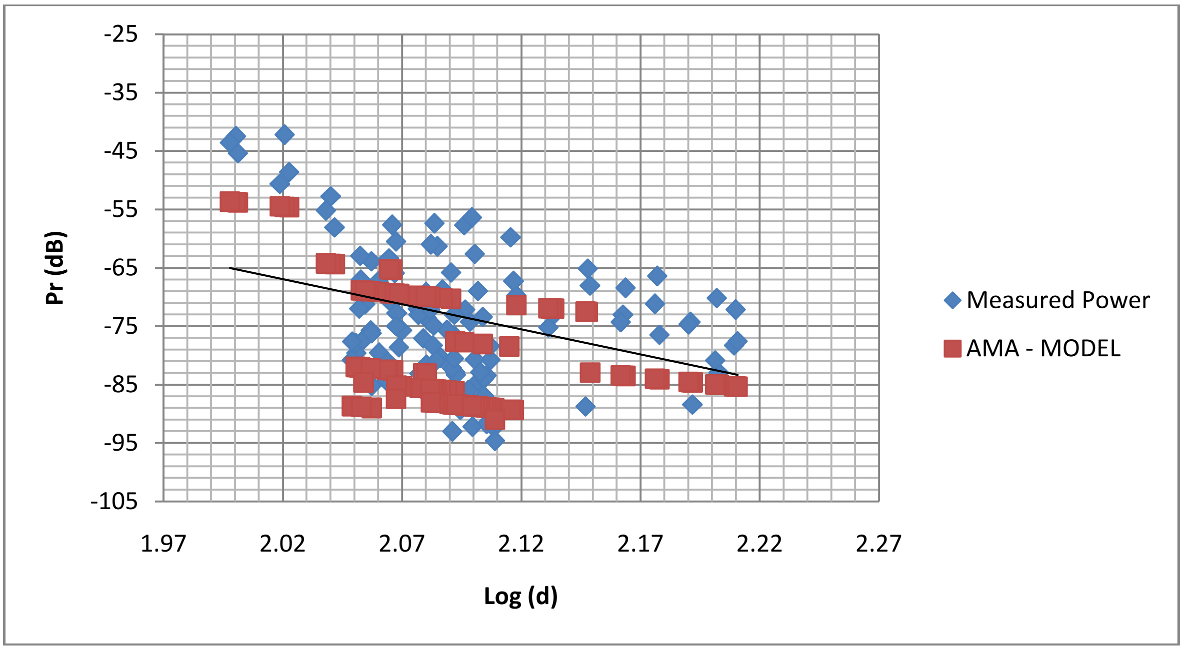
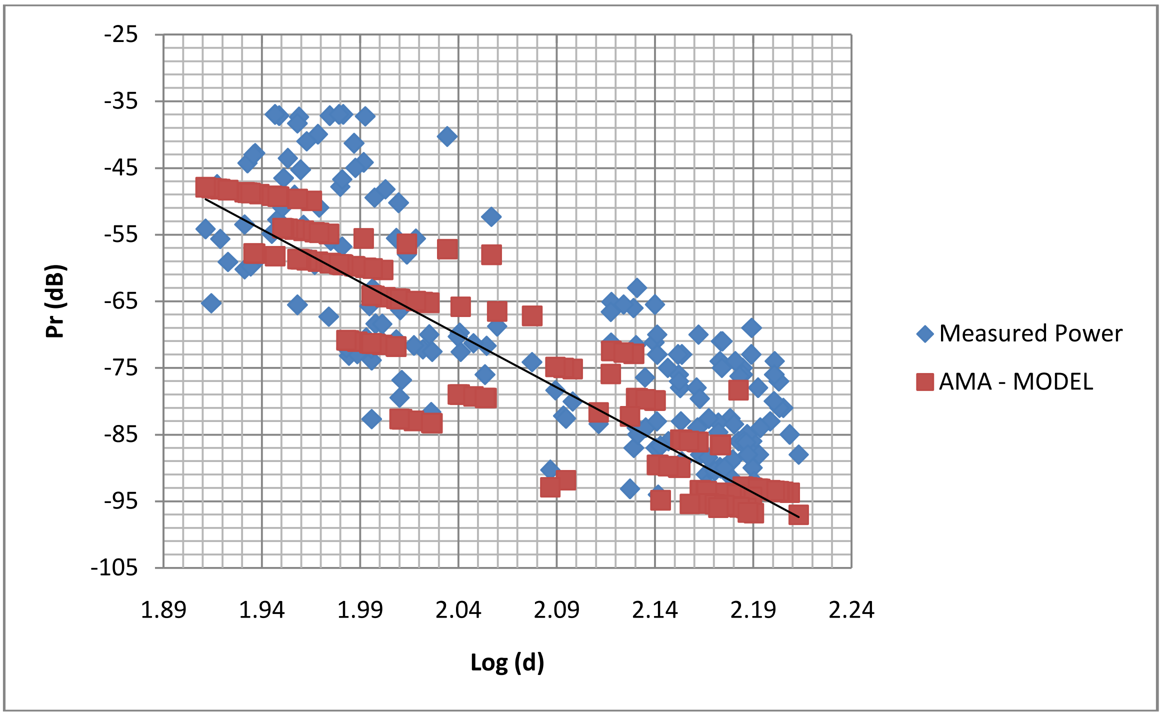
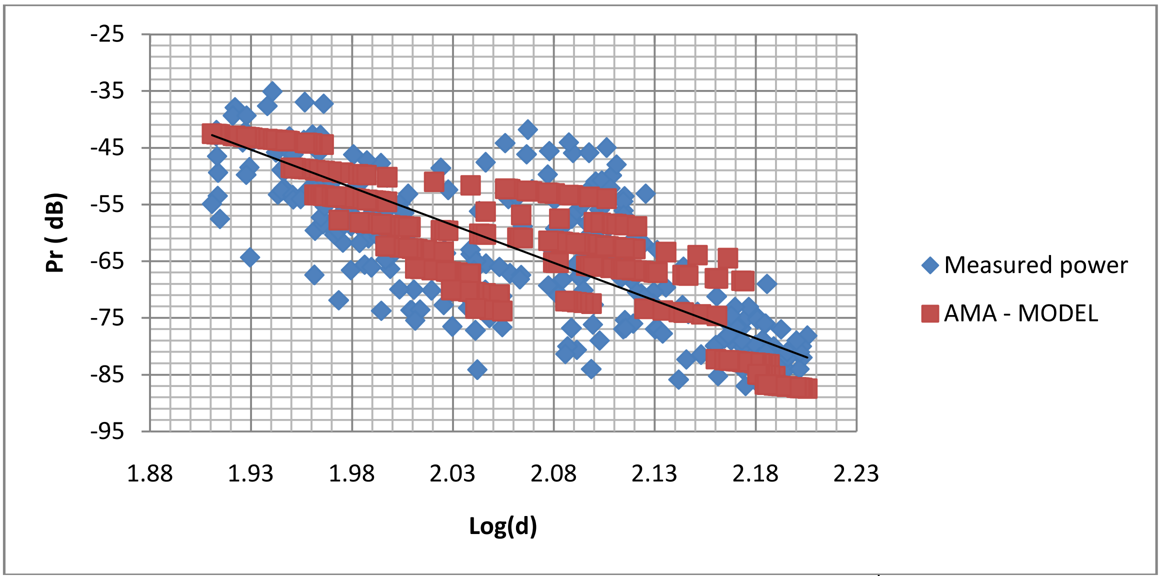


Figure 4.6:Measuerd and calculated data for Al-Ahli hospital 1^{st} floor.



4.7:Measuerd and calculated data for Al-Ahli hospital 2^{nd} floor.



4.8:Measuerd and calculated data for Al-Ahli hospital 3rd floor.

The exponent path loss and the standard deviation of measured data for all floors of the Al-Ahli hospital in the table (4.2)

Number of floor	n_0	σ ITU (dB)	σ AMA (dB)	% of Improvement
Floor One	3.47741	15.09624	10.35020	31.438
Floor Two	3.7573	16.03312	11.68996	27.088
Floor Three	3.88362	10.97423	7.545272	31.245

Table 4.2: comparison between the ITU and the AMA model for the AL-Ahli hospital.

Table (4.2) shows the standard deviation of measurements made on the Al-Ahli hospital building. It illustrates the improvement that occurred after the modification on the ITU model.

4.5.3 Abu Rumman Building

Abu Rumman building is a three-storey building structure that contains large glass windows. When we applied the AMA – model, the difference between the measured mean and the AMA mean reduced from (6 - 4) dB. The figures (4.9, 4.10, and 4.11) bellow show the measured, and modeled values related to the 1st, 2nd, 3rd floor respectively:

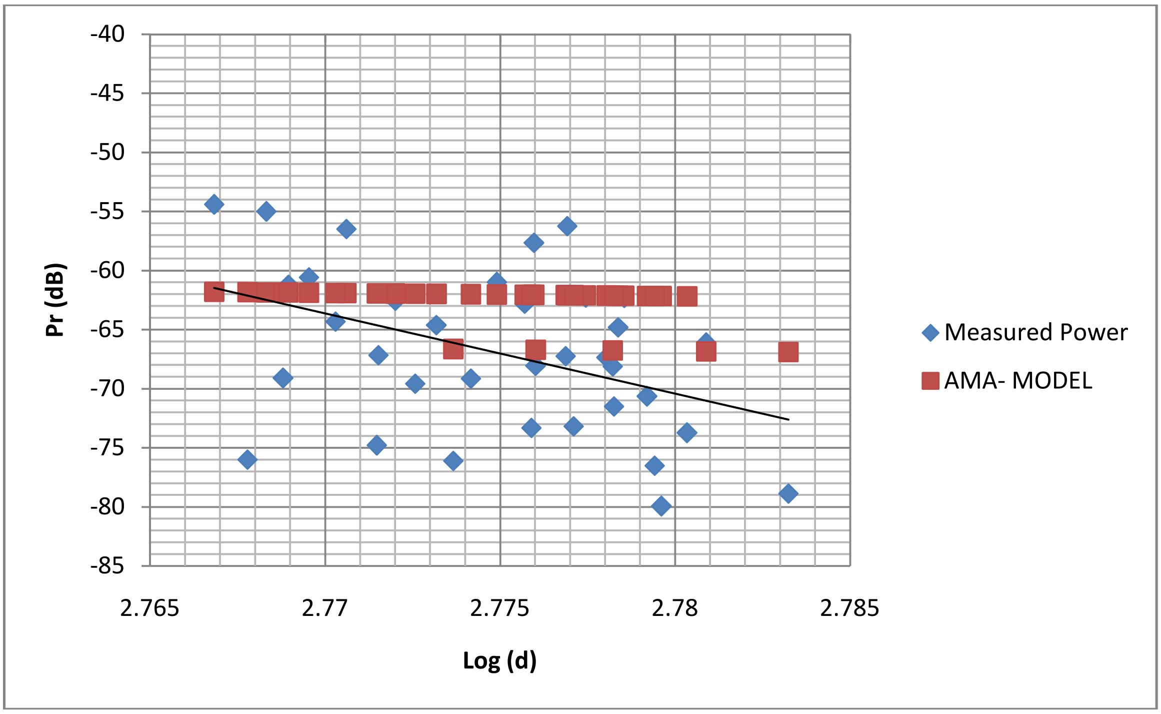


Figure 4.9: Measured and calculated data for Abu Rumman 1st floor.

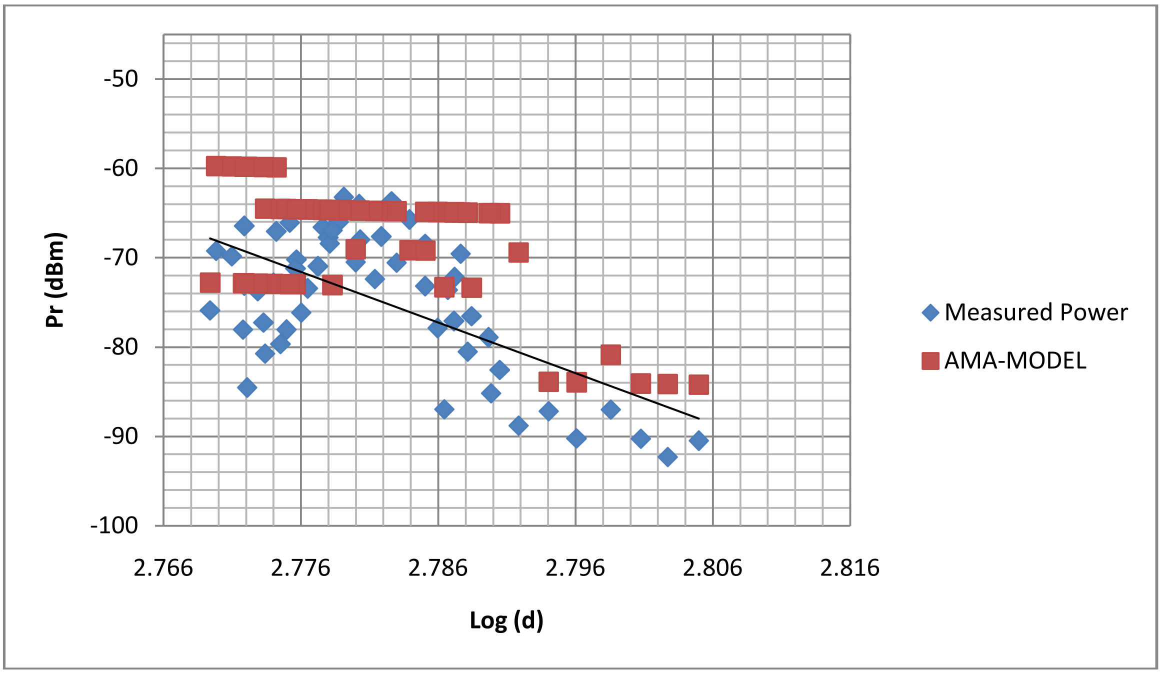


Figure 4.10: Measured and calculated data for Abu Rumman 2nd floor.

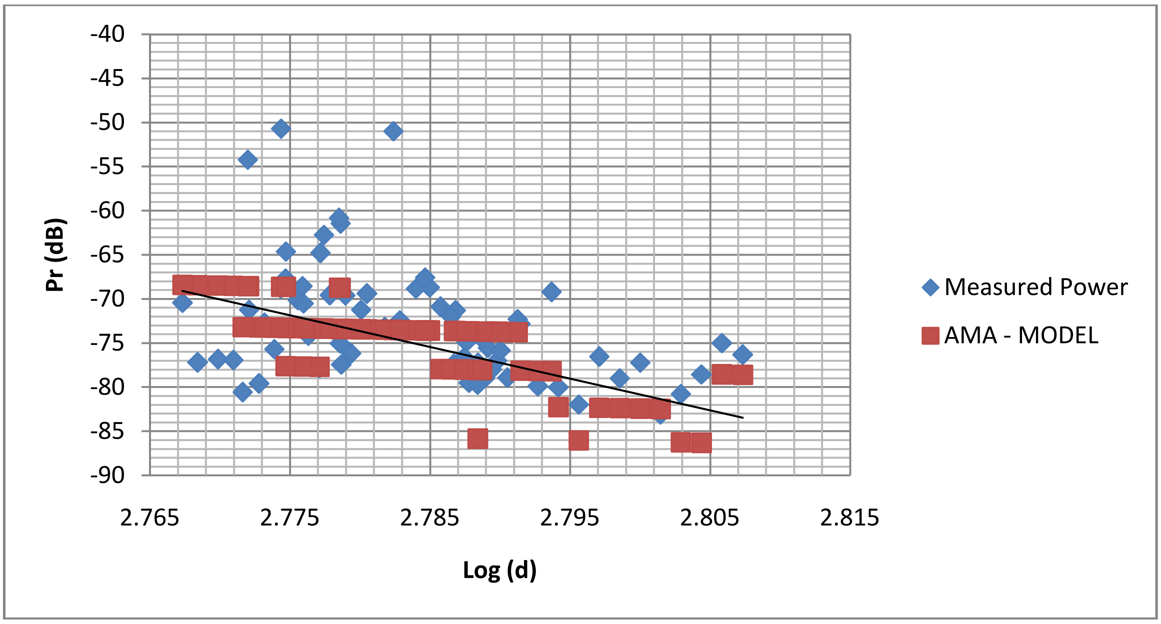


Figure 4.11: Measured and calculated data for Abu Rumman 3rd floor.

The exponent path loss and the standard deviation of measured data for all floors of the Abu Rumman building are shown in the Table (4.3). Improvement in standard deviation is around 6 dB in the first floor, 16 dB in the 2nd and third.

Number of floor	n_0	σ ITU (dB)	σ AMA (dB)	% of Improvement
Floor One	2.7368	8.36574723	7.86590334	5.974
Floor Two	3.02212	9.12203889	7.71575209	15.416
Floor Three	2.93869	7.6763022	6.44672008	16.017

Table 4.3: comparison between the ITU and the AMA model for the Abu Rumman.

.

4.5.4 PPU Building A

Building A is a four-storey building structure containing a large number of classrooms and narrow corridors , Figure (4.12). The signal that covered the second, third and fourth floors was line of sight (LOS), but he one that covered the first floor was non line of sight (NLOS).

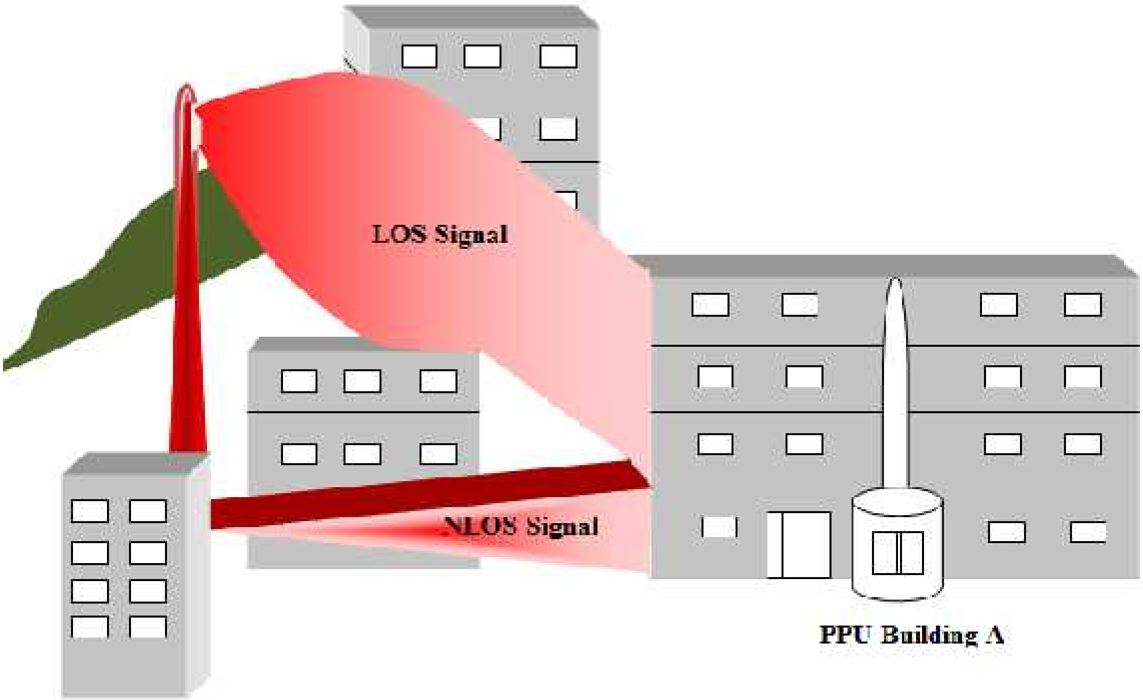


Figure 4.12: A building and the transmitting antenna sketch.

The figures bellow show the measured, and modeled values related to the 1st,2nd, 3rd and 4th floor respectively :

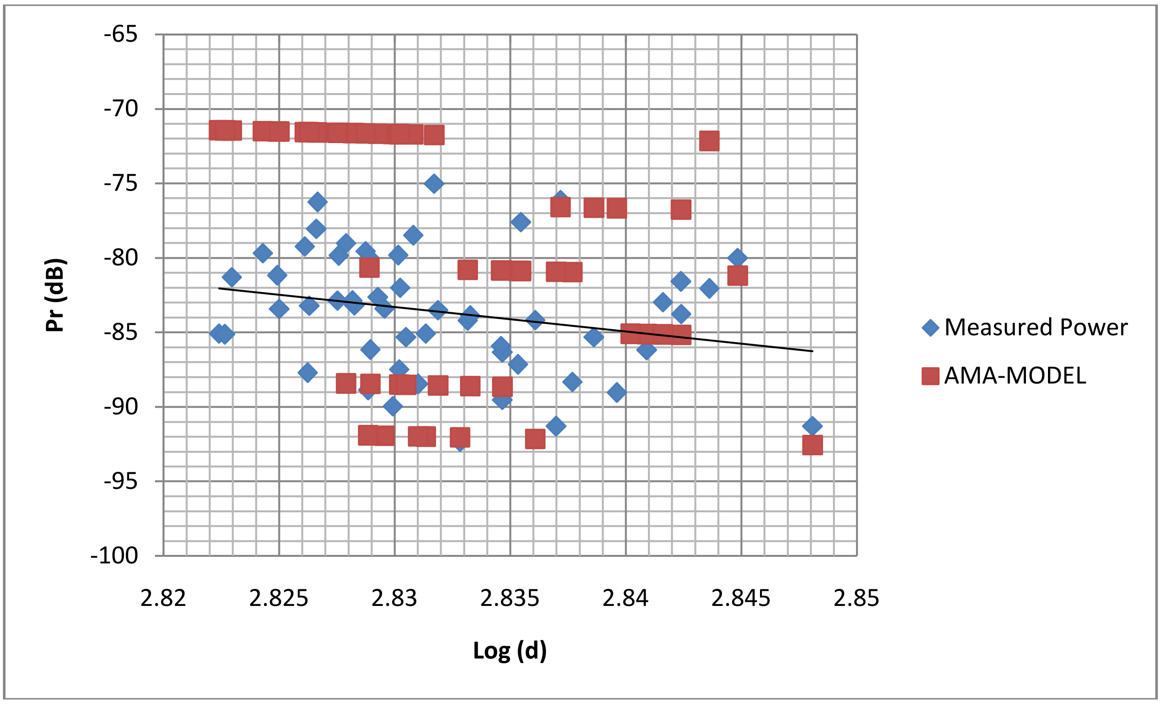


Figure 4.13: Measured and calculated data for A 1st floor.

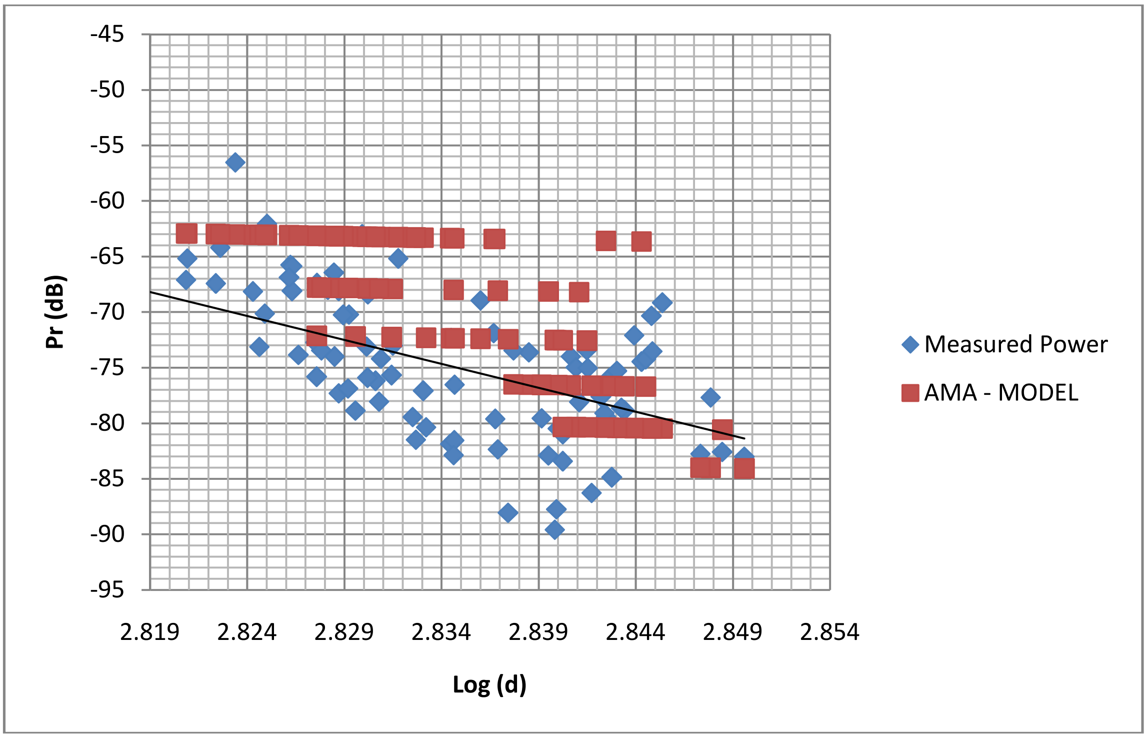


Figure 4.14: Measured and calculated data for A 2nd floor.

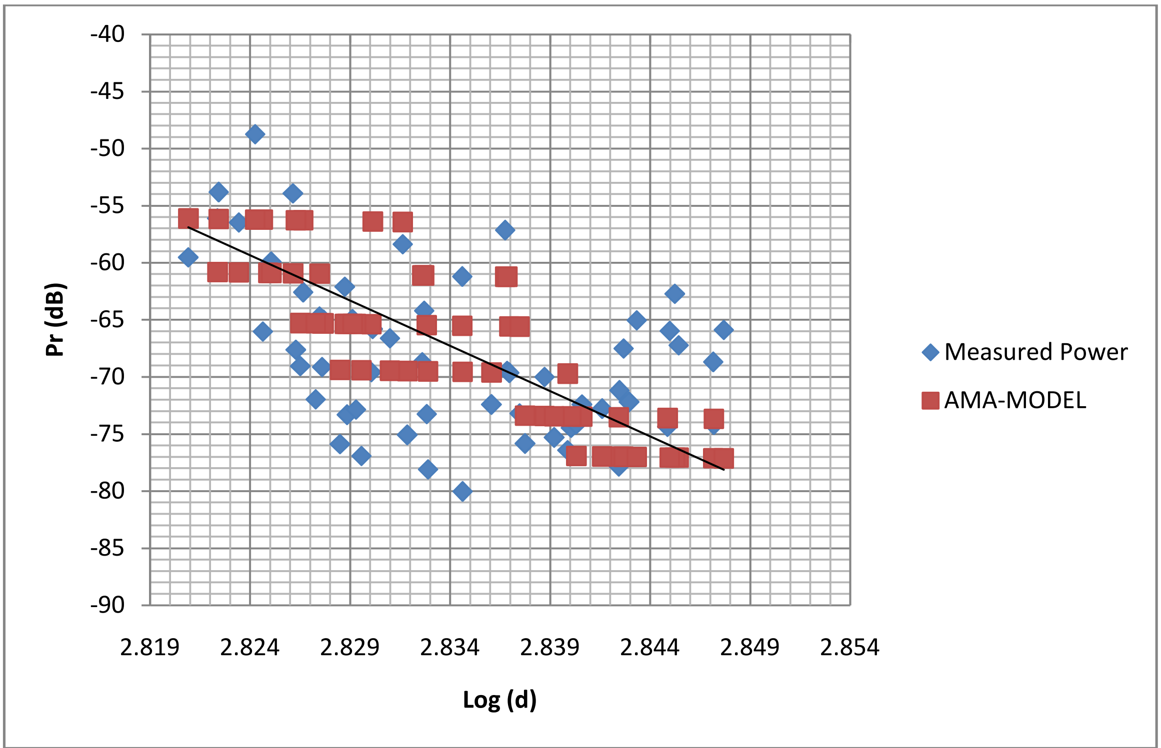


Figure 4.15: Measured and calculated data for A 3rd floor.

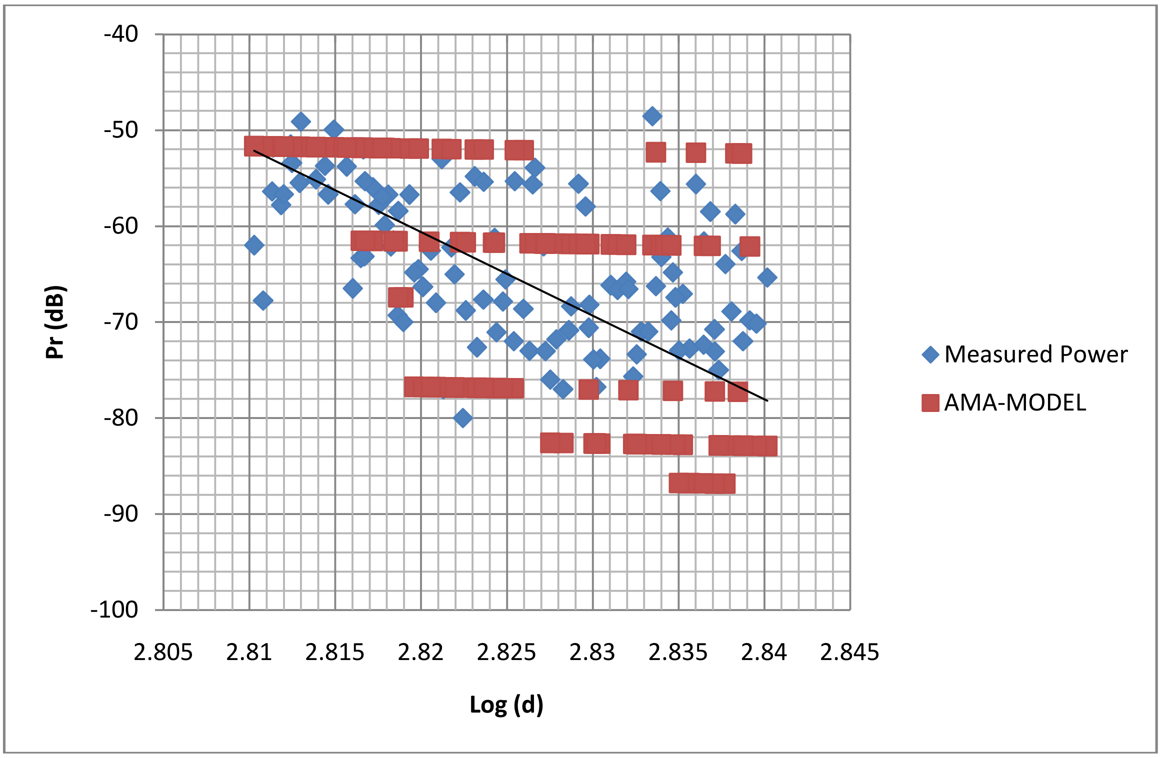


Figure 4.16: Measured and calculated data for A 4th floor.

The exponent path loss and the standard deviation of measured data for all floors of the building A are shown in Table (4.4). The standard deviation improvement ranged between approximately 10 % to 47 %.

Number of floor	n_0	σ ITU (dB)	σ AMA (dB)	% of Improvement
Floor One	3.3783	15.8286068	14.095949	10.946
Floor Two	3.07879	13.0804888	8.49250302	35.075
Floor Three	2.83748	13.283776	6.97866435	47.464
Floor Four	2.68941	14.0035705	7.370808	47.364

Table 4.4: comparison between the ITU and the AMA model for the A building.

4.5.5 PPU Building B

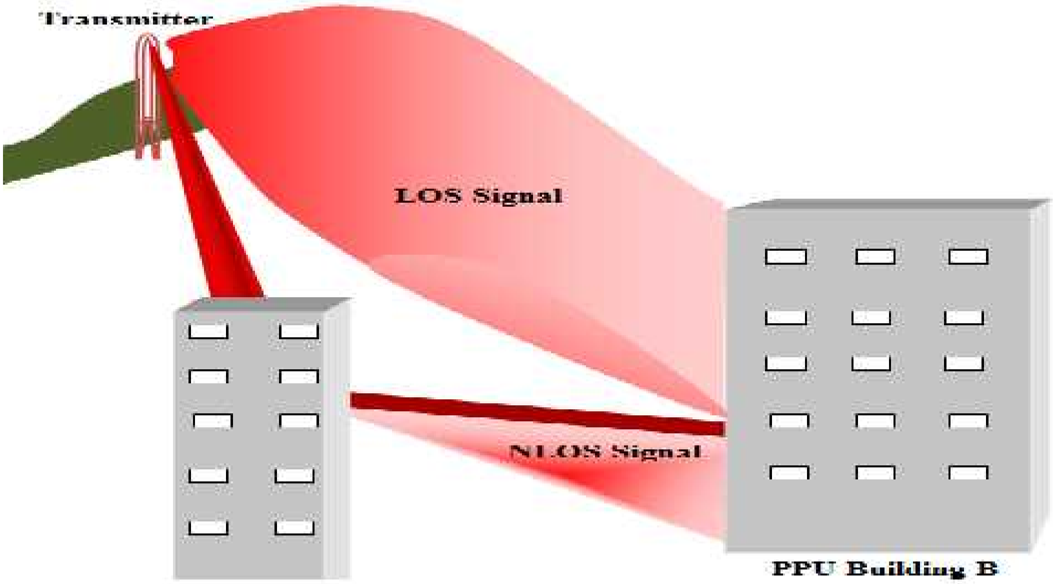


Figure4.17: B building and the transmitting antenna sketch.

The signal that covered the third, fourth and fifth floors, in Figure 4.17, was LOS but that of the first and second floors was NLOS. The results of building B in Figures (4.18 to 4.22) show the measured and modeled values related to the 1^{st}, 2^{nd}, 3^{rd} ,4^{th} ,5^{th} floor respectively .

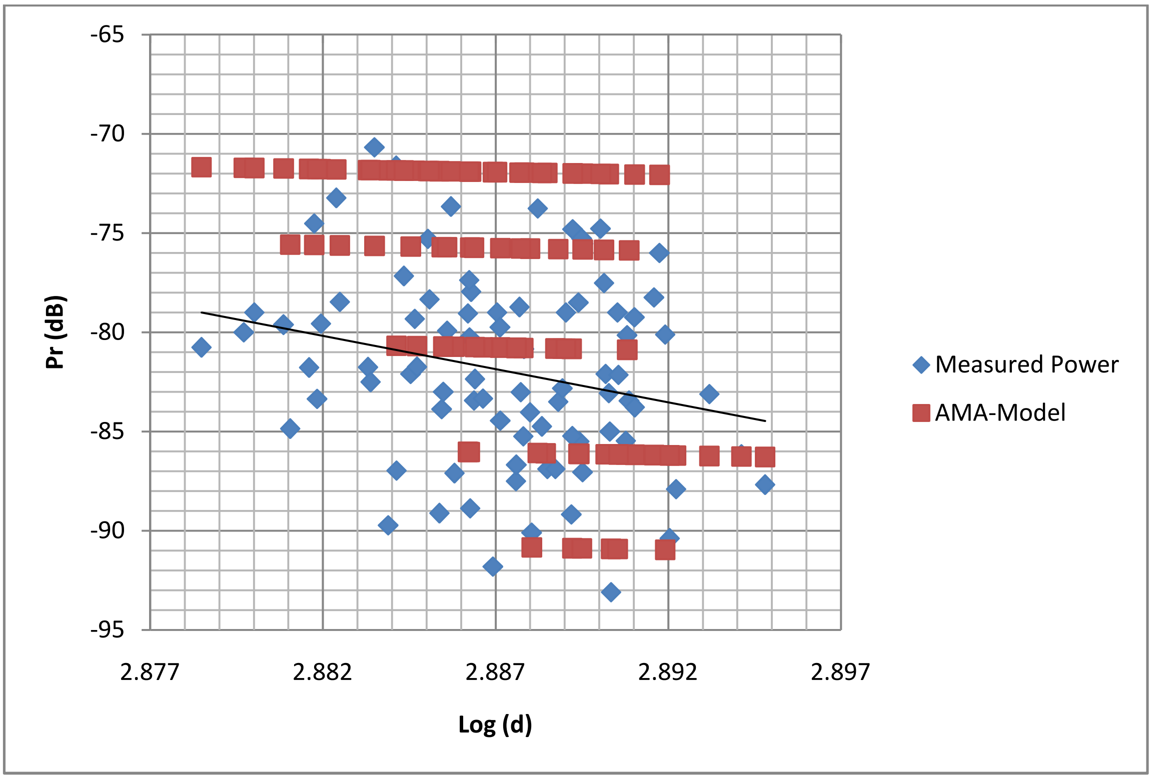


Figure 4.18: Measured and calculated data for B 1^{st} floor.

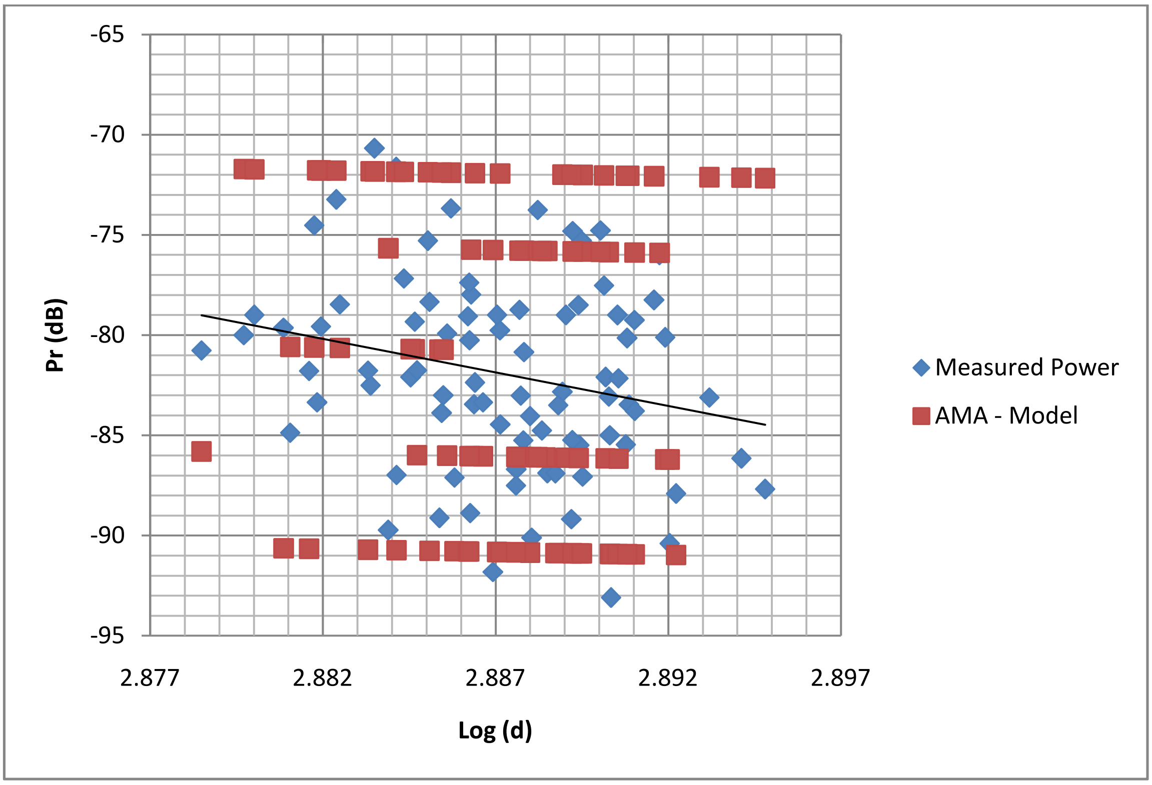


Figure 4.19: Measured and calculated data for B 2nd floor.

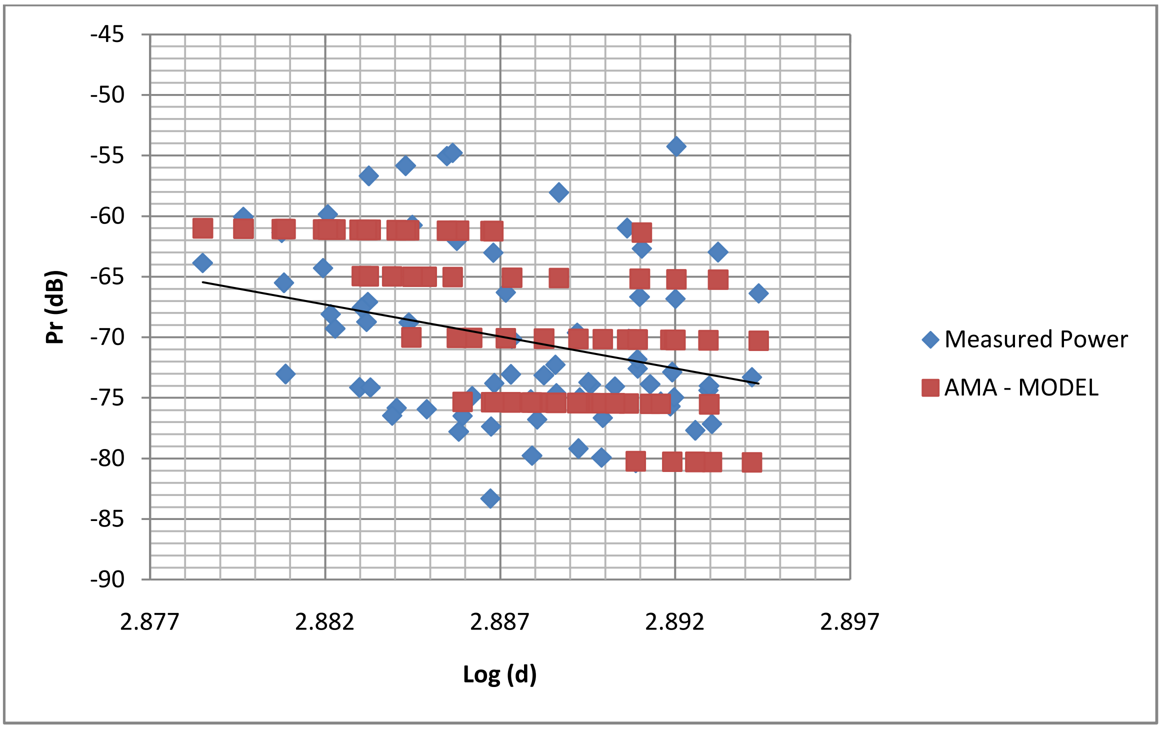


Figure 4.20: Measured and calculated data for B 3rd floor.

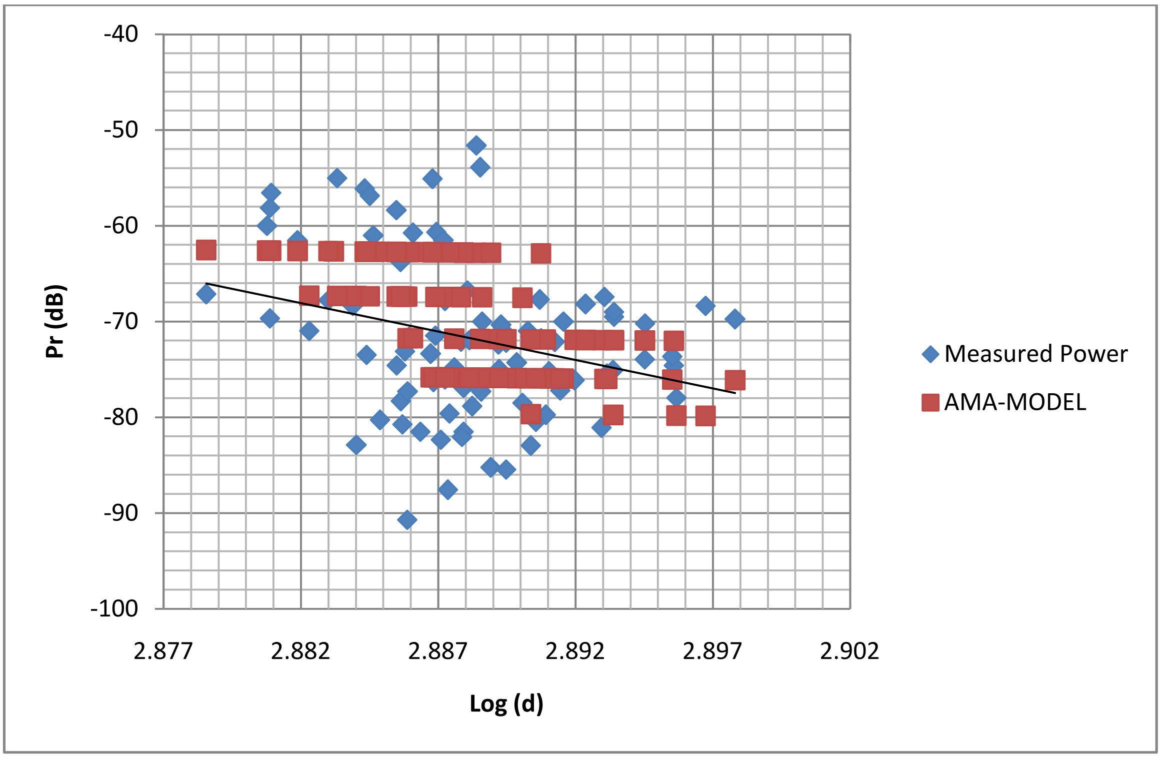


Figure 4.21: Measured and calculated data for B 4th floor.

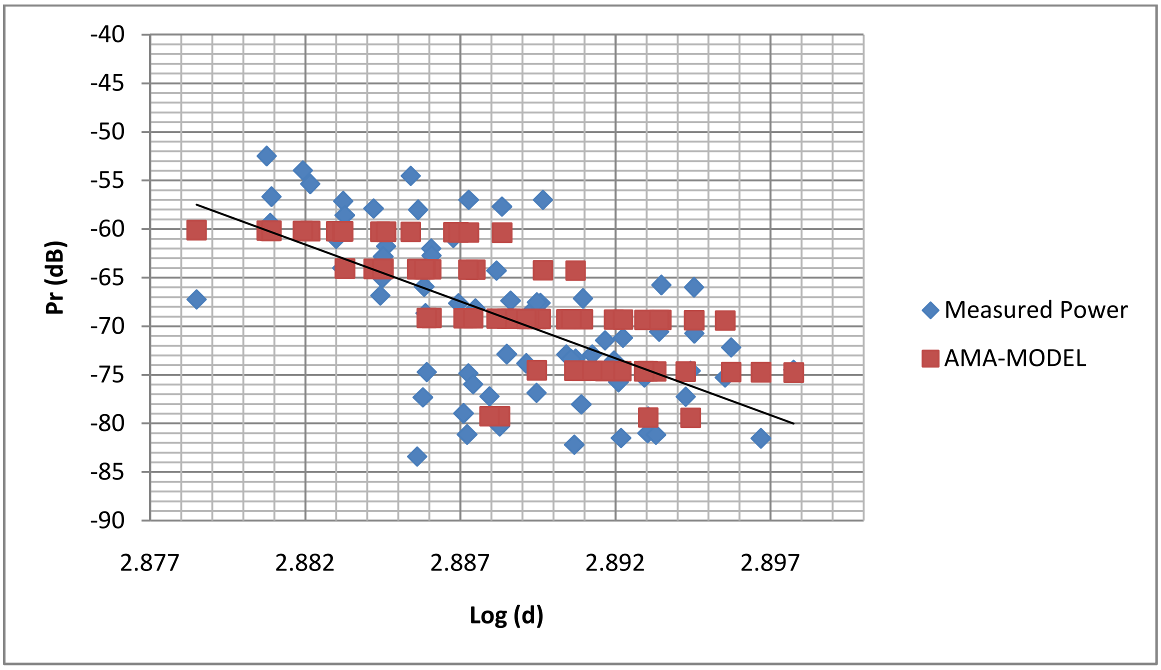


Figure 4.22: Measured and calculated data for B 5th floor.

The exponent path loss and the standard deviation of measured data for all floors of the building B are shown in Table (4.5). The standard deviation improvement ranged between 20 % to 52% approximately.

Number of floor	n_0	σ ITU (dB)	σ AMA (dB)	% of Improvement
Floor One	3.1842	11.0689507	7.60388838	31.304
Floor Two	2.9736	10.0689507	8.01930109	20.356
Floor Three	2.77639	11.3028491	6.68365572	40.867
Floor Four	2.82934	12.043308	8.58673893	28.701
Floor Five	2.7452	12.0234045	5.68088594	52.751

Table 4.5: comparison between the ITU and the AMA model for the A building.

Table (4.5) shows the standard deviation of measurements made on the B building and illustrates the improvement that occurred after the modification on the ITU model.

4.5.6 Standard deviation summary of the AMA–Model for all selected buildings

Table (4.6) shows the standard deviation summary of the AMA – Model for all selected buildings. It illustrates the standard deviation range from (6 to 8.5) mostly.

Floor / Building	First Floor σ (dB)	Second Floor σ (dB)	Third Floor σ (dB)	Fourth Floor σ (dB)	Fifth Floor σ (dB)
Al-Ahli Hospital	10.3502	11.68996	7.545272	--	--
Services Building	6.419908	5.638979	4.589721	--	--
PPU Building A	14.09595	8.492503	6.978664	7.370808	--
PPU Building B	7.603888	8.019301	6.683656	8.586739	5.680886
Abu Rumman	7.865903	7.715752	7.545272	--	--

Table 4.6: Standard deviation summary.

4.6 Outdoor Analysis

To complete our GSM measurements, we have measured the GSM signal in the outdoor environment, analyzed those and calculated the exponent path loss and the standard deviation of PPU-A, PPU-B and Abu Rumman buildings. Table 4.7 shows the path loss exponent and standard deviation results between those buildings and their serving base stations.

Building	n	σ
PPU - A	2.3178	4.279135
PPU -B	2.4045	5.903383
Abu Rumman	2.3845	6.841645

Table 4.7: Outdoor standard deviation and path loss exponent in different locations.

Measurements are shown in Appendix C.

4.7 Floor Height Gain factor

We have not attempted to generalize the effect of floor height gain on the indoor propagation loss and its standard deviation. However, we conducted a study on this effect on the PPU engineering building-B which constitutes 5 floors. We took measurements conducted on the inner side of the external wall, facing the serving base station, for each floor. We averaged those readings for each floor then subtracted those results for all consecutive floor separations. Table 4.8 shows the floor height gain with the number of floors. For the upper floors (3rd, 4th and fifth) the height gain per floor amounted to approximately 2 dB.. This is consistent with reference [19] that the height gain measured was 2 dB/floor, whereas between the 1st and the 2nd floors around 6.5 dB. The result is sensible due to the fact that the first floor is more influenced by obstructions near the building. The 2 dB / floor gain is not surprising since the higher the floor, the higher the probability that line-of-sight to the base station exists.

Floor No.	1st	2nd	3rd	4th	5th
Floor height gain	0	6	8.3	10.5	12.5
σ with height gain	-	-	6.68	8.58	5.68
σ without height gain	-	-	9.55	12.35	12.38
Improvement percentage	-	-	43%	44%	54%

Table 4.8: Height gain analysis for PPU building B

From the table(4.8) the floor height gain resulted into standard deviation improvement. We worked out the standard deviation before the floor height gain by deducing the height gain factor from the originally measured value. It is not surprising that the standard deviation after taking out the height gain effect worsened off. For the second we didn`t take into account the height gain because LOS condition was not satisfied.

4.8 Results Summary

ITU model has been modified to reflect the separate addition of indoor walls and their attenuation loss factor, in all floors of all buildings there was a very clear improvement in the standard deviation of the improved model compared to measurements. We also stated potential of adding the height gain and measured its improvement effect to the model. We note that the height gain measurement was done for building B only hence would not generalize it in our AMA model. It is worth mentioning that we also took measurements of the outdoor serving base stations to three of our selected buildings and studied the standard deviation which ranged between n equals 4 to 7 and path loss exponents that ranged between 2.3 to 2.4. .

Chapter Five

WLAN ANALYSIS

5.1 Introduction

In the previous chapter we presented the GSM measured data analysis. In this chapter we present measured data analysis in four different buildings (Al-Ahli hospital, PPU Abu Rumman, PPU-A and C buildings). The main purpose of finding a new model is to reduce the standard deviation between measured values and those of the modified ITU model to a possible minimum. And in this chapter we did a comparison between the ITU and the modified ITU, at the floor analysis level in each building..

5.2 Building Structure and Location

Four difference buildings were selected for WLAN indoor signal measurement. These buildings are different from each other in structure, number of floors, area of buildings, obstacles and wall obstructions, and access point location on each building. Once the analysis is complete, we will attempt to generalize the modified ITU model for 900 MHz to include WLAN sources transmitting at 2.4 GHz.

These buildings are:

1- The faculty of applied science (building A).

   The building location is at Wadi Al-Hariya in Hebron. It is a three-storey building with a ground floor. Its contain three WLAN transmitters; first transmitter on ground floor, second transmitter on second floor , and transmitter number three on third floor.

2- The faculty of administrative sciences and informatics (Abu Rumman building).

   The building location is at Mount Abu Rumman in Hebron, it is three-storey building with a ground floor. Its contain three WLAN transmitters, one transmitter on each floor.

3- Al-Ahli Hospital.

   The building location is at Faresh Al-Hawa in Hebron, it is three-storey building with a ground floor. Its contain two WLAN transmitters, one transmitter on ground floor, one transmitter on second floor.

4- Engineering and Technology Building (building C).

   The building location is at Wadi Al-Haria in Hebron , it is a two-storey building with a ground floor. Its contain three WLAN transmitters, first transmitter on ground floor, second transmitter on first floor , and transmitter number three on second floor.

5.3 Measurement Setup

We required the following measurement setup hardware and software components for WLAN measurements; namely NetStumbler, AutoCAD and a laptop.

NetStumbler is used to measure the power of received WLAN signal. It is installed in an HP 530 laptop computer with XP operation system.

AutoCAD software was used to locate test points and transmitters locations, to measure distance between those test points and source locations.

Values of signal strength in each test point in the same floor were recorded with to location of transmitting access point in the same floor.

Record steps:-

1. Locate a test point on AutoCAD map and provide it with a label..
2. Adjust the laptop height to 120 cm in the direction of the transmitter.
3. Record signal strength values with respect to the transmitter in the same floor and other floors.

5.4 WLAN Analysis

This section shows the modified ITU validation for wireless LAN measurements, and a comparison with the standard ITU through calculations of the standard deviation and the path loss exponent.

To know the accuracy of measurements standard deviation gives the variance between measurements values and calculations results, standard deviation can be determine by the following equation:

$$\sigma = \sqrt{\frac{1}{k}\sum_{i=1}^{k}[P_{measured}\ d_i\ - P_{model}(d_i)]^2} \qquad (5.1)$$

Where:

K: the number of values.

P: received power

.

Analysis of the measurements by using the ITU and our model "modified ITU (AMA Model) ", by these equations:

ITU Model:

$$Pr\ dBm = Pt\ dBm - 20Log_{10}f\ \ MHz - 10nLog_{10}d + 28 \qquad (5.2)$$

Where:

P_t : Transmitter power.

f : Frequency of signal in MHz.

d : Distance between test point and transmitter location.

AMA Model:

$$Pr\ dBm = Pt\ dBm - 20Log_{10}f\ \ MHz - 10nLog_{10}d - X\alpha + 28 \qquad (5.3)$$

Where:

P_t : the transmitted power

f : the frequency in MHz

d : the distance in meters

I : indicate the number of wall types.

X_α : the value of the wall attenuation factor.

From chapter three we can determine the value of Xα from Figure (3.33) of multi wall attenuation loss for 2.4 GHz where the attenuation loss factor obtained from eq.(3.3).

$$X_\alpha\ (dB) = 0.0032\ K^4 - 0.086\ K^3 - 0.17\ K^2 + 9.3\ K$$

K = number of separated walls.

5.4.1 Al-Ahli hospital Building

In Al-Ahli hospital, we conducted measurements in two floors; the ground floor and the second floor, for two different access points in each floor. All measurements are shown in appendix (D).

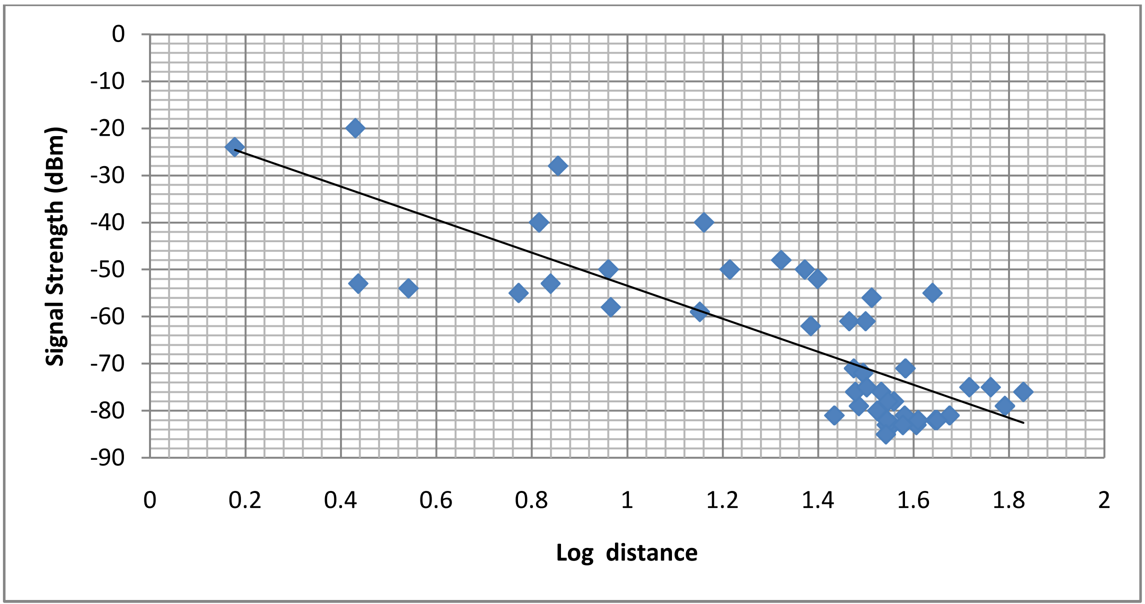


Figure 5.1: Measured data plot for Al-Ahli ground floor

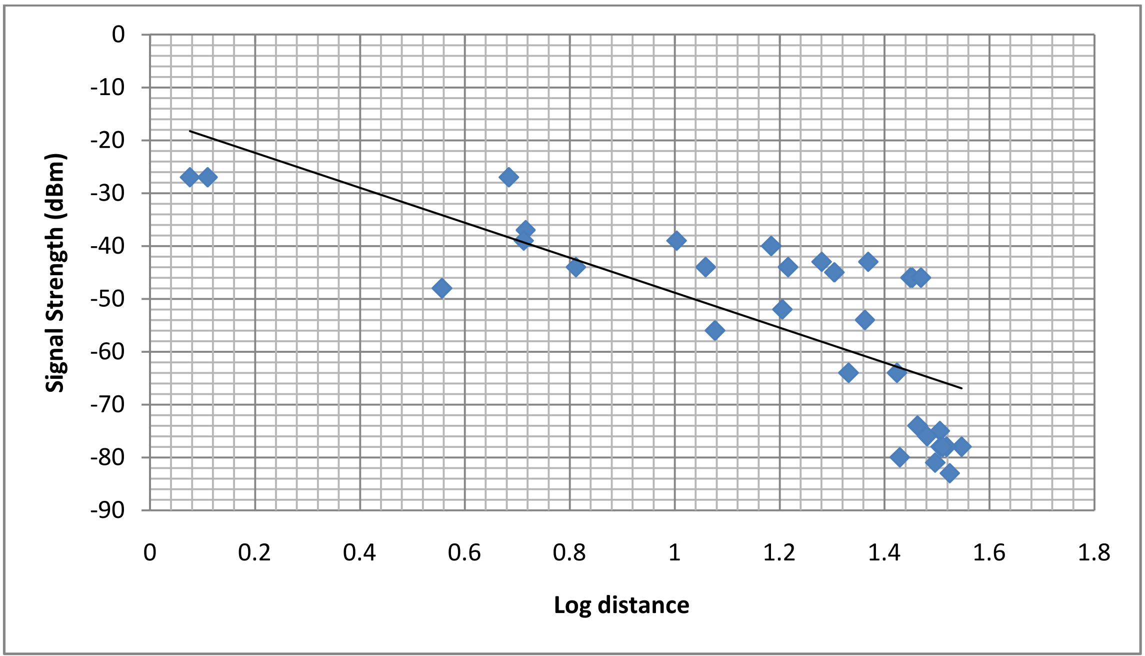


Figure 5.2: Measured data plot for the Al-Ahli second floor.

Figure (5.1) shows the measured data plot for Al-Ahli ground floor. Figure (5.2) shows the measured data plot for the second floor. As noticed the x-axis is the distance in dB and the y-axis is the signal strength in dBm. As we see average received power decreases logarithmically with distance, due to attenuation of walls, floors and propagation mechanism that all cause penetration losses.

We analyzed the measurements by first calculating the standard deviation and the path loss exponent for both the ITU equation (5.2) "ITU model" and our model equation (5.3) "AMA model" as shown in table (5.1).

Number of Floor	The path exponent ITU (n)	Standard deviation ITU (σ)	The path exponent AMA (n_0)	Standard deviation AMA (σ)
The ground floor	4.23	11.6	2.65	4.49
The second floor	3.83	11.8	2.26	9.8

Table 5.1:calculated standard deviation and the path loss exponent for Al-Ahli hospital.

Since the standard is also a measure of the relative error we can calculate percentage improvement that the new model provides us which is 18.3% for the second floor and 61.3% for the ground floor. This is in fact a significant improvement due to the use of the developed AMA model.

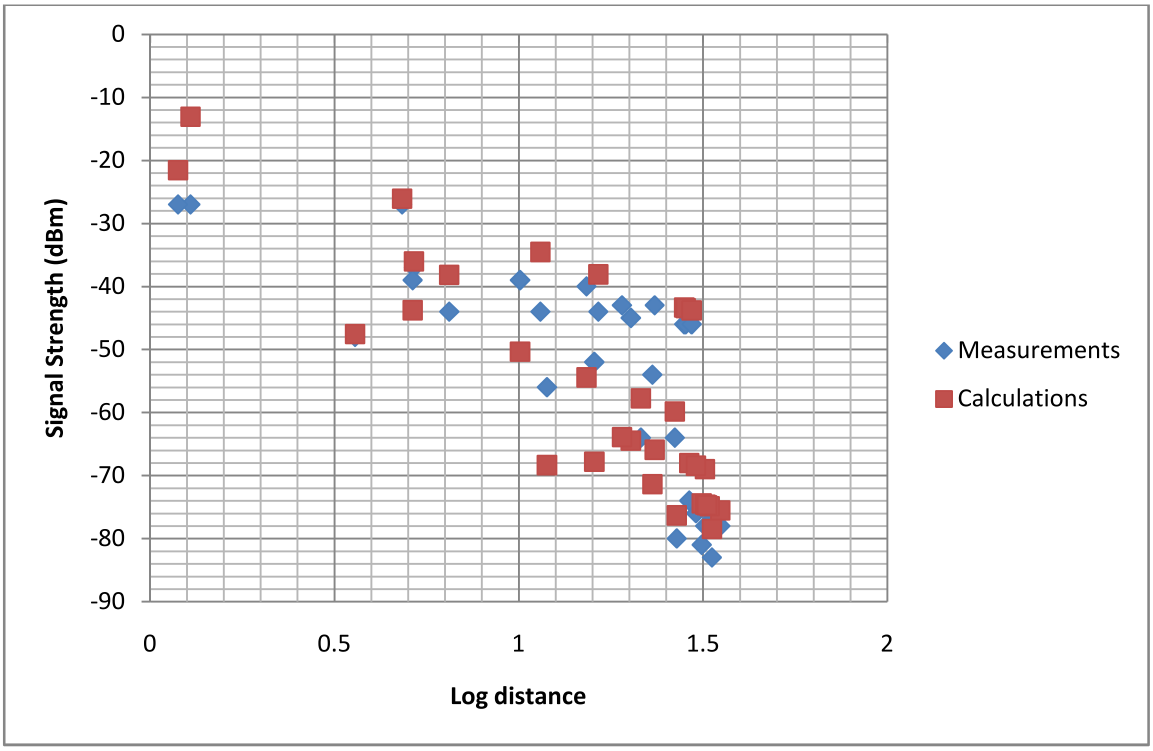


Figure 5.3: Measured and the calculated data plot for Al-Ahli second floor

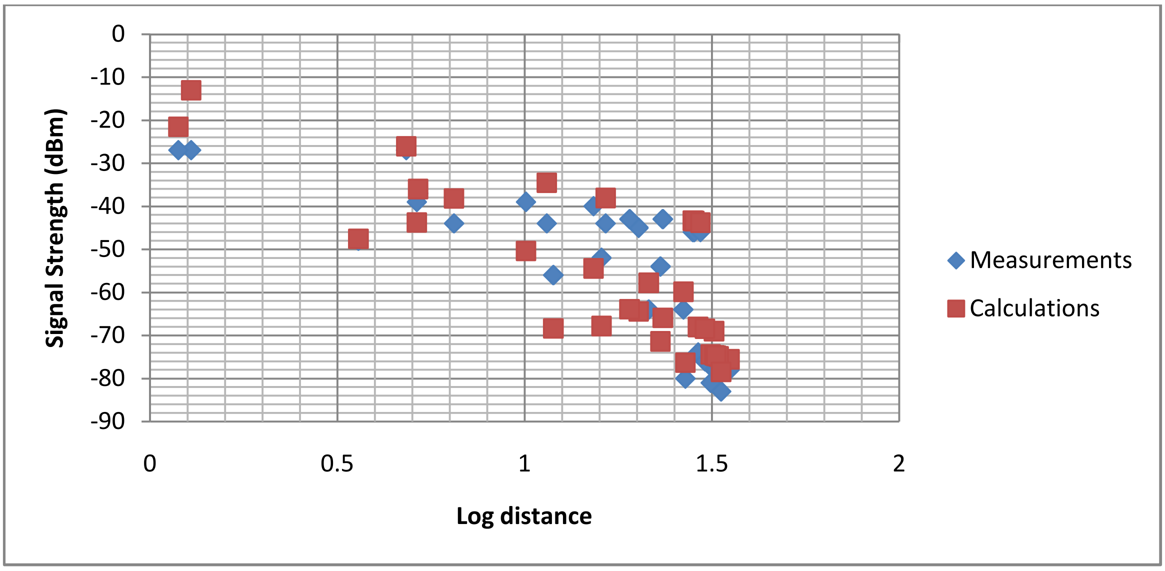


Figure 5.4: Measured and the calculated data plot for Al-Ahli ground floor

The above Figure (5.3and 5.4) shows the measured calculated data for the modified ITU for Al-Ahli building second and ground floor respectively. As we see the measurements values very close to the values calculated by modified ITU model which is verified by the standard deviation calculations. Since modified ITU model contains the effect of walls between any test point and transmitter.

5.4.2 Abu Rumman Analysis

For Abu Rumman we did similar measurements in the three floors. (2^{nd}, 3^{rd} and 4^{th}) All measurements are shown in appendix (D).

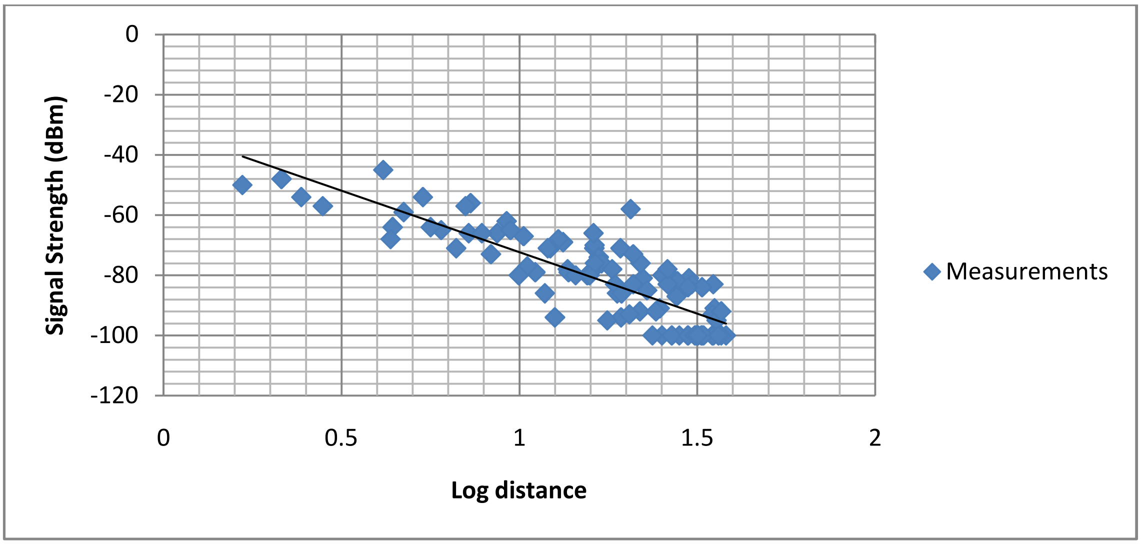


Figure 5.5: Measured data plot for the Abu Rumman 2^{nd} floor.

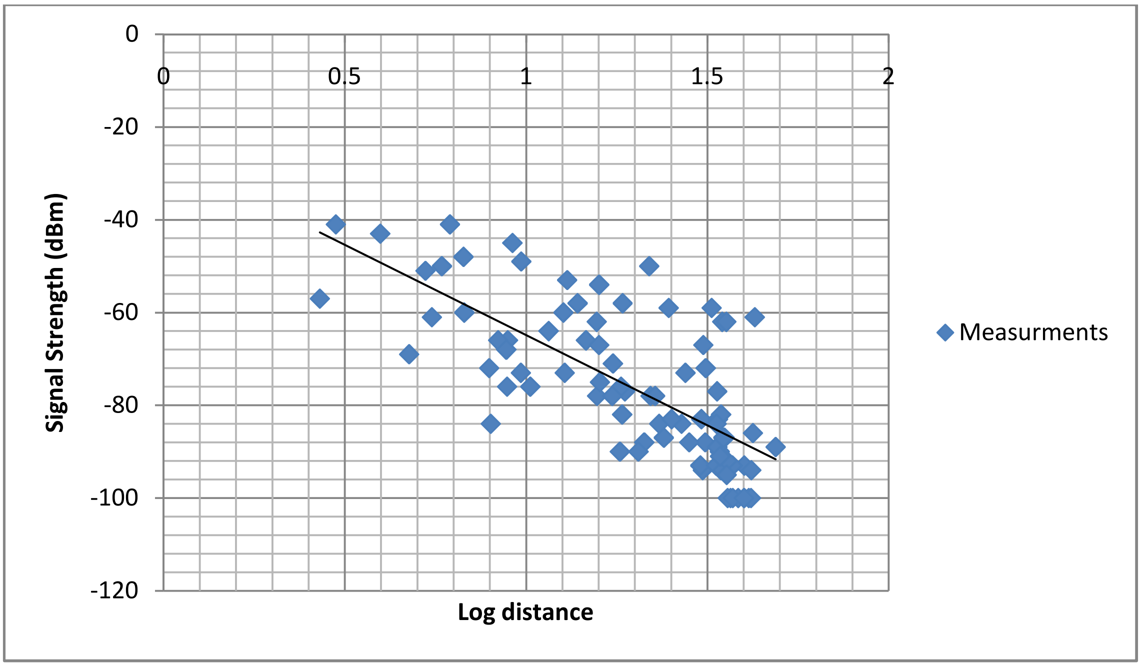


Figure 5.6: Measured data plot for the Abu Rumman 3rd floor.

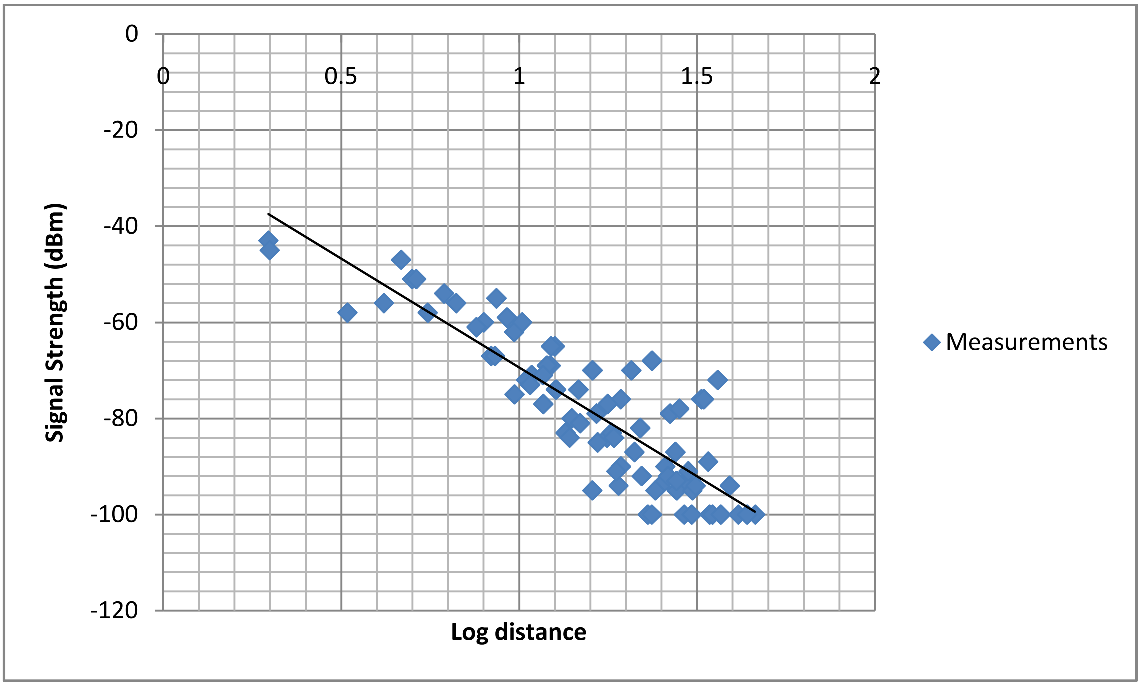


Figure 5.7: Measured data plot for the Abu Rumman 4th floor.

Figures (5.5,5.6,5.7) shows the measured data for the Abu Rumman 2nd 3rd and 4th respectively. As can be noticed from the figures the exponent path loss factor can be calculated by the slope of the line which represents the arithmetic mean value of the measurements, this value depends on the specific propagation environments, type of construction materials, including wall obstructions.

For the analysis of Abu Rumman building we did the same as in Al-Ahli by first calculating the standard deviation and the path loss exponent using both the ITU equation (2) "ITU" and our model equation (3) " AMA model" as shown in table (2).

Number of Floor	The path exponent ITU (n)	Standard deviation ITU (σ)	The path exponent AMA (n_0)	Standard deviation AMA (σ)
2nd floor	4.85	8.27	3.2	4.98
3rd floor	4.2	11.3	2.81	4.14
4th floor	4.7	7.74	3.3	5.1

Table 5.2: calculated standard deviation and the path loss exponent for Abu Rumman building.

The improvement in standard deviation due to the new model amounts to 39.8% for the 2nd floor, 63.3% for the 3rd floor and 34.14 % for the 4th floor.

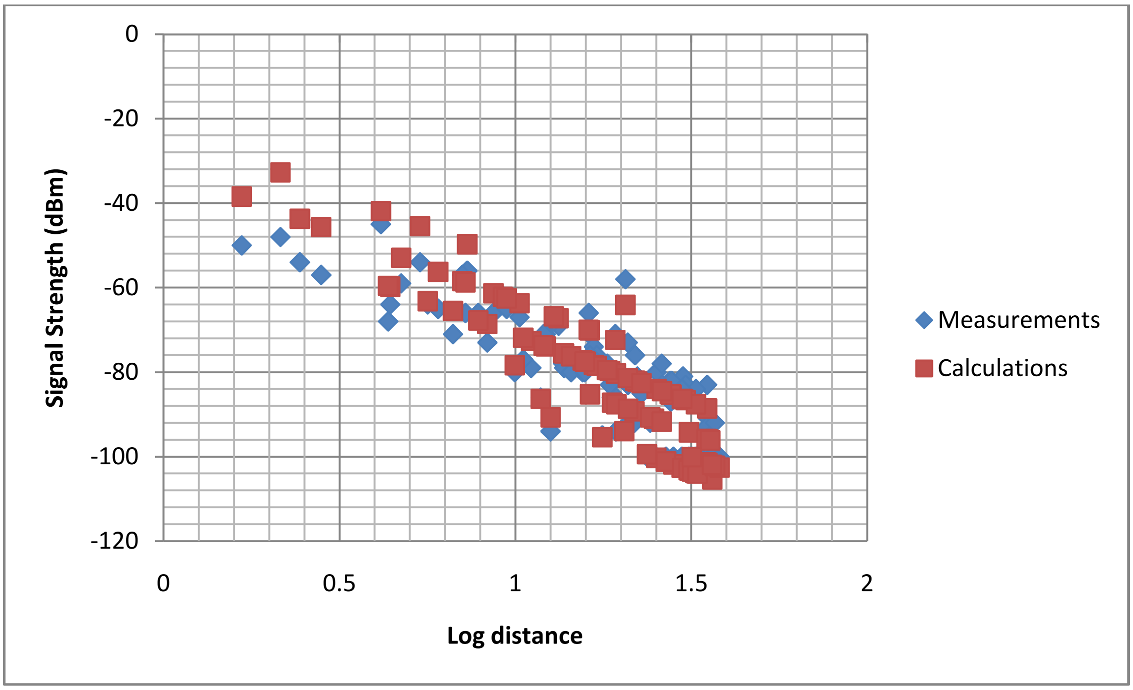


Figure 5.8: Measured and the calculated data plot for Abu Rumman 2nd floor.

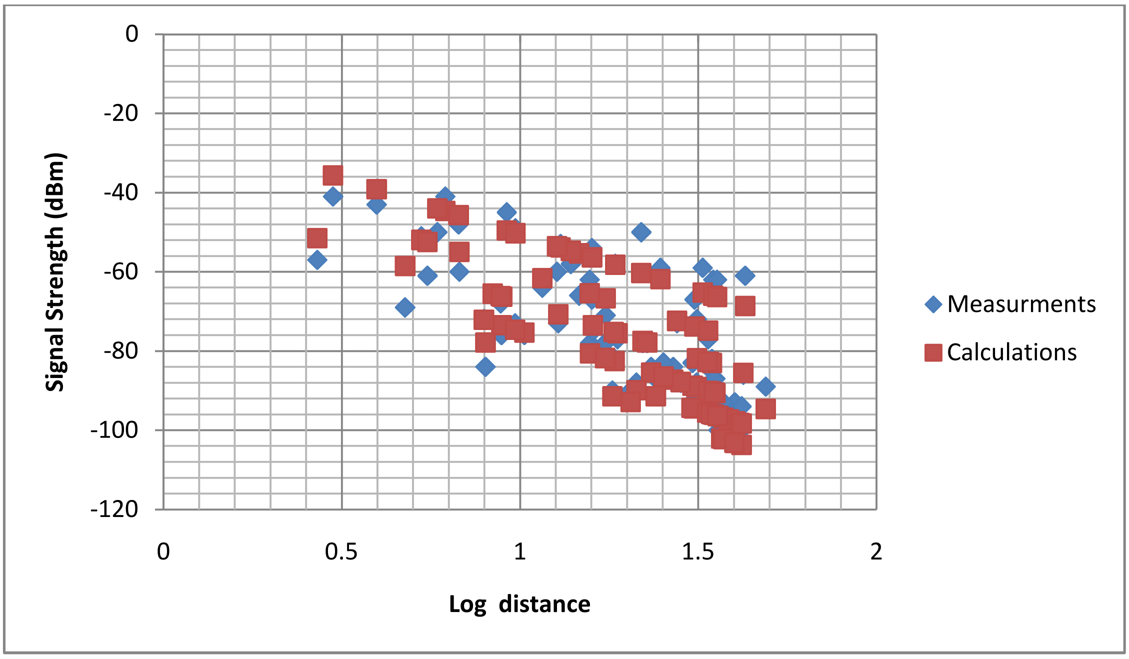


Figure5.9: Measured and the calculated data plot for Abu Rumman 3rd floor.

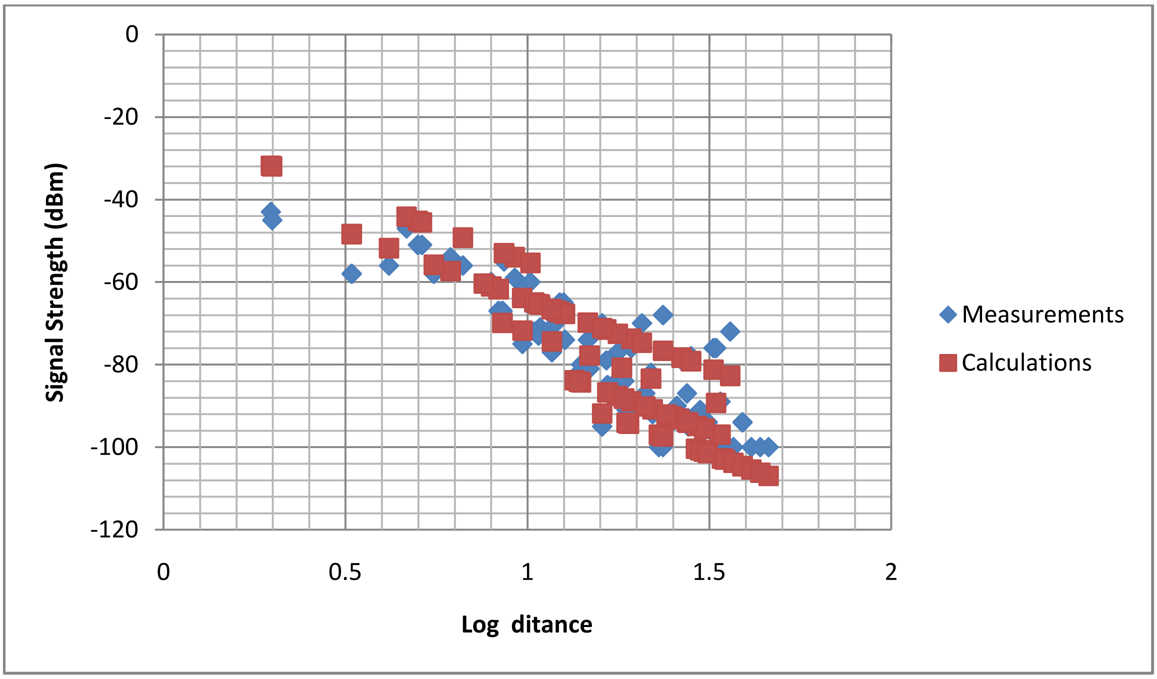


Figure 5.10: Measured and the calculated data plot for Abu Rumman 4th floor.

The above figure (5.5) shows the measured calculated data for the modified ITU model. As we observe the measurements values are very close to those calculated by the AMA model.

5.4.3 PPU Building A

We took measurements in the four floors. There were three access points in the 1st, 3rd and 4th floors. All measurements are shown in Appendix(D).

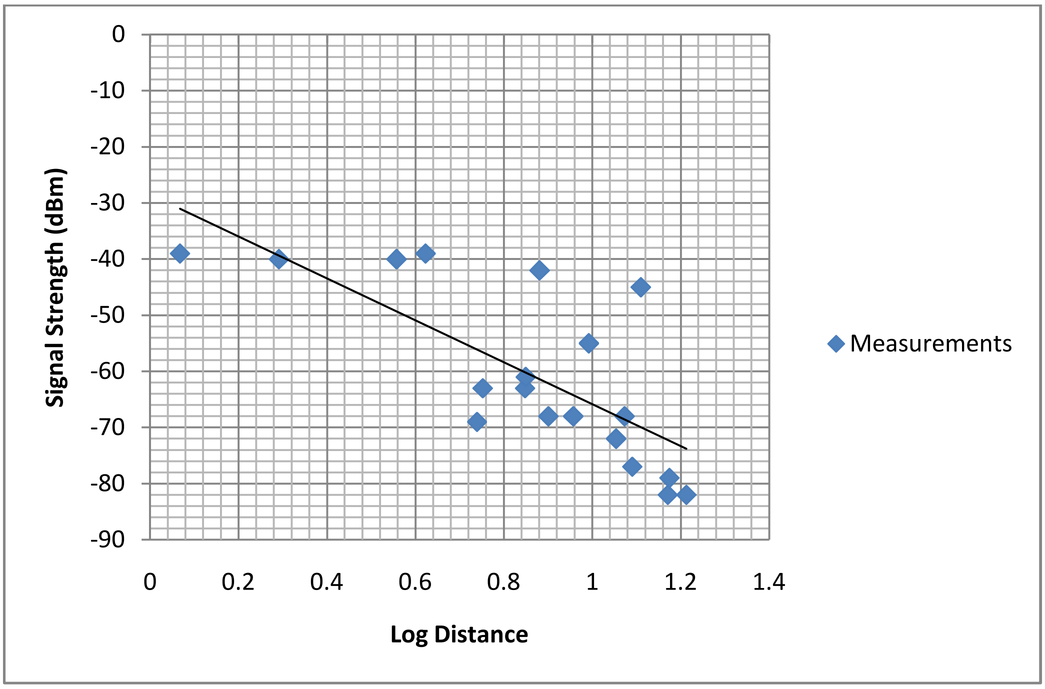


Figure 5.11: Measured data plot for the A 1st floor.

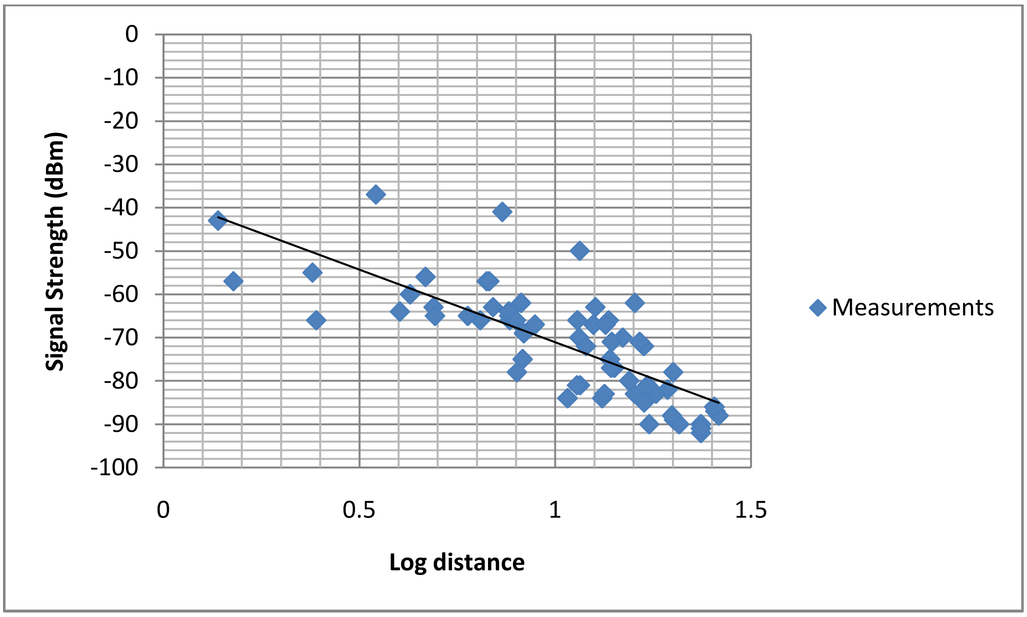


Figure 5.12: Measured data plot for the A 3rd floor.

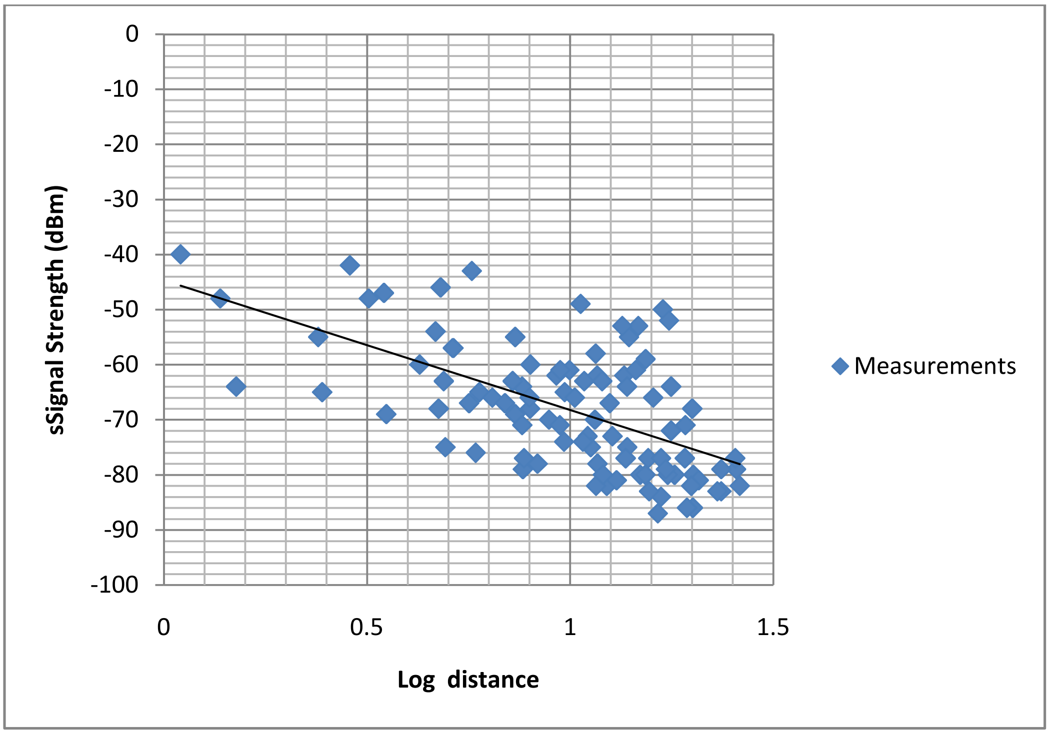


Figure 5.13: Measured data plot for the A 4th floor.

Figure (5.11) shows the measured data for the 1st floor and, figure (5.12) shows the measured data for the 3rd floor and, figure (5.13) shows the measured data for the 4th floor.

The standard deviation and the exponent path loss calculation of building-A for both the ITU equation (5.2)"ITU model" and our model equation (5.3) "AMA model" is shown in table (5.3).

Number of Floor	The path exponent ITU (n)	Standard deviation ITU (σ)	The path exponent AMA (n_0)	Standard deviation AMA (σ)
1st floor	4.48	10.43	2.56	3.64
3rd floor	4.9	9.3	3.14	5.37
4th floor	4.63	11.2	3.1	3.95

Table: 5.3: calculated standard deviation and the path loss exponent for A building.

The improvement in the standard deviation using the AMA model amounts to 65.1% for the 1st floor , 42.2% for the 3rd floor and 64.8 % for the 4rd floor.

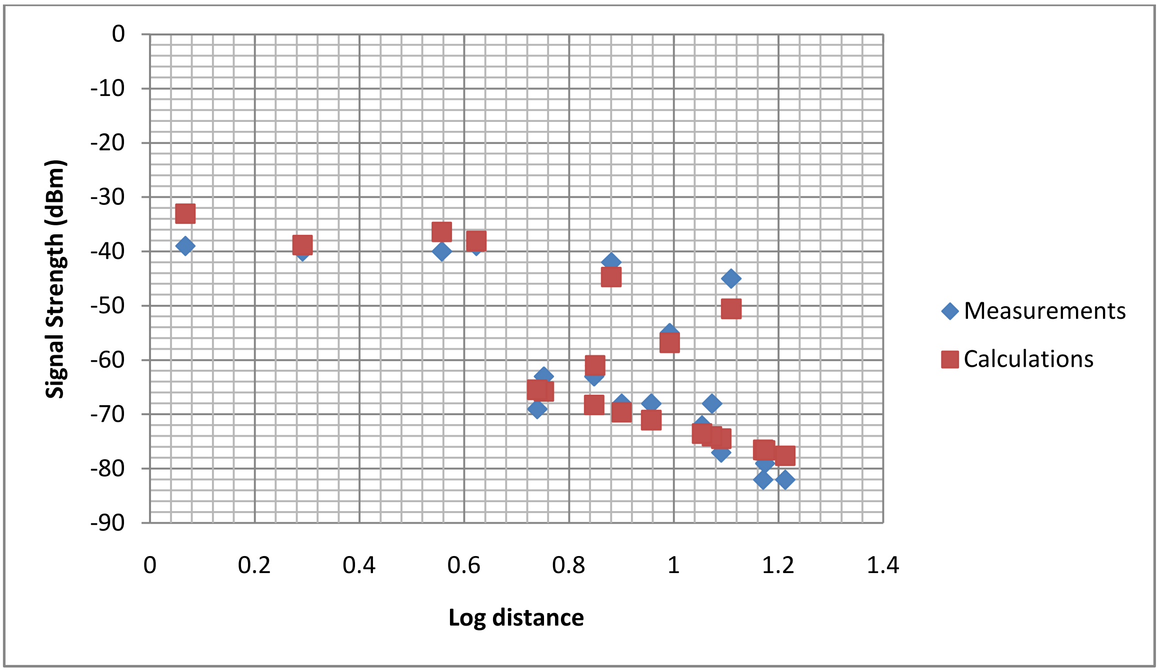


Figure 5.14: Measured and the calculated data plot for A 1st floor.

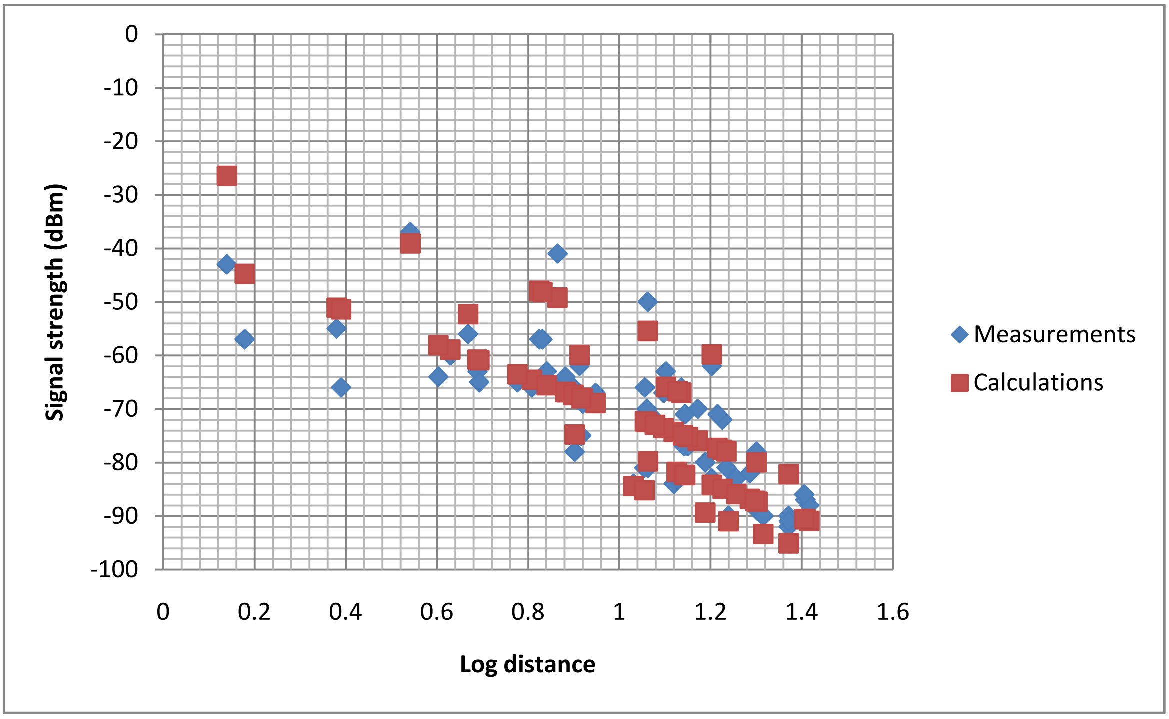


Figure 5.15: Measured and the calculated data plot for A 3rd floor.

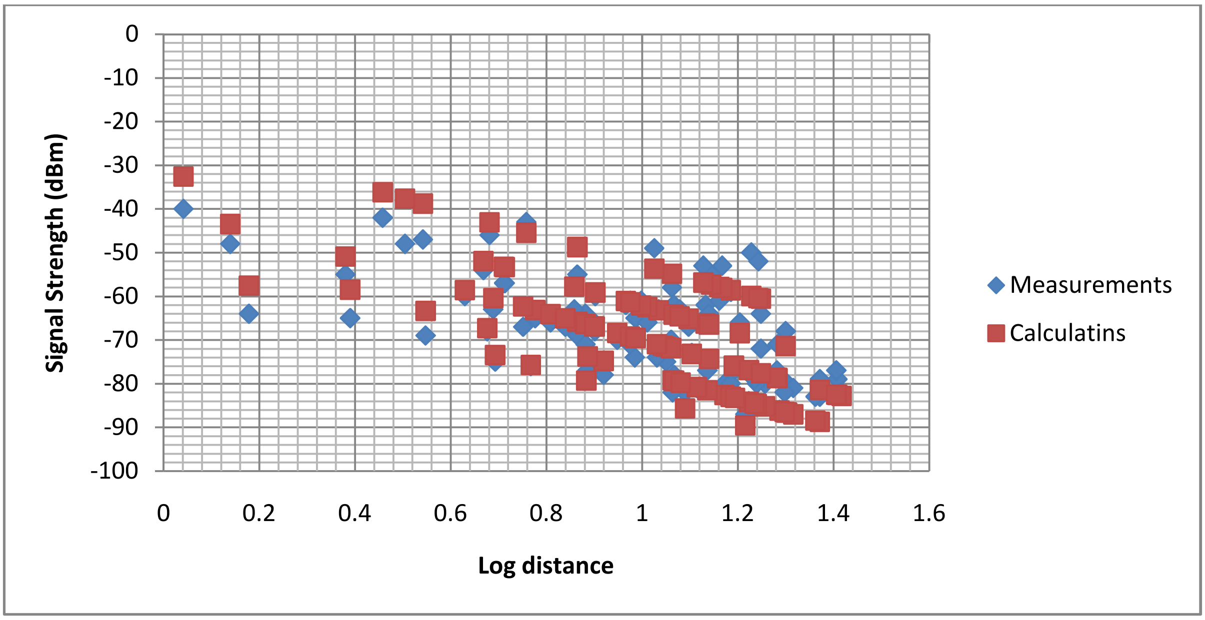


Figure 5.16: Measured and the calculated data plot for A 4th floor.

The above Figures (5.14, 5.15, and 5.16) show the measured data and the calculated data for the modified ITU. As we see the measurements values is very close to the values calculated by modified ITU model. Since modified ITU model contains the effect of walls between any test point and transmitter.

5.4.4 PPU Building C

For building C we took measurements in the three floors. For three access points in the 3rd, 2nd and the 1st for three different access points in each floor. All measurements are shown in appendix (D).

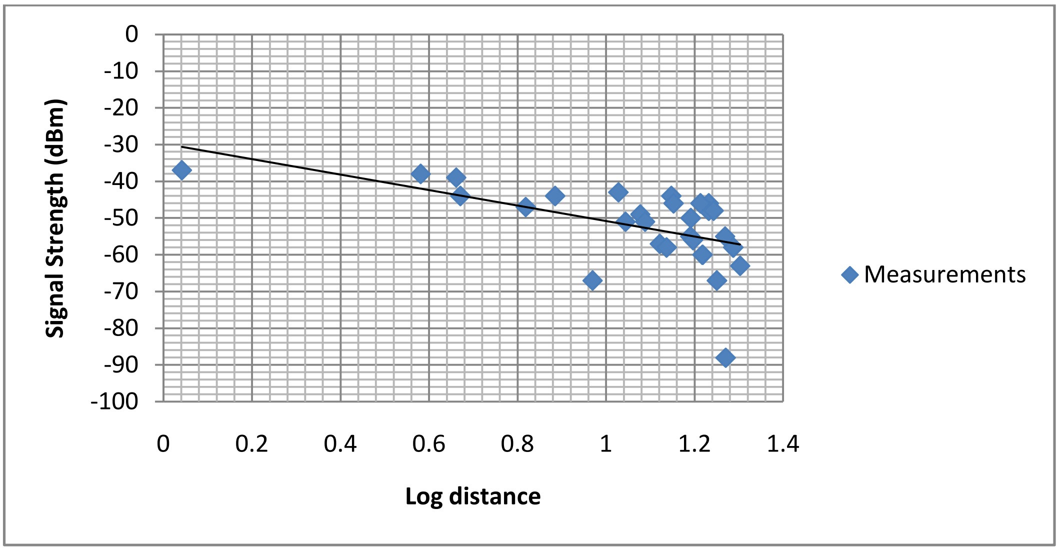


Figure 5.17: Measured data plot for the C 1st floor.

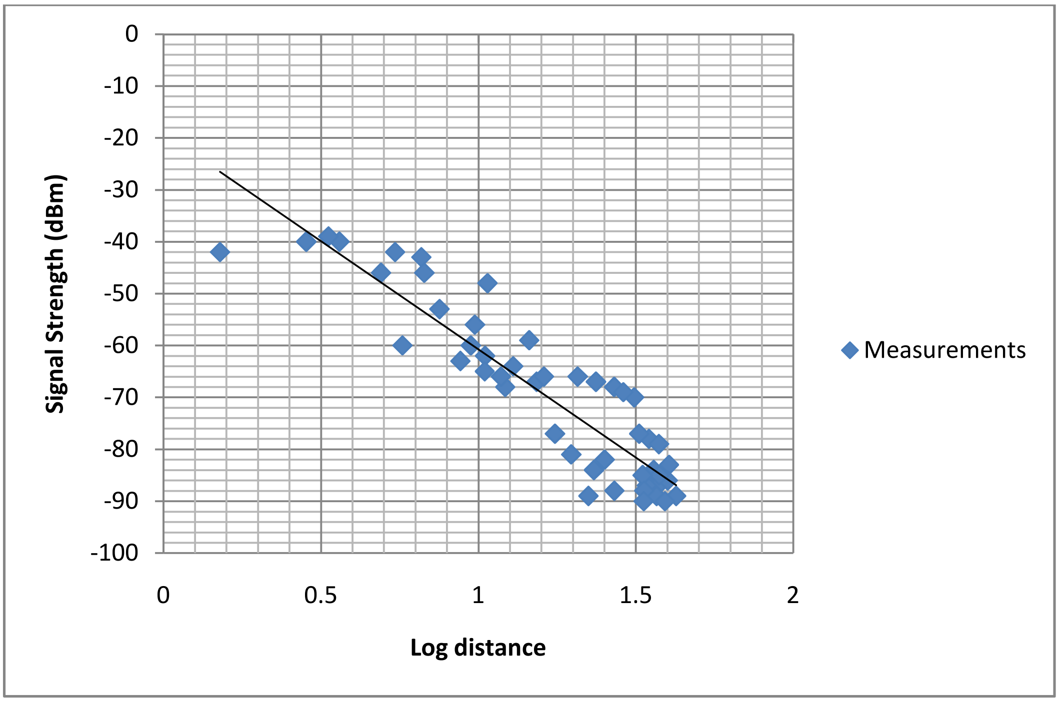


Figure 5.18: Measured data plot for the C 2nd floor.

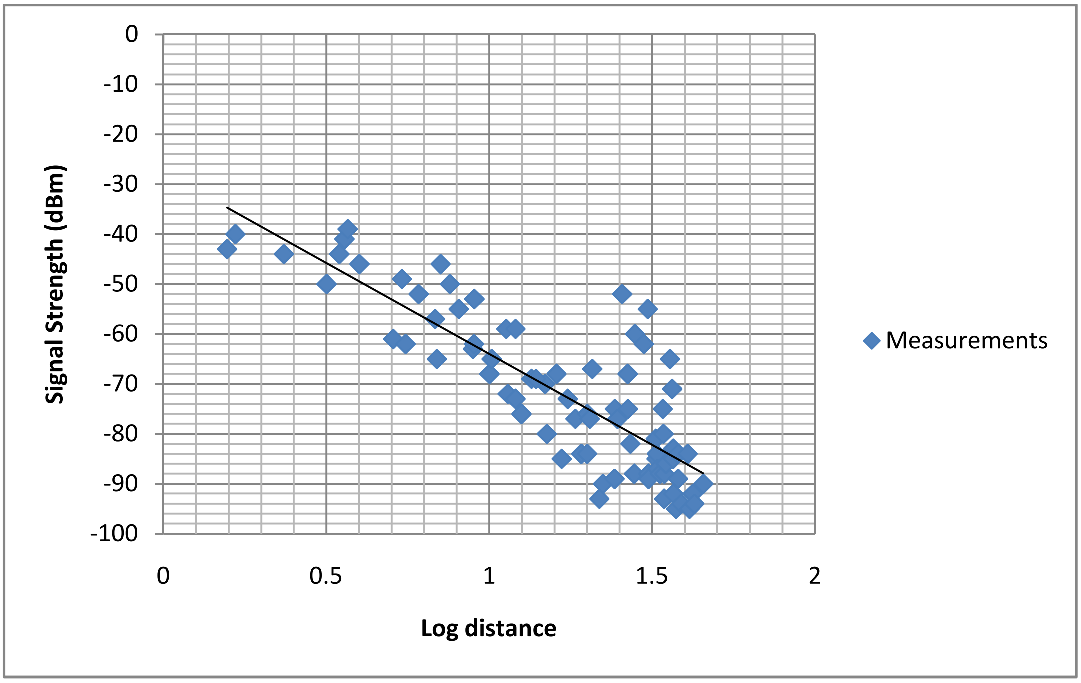


Figure 5.19: Measured data plot for the C 3rd floor.

Figure (5.17) shows the measured data for the 1st floor, figure (5.18) shows the measured data for the 2nd floor and, figure (5.19) shows the measured data for the 3rd floor. As we see average received power decreases logarithmically with distance.

Table 5.4 shows the results in the three floors of Building-C

Number of Floor	The path exponent ITU (n)	Standard deviation ITU (σ)	The path exponent AMA(n_0)	Standard deviation AMA (σ)
1st floor	2.8	9	2.16	5.07
2nd floor	3.9	6.63	2.4	2.41
3rd floor	4.1	8.85	2.64	3.45

Table: 5.4: calculated standard deviation and the path loss exponent for C building.

The improvement in the standard deviation , using the AMA model , amounts to 43.7% for the 1st floor , 63.7% for the 2nd floor and 61 % for the 3rd floor.

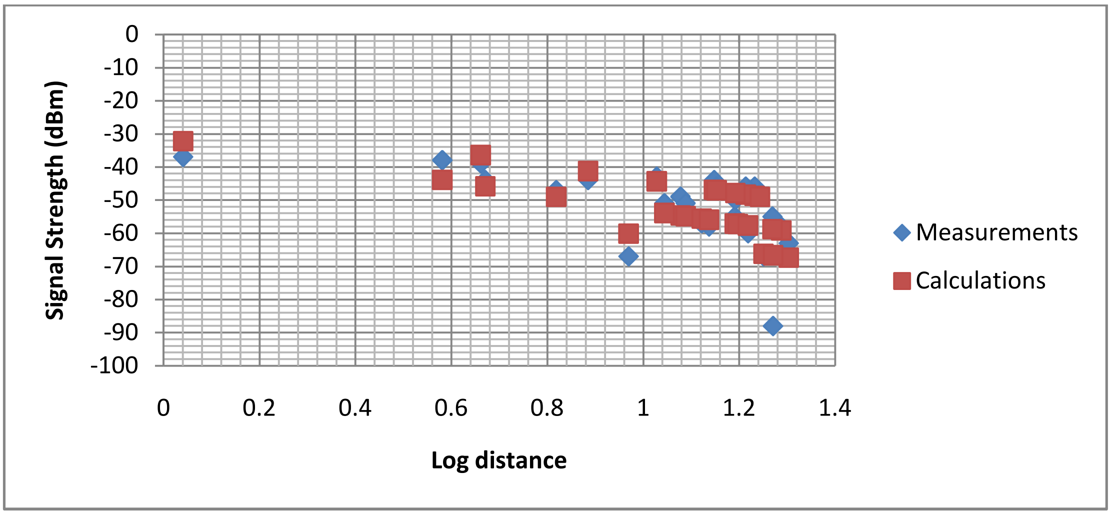


Figure 5.20: Measured and the calculated data plot for C 1st floor.

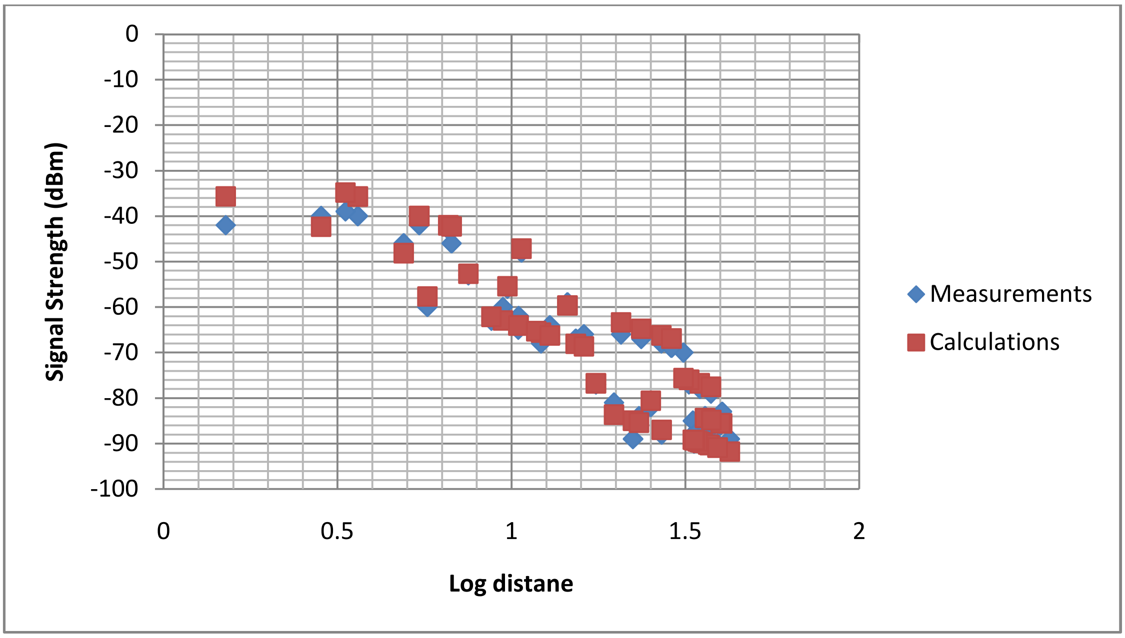


Figure 5.21: Measured and the calculated data plot for C 2nd floor.

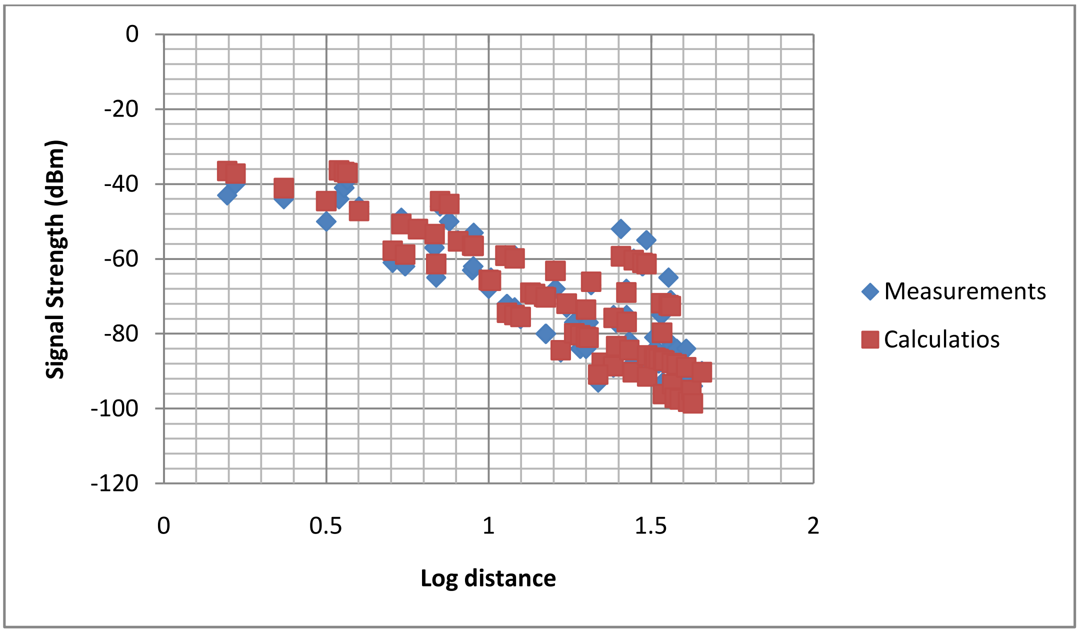


Figure 5.22: Measured and the calculated data plot for C 3rd floor.

The above figures (5.20,5.21,5.22) shows the measured calculated data , using the AMA model. As we see the measurements values are very close to those calculated by modified ITU model.

5.5 Multi-Floor analysis

We mean by multi-floor measurements that we take measurements for an access point in a floor while the measuring device is located in another. This is a one of the ITU model specification which is considered a multi-floor model. Because of that we gathered data from the four building that we investigated for multi-floor analysis and this data is shown in appendix(D).

For the data analysis add another term to the AMA model which is:

$$Pr\ dBm = Pt - 20Log_{10}f\ \ MHz - 10nLog_{10}d - X\alpha - Lf\ \ n + 28 \qquad (5.4)$$

Where: $Lf(n)$ is the multi-floor attenuation factor which is the subject of our investigation?

The data analysis and comparisons depended on the following equations [9]:

$$Lf\ \ n = 6 + 3\ \ n + 1 \qquad (5.5)$$

$$Lf\ \ n = 15 + 4(n - 1) \qquad (5.6)$$

Where:

n : Number of floors between the transmitter and receiver.

Equation (5.5) and (5.6) is an empirical constants from the ITU recommendation at frequency of 2.0 GHz dependent on the number of floors the waves need to penetrate. Where Equation (5.5) are often used for commercial area and Equation (5.6) are often used for office area.

Equation (5.5) indicates that the signal suffers a 6dB loss in case of one floor separation and 15dB in Equation (5.6) which is due to the floor height gain phenomena; which indicates that the floor attenuation factor decreases when the floor height increase. And since offices ceilings height is lower than commercial buildings ceilings the attenuation loss factor is higher in office areas.[19]

And the equation from Indoor Radio Propagation at 900 MHz & 2400 MHz Frequencies for building C model [20] .

$$Lf\ n = \begin{cases} 5n & \textit{for one floor separation} \\ 18\ n-1 & \textit{for two floor separation} \end{cases} \qquad (5.7)$$

After numerical tuning and analysis, we suggest the following equation:

$$Lf\ n = 12 + 7(n-1) \qquad (5.8)$$

5.5.1 Al-Ahli Hospital Multi-Floor Analysis

We did multi-floor analysis for Al Ahli hospital for <u>two floor separation</u> and the we calculated the standard deviation between the measurement and calculation for the four equations above (eq(5.5),(5.6),(5.7) and (5.8)). And the results were in table (5.5).

σ for eq (5.5) (dB)	σ for eq (5.6) (dB)	σ for eq (5.7) (dB)	σ for eq (5.8) (dB)
9.14	5.67	6.48	5.672

Table 5.5: standard deviation values for multi floor comparisons in Al-Ahli hospital.

From Table (5.5) we notice that eq (5.8) had the best performance. Which indicates that the Ahli hospital has similar construction to an office area structure which is convenient since both have a floor separation of 3-5m .

5.5.2 Abu Rumman

We did multi-floor analysis for Abu Rumman building for one floor separation and the we calculated the standard deviation between the measurement and calculation for the four equations above (eq(5.5),(5.6),(5.7) and (5.8)) . and the results were in table(5.6).

σ for eq (5.5) (dB)	σ for eq (5.6) (dB)	σ for eq (5.7) (dB)	σ for eq (5.8) (dB)
9.27	6.56	10.04	6.28

Table 5.6: standard deviation values for multi floor comparisons in Abu Rumman building.

From table (5.6) we notice that eq.(5.8) has the best performance.

5.5.3 PPU Building A

We did multi-floor analysis for A building for one and two floor separation and the we calculated the standard deviation between the measurement and calculation for the four equations above (eq(5.5),(5.6),(5.7) and (5.8)) . and the results were in Table (5.7).

Standard deviation	σ for eq (5.5) (dB)	σ for eq (5.6) (dB)	σ for eq (5.7) (dB)	σ for eq (5.8) (dB)
One floor separation	6.51	6.69	7.22	5.1
Two floor separation	13.48	6.07	6.51	6.07

Table 5.7: standard deviation values for multi floor comparisons in A building.

From table (5.7) we notice that eq(5.8) has the best performance.

5.5.4 PPU Building C Analysis

We did multi-floor analysis for C building for one and two floor separation and the we calculated the standard deviation between the measurement and calculation for the four equations above (eq.(5.5),(5.6),(5.7) and (5.8)). And the results were table(5.8).

Standard deviation	σ for eq. (5.5) (dB)	σ for eq. (5.6) (dB)	σ for eq. (5.7) (dB)	σ for eq. (5.8) (dB)
One floor separation	10.89	4.81	4.87	4.81
Two floor separation	8.68	4.11	9.58	3.93

Table 5.8: standard deviation values for multi floor comparisons in C building.

From table (5.8) we notice that eq(5.8) has the best performance.

5.5.5 Multi-floor Analysis Summary

Measurements was done in four difference building in Hebron. analysis and calculation of these measurements were done using the AMA model , were the modification in two cases of this model (Same Floor Multi-Floor), were we did numerical tuning in multiple floor case to generate equation of the multi-floors effects Lf(n).

The results for the multi floor measurement showed that the floor attenuation factor is conformable with office area floor attenuation factor. And that is because that structure of our investigated building is corresponding to an office area structure.

Our results after using AMA model in analysis and calculation of our extensive WLAN measurements its reduced the variance, were AMA model formula is:

$$\Pr(dBm) = Pt - 20Log_{10}f(MHz) - 10nLog_{10}d - \mathrm{Lf}(n) - X\alpha + 28 \quad (5.9)$$

Where: $Lf(n) = 12 + 7(n-1)$

The value of $Lf(n)$ obtained from the analysis above and which gave as the minimum standard deviation.

5.6 Results Summary

ITU model has been modified to reflect the effect of internal walls and their attenuation loss factor. In all floors of all buildings there was a very clear improvement in the standard deviation of the improved model compared to measurements. We also used numerical tuning in order to develop a new formula for the multi floor attenuation loss which has the minimum standard deviation.

CHAPTER SIX

Conclusion and future work

6.1 Introduction

A comprehensive study to the indoor wave propagation at 900 MHz and 2.4 GHz is presented . We proposed a model that described the indoor path loss in five selected building structures in Hebron city which attempts to generalize it for all similar building structures in Palestine. We focused on modeling the inner walls penetration loss and height gain and their effect on improving the standard deviation from the path loss mean. In this chapter we will present the conclusion of our entire work for GSM and wireless LAN analysis, and the future work that could be done on the project.

6.2 Model Presentation

We will discuss the steps that led to the development of the model, such as the effect of wall attenuation and the environment.

6.2.1 Internal Walls Effect

The model attempts to isolate the effect of penetration loss of inner walls, in the developed model, from the indoor measurements that indispensably take into account the effect of walls on indoor path loss. The penetration loss through inner walls affects the path loss exponent and consequently the signal power loss received and their standard deviation. We modeled a nonlinear best fit fourth power degree equation that related the effective penetration loss to the number of existing walls in the building floor for both GSM and wireless LAN frequencies.

The values of the average wall attenuation factors for GSM were shown in Table (3.6). The values of the average wall attenuation factors for wireless LAN were presented in Table (3.11).

The average wall attenuation factor could be used for all five buildings in wireless LAN and GSM analysis with a high confidence level. We have proven that the average standard deviation between the average wall attenuation factor and the wall attenuation factor for all buildings was 0.5 dB for wireless LAN and 1.5 dB for GSM . These values reveal a high confidence level.

6.2.2 Outer Wall Attenuation

Also in GSM and because we have an outside source another factor is presented which is the outer wall attenuation illustrate in table (6.1).

Building	PPU Building B	PPU Building A	PPU Building AbuRumman	Services Building	Al-Ahli Hospital
Outer wall attenuation loss	14 dB	12 dB	15 dB	16 dB	16 dB

Table 6.1: Outer wall attenuation

6.2.3 Floor attenuation factor

In wireless LAN analysis an important factor that affects the received signal strength is the floor attenuation factor Lf (n). After analysis that we did the derived formula is expressed in equation (5.8).

6.2.4 Modified ITU model (The AMA-Model)

$$L = 20Log_{10}f \;\; MHz \; + 10nLog_{10}d + L_{outer} + \chi_{\alpha} \;\; + Lf(n) + 28$$

Where:

f : Frequency in MHz

d : Distance in meter

L_{outer} : Attenuation loss factor for the outer wall

χ_{α} : Multi internal wall attenuation loss factor

$Lf(n)$: Multi-floor attenuation factor

X_{α} (dB) = $0.0032\, K^4 - 0.086\, K^3 - 0.17\, K^2 + 9.3\, K$ for WLAN

X_{α} (dB) = $0.0075\, K^4 - .018\, K^3 + 1.1\, K^2 + 2.9\, K$ for GSM

Lf (n)= 0 , for GSM external source

Lf (n)= $12 + 7(n-1)$, for WLAN internal source

L_{outer}= 0 , for internal source

6.3 Results Discussion

Our main objective was to come up with a general model that minimum relatively has a clearly reduced standard deviation. Our model reduced the average standard deviation in all investigated buildings by 50.6% for wireless LAN and by 40 % for GSM. So the model provides a very good representation to the indoor wave propagation in a wide sample of building structures, similar to our selected sample.

We have derived a formula for the floor separation attenuation factor Lf(n), and it worked out as 12 dB for one floor separation and 19 for two floor separations. . The relative improvement in the standard deviation over those used by published authors and previous research groups stands out amongst all others.

As expected, the wall attenuation factor is frequency dependant. Results showed that the wall attenuation factor is higher for wireless LAN which operate at frequency 2.4GHz than for GSM which operates at 900MHz frequency . This is recorded in Tables (3.6) and (3.11). For almost three times the frequency at WLAN compared to GSM, it is not surpassing that 5dB extra alternative per wall was measured at the higher frequency.

6.4 Future work

Indoor environments differ widely in the materials used for walls and floors, the layout of rooms, hallways, windows, and open areas, the location and material in obstructing objects, and the size of each room and the number of floors. All of these factors have a significant impact on path loss in an indoor environment. Thus, it is difficult to find generic models that can be accurately applied to determine empirical path loss in a specific indoor setting , . Despite that, we suggest the following for future work:

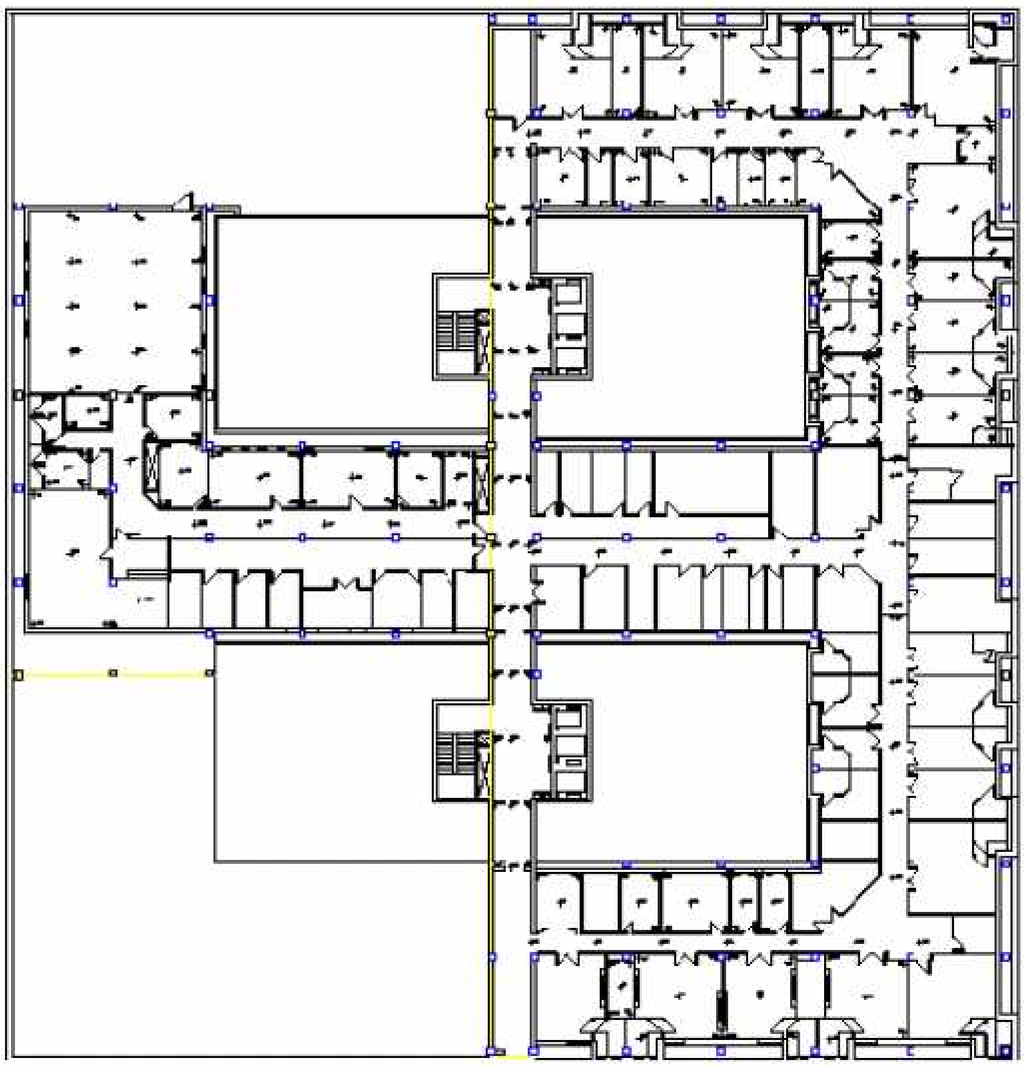
1- Apply the same analysis we have done on the selected buildings for the attenuation loss factor of internal walls for different types of materials such as gypsum, glass, etc...

2- Find a model that optimizes the location of the transmitter so as to ensure greater coverage in a certain building.

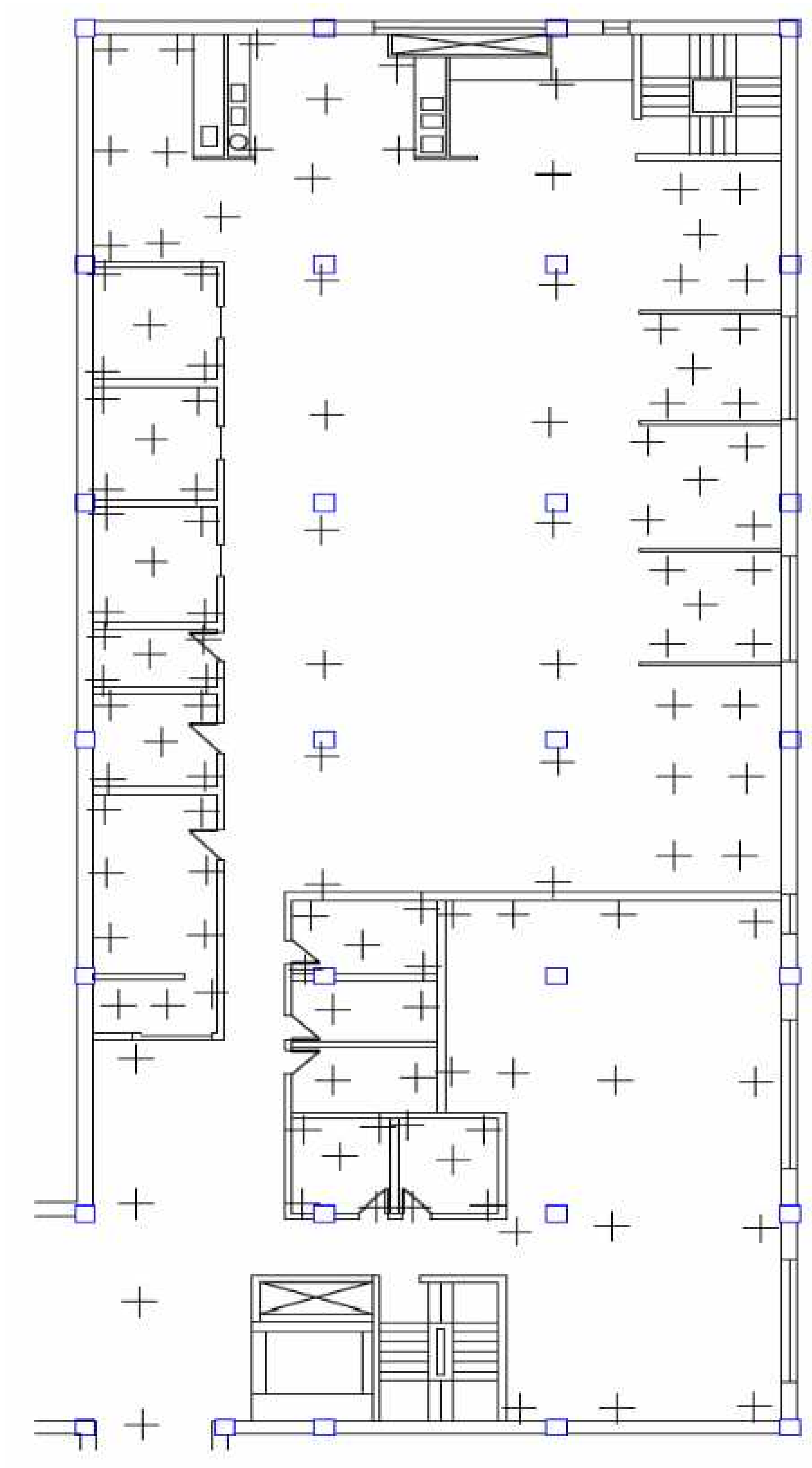
3- Floor height gain was studied on one building only. Building B results reveal improvement of standard deviation of path loss with height gain.

Sampeles From Autocad Files Of Buldings

AL-Ahli Hospital Building Thrid Floor

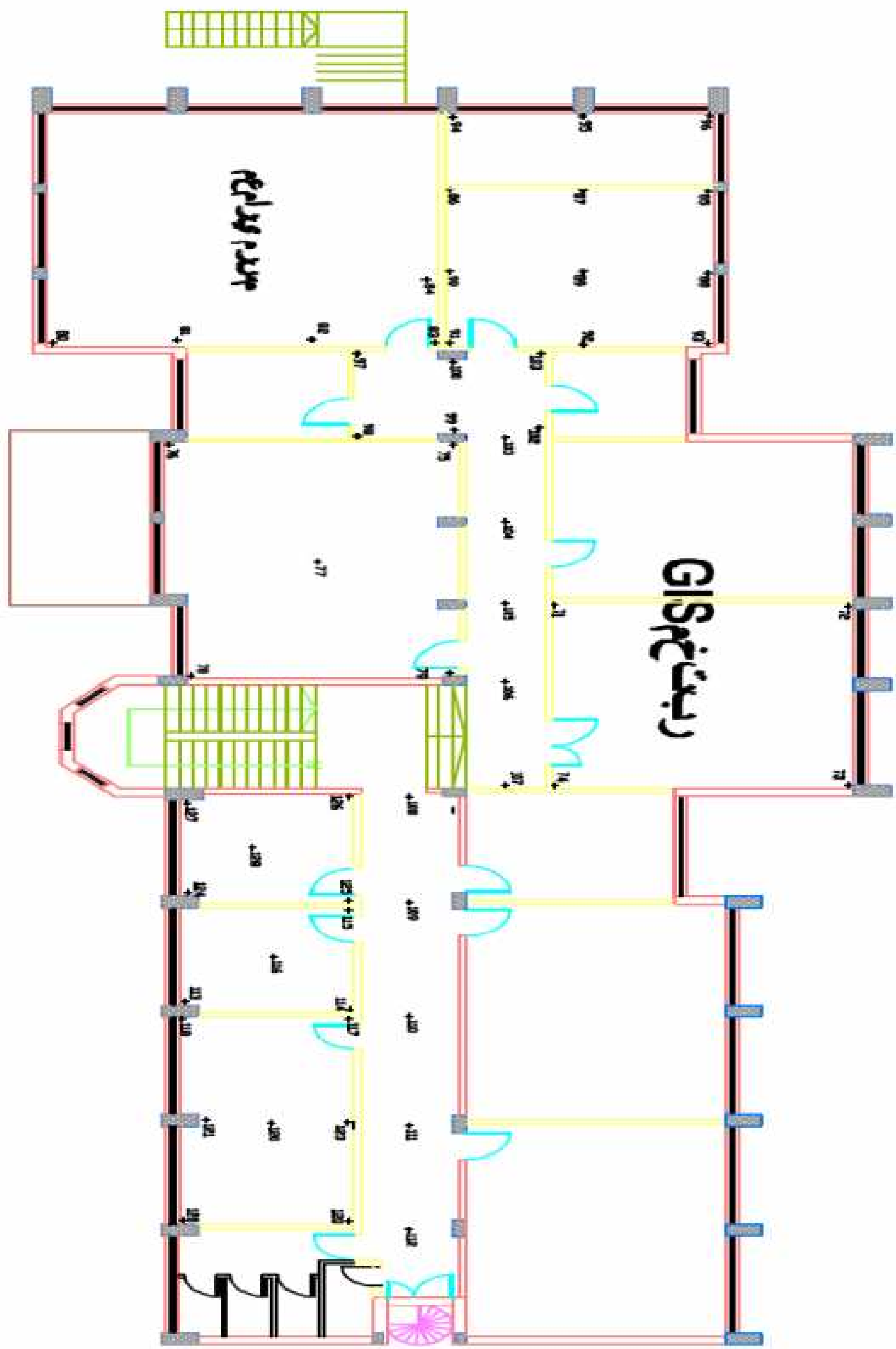


Service Building Second Floor

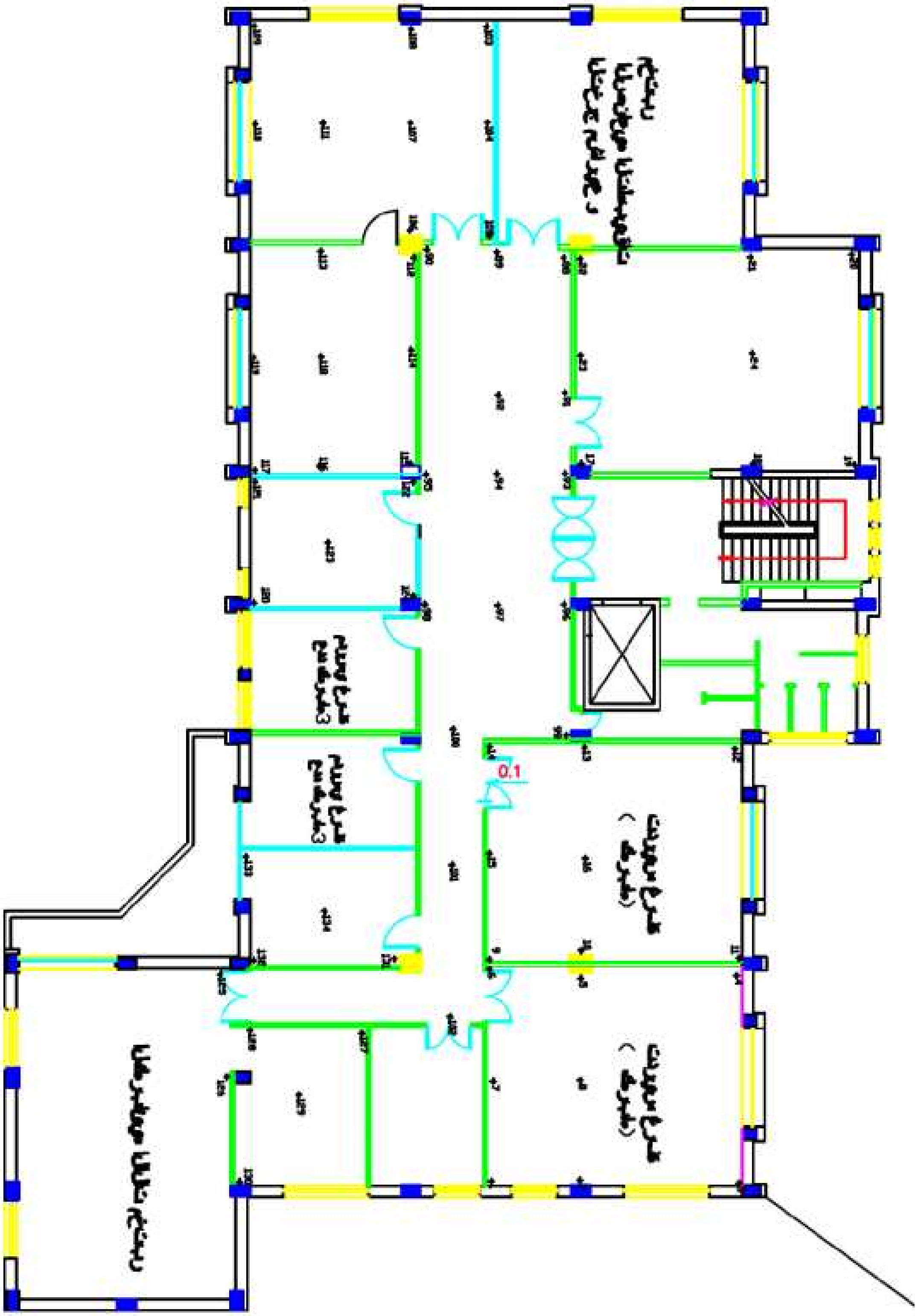


PPU Abu Ruman Building Second Floor

PPU Building A



PPU Building B



APPENDIX A

APPENDIX B

SAMPLES OF CALCULATIONS IN GSM (900MHZ)

Samples from AL-Ahli Hospital Building

AL-Ahli AL-Ahli Third Floor

Point	Measured power	No. of Walls	AMA-Model	ITU-Model
1	-35.1367	0	-48.09407102	-48.09407102
2	-43.8765	0	-47.76328284	-47.76328284
3	-53.4013	1	-52.25681654	-48.43211654
4	-53.2197	1	-52.79202375	-48.96732375
5	-52.6667	2	-57.95376476	-49.11856476
6	-49.1355	2	-57.63388846	-48.79868846
7	-69.6176	3	-68.74700366	-54.62630366
8	-76	3	-68.20379502	-54.08309502
9	-64.8132	4	-69.81063503	-50.92743503
10	-65.9423	4	-69.53670842	-50.65350842
11	-75.4577	5	-72.9030027	-50.4655027
12	-63.6043	5	-73.41321266	-50.97571266
13	-65	6	-75.68627579	-51.47507579
14	-66.6561	6	-75.65314093	-51.44194093
15	-76.6292	7	-75.65268409	-51.90798409
16	-84.15	7	-75.23778758	-51.49308758
	Variance		7.545272499	13.40793806

AL-Ahli AL-Ahli Second Floor

Point	Measured power	No. of Walls	AMA-Model	ITU-Model
1	-58.431	0	-51.6431	-51.6431
2	-60.2	0	-51.369	-51.369
3	-67.3158	1	-56.7568	-52.9321
4	-59.5333	1	-56.4915	-52.6668
5	-71.1379	2	-62.7698	-53.9346
6	-59.6744	2	-62.0059	-53.1707

7	-74.1416	3	-70.8162	-56.6955
8	-68.7733	3	-70.1683	-56.0476
9	-87	4	-77.4628	-58.5796
10	-71.2071	4	-77.0412	-58.158
11	-73.1786	5	-75.7379	-53.3004
12	-82.6667	5	-76.1635	-53.726
13	-63	6	-82.8465	-58.6353
14	-71.1538	6	-83.1707	-58.9595
15	-93.1638	7	-82.2523	-58.5076
16	-83.4082	7	-81.6702	-57.9255
17	-78	8	-80.1295	-59.4383
18	-74	8	-80.8658	-60.1746
19	-76.8203	9	-69.0997	-54.283
20	-72.5714	9	-69.6625	-54.8458
21	-76	10	-65.4084	-59.4084
22	-73	10	-65.0131	-59.0131
	Variance		11.68997	16.03313

AL-Ahli AL-Ahli First Floor

Point	Measured power	No. of Walls	AMA-Model	ITU-Model
1	-48.6125	0	-54.6367	-54.6367
2	-42.2353	0	-54.563	-54.563
3	-57.6667	2	-65.1496	-56.3144
4	-63.3879	2	-65.0992	-56.264
5	-70.7778	3	-70.4064	-56.2857
6	-79.575	3	-70.2216	-56.1009
7	-78.5745	5	-80.6581	-58.2206
8	-73.4219	5	-80.2253	-57.7878
9	-78.29	6	-86.091	-61.8798
10	-72.1798	6	-86.1182	-61.907
11	-62.9531	7	-79.5367	-55.792
12	-77.0735	7	-80.5643	-56.8196
13	-76.6458	8	-78.0232	-57.332
14	-75.6857	8	-77.8966	-57.2054
15	-89.3592	9	-72.2421	-57.4254
16	-86.495	9	-72.1767	-57.36
17	-77.6265	10	-61.6621	-55.6621
18	-80.8261	10	-61.6562	-55.6562

Samples from Abu Ruman Building

Abu Ruman Third Floor

Point	Measured power	No. of Walls	AMA-Model	ITU-Model
1	-77.1923	0	-68.4394	-68.4394
2	-70.4267	0	-68.4079	-68.4079
3	-79.5882	1	-72.3932	-68.5685
4	-80.5729	1	-72.3585	-68.5338
5	-77.8226	2	-77.5304	-68.6952
6	-68.5405	2	-77.4946	-68.6594
7	-83.0992	3	-83.5318	-69.4111
8	-77.2125	3	-83.4889	-69.3682
9	-78.5495	4	-88.3802	-69.497
10	-80.7755	4	-88.337	-69.4538
	Variance		6.44672	7.6763022

Abu Ruman Second Floor

Point	Measured power	No. of Walls	AMA-Model	ITU-Model
1	-69.2258	0	-69.7432	-69.7432
2	-69.8411	0	-69.7783	-69.7783
3	-80.7286	1	-73.676	-69.8513
4	-79.65	1	-73.7099	-69.8852
5	-70.5056	2	-78.8855	-70.0503
6	-65.733	2	-79.0037	-70.1685
7	-72.7692	3	-83.99	-69.8693
8	-73.7523	3	-83.9559	-69.8352
9	-87	5	-93.0489	-70.6114
10	-90.2667	6	-94.8891	-70.6779
11	-87.175	6	-94.686	-70.4748
	Variance		7.715752	9.122039

Abu Ruman First Floor

Point	Measured power	No. of Walls	AMA-Model	ITU-Model
1	-55.0088	0	-61.8482	-61.8482
2	-60.5818	0	-61.8816	-61.8816
3	-56.4969	0	-61.9109	-61.9109
4	-69.1047	0	-61.8614	-61.8614
5	-54.4125	0	-61.8075	-61.8075
6	-69.5821	0	-61.9646	-61.9646
7	-67.1692	0	-61.9359	-61.9359
8	-76.1163	1	-65.8191	-67.5286
9	-68.0678	1	-65.8836	-67.5931
10	-68.1111	1	-65.9438	-67.6533
11	-66.1277	1	-66.0168	-67.7263
12	-78.8824	1	-66.0811	-67.7906
	Variance		7.865903	8.36574723

Samples from Service Building

Service Building Third Floor

Point	Measured power	No. of Walls	AMA-Model	ITU-Model
1	-35	0	-34.5953	-34.5953
2	-42.5867	0	-35.2232	-35.2232
3	-37.0612	0	-36.0799	-36.0799
4	-35.3721	0	-35.6134	-35.6134
5	-35.381	0	-36.211	-36.211
6	-42.5926	0	-30.7142	-30.7142
7	-37.6545	0	-37.4775	-37.4775
8	-42.8837	2	-40.6859	-37.6507
9	-51.7	2	-41.4166	-38.3814
10	-41.2222	2	-41.8969	-38.8617
11	-47.8545	2	-42.2128	-39.1776
12	-45.9024	2	-42.4563	-39.4211
	Variance		4.589721	5.538141

Service Building Second Floor

Point	Measured power	No. of Walls	AMA-Model	ITU-Model
1	-40.2857	0	-34.0024	-34.0024
2	-45.5862	0	-35.915	-35.915
3	-38.4412	0	-37.6242	-37.6242
4	-59.4419	1	-43.963	-40.1383
5	-52.7321	1	-44.407	-40.5823
6	-43.8537	1	-42.9486	-39.1239
7	-48.0345	2	-48.6044	-39.7692
8	-44.125	2	-49.3544	-40.5192
9	-47.1111	2	-49.2906	-40.4554
10	-51.1875	3	-55.1847	-41.064
11	-52.6552	3	-55.5284	-41.4077
12	-45.1778	3	-56.2454	-42.1247
	Variance		5.638979	6.101825711

Service Building First Floor

Point	Measured power	No. of Walls	AMA-Model	ITU-Model
1	-53.5098	0	-45.9433	-45.9433
2	-45.9767	0	-47.0388	-47.0388
3	-43.9643	0	-44.6072	-44.6072
4	-39.6897	0	-46.6536	-46.6536
5	-39.5	0	-47.5536	-47.5536
6	-36.5789	0	-46.1106	-46.1106
7	-52	1	-54.2995	-50.4748
8	-48.5238	1	-53.6659	-49.8412
9	-59.5556	1	-54.8911	-51.0664
10	-58.4	1	-55.0959	-51.2712
11	-66.9259	2	-58.4437	-49.6085
12	-64.6667	2	-50.4732	-41.638
13	-63.2593	2	-57.1872	-48.352
14	-59.1053	2	-57.4707	-48.6355
	Variance		6.419908	9.249057331

Samples from PPU Building A

PPU Building A Fourth Floor

Point	Measured power	No. of Walls	AMA-Model	ITU-Model
1	-57.78	0	-51.8597	-51.8597
2	-56.7377	0	-51.9078	-51.9078
3	-53	0	-51.9589	-51.9589
4	-69.3	1	-55.7141	-51.8894
5	-62.175	1	-55.7635	-51.9388
6	-56.4848	1	-55.8121	-51.9874
7	-70	2	-60.7335	-51.8983
8	-58.4203	2	-60.7259	-51.8907
9	-68	3	-66.0705	-51.9498
10	-80	3	-66.1125	-51.9918
11	-71.0566	3	-66.1651	-52.0444
12	-65.345	4	-71.3518	-52.4686
13	-68.8929	4	-71.2957	-52.4125
14	-75	4	-71.276	-52.3928
	Variance		7.370808	14.00357

PPU Building A Third Floor

Point	Measured power	No. of Walls	AMA-Model	ITU-Model
1	-58.3846	0	-56.4319	-56.4319
2	-65.8043	0	-56.3893	-56.3893
3	-66.0385	0	-56.2333	-56.2333
4	-64.2157	1	-60.287	-56.4623
5	-68.7143	1	-60.2843	-56.4596
6	-57.1667	1	-60.4019	-56.5772
7	-73.325	2	-65.1882	-56.353
8	-69.137	2	-65.1525	-56.3173
9	-69.0556	2	-65.1219	-56.2867
10	-76.925	3	-70.4938	-56.3731
11	-75.0952	3	-70.5591	-56.4384
12	-78.1053	3	-70.5883	-56.4676
13	-77.8571	4	-75.6214	-56.7382
14	-74.3611	4	-75.6908	-56.8076

15	-74.1932	4	-75.7565	-56.8733
16	-71.2	5	-79.1767	-56.7392
17	-74.1538	5	-79.1157	-56.6782
18	-72.7952	5	-79.1521	-56.7146
	Variance		6.978664347	13.28377598

PPU Building A Second Floor

Point	Measured power	No. of Walls	AMA-Model	ITU-Model
1	-74.4762	0	-63.6546	-63.6546
2	-79.4118	0	-63.5984	-63.5984
3	-65.1895	0	-62.9348	-62.9348
4	-78.1053	1	-68.2059	-63.5559
5	-82.8974	1	-68.1574	-63.5074
6	-82.35	1	-68.077	-63.427
7	-87.75	2	-72.52	-63.52
8	-88.0645	2	-72.4434	-63.4434
9	-89.58	2	-72.5172	-63.5172
10	-77.6154	3	-76.6405	-63.5905
11	-76.6061	3	-76.6486	-63.5986
12	-86.2778	3	-76.6255	-63.5755
13	-78.6557	4	-80.423	-63.623
14	-76	4	-80.4032	-63.6032
15	-69.1739	4	-80.4878	-63.6878
16	-77.6923	5	-84.0144	-63.7644
17	-82.75	5	-83.9978	-63.7478
18	-83.0227	5	-84.0678	-63.8178
	Variance		8.492503	13.08049

PPU Building A First Floor

Point	Measured power	No. of Walls	AMA-Model	ITU-Model
1	-89.9512	0	-71.6881	-71.6881
2	-79.8235	0	-71.6959	-71.6959
3	-78.4923	0	-71.7178	-71.7178
4	-76.1111	1	-75.7579	-71.9332
5	-85.3158	1	-75.8067	-71.982
6	-89.0435	1	-75.8403	-72.0156
7	-84.2083	2	-80.6327	-71.7975

8	-86.3333	2	-80.6834	-71.8482
9	-87.1471	2	-80.706	-71.8708
10	-86.1795	3	-86.18	-72.0593
11	-83.7674	3	-86.2302	-72.1095
12	-82.975	3	-86.2037	-72.083
13	-87.4792	4	-90.5804	-71.6972
14	-86.1628	4	-90.5385	-71.6553
15	-79.0154	4	-90.5027	-71.6195
16	-83.4	5	-94.1132	-71.6757
17	-85.0789	5	-94.1737	-71.7362
18	-84.1765	5	-94.3338	-71.8963
	Variance		14.09595	15.82861

Samples from PPU Building B

PPU Building B Fifth Floor

Point	Measured power	No. of Walls	AMA-Model	ITU-Model
1	-55.3704	0	-60.2059	-60.2059
2	-59.3636	0	-60.1705	-60.1705
3	-67.2407	0	-60.1055	-60.1055
4	-62.8372	1	-64.0954	-60.2707
5	-58.5833	1	-64.0614	-60.2367
6	-58.037	1	-64.1262	-60.3015
7	-72.88	2	-69.2151	-60.3799
8	-62.7414	2	-69.1485	-60.3133
9	-67.1515	2	-69.2825	-60.4473
10	-74.4855	3	-74.7545	-60.6338
11	-81.5405	3	-74.7256	-60.6049
12	-72.1724	3	-74.6991	-60.5784
13	-79.2892	4	-79.3882	-60.505
14	-74.5714	4	-79.4258	-60.5426
15	-80.2895	4	-79.2569	-60.3737
	Variance		5.680886	12.0234

PPU Building B Fourth Floor

Point	Measured power	No. of Walls	AMA-Model	ITU-Model
1	-67.1351	0	-62.5288	-62.5288
2	-60	0	-62.5916	-62.5916
3	-69.6753	0	-62.5943	-62.5943
4	-70.9667	1	-67.285	-62.635
5	-67.3333	1	-67.3305	-62.6805
6	-74.5882	1	-67.3751	-62.7251
7	-77.2857	2	-71.7364	-62.7364
8	-72.3864	2	-71.83	-62.83
9	-74.7692	2	-71.7845	-62.7845
10	-73.3614	3	-75.8101	-62.7601
11	-76.9302	3	-75.844	-62.794
12	-70.9706	3	-75.8832	-62.8332
13	-71.5319	4	-79.6634	-62.8634
14	-75.1026	4	-79.7481	-62.9481
15	-77.9615	4	-79.8132	-63.0132
	Variance		8.586739	12.04331

PPU Building B Third Floor

Point	Measured power	No. of Walls	AMA-Model	ITU-Model
1	-63.8657	0	-61.0034	-61.0034
2	-60.0638	0	-61.0357	-61.0357
3	-61.3673	0	-61.0661	-61.0661
4	-75.9394	1	-65.0057	-61.181
5	-67.5745	1	-64.9542	-61.1295
6	-76.4565	1	-64.9782	-61.1535
7	-69.7451	2	-70.004	-61.1688
8	-74.8537	2	-70.0521	-61.2169
9	-62.0508	2	-70.0401	-61.2049
10	-72.2679	3	-75.4037	-61.283
11	-73.8958	3	-75.4319	-61.3112
12	-73.7288	3	-75.4299	-61.3092
13	-80.3684	4	-80.2299	-61.3467
14	-72.8889	4	-80.2588	-61.3756
15	-73.2903	4	-80.3221	-61.4389
	Variance		6.683656	11.30285

PPU Building B Second Floor

Point	Measured power	No. of Walls	AMA-Model	ITU-Model
1	-80	0	-71.716	-71.716
2	-79.5714	0	-71.7822	-71.7822
3	-79	0	-71.7249	-71.7249
4	-77.9655	1	-75.7363	-71.9116
5	-80.8451	1	-75.782	-71.9573
6	-75.54	1	-75.8328	-72.0081
7	-79.3235	2	-80.6982	-71.863
8	-89.125	2	-80.7195	-71.8843
9	-84.8684	2	-80.591	-71.7558
10	-80.7692	3	-85.8001	-71.6794
11	-88.871	3	-86.0315	-71.9108
12	-83.0189	3	-86.075	-71.9543
13	-79.6271	4	-90.6334	-71.7502
14	-81.7841	4	-90.6552	-71.772
15	-86.9706	4	-90.7307	-71.8475
	Variance		8.019301	11.06895

PPU Building B First Floor

Point	Measured power	No. of Walls	AMA-Model	ITU-Model
1	-77.9655	0	-71.9116	-71.9116
2	-80.8451	0	-71.9573	-71.9573
3	-75.54	0	-72.0081	-72.0081
4	-84.8684	1	-75.5805	-71.7558
5	-74.5227	1	-75.6013	-71.7766
6	-78.4706	1	-75.6233	-71.7986
7	-86.9706	2	-80.6827	-71.8475
8	-87.1064	2	-80.7326	-71.8974
9	-82.825	2	-80.8256	-71.9904
10	-83.1132	3	-86.2375	-72.1168
11	-78.25	3	-86.1899	-72.0692
12	-85.4688	3	-86.1656	-72.0449
13	-90.1053	4	-90.8471	-71.9639
14	-85.2308	4	-90.882	-71.9988
15	-93.102	4	-90.9154	-72.0322
	Variance		7.603888	11.06895

APPENDIX C

OUTDOOR MEAUREMENTS

PPU Building A

Distance	Log (d)	Measured Power(dBm)
270	2.43136376	-62.2642
290	2.462398	-59.56
310	2.49136169	-68
480	2.68124124	-68.0641
490	2.69019608	-72.971
560	2.74818803	-69.6875
575	2.75966784	-68
590	2.77085201	-69.9839
610	2.78532984	-71.6098
630	2.79934055	-74.0145

PPU Building B

Distance	Log (d)	Measured Power
92	1.96378783	-50.2105
126	2.10037055	-49.0805
168	2.22530928	-49.59
270	2.43136376	-57.8889
312	2.49415459	-54.7435
450	2.65321251	-58.4521
500	2.69897	-53.6707
514	2.71096312	-66.4808

PPU Building Abu Rumman

Distance	Log (d)	Measured Power
268	2.42813479	-54.7105
280	2.44715803	-63.6923
370	2.56820172	-68.1017
476	2.67760695	-51.3469
551	2.7411516	-65.0924
600	2.77815125	-68.9524

APPENDIX D

SAMEPLES FROM FLOOR CALCULATIONS IN WLAN (2.4GHZ)

Samples From Al-Ahli Hospital Building

Al-Ahli Second Floor

Point	Measurements	No. Of Walls	AMA- Model	ITU- Model
1	-37	0	-36.0157	-38.0182
2	-44	0	-38.179	-41.6832
3	-27	1	-21.5515	-13.5135
4	-27	1	-13.0845	-14.8062
5	-46	2	-43.4458	-66.2431
6	-46	2	-43.8136	-66.8663
7	-81	3	-74.4093	-67.9092
8	-45	3	-64.4563	-60.5516
9	-75	4	-69.0035	-68.2552
10	-74	4	-68.0407	-66.6241
11	-76	4	-68.4513	-67.3197
12	-48	5	-47.5483	-31.9067
13	-78	5	-74.6362	-68.2936
	Standard Deviation		9.855871	12.06928

Al-Ahli Ground Floor

Point	Measurements	No. Of Walls	AMA- Model	ITU-Model
1	-40	0	-32.1862	-45.1159
2	-40	0	-41.3419	-59.7567
3	-52	1	-56.8697	-69.8275
4	-56	1	-59.8723	-74.6288
5	-62	2	-64.3424	-69.224
6	-59	2	-58.1842	-59.3766
7	-72	3	-74.5403	-73.8741
8	-75	3	-74.7356	-74.1864
9	-80	4	-80.9212	-75.1069
10	-82	4	-84.2474	-80.4257
11	-85	5	-84.8506	-75.8893
12	-83	5	-85.7917	-77.3943
	Standard Deviation		4.48785	11.60044

Samples From PPU Abu Ruman Building

Abu Ruman Second Floor

Point	Measurements	No. Of Walls	AMA-Model	ITU-Model
1	-56	0	-49.7186	-63.9486
2	-45	0	-41.8583	-52.0378
3	-65	1	-62.5301	-69.3757
4	-66	1	-69.9953	-80.6879
5	-80	2	-77.4884	-80.147
6	-85	2	-82.6659	-87.9926
7	-93	3	-95.8535	-96.9293
8	-95	3	-96.1984	-97.452
9	-100	4	-102.243	-98.11
10	-100	4	-101.973	-97.7016
11	-100	5	-103.589	-94.938
12	-100	5	-104.097	-95.7066
	Standard Deviation		4.9799	8.267323

Abu Ruman Third Floor

Point	Measurements	No. OF Walls	AMA-Model	ITU-Model
1	-67	0	-56.3484	-72.4665
2	-61	0	-68.5904	-90.4706
3	-62	1	-65.3976	-72.2006
4	-77	1	-74.8655	-86.1248
5	-78	2	-77.8384	-78.9521
6	-86	2	-85.526	-90.2582
7	-78	3	-81.756	-73.9925
8	-89	3	-94.6016	-92.8842
9	-95	4	-96.3612	-87.2216
10	-94	4	-98.2977	-90.0694
11	-90	5	-92.8646	-77.02
12	-90	5	-91.4068	-74.876
13	-100	6	-103.682	-90.0464
14	-100	6	-103.116	-89.214
	Standard Deviation		4.14428	11.29733

Abu Ruman Fourth Floor

Point	Measurements	No. Of Walls	AMA-Model	ITU-Model
1	-51	0	-45.5355	-55.4656
2	-45	0	-31.9502	-36.1229
3	-60	1	-61.0381	-64.3964
4	-67	1	-61.7088	-65.3514
5	-75	2	-71.726	-68.437
6	-77	2	-74.3965	-72.2392
7	-80	3	-84.3199	-75.9888
8	-84	3	-87.5853	-80.638
9	-94	4	-94.2715	-82.1703
10	-100	4	-102.716	-94.193
	Standard Deviation		5.094239	7.735488

Samples From PPU Building A

Building A First Floor

Point	Measurements	No. Of Walls	AMA- Model	ITU-Model
1	-40	0	-36.3996	-47.0665
2	-39	0	-38.0853	-50.0099
3	-39	1	-33.071	-25.1369
4	-40	1	-38.8102	-35.1585
5	-61	2	-60.9791	-60.1617
6	-79	3	-76.598	-74.7055
7	-72	3	-73.5093	-69.312
	Standard Deviation		3.637832	10.42787

Building A Second Floor

Point	Measurements	No. Of Walls	AMA-Model	ITU-Model
1	-43	0	-26.467	-28.9055
2	-37	0	-39.0937	-48.59
3	-62	1	-59.9636	-66.736
4	-67	1	-66.7141	-77.2596

5	-70	2	-75.9411	-79.4062
6	-69	2	-68.0258	-67.0667
7	-88	3	-87.1779	-85.559
8	-86	3	-90.5685	-90.8448
9	-90	4	-90.9661	-82.719
10	-91	4	-95.1003	-89.164
	Standard Deviation		5.367923	9.297621

Building A Fourth Floor

Point	Measurements	No. Of Walls	AMA-Model	ITU-Model
1	-47	0	-38.7888	-47.184
2	-55	0	-48.7328	-62.1316
3	-57	1	-53.2348	-55.0246
4	-68	1	-71.3784	-82.2975
5	-48	2	-43.4687	-28.5445
6	-73	2	-71.3075	-70.3911
7	-77	3	-81.4699	-74.7087
8	-84	3	-84.1477	-78.734
9	-64	4	-57.5706	-30.3513
10	-87	4	-89.5221	-78.3798
	Standard Deviation		3.947748	11.22498

Samples from PPU Building C

Building C First Floor

Point	Measurements	No. Of Walls	AMA-Model	ITU-Model
1	-39	0	-36.4053	-40.8285
2	-44	0	-41.2446	-47.1645
3	-38	1	-43.9026	-38.5599
4	-44	1	-45.8421	-41.0992
5	-67	2	-60.1512	-49.5561
6	-88	2	-66.6599	-58.078
	Standard Deviation		5.072959	9.004247

Building C Second Floor

Point	Measurements	No. Of Walls	AMA-Model	ITU-Model
1	-43	0	-42.0502	-54.2044
2	-40	0	-35.7103	-44.0012
3	-66	1	-63.3766	-73.6718
4	-69	1	-66.9095	-79.3576
5	-64	2	-66.2411	-65.6483
6	-66	2	-68.6202	-69.4773
7	-86	3	-85.4815	-84.8808
8	-85	3	-84.8385	-83.846
9	-88	4	-89.2718	-81.9522
10	-90	4	-89.2413	-81.9031
	Standard Deviation		2.407921	6.626153

Building C Third Floor

Point	Measurements	No. Of Walls	AMA-Model	ITU-Model
1	-44	0	-36.362	-44.1999
2	-41	0	-36.777	-44.843
3	-65	1	-72.3821	-85.7175
4	-71	1	-72.5589	-85.9914
5	-61	2	-57.8051	-50.9616
6	-65	2	-61.3441	-56.446
7	-84	3	-88.959	-87.9443
8	-90	3	-90.2305	-89.9148
9	-92	4	-93.4165	-86.1582
10	-92	4	-94.9806	-88.5821
11	-93	5	-90.854	-76.8559
12	-94	5	-98.5527	-88.7869
	Standard Deviation		3.449755	8.846601

SAMPLES From MULTI-FLOOR CALCULATIONS IN WLAN (2.4GHZ)

One Floor Separations

Abu Ruman Building

Point	Measurements	ITU Model 6 + 3(n-1)	ITU Model 15+4(n-1)	PPU Building C Model 5n	AMA Model 12+7(n-1)
1	-80	-72.2788	-81.2788	-71.2788	-78.2788
2	-75	-65.6946	-74.6946	-64.6946	-71.6946
3	-72	-59.9328	-68.9328	-58.9328	-65.9328
4	-76	-70.4428	-79.4428	-69.4428	-76.4428
5	-80	-71.8195	-80.8195	-70.8195	-77.8195
6	-74	-61.4017	-70.4017	-60.4017	-67.4017
7	-98	-85.3119	-94.3119	-84.3119	-91.3119
8	-88	-85.6591	-94.6591	-84.6591	-91.6591
9	-87	-81.6065	-90.6065	-80.6065	-87.6065
10	-81	-77.1318	-86.1318	-76.1318	-83.1318
	Standard Deviation	9.275882	6.566499	10.04048	6.279061

Building A

Point	Measurements	ITU Model 6 + 3(n-1)	ITU Model 15+4(n-1)	PPU Building C Model 5n	AMA Model 12+7(n-1)
1	-94	-83.903	-92.903	-82.903	-89.903
2	-90	-78.767	-87.767	-77.767	-84.767
3	-95	-81.0445	-90.0445	-80.0445	-87.0445
4	-83	-70.504	-79.504	-69.504	-76.504
5	-87	-88.6021	-97.6021	-87.6021	-94.6021
6	-88	-79.0141	-88.0141	-78.0141	-85.0141
7	-86	-72.5123	-81.5123	-71.5123	-78.5123
8	-92	-81.8654	-90.8654	-80.8654	-87.8654
9	-77	-81.3879	-90.3879	-80.3879	-87.3879
10	-83	-83.2093	-92.2093	-82.2093	-89.2093
	Standard Deviation	6.510964	6.695317	7.219566	5.100562

Building C

Point	Measurements	ITU Model 6 + 3(n-1)	ITU Model 15+4(n-1)	PPU Building C Model 5n	AMA Model 12+7(n-1)
1	-93	-89.32557	-98.3255699	-88.32556995	-95.3255699
2	-89	-87.633581	-96.6335814	-86.63358141	-93.6335814
3	-92	-87.660885	-96.6608852	-86.66088516	-93.6608852
4	-94	-85.281436	-94.2814362	-84.28143622	-91.2814362
5	-92	-84.120448	-93.1204479	-83.12044788	-90.1204479
6	-88	-79.557348	-88.5573478	-78.55734782	-85.5573478
7	-89	-82.17981	-91.1798098	-81.17980982	-88.1798098
8	-92	-82.130697	-91.1306969	-81.13069687	-88.1306969
9	-92	-79.536495	-88.5364951	-78.53649512	-85.5364951
10	-89	-75.262112	-84.2621123	-74.26211233	-81.2621123
	Standard Deviation	8.685895	4.117614032	9.588725825	4.29551168

Two Floor Separations

Al-Ahlyi Hospital Building

Point	Measurements	ITU Model 6 + 3(n-1)	ITU Model 15+4(n-1)	PPU Building C Model 18(n-1)	AMA Model 12+7(n-1)
1	-80	-72.355	-76.355	-75.355	-76.355
2	-81	-67.2329	-71.2329	-70.2329	-71.2329
3	-70	-58.7927	-62.7927	-61.7927	-62.7927
4	-77	-61.1986	-65.1986	-64.1986	-65.1986
5	-75	-69.8028	-73.8028	-72.8028	-73.8028
6	-75	-67.3974	-71.3974	-70.3974	-71.3974
7	-63	-56.2983	-60.2983	-59.2983	-60.2983
8	-56	-55.258	-59.258	-58.258	-59.258
	Standard Deviation	9.142715	5.672964	6.483379	5.672964

Building A

Point	Measurements	ITU Model 6 + 3(n-1)	ITU Model 15+4(n-1)	PPU Building C Model 18(n-1)	AMA Model 12+7(n-1)
1	-90	-73.5551	-83.5551	-82.5551	-83.5551
2	-93	-75.2566	-85.2566	-84.2566	-85.2566
3	-92	-80.2331	-90.2331	-89.2331	-90.2331
4	-93	-85.9508	-95.9508	-94.9508	-95.9508
5	-95	-92.9513	-102.951	-101.951	-102.951
6	-95	-74.3104	-84.3104	-83.3104	-84.3104
7	-94	-77.4268	-87.4268	-86.4268	-87.4268
8	-91	-95.1444	-105.144	-104.144	-105.144
9	-94	-94.5308	-104.531	-103.531	-104.531
10	-94	-91.1293	-101.129	-100.129	-101.129
	Standard Deviation	13.48441	6.075462	6.511762	6.075462

Building C

Point	Measurements	ITU Model 6 + 3(n-1)	ITU Model 15+4(n-1)	PPU Building C Model 18(n-1)	AMA Model 12+7(n-1)
1	-95	-77.2842	-87.2842	-86.2842	-87.2842
2	-95	-77.7139	-87.7139	-86.7139	-87.7139
3	-88	-82.0901	-92.0901	-91.0901	-92.0901
4	-95	-85.0059	-95.0059	-94.0059	-95.0059
5	-95	-84.7416	-94.7416	-93.7416	-94.7416
6	-94	-87.1968	-97.1968	-96.1968	-97.1968
7	-94	-90.6465	-100.646	-99.6465	-100.646
8	-94	-90.6737	-100.674	-99.6737	-100.674
9	-95	-88.2982	-98.2982	-97.2982	-98.2982
10	-94	-82.5892	-92.5892	-91.5892	-92.5892
	Standard Deviation	10.8991	4.815393	4.873216	4.815393

APPENDIX
E

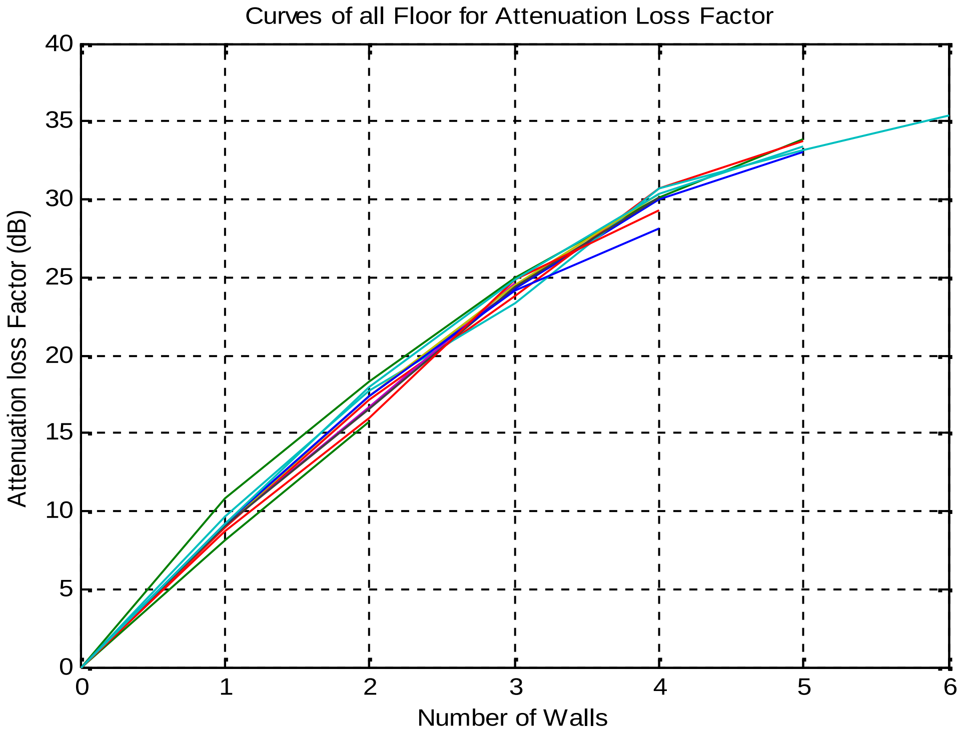


Figure E1

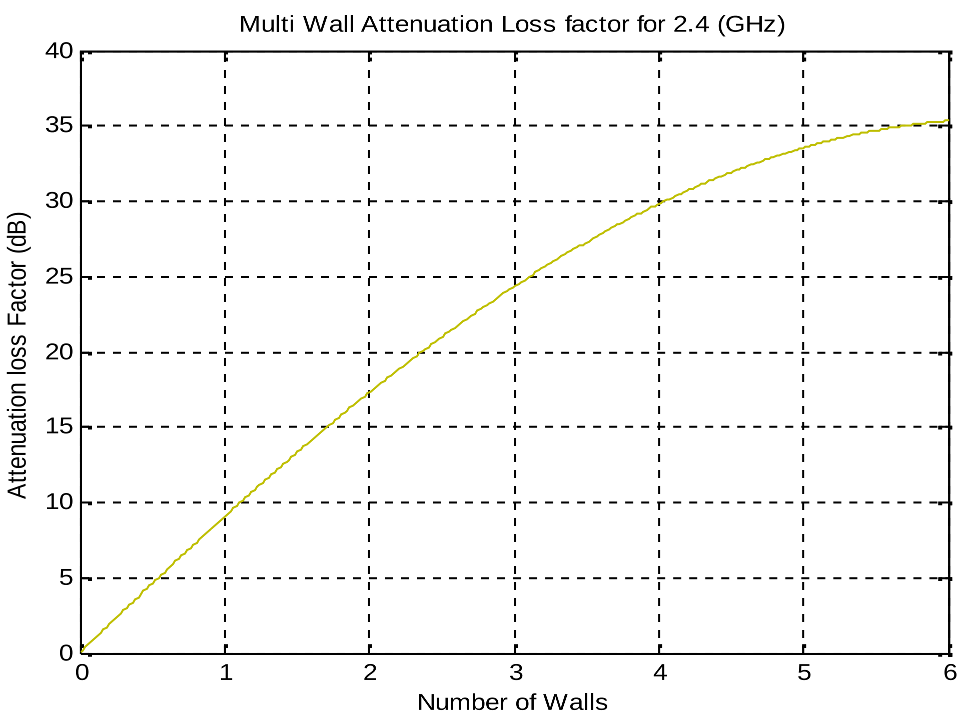


Figure E2

[1] P. PECHACA, M.KLEPAL, K. NOVSTNY: "Novel approach to indoor propagation modeling", *Radio-engineering of Department of Electromagnetic Field Czeh Technical University in Prague*, vol.9,No.3,pp12-15, September 2000.

[2] Abu-Bakar, A.H.; Matthews, P.A.; ," Direction of arrival of radio signals inside and outside buildings" , *Vehicular Technology Conference, 1994 IEEE 44th* , vol., no., pp.1754-1758 vol.3, 8-10 Jun 1994.

[3] Chandra, A.; Chandra, P.; "Attenuation of 900 MHz and 1.35 GHz signal inside room of a building, Personal Wireless Communications", 1997 *IEEE International Conference on* , vol., no., pp.198-200, 17-19 Dec 1997.

[4] Springer Netherlands." *Wireless Personal Communications*"pp95-111, Volume 9, Number 2 / February, 1999.

[5] IEEE antennas and propagation society. "*Antennas and Propagation, IEEE Transactions on*",PP585 – 594, 2003.

[6] Suhas Mathur." Wireless Communication Technologies", *Department of Electrical Engineering, Rutgers University*, 2005.

[7] T.S.Rappaport, "Wireless Communications, Principle and Practice", *Pearson Education, PTE*, Singapore, 2002.

[8] ANDREJ HROVAT, TOMAŽ JAVORNIK, GORAZD KANDUS "Adjacent Channel Interference Analyses in TETRA Direct Mode Operation", *Department of Communication Systems*, Jozef Stefan Institute Jamova 39, 1000 Ljubljana SLOVENIA.

[9] ITU-R Recommendations, *"Propagation data and prediction methods for the planning of indoor radio communication systems and the radio local area networks in the frequency range 900 MHz to 100 GHz"*, Geneva, 2001

[10] A. Agelet, A. Formella, J. Rabanos, I. de Vicente, and P. Fontan, “Efficient ray-tracing acceleration techniques for radio propagation modeling,” *IEEE Veh. Technol. Conf.*, vol. 49, pp. 2089–2104, November 2000.

[11] T. Chrysikos, G. Georgopoulos, S. Kotsopoulos, “Site-Specific Validation of ITU Indoor Path Loss Model at 2.4 GHz*”Wireless Telecommunications Laboratory Department of Electrical & Computer Engineering University of Patras”, Greece,* 2009, pp.1-6.

[12] Tarnevik, Christer et al "Propagation Models, Cell Planning and Channel Allocation for Indoor Applications of Cellular Systems" *Vehicular Technology Conference, 1993 IEEE 43rd, Location: Secaucus, NJ , USA,* May 1993.

[13] Jyotshna Cherukuriin, “Comparative Study of Stochastic Indoor Propagation Models”, *MS Thesis, Electrical Engineering Department, UNCC, May 2004.*

[14] Lucio Ferreirant Martijn Kuipersnt Carlos Rodriguest, Luis M. CorreiaL “Characterizations of Signal Penetration into Buildings for GSM and UMTS”, *in IEEE Wireless Communication Systems*, 22 October 2007, pp. 63 - 67.

[15] P. Pechač, M. Klepal, M. Mazánek. “INDOOR PROPAGATION MODELLING IN MULTI-STOREY BUILDINGS IN PRAGUE”, *Czech Technical University in Prague Department of Electromagnetic Field Technická 2, 166 27 Praha 6, Czech Republic*,2001.

[16] T. Chrysikos, G. Georgopoulos, S. Kotsopoulos , D. Zevgolis.” Site-Specific Validation of Indoor RF Models for Commercial Propagation Topologies at 2.4 GHz”, *Department of Electrical and Computer Engineering, University of Patras Rio Patras, Greece*,2010.

[17] Andrea Goldsmith ,*’WIRELESS COMMUNICATIONS’* , Cambridge University Press,pp.43-44,2005.

[18] T. Chrysikos, G.Georgopoulos, S.Kotsopoulos,” Impact of Shadowing on Wireless Channel Characterization for a Public Indoor Commercial Topology at 2.4 GHz”, *International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT), Greece*, 2010, pp. (1-6).

[19] Nickolas J. LaSorte, Yohann Burette, Hazem H. Refai "Experimental Characterization of Electromagnetic Propagation of a Hospital from 55-1950MHz", *Electrical and Computer Engineering, University of Oklahoma Tulsa, Oklahoma, USA,2009.*