Palestine Polytechnic University

College of Engineering & Technology

Electrical and Computer Systems Engineering Department

Graduation Project

Indoor Radio Propagation at 900MHz and 2.4GHz Frequencies

Project team

Ramzi Shahateet **Abdul-Aziz Sharawneh**

Amer Zamareh

Project Supervisor

Dr. Osama Ata

Hebron- Palestine

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Palestine Polytechnic University

Hebron- Palestine

College of Engineering & Technology

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Ramzi Shahateet Abdul-Aziz Sharawneh

Amer Zamareh

Based on the requirements of College of Engineering and Technology and the supervision of the immediate supervisor of the project and the approval of members of the Committee discussion of this project was submitted to the Department of Electrical Engineering and Computer in order to meet the requirements of a bachelor's degree in Engineering for Telecommunications and Electronics Engineering.

Supervisor Signature

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Testing Team Signature

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Department Manager Signature

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Dedication

To our parents and families

To whom who have added anything to the science

To whom who taught us any letter, word or information

To our colleges and instructors

To our Arabic and Islamic nation

To our university

Acknowledgment

First and for most we should offer our thanks, obedience and gratitude to Allah.

Here as we finished our project we stop for a moment every to thank body who has helped us to complete this work.

First we want to thank our supervisor Dr. Osama Ata who gave us a lot of this time and experience in order to complete the project and gave us the opportunity to start scientific life and methodology in the real life by asking us to do this work

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Abstract

Radio frequency signal dispersion for indoor wireless areas is highly distributed than the outdoor one. This makes the reflection, diffraction, and scattering of the RF signal is more complex and difficult to predict. So in WLAN and cellular phone networks a small change in the receiver position relative to the transmitter may result in wide variation in the signal strength. Indoor coverage is also supported by GSM and may be achieved by using an indoor picocell base station, or an indoor repeater with distributed indoor antennas fed through power splitters, to deliver the radio signals from an antenna outdoors to the separate indoor distributed antenna system. These are typically deployed when a lot of call capacity is needed indoors; for example, in shopping centers or airports. However, this is not a prerequisite, since indoor coverage is also provided by in-building penetration of the radio signals from any nearby cell. The main problem that exists for indoor environments is that the signal propagated from the transmitter antenna will experience many different signal transformations and paths with a small portion reaching the receiver antenna[1]page 1.So one of our main attentions of this project is to assist the user to understand the radio performance limitations. Not only the radiated power and the Transmitter/Receiver separation (transmission rate) but there is also the effect of the surrounding physical environment such as room dimension, obstructions, materials, etc.

Put in mind that indoor propagation is not limited to WLAN or any other local wireless network; the indoor coverage is one of the biggest challenges for all cellular network operators. From this hint our measurement will be at 900 MHZ used in jawwal operator and on 2.4 GHZ used in WLAN networks for the college of engineering and technology building (building B). The measurement will be compared to the propagation model used for indoor environment. A simulation to the indoor radio propagation behavior will be also done by the end of this project. Those steps will be done using GSM frequency (900MHZ). the wireless lane for building B is also our goal; a study of the access points of the WLAN will be done and using the netstumbler program we will predict the suitable arrangement for the indoor wireless access points such that WLAN could coverage most of the building areas.

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Chapter One

1 Indoor Propagation Models for 900MHz and 2.4 GHz frequencies

1.1 History of Indoor Radio Propagation.

1.2 Definition of Indoor Radio Propagation.

1.3 Indoor Radio Wave Vision.

1.4 Current Indoor Radio Models.

1.5 Difference between the Indoor and Outdoor Propagation.

1.6 Previous study of Indoor Radio Propagation.

Chapter One

1 Indoor Propagation Models for 900MHz and 2.4 GHz frequencies

1.1 History of Indoor Radio Propagation.

1.2 Definition of Indoor Radio Propagation.

1.3 Indoor Radio Wave's form.

1.4 Current Indoor Radio Models.

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Chapter One

Overview of Indoor Propagation

1.1 History of indoor radio propagation

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.

1.2 Definition of Indoor Radio Propagation

This title consists of two main titles: the indoor environment and the radio propagation. We mean by indoor environment the internal building environment (propagation of electromagnetic wave inside the building), this environment depends on the building structure. The structure is the walls, ceilings, corners, and corridors. The penetration loss in walls is different depending on the wall material and width; the built material of the walls is also different, it could be for example from brick or concrete. The width of the walls usually varies depending on its material for example if its material built from brick the width could be 12 cm if the used brick is 10 cm width or 22 cm if the brick width is 20 cm and so on for other types of materials, and so on for the ceilings, corridors etc… The building structure will be discussed widely in the next chapters.

The second title is the radio propagation, it refers to the wireless signal that propagates from the transmitter to the receiver this propagating signal could be a LOS (line of site) or NLOS (non line of site). Indoor propagation at NLOS condition faces several obstacles causing it to be reflected, diffracted and scattered. The result is that depending on the size of the obstacles and its type (the penetration loss) the signal will be attenuated or phase shifted or even it could be at some locations disappeared. In LOS condition the signal parameters will be slightly changed comparing it to the NLOS condition.

1.3 Indoor Radio Wave Vision

Investigators have tried to compute and to determine a radio coverage that will predict a suitable antenna spanning for each building characteristics and wireless system requirements. There are many models, developed in recent decades, which describe the propagation of signals in space. The ability to predict the behavior of signals in indoor environments is crucial. The full understanding of these models and their unification to a more applicable one will allow a better behavioral prediction and better capabilities in the design of indoor communication networks.

The indoor radio propagation environment is specified by many features and characteristics and is very complex. Adding all these variables together forms a great problem. Due to this fact, dealing with these characteristics and with different propagation models, used to calculate them, has to be done efficiently and accurately. Indoor environment is different from one building to another depending on the building structure. So to give an accurate answer to the indoor propagation using the same model is difficult. Calculating the path loss for indoor environment is also difficult because of the variety of the indoor environments distribution (for example the rooms, walls and furniture are not uniformly distributed inside the buildings). Finally, those who are involved in the wireless discipline whether as a designer or a user must be aware of the interiors and exteriors construction materials, and of the obstructions locations of a building to best position wireless equipment [2].

1.4 Current Indoor Radio Models

Many models have been discussed for the indoor propagation. The reason is that we couldn't find a general model that predicts the signal strength for any type of buildings because as we mentioned in the indoor propagation vision the building structure is not a unique one, buildings are different since there use is different, for example the school building structure is different compared to small home. Those models are divided into two types: empirical and deterministic models [3].

In this section the models discussed briefly but they will be widely mentioned in the indoor propagation chapter 3.

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 much variable relative to the path length, and the coverage size 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. As is 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 [3].

1.6 Previous study of Indoor Radio Propagation [4]

Several studies were produced for the indoor radio propagation and many models were used for simulation and calculation path loss, spread delay and arrival angel.

For example a study was done in Prague University. It was done in 2000. Special mobile measurement tool was used. The measurement was at 900 MHz (GSM frequency). The system consists of special measurement transmitter and special measurement receiver. The parameters are mentioned in table [1.1]. The receiver antenna was turned fat 45 grades from vertical direction to receive both vertical and horizontal polarization.

Frequency band	870 – 999 MHz, 1 MHZ step
Frequency stabilization	Phase locked loop(PLL)
Transmitter output power	30 dBm +/- 0.5 dB, ALC loop
Modulation	1 KHz AM square wave
Measurement bandwidth	o.3 MHz
Rec. input signal range	-30 to -90 dBm
A/D converter	12 bit, parallel output
Receiver resolution	Min. 0.1 dB

Table [1.1]: Transmitter and receiver parameters

Locations:

The first building (building I) was a modern nine-story building made with concrete skeleton and large windows. The partitions are made from concrete and brick, measured corridors are 3 m wide. And central heating is integrated into floors.

The second four-story building (building II) is the older one, made with high ceilings and wide corridors.

There are offices, laboratories and lecture rooms in both buildings. Situations: Empty interior and Filled corridor with people were studied.

The used model was the multi-floor model. And the transmitter located inside the building. As shown at figure [1.1] below.

Two models of multi-floor were used the first one equation is:

$$L(d) = L_0 + 10n \log d + kF_1 \qquad (1)$$

Where:

L(d) is the path loss of the electromagnetic wave at a distance d from the transmitter.

L_0 : the attenuation in reference distance

n: path loss exponent

K: number of floors between the transmitter and the receiver

F1: single-floor propagation attenuation

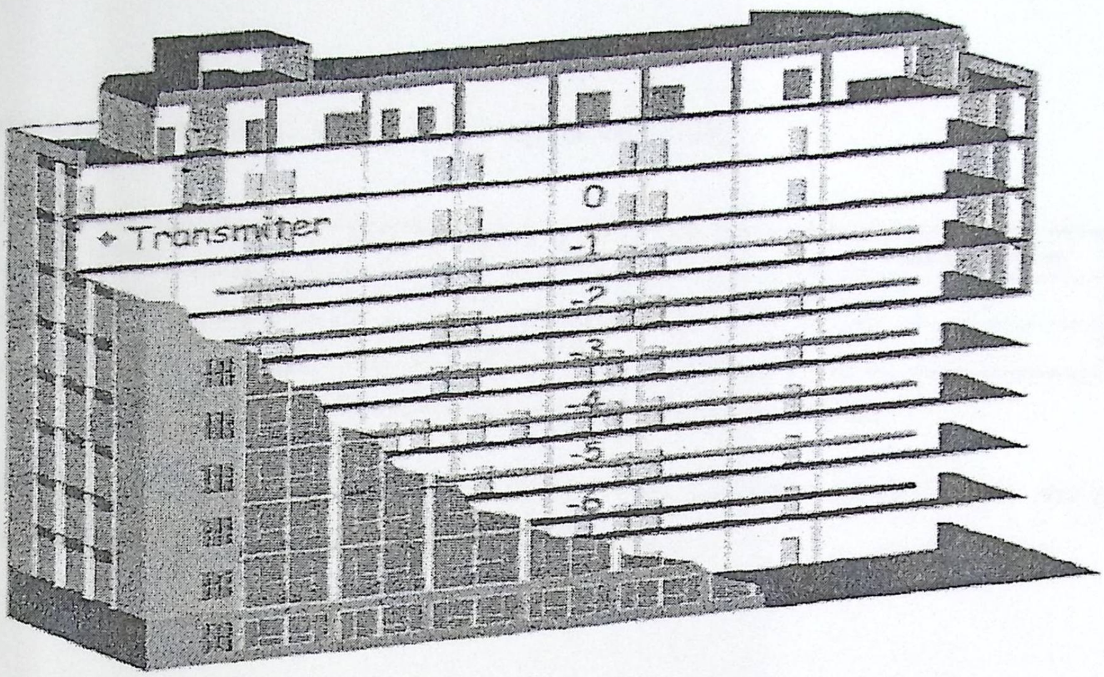


Fig. [1.1] Building I structure with measurement paths of the receiver antenna in each floor

The second model is:

$$L(d) = L_0 + 10n\log d + F_k \qquad (2)$$

Fk : represents the propagation attenuation through K floors between transmitter and receiver antennas. So it differs from F1 since F1 is for only one floor separation but Fk for multifloor separation

The first model parameters and the standard deviations are on table [1.2]:

Location	n	F_l	standard deviation
Building I	1.8	7.4	5.2
Building II	0.9	11.7	4.3

Table [1.2] The first model parameters and the standard deviations.

The second model parameters are also mentioned at table [1.3]:

Location	n	F_1	F_2	F_3	F_4	F_5	F_6	standard deviation
Building I	1.8	4.5	14.6	23.5	30.9	35.6	41.2	5.0
Building II	0.9	12.3	25.8	33.2				4.1

Table [1.3]: Model two parameters and standard deviations.

These parameters are obtained by applying the resultant measurements using the measurement tools to the first and second models equations.

The measurement is compared to the used models, this was done at this work as shown at figure [1.2] bellow:

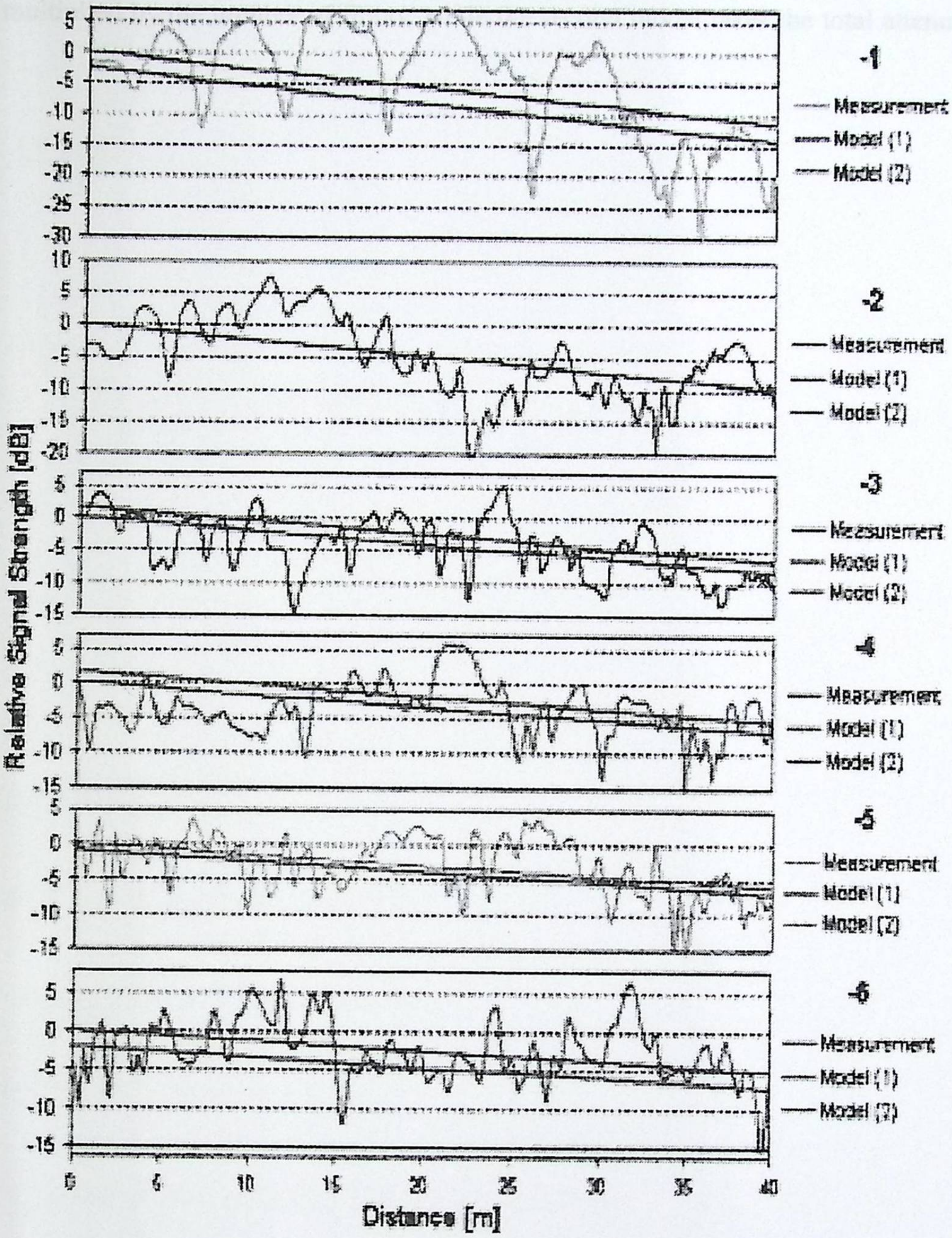


Fig. [1.2]: Comparison between the measurement and the model I and model II

From figure [1.2] as readers we could notice the variability of the signal strength of the measurement with respect to the distance. This graph gives us good indication about the difficulty of having a model that approximately closed to the indoor measurements with its values.

In this study we see that the second model has a less standard deviation and it is more accurate than the first model, this difference is due to third component of each model equation because the first model consider the same attenuation value for all the floors and the total attenuation equals the attenuation of single floor multiplied by the number of floors ,while the second model takes the total attenuation for all the floors .

Chapter 2

2 [Indoor Propagation Factors]

2.1 Introduction

2.2 Path Loss and Shadowing

2.3 Propagation Mechanisms

2.4 Multipath and Fading

2.5 Doppler Spread and Doppler Shifts

2.6 Wave Polarization

Chapter Two

Indoor Propagation Factors

2.1 Introduction

The outdoor propagated electromagnetic signal is considered as LOS (line of site) if it does not face any obstacle 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 distance between the transmitter and the receiver is the most affecting factor here. Comparing it to the NLOS the situation is so different; the propagated signal here faces extra propagation factors that cause increased path loss. The multipath, fading, reflection, refraction, scattering and diffraction modes attenuates, phase shifts and polarizes electromagnetic signal. In indoor environment the situation is even worse. The signal propagating inside the building is a NLOS. Ceilings, furniture, people and walls etc. are common obstacles affecting the path of the signal.

2.2 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 (2.1) [5] shows path loss, shadowing and multipath affect over distance. When the attenuation is very strong, the signal is blocked.

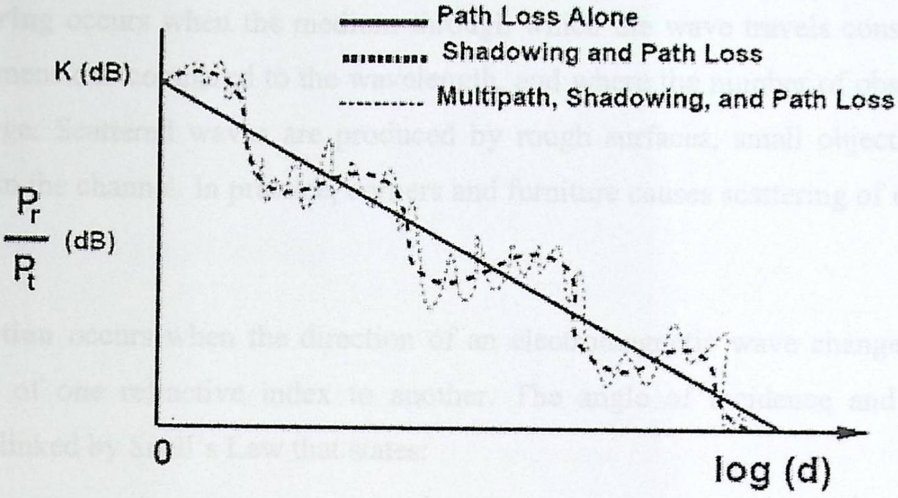


Fig. [2.1]: Path loss, Shadowing and Multipath over distance

2.3 Propagation Mechanisms

Any NLOS propagated signal faces obstacles during its journey. The propagated signal faces four mechanisms [6], reflection, diffraction refraction and scattering. The received signal at the mobile station will be attenuated (its amplitude is reduced) and delayed in time (phase shifted). The three propagation mechanisms are mentioned bellow:

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 floors, ceilings, walls and furniture.

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 object, as well as the amplitude, phase, and polarization of the incident wave at the point of diffraction.

Scattering occurs when the medium through which the wave travels consists of objects with small dimensions 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, corners and furniture causes scattering of the propagated signal.

Refraction occurs when the direction of an electromagnetic wave changes as it moves from an area of one refractive index to another. The angle of incidence and the angle of refraction are linked by Snell's Law that states:

$$n_1 \sin(\Theta_1) = n_2 \sin(\Theta_2) = n_1 \sin(\Theta_3) \quad (1)$$

Where:

Θ_1: angle between the ray and the vertical line in the first medium

Θ_2: angle between the ray and the vertical line in the second medium

Figure (2.2) shows an electromagnetic wave refracted when hits a wall, due to refraction the signal will lose some of its energy.

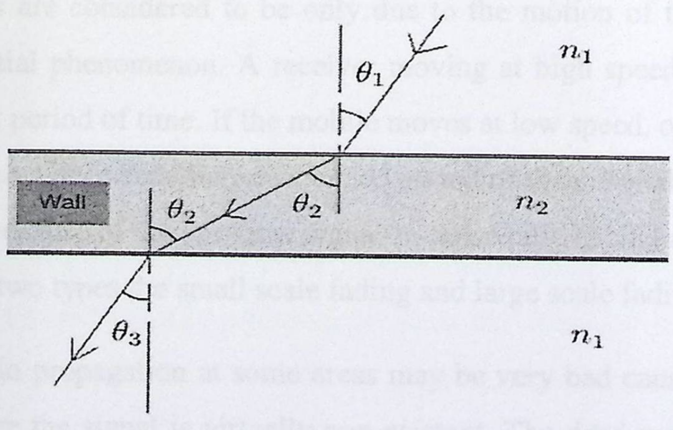


Figure [2.2]: Snell's law

This causes the direction of the signal to bend rather than undergo an immediate change in direction inside the wall.

2.4 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.

The indoor radio propagation at some areas may be very bad causing phenomena called "Dead Spots" [7] 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 three 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.

2.4.1 Mitigating the Multipath Problem

The multipath problem can be solved through several strategies [6]:

1. Radio system design.
2. Antenna system design.
3. Signal / waveform design.
4. Building / environment design.

Many wireless systems demand "robust" and error free radio communications, since the overall system fails if the radio system fails. The major features that each subsystem design will have are outlined below:

1. **Radio system design** — redundant paths for each receiver, if at all possible
2. **Antenna system design** — dual diversity antennas used at each receiver, as a minimum
3. **Signal / waveform design** — Spread Spectrum radio design with the highest feasible chip rate
4. **Building / environment design** — it is very difficult to design an "RF friendly" building that is free from multipath reflections, diffraction around sharp corners or scattering from wall, ceiling, or floor surfaces (let alone operate perfectly in a randomly chosen building location). The closest one could probably get to an "RF friendly" building would be an all wooden or all fiber glass structure, but even this must have a structurally solid floor of some kind and this more ideal RF building will still have reflections, multipath and other

radio propagation disturbances which will prove to be less than ideal. Not much can be done in this area, unless new "RF Friendly" buildings are constructed.

2.4.2 Small-Scale Fading

An important parameter that describes the multipath fading is the channel coherence bandwidth [8], which is inversely proportional to the delay spread. The coherence bandwidth of the channel is the range of frequencies over which the channel is relatively flat. If the coherence bandwidth of the channel is smaller than the signal bandwidth (or the delay spread is greater than the symbol duration), then the signal is said to undergo frequency selective fading, giving rise to inter-symbol interference (ISI). However, if the coherence bandwidth is greater than the signal bandwidth, then the signal is said to undergo flat (or frequency non-selective) fading. Flat fading typically has a Rayleigh distribution.

If the channel coherence time is less than the symbol duration of the signal (or the Doppler shift is greater than the signal bandwidth), then the signal is said to undergo fast fading. However, if the coherence time is greater than the symbol duration, then the signal is said to undergo slow fading

As shown in Figure (2.3) the small scale fading is divided into two types based on multipath time delay spread, flat fading, and frequency selective fading.

In flat fading the bandwidth of the signal should be less than the bandwidth of channel and the delay spread is also less than the symbol period.

In frequency selective fading the bandwidth of signal should be greater than the bandwidth of channel, and delay spread also should be greater than symbol period.

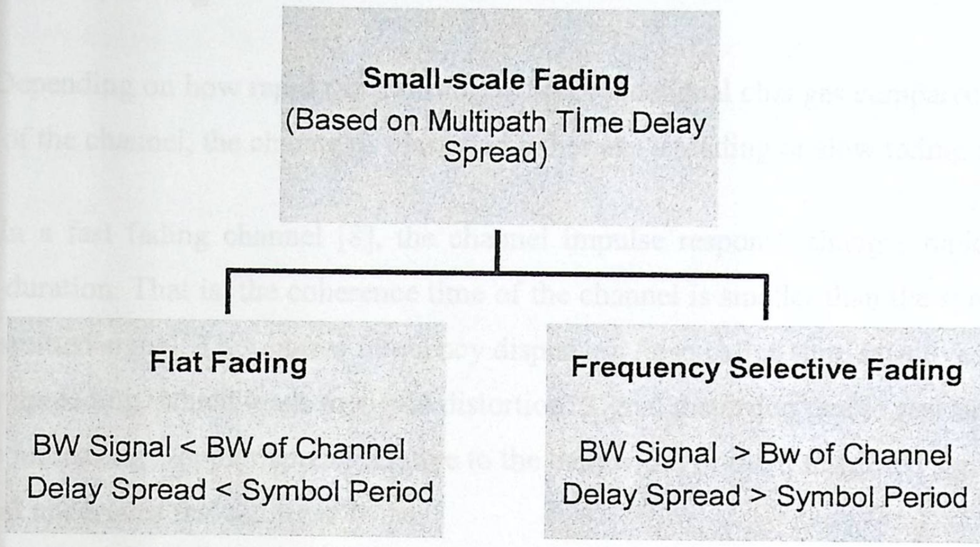


Figure [2.3] Types of small scale fading (based on multipath time delay spread)

In Figure (2.4) small scale fading is divided into two types based on Doppler spread, fast fading and slow fading.

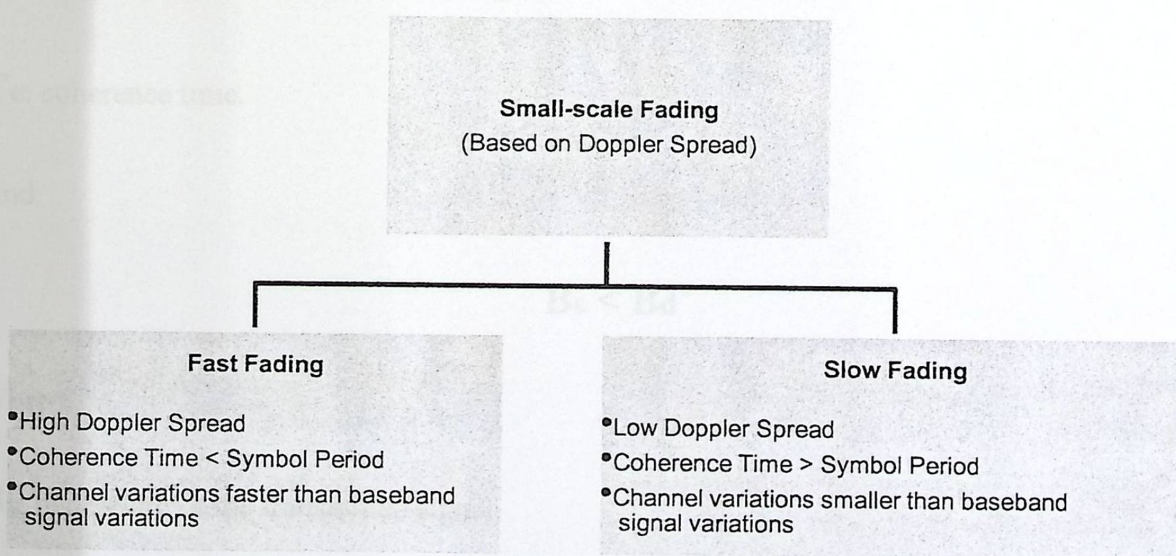


Figure [2.4] Type of small scale fading (based on Doppler spread)

2.4.2.1 Fast Fading

Depending on how rapid the transmitted baseband signal changes compared to the rate of change of the channel, the channel is classified either as fast fading or slow fading channel.

In a fast fading channel [8], the channel impulse response changes rapidly within the symbol duration. That is, the coherence time of the channel is smaller than the symbol period of the transmitted signal. This causes frequency dispersion (also called time selective fading) due to Doppler spreading, which leads to signal distortion. Signal distortion due to fast fading increases with the increasing Doppler spread relative to the bandwidth of the transmitted signal. Therefore, the signal undergoes fast fading if

$$T_s > T_c$$

Where:

T_s: symbol period of the transmitted signal.

T_c: coherence time.

And:

$$B_s < B_d$$

Where:

B_s: bandwidth of the transmitted signal.

B_d: Doppler spread bandwidth.

2.4.2.1 Fast Fading

Depending on how rapid the transmitted baseband signal changes ... change of the channel, the channel is classified either as fast fading or slow fading ...

In a fast fading channel [8], the channel impulse response ... symbol duration. That is, the coherence time of the channel is ... the transmitted signal. This causes frequency dispersion (also called ... Doppler spreading, which leads to signal distortion. Signal distortion ... with the increasing Doppler spread relative to the bandwidth of the ... the signal undergoes fast fading if

$$T_s > T_c$$

Where:

T_s: symbol period of the transmitted signal.

T_c: coherence time.

And:

$$B_s < B_d$$

Where:

B_s: bandwidth of the transmitted signal.

B_d: Doppler spread bandwidth.

It should be noted that when a channel is specified as fast or slow fading channel, it does not specify whether the channel is flat fading or frequency selective in nature. Fast fading only deals with the rate of change of the channel due to motion. In the case of the flat fading channel, we can approximate the impulse response to be simply a delta function (no time delay). A flat fading, fast fading channel is a channel in which the amplitude of the delta function varies faster than the rate of change of the transmitted baseband signal. In the case of a frequency selective, fast fading channel, the amplitudes, phases, and time delays of any one of the multipath components vary faster than the rate of change of the transmitted signal. In practice, fast fading only occurs for very low data rates.

2.4.2.2 Slow Fading

In a slow fading channel [8], the channel impulse response changes at a rate much slower than the transmitted baseband signal s(t). In this case, the channel may be assumed to be static over one or several reciprocal bandwidth intervals. In the frequency domain, this implies that the Doppler spread of the channel is much less than the bandwidth of the baseband signals. Therefore, the signal undergoes slow fading if:

$$T_s \ll T_c$$

Where:

T_s: symbol period of the transmitted signal.

T_c: coherence time.

And:

$$B_s \gg B_d$$

Where:

Bs: bandwidth of the transmitted signal.

Bd: Doppler spread bandwidth.

It should be clear that the velocity of the mobile (or velocity of objects in the channel) and the baseband signaling determines whether a signal undergoes fast fading or slow fading.

2.4.3 Large-Scale Fading

Large-scale fading [9] represents the average power attenuation or the path loss due to motion over large areas. This phenomenon is affected by prominent terrain contours (e.g. hills, forests, billboards, clumps of buildings, etc) between the transmitter and receiver, so we can neglect it here in the case of indoor propagation.

2.5 Doppler spread and Doppler shifts

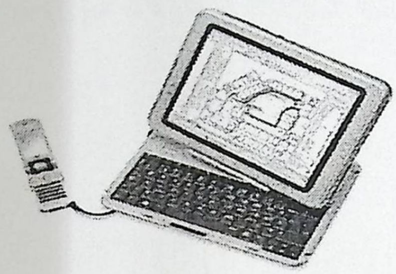
Relative motion between the transmitter and receiver imparts a Doppler shift on the signal, where the entire signal spectrum is shifted in frequency. When multipath is combined with relative motion, the electromagnetic wave may experience both positive and negative Doppler shifts, smearing and spreading the signal in frequency. This effect is called Doppler spread.

When a signal of frequency fc is transmitted, the received signal spectrum, called the Doppler spectrum, will have components fc – fd to fc + fd, where fd is the Doppler shift.

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 [8].

2.6 Wave Polarization

Polarization is defined as the orientation of the plane that contains the electric Field component of the radiated waveform. A vertical antenna generates and receives vertical polarization; a horizontal antenna also generates and receives horizontal polarization Figure (2.5). In our measurements the TEMS handset should be adjusted to 45 degree upon the horizon to receive either the vertical or the horizontal polarization [10].



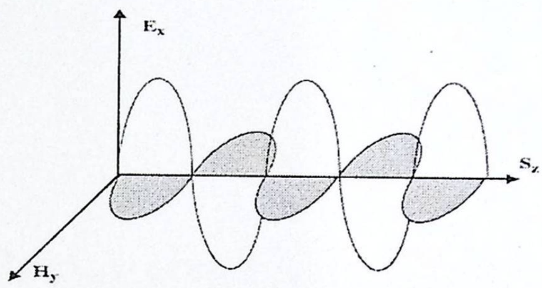


Figure [2.5]: Vertical and horizontal polarization

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.

...Hz and 2.4 GHz frequencies

... inside a building is important especially for ... (Wireless local area networks).The design of ... ves the use of an indoor propagation model. ... eters to be predicted. The path loss and the ... al envelope are vital for coverage planning ... haracteristics are essential for evaluation of the ... oftware simulation.

... nto four groups: empirical narrow-band models, ... variations and deterministic models. Empirical ... f simple mathematical equations which give the ... ned by fitting the model to measurement results. ... a form of a table listing average delay spread ... hapes. Models for time variations are used for ... f the received signal. Deterministic models are ... the propagation of radio waves. These models ... on of the channel [11].

Chapter Three

3 [Indoor Propagation models for 900MHz and 2.4GHz]

3.1 General

3. 2 Empirical Narrow-Band Models

3.3 Empirical wide-band models

3.4 Modeling the time fluctuations of the indoor channel

3.5 Deterministic models

3.6 Comparison between empirical and deterministic models

3.7 Indoor Propagation Models (WLAN 2.4 GHz)

Chapter Three

Indoor Propagation Models for 900MHz and 2.4 GHz frequencies

3.1 General

Predicting the propagation characteristics between inside a building is important especially for the design of cordless telephones and WLANs (Wireless local area networks).The design of cellular systems with indoor base stations involves the use of an indoor propagation model. There are several important propagation parameters to be predicted. The path loss and the statistical characteristics of the received signal envelope are vital 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.

The considered propagation models are divided into four groups: empirical narrow-band models, empirical wide-band models, models for time variations and deterministic models. Empirical narrow-band models are expressed in a form of simple mathematical equations which give the path loss as the output. The equations are obtained by fitting the model to measurement results. Empirical wide-band models are expressed in a form of a table listing average delay spread values and typical power delay profile (PDP) shapes. Models for time variations are used for example to estimate the Doppler spectrum of the received signal. Deterministic models are calculation methods which physically simulate the propagation of radio waves. These models yield both narrow-band and wide-band information of the channel [11].

3. 2 Empirical Narrow-Band Models:

Empirical indoor models [11].fall under several types. The one slope model (1SM) assumes a linear dependence between the path loss (dB) and the logarithmic distance

$$L = Lo + 10n. \text{Log}(d) \qquad (1)$$

Where:

Lo = the path loss at 1 meter distance,

n = power decay index,

d = distance between transmitter and receiver in meters.

This model is easy to use, because only the distance between transmitter and Receiver appears as an input parameter. However, the dependence of these Parameters on environment category has to be taken into account.

The multi-wall model gives the path loss as the free space loss added with losses introduced by the walls and floors penetrated by the direct path between the transmitter and the receiver. It has been observed [11].that the total floor loss is a non-linear function of the number of penetrated floors. This characteristic is taken into account by introducing an empirical factor *b*. The **multi-wall model (MWM)** can then be expressed in the form:

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

Where

LFS: free space loss between transmitter and receiver,

Lc : constant loss, derived from measurement values.

Kwi : number of penetrated walls of type *I*,

kf= number of penetrated floors,

Lwi= loss of wall type *i*,

Lf = loss between adjacent floors,

b = empirical parameter,

1 = number of wall types.

The constant loss in equation (2) is a term which results when wall losses are determined from measurement results by using the multiple linear regressions. Normally it is close to zero. The third term expresses the total wall loss as a sum of the walls between transmitter and receiver. For practical reasons the number of different wall types must be kept low. Otherwise, the difference between the wall types is small and their significance in the model becomes unclear.

It is important to notice that the loss factors in equation (2) are not physical wall losses but model coefficients which are optimized along with the measured path loss data. Consequently, the loss factors implicitly include the effect of furniture as well as the effect of signal paths guided through corridors as seen in table (3.1):

Wall type	Description
Light wall (L_{W1})	A wall that is not bearing load: e.g. plasterboard, particle board or thin (<10 cm), light concert wall.
Heavy wall (L_{W2})	A load-bearing wall or other thick (>10 cm) wall, made of e.g. concrete or brick.

Table [3.1]. Wall types for the multi-wall model.

The third considered propagation model is the linear attenuation model (LAM),[11].which assumes that the excess path loss (dB) is linearly dependent on the distance (m), where *a* (dB/m) is the attenuation coefficient:

$$L = LFs + ad \qquad (3)$$

In some studies wall loss terms are added to the linear model which improves the performance to some extent since degrees of freedom is increased in the following the LAM is used in the simple form of equation (3).

3.3 Empirical wide-band models

Empirical wide-band model is considered as a means for evaluation of either the delay spread or the average power delay profile (PDP). Factors together with Doppler characteristics are typically required as an input to system simulations.

Example:

The overall results of wide-band measurements are listed in Table (3.2); the delay spread has lowest values in dense environment and larger values in open and large environments. The dependency of the delay spread on the dimensions of the environment can even be utilized in prediction as shown bellow.

Table [3.2]: Delay spread and PDP shape in different environments.(VTT, TUW, ETH are university buildings)

Environment	Average rms delay spread [ns]	Variability of rms delay spread[ns]	Typical profile shape
Dense : Lund	22.5	5 – 40 1)	Power /exponential
VTT	15.3	3.4 2)	Exponential
TUW	20.0	8 – 31 3)	-
Average	**19.3**		
Open : Lund	35.0	5 – 95 1)	Power
VTT	17.7	3.1 2)	Power
ETH	30.5	4.1 2)	Exponential
Average	**27.7**		
Large : VTT	55.4	27.2 2)	Exponential
ETH	79.4	4.3 2)	Exponential
Average	**67.4**		

1) *peak-to-peak delay spread* ,2) *standard deviation of delay spread local averages*

,3) *peak-to-peak of delay spread local averages*

Although instantaneous values and local averages of the PDP may include a lot of environment dependent details, the overall average PDP has quite regular shape. As seen in Table (3.2), the PDP in dense environment has been observed to follow either power function (the decay is logarithmic in dB scale) or exponent function (the decay is linear in dB scale). In open environment the PDP follows best the power function, because of the strong effect of the direct path. Typical averaged power delay profiles in Line- of-sight, (LOS), Non-line-of-sight (NLOS), and Obstructed-line-of-sight (OLOS) conditions are shown in Figure (3.1) OLOS means a condition where the direct path is blocked only by an obstacle, e.g. apiece of furniture[11].

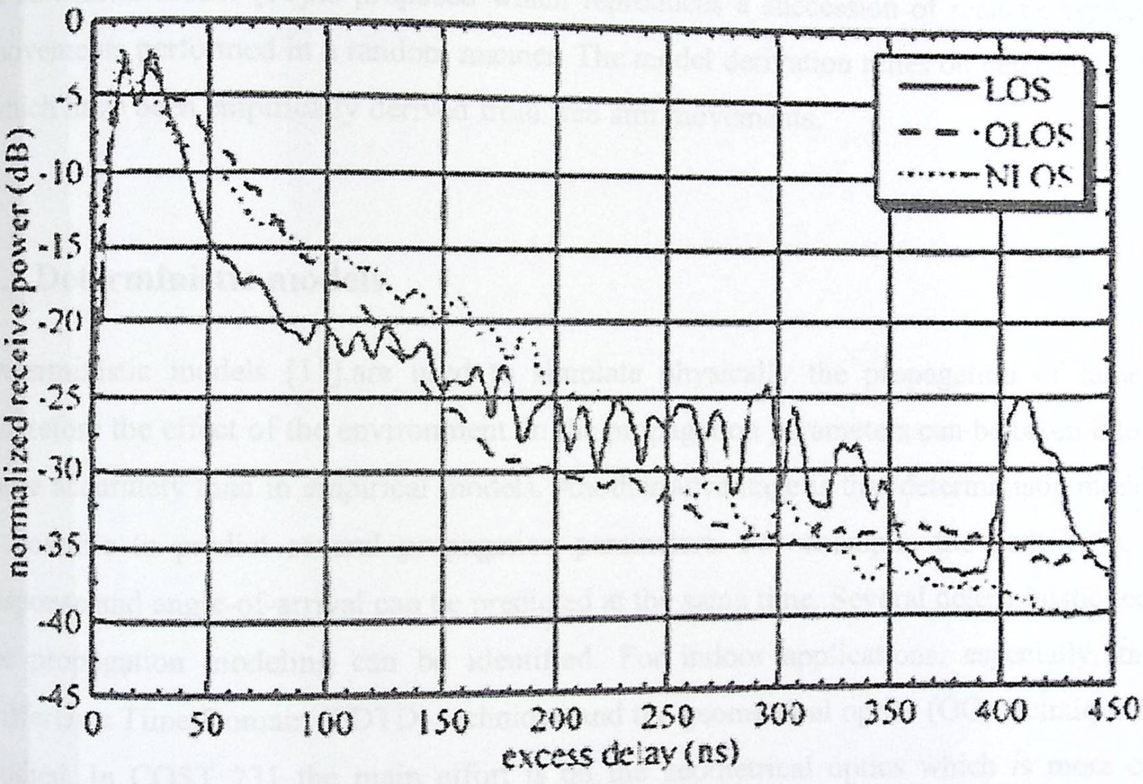


Figure [3.1]: Overall average power delay profiles in three configurations (Lund) [11].

3.4 Modeling the time fluctuations of the indoor channel

Time variations of the indoor radio channel essentially result from the following three mechanisms: As the location of the receiving antenna changes, the spatial fluctuations of the electric field along the receiver trajectory are translated into corresponding time variations. Time variability also arises when the orientation of the antenna changes, due to its usually non-isotropic field pattern. Finally, movements of scattering objects such as persons or furniture also contribute to make the channel system functions time-variant. Time-variations of the mobile channel have been studied almost all attention has focused on the time variability resulting from receiver movements with constant velocity. However, the consideration of such receiver displacements in the indoor environment is questionable since they are not realistic for describing human motion. Moreover, they force to restrict the investigations of the spatial field dependency to one specific direction determined by the receiver velocity vector. Finally, such movements do not allow taking the Doppler rate, i.e., the change of Doppler frequency, into account.

A stochastic model [11].is proposed which reproduces a succession of realistic typical human movements performed in a random manner. The model derivation relies on deterministic models which have been empirically derived from free arm movements.

3.5 Deterministic models

Deterministic models [11].are used to simulate physically the propagation of 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. For example, the path 199s, impulse response and angle-of-arrival can be predicted at the same time. Several deterministic techniques for propagation modeling can be identified. For indoor applications, especially, the Finite Difference Time Domain (FDTD) technique and the geometrical optics (GO) technique has been studied. In COST 231 the main effort is on the geometrical optics which is more computer efficient than the FDTD. There are two basic approaches in the geometrical optics technique. The ray launching approach and the image approach.

3.5.1 Ray launching model (RLM)

The ray launching approach [11].involves a number of rays launched at the transmit antenna in specified directions. For each ray its intersection with a wall is determined and the incident ray is divided into a wall penetrating ray and a reflected ray; each of them is traced to its next intersection and so on. A ray is terminated when its amplitude falls below a specified threshold, or a chosen maximum number of ray-wall interactions are succeeded.

3.5.2 Image approach method (IAM):

The image approach [11].makes use of the images of the transmit antenna location relative to all the surfaces of the environment. The coordinates of all the images is calculated and then rays are traced towards these images.

3.5.3 Building information

Deterministic models require detailed building information, i.e. location and material parameters of walls, floors and even furniture. Usually, accurate information of materials and internal structures of walls and floors is not available and somewhat approximate values have to be adopted [11].

3.5.4 Suggested Propagation Values

Some of the suggested values for the Path loss exponent model [12], that we could use for the simulation are tabulated at table (3.3).

Building	Freq (MHz)	n	σ dB
Retail Stores	914	2.2	8.7
Grocery Stores	914	1.8	5.2
Office, Hard Partitions	1500	3.0	7.0
Office, Soft Partitions	900	2.4	9.6
Office, Soft Partitions	1900	2.6	14.1
Factory LOS			
Textile/Chemical	1300	2.0	3.0
Textile/Chemical	4000	2.1	7.0
Paper/cereals	1300	1.8	6.0
Metalworking	1300	1.6	5.8
Suburban home			
Indoor to street	900	3.0	7.0
Factory OBS			
Textile/chemical	4000	2.1	9.7
Metalworking	1300	3.3	6.8

Table [3.3]: Suggested Propagation Values

It is noted that n falls between 1.8 and 3, with standard deviation 5 and 10 in the 900 MHz, depending on the in building environment structure.

3.5.5. ITU Model for Indoor Attenuation (Used model in our study for 900MHz)

There are two Indoor propagation modeling methods: site general [13] and site specific [14]. Since its flexibility in dealing with internal content of the building such as furniture, space distribution and materials used in construction, site general is the adopted method on this project that is the ITU indoor path loss related to. Reasons for using ITU model can be summarized that it is simple and easy to deal with, , and its power decay index can be calculated.

It should be noticed that ITU doesn't have terms that describes wall type and its penetration loss, but by finding the power decay index from the measurements that characteristics are found implicitly.

The ITU Indoor Propagation Model, also known as ITU Model for Indoor Attenuation, is a radio propagation model that estimates 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. And it is applicable to only the indoor environments.

The ITU model for site-general indoor propagation path loss prediction [13] is.

$$L_{total} = 20\, log10\,(f) + N\, log10\,(d) + Lf\,(n) - 28\, dB \qquad (4)$$

Where

N: is the distance power loss coefficient,
Where
N=10n. (n: power decay index).
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.

Since the transmitter in GSM case is outside the building ,So there is no floor penetration loss factor an f it is equals zero, consequently equation (4) becomes:

$$L_{total} = 20\, log10\,(f) + N\, log10\,(d) - 28\, dB \qquad (5)$$

It is known that the frequency in GSM is equal to 900MHz thus

$$Ltotal = 20\, log10\,(900MHz) + N\, log10\,(d) - 28\, dB \qquad (6)$$

$$Ltota = 59 + N\, log\,(d) - 28\, dB \qquad (7)$$

Finally and after rearranging terms, the total path loss is characterized as follows:

$$Ltotal = 31 + Nlog10\,(d) \qquad (8)$$

The transmitted power is equal to -36 dBm, so the power received is equal to the power transmitted subtracted the total path loss from .

$$Pr(dBm) = 36(dBm) - Ltotal(dB) \qquad (9)$$

$$Pr\,(dBm) = 36 - 31 - N\, log10\,(d) \qquad (10)$$

Therefore the total received power is given by:

$$Pr\ (dBm) = \quad 5 \quad - \quad N\ log10\ (d) \tag{11}$$

$$Pr\ (dBm) = \quad 5 \quad - \quad 10n\ log10\ (d). \tag{12}$$

Since the serving microcell located outside the building, this means that we must take into account the penetration loss of the outer wall and it is equals 20.14 dB

So the total received power is given by :

$$Pr\ (dBm) = \quad -15.14 \quad - \quad 10n\ log10\ (d) \tag{13}$$

The penetration loss through this external wall was measured by the group who work on the outdoor model, they are concentrate their work on calculating penetration loss for all wall types

.

3.6 Comparison between empirical and deterministic models

In the empirical models [11].All environmental influences are implicitly taken into account regardless of whether they can be separately recognized. This is the main advantage of these models. Because deterministic models are based on the principles of physics they may be applied to different environments without affecting the accuracy. In practice, their implementation usually requires a huge database of environmental characteristics, which is sometimes either impractical or impossible to obtain. The algorithms used by deterministic models are usually very complex and lack computational efficiency. For that reason, the implementation of the deterministic models is commonly restricted to smaller areas of microcell or indoor environments.

Both theoretical [11].and measurement based propagation models indicate that average received signal power decreases logarithmically with distance. Empirical models help in reducing computational complexity as well as increasing the accuracy of the predictions.

3.7 Indoor Propagation Models (WLAN 2.4 GHz)

One of the main objectives of this project is to characterize the indoor channel for 802.11 wireless local area networks at 2.4 GHz frequency. This work presents a channel model based on measurements conducted in commonly found scenarios in buildings. These scenarios include closed corridor, open corridor, classroom, and computer lab. Path loss equations are determined using log-distance path loss model and lognormal shadowing. The Chi-square test statistic values for each access point are calculated to prove that the observed fading is a normal distribution at 5% significance level. A numerical analysis of measurements in each scenario was conducted and the study determined equations that describe path loss for each scenario.

Indoor channels are highly dependent upon the placement of walls and partitions within the building, as placement of these walls and partitions dictate the signal path inside a building. In such cases, a model of the environment is a useful design tool in constructing a layout that leads to efficient communication strategies. To achieve this aim, a channel model of an indoor environment must be applied to various layout plans of offices which will lead to the characterization of design methodologies.

A channel model is useful in determining the mechanism by which propagation in the indoor environment occurs, which in turn is useful in the development of a communication system. By examining the details of how a signal is propagated from the transmitter to the receiver for a number of experimental locations, a generic model may be developed that highlights the important characteristics of a given indoor environment. Generic models of indoor communications can then be applied to specific situations to describe the operation of a radio system, and may also be used to generate designs that are particularly suited to supporting radio communication systems.

In the literature [11].There are numerous experimental and theoretical studies of indoor propagation. These models tend to focus on a particular characteristic like temporal fading or inter-floor losses. This study aims to studying an indoor propagation model from measurements taken using 802.11 (2.4GHZ) compliant access point and client adapters.

3.7.1 Log-distance Path Loss Model

In both indoor and outdoor environments the average large-scale path loss for an arbitrary Transmitter-Receiver (T-R) separation is expressed as a function of distance by using a path loss exponent n [6]. This value of n depends on the specific propagation environment, i.e., type of construction material, architecture, and location within a building. Lowering the value of n lowers the signal loss. The values of n ranges from 1.2 (Waveguide effect) to 8. For example, in free space, n is equal to 2, and when obstructions are present, n will have a larger value

3.7.2 Log-Normal Shadowing

Random shadowing effects occur over a large number of measurement locations which have the same T-R separation, but different levels of clutter on the propagation path [6]. This phenomenon is referred to as log-normal shadowing. Hence, Variations in environmental clutter at different locations having the same T-R separation is not accounted for by the log distance path loss model alone. This leads to measured signals which are vastly different than the average value predicted by using the log-distance path loss model. To account for these variations, the average path loss PL(d) for a transmitter and receiver with separation d thus becomes .

$$PL(dB) = PL(d_0) + 10\, n \log\left(\frac{d}{d_0}\right) + X_{\sigma(5)} \qquad (14)$$

Where Xσ is a zero-mean Gaussian distributed random variable with standard deviation σ the close-in reference distance d_0, the path loss exponent n, and the standard deviation σ, statistically describes the path loss model for an arbitrary location having a specific T-R separation. This model can be used in computer simulation to provide received power levels for random locations in communication system design and analysis.

3.7.3 Two-Ray Model

The ray-tracing approach approximates the scattering of electromagnetic waves by simple reflection and refraction. The degree of transmission and reflection of a signal through and off an obstacle is related to the complex permittivity's of the obstacle. One of the propagation models based on ray-optic theory is the Two-Ray model. i.e., we have a direct path and reflected path. It is used for modeling of Line of Sight radio channel as shown in Figure 3.2 the transmitting antenna of height h1 and the receiving antenna of height h2 are placed at distance d from each other.

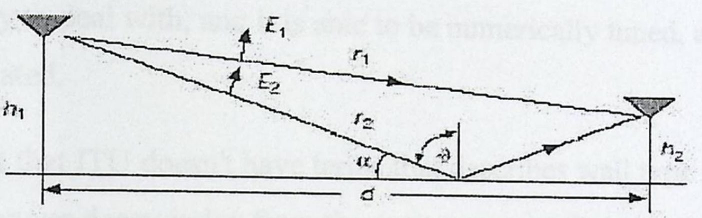


Figure [3.2.]: Tow ray model

The received signal Pr for isotropic antennas, obtained by summing the contribution from each ray, can be expressed as [15]:

$$P_r = P_t\left(\frac{\lambda}{4\pi}\right)\left[\frac{1}{r_1}e^{(-jkr_1)} + \Gamma(\alpha)\frac{1}{r_2}e^{(-jkr_2)}\right]^2 \qquad (15)$$

Where Pt is the transmitted power, r1 is the direct distance from the transmitter to the receiver, r_2 is the distance through reflection on the ground, and T(α) is the reflection coefficient depending on the angle of incidence _ and the polarization. The reflection coefficient is given by

$$\Gamma\,(\alpha) = \frac{\cos\Theta - a\sqrt{\varepsilon_r - \sin^2\Theta}}{\cos\Theta + a\sqrt{\varepsilon_r - \sin^2\Theta}} (7) \qquad (16)$$

Where θ = 90-αand a = 1/ε or 1 for vertical or horizontal polarization, respectively. εr is a relative dielectric constant of the reflected surface. The signal strengths from theoretical and empirical models are compared in this study.

3.7.4. ITU Model for Indoor Attenuation

There are two Indoor propagation modeling methods: site general [13] and site specific [14]. Since its flexibility in dealing with internal content of the building such as furniture, space distribution and materials used in construction, site general is the adopted method on this project that is the ITU indoor path loss related to. Reasons for using ITU model can be summarized that it is simple and easy to deal with, and it is able to be numerically tuned, and its power decay index can be calculated.

It should be noticed that ITU doesn't have terms that describes wall type and its penetration loss, but by finding the power decay index from the measurements that characteristics are found implicitly.

The ITU Indoor Propagation Model, also known as ITU Model for Indoor Attenuation, is a radio propagation model that estimates 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.

This model is applicable to only the indoor environments. Typically, such appliances use the lower microwave bands around 2.4 GHz.

The ITU model for site-general indoor propagation path loss prediction [16] is:

$$\mathbf{Ltotal = 20\ log10\ (f) + N\ log10\ (d) + Lf\ (n) - 28\ dB} \qquad \mathbf{(17)}$$

Where

N: is the distance power loss coefficient,

Where:

N=10n. (n: power decay index).

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.

3.7.4.1. Same floor measurements

It makes sense that the floor penetration loss factor is zero in the case of the same floor propagation, consequently equation **(17)** becomes:

$$Ltotal = 20\,log10\,(f) + N\,log10\,(d) - 28\,dB \qquad \textbf{(18)}$$

It is known that the frequency in WLAN is equal to 2.4GHz thus

$$Ltotal = 20\,log10\,(2400MHz) + N\,log10\,(d) - 28\,dB \qquad \textbf{(19)}$$

$$= 67.6 + N\,log\,(d) - 28\,dB \qquad \textbf{(20)}$$

Finally and after rearranging terms, the total path loss is characterized as follows:

$$\mathbf{Ltotal} = \mathbf{39.6} + \mathbf{Nlog10\,(d)} \qquad (21)$$

The transmitted power is equal to -17dBm, so the power received is equal to the power transmitted subtracted the total path loss from.

$$\mathbf{Pr(dBm)} = \mathbf{17(dBm)} - \mathbf{Ltotal(dB)}. \qquad (22)$$

$$\mathbf{Pr\ (dBm) = \ \ 17 \ - \ 39.6 \ - \ N\ log10\ (d).} \qquad (23)$$

Therefore the total received power is given by:

$$\mathbf{Pr\ (dBm) = \ \ -23 \ - \ N\ log10\ (d).} \qquad (24)$$

$$\mathbf{Pr\ (dBm) = \ \ -23 \ - \ 10n\ log10\ (d).} \qquad (25)$$

And then, the unknown parameter remains in the equation is the direct distance which is determined utilizing from AutoCAD™, And n can be calculated.

3.7.4.2. Multi-floor measurements

The general form of the ITU model, equation **(25):**

$$\mathbf{Ltotal \ = \ 20\ log10\ (f\ ) + \ N\ log10\ (d) + Lf\ (n) - \ 28\ dB} \qquad (26)$$

Where **N** is the power decay index between floors that separate the distance between transmitter and receiver can be calculated from the measured values, and the floor loss coefficient Lf (n) can be obtained by numerical tuning for the model with respect to the measured values.

CHAPTER 4

4

Measurements and data analysis for 2.4GHz frequency

4.1 Introduction

4.2 Building Location and Structure

4.3 Measurement Plan

4.4 Data Analysis

4.5 Model Calculations

4.6 IBWave™ Simulation

4.7 Comparison between Measured, Modeled and Simulated Values

CHAPTER 4

Measurements and Data Analysis for 2.4GHz Frequency

4.1 Introduction

This chapter presents a site-specific validation of the ITU indoor path loss model at 2.4 GHz. Based on measurements acquired in a recent experiment for a WLAN indoor office environment, we are able to accomplish a numerical adjustment of the Site-general ITU model to the specific measured data that reflect the intrinsic characteristics of the complex indoor topology, thus validating the Site-Specific ITU model at 2.4 GHz. For the first time, we are in position to provide values for the model's parameters that concern specifically this frequency band, which is of utmost importance for wireless networks, mostly for WLAN channels.

4.2 Building Location and Structure

First of all a study of the building location and structure was done, measurement also done at the college of engineering and technology (building B), The building location is at Wadi Al-Haria in Hebron. It's a five storey-building with ground floor, a sketch of each floor is shown in the appendix A .

4.3 Measurement Plan

When we start talking about the measurement process ,The first thing we would like to make clear is the software that we used During the measurements process this software is called Netstumbler Version 0.4.0 .

NetStumbler is a tool for Windows that allows us to detect Wireless Local Area Networks (WLANs) using 802.11b, 802.11a and 802.11g Fig [4.1]. It has many uses:

- Verify that your network is set up the way you intended.
- Determining the signal strength and Find locations of poor coverage in your WLAN.
- Detect other networks that might be causing interference with your network.
- Detect unauthorized "rogue" access points in your workplace.
- Help aim directional antennas for long-haul WLAN links.
- Use it recreationally for War Driving.

Here we are only interested in measuring the signal level of WLANs :

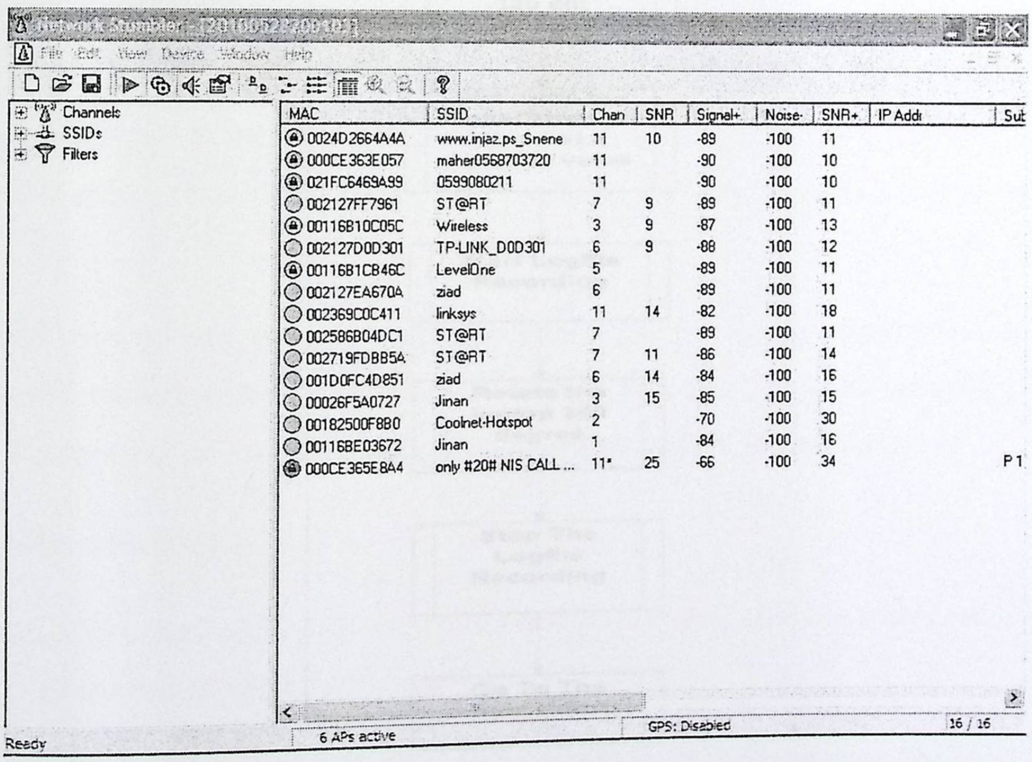


Fig [4.1]: The Netstumbler Software.

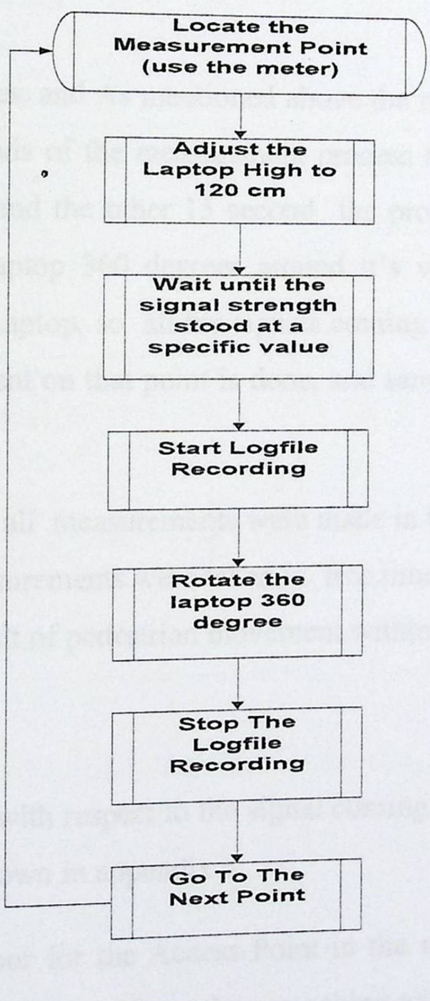
The first stage did was the process of measurement of a signal inside the building, with the presence of two Access Point distributed in the second and fifth floors

In the beginning, Center locations have been located for each classroom , laboratory, offices and corridors on each floor of the building using AutoCAD software(sketches where the centers has been located shown in appendix B) , and then data were recorded at all points in a two cases :

Case one :Values of signal strength in each center in all the five floors were recorded with respect to the access point located in second floor.

Case two : Values of signal strength in each center in all the five floors were recorded with respect to the access point located in fifth floor.

The method of measurement is clarified in figure (4.2) :



Fig(4.2): Measurement Procedures.

From the previous chart it's obvious that the first step is the locating of points(centers) at which the signal strength is measured, and this is what has been done using AutoCAD software, then adjusting the laptop height to 120 cm in the direction of the access point (we have selected this height because in natural situation the building is full of tables, offices and desktop computers ,Therefore by choosing this height, we have avoided the effects of such obstacles , then waiting for the stability of the signal due to the normal fluctuations of the electromagnetic waves, then start recording the logfile .

At the beginning of recording every logfile, Netstumbler records two values every second, and the duration of recording each logfile is 30 second, thus each logfile contains 15 readings per point, then we took the average of these readings which represents the signal strength at this point .

During recording of logfiles, and As mentioned above the recording time of each logfile was 30 second, the first 15 seconds of the measurement process takes place while the Laptop was installed in normal position, and the other 15 second the process of recording the logfile take place while rotating the laptop 360 degrees around it's vertical axis because of the wireless transceiver unit of the Laptop, so all the signals coming from the transmitter antenna were recorded, thus the measurement on that point is done, and same procedure is done with the next.

It should be noted here that all measurements were made in the case that no human interruption in the building so measurements were taken in free times, to get rid of the signal fluctuations that happens as a result of pedestrian movement within the building.

4.4 Data Analysis

Measurements were taken with respect to the signal coming from the access point on the second floor in all the floors., as shown in appendix c

Readings in the second floor for the Access Point in the second floor shown in Table (4.1), here we took the 2^{nd} floor and analyze it, so the same thing will applied to the 5^{th} floor .

SSID	slope distance	signal strength
WH-B-Floor 2	18.8	-55
WH-B-Floor 2	14.06	-57
WH-B-Floor 2	8	-55
WH-B-Floor 2	13.7	-60
WH-B-Floor 2	13.37	-57
WH-B-Floor 2	17.06	-65
WH-B-Floor 2	5.95	-60
WH-B-Floor 2	3.22	-43
WH-B-Floor 2	5.69	-42
WH-B-Floor 2	10.89	-58
WH-B-Floor 2	17.84	-60
WH-B-Floor 2	14.22	-52
WH-B-Floor 2	11.68	-47
WH-B-Floor 2	9.19	-45
WH-B-Floor 2	6.75	-40
WH-B-Floor 2	4.46	-37
WH-B-Floor 2	2.79	-33
WH-B-Floor 2	2.99	-34
WH-B-Floor 2	5.47	-47
WH-B-Floor 2	9.82	-46
WH-B-Floor 2	10.13	-59
WH-B-Floor 2	11.27	-62
WH-B-Floor 2	7.86	-63

Table (4.1): signal strength with respect to the slope distance

The relationship between the logarithm of the distance and the signal strength shown in the following graph:

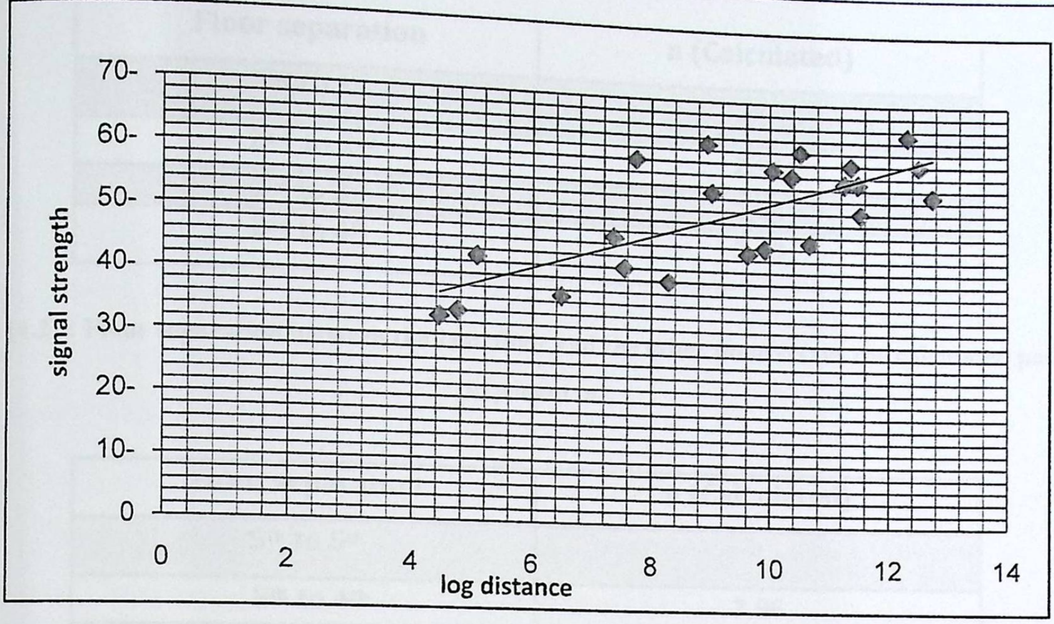


Fig (4.3) :The relationship between the logarithm of the distance and the signal strength (2nd to 2nd).

It is clear from the graph above that the signal strength associated with the distance between the transmitter and receiver and indicates that average received signal power decreases logarithmically with distance, Because The primary causes of attenuation are distance, penetration losses through walls, floors and multipath propagation.

Also from the graph shown above it could be noticed that the path loss exponent factor (n) can be calculated by the slope of the line which represent the arithmetic mean value of the readings ,so(n) for the following table equals 2.96 .This value of(n) depends on the specific propagation environment, i.e., type of construction materials, architectural design and location within a building. Lowering the value of(n) lowers the signal loss. The values of (n) range from 1.2 (Waveguide effect) to 8 [17]. For example, in free space, (n) is equal to 2, and when obstructions are present, n will have a larger value. Table (4.2) and table (4.3) below show the values of (n) between the second and fifth floor with other floors :

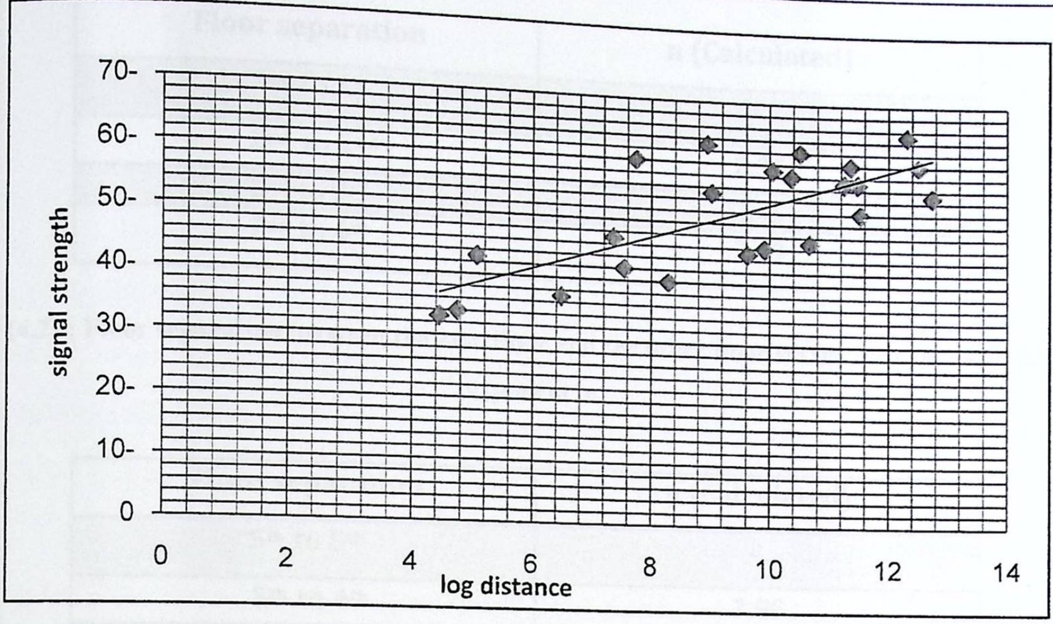


Fig (4.3) :The relationship between the logarithm of the distance and the signal strength (2nd to 2nd).

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Floor separation	n (Calculated)
2^{nd} to 1^{st}	4
2^{nd} to 2^{nd}	2.96
2^{nd} to 3^{rd}	3.45
2^{nd} to 4^{th}	2.49

Table (4.2) : Floor separation between the 2nd floor and the other floor versus the calculated path loss exponent n.

Floor separation	n (Calculated)
5^{th} to 5^{th}	4
5^{th} to 4^{th}	2.96
5^{th} to 3^{rd}	3.45

Table (4.3) : Floor separation between the 5th floor and the other floor versus the calculated path loss exponent n.

The points in the y-axis linked to other points on the x-axis, and all of these points is restricted in a particular area, it is necessary to find the mean value of these points by summing all points and dividing it by the number of points as shown in the following equation :

$$\text{Arithmetic mean} = \frac{\sum \text{data point}}{\text{number of data points (N)}} \quad (1)$$

Here is also essential to find the value of standard deviation of all points with respect to its mean .

The standard deviation equation is :

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \mu)^2}{N}} \qquad (2)$$

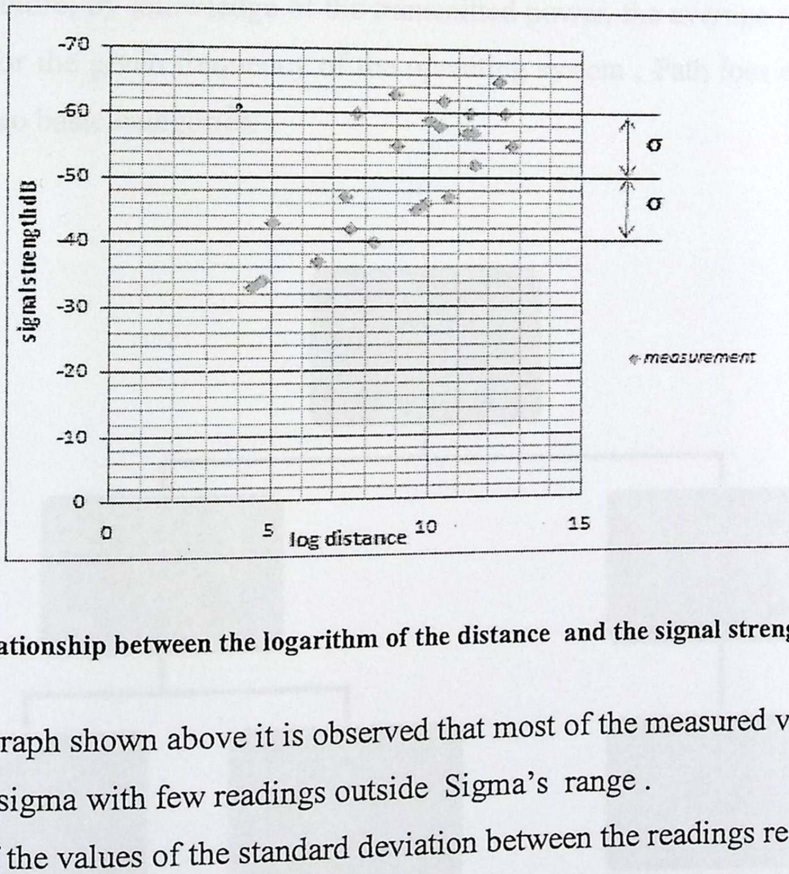
where :

N : number of points,

Xi : measured value ,

μ: mean value of all points .

After applying the previous equation and finding the value of standard deviation as shown in table(4.4), the result was σ = 9.75 (only for 2nd to 2nd measurement), this standard deviation with respect to the measurement is illustrated at figure(4.4).



Fig(4.4) The relationship between the logarithm of the distance and the signal strength (2nd to 2nd).

Form the graph shown above it is observed that most of the measured values are confined within the area of sigma with few readings outside Sigma's range .

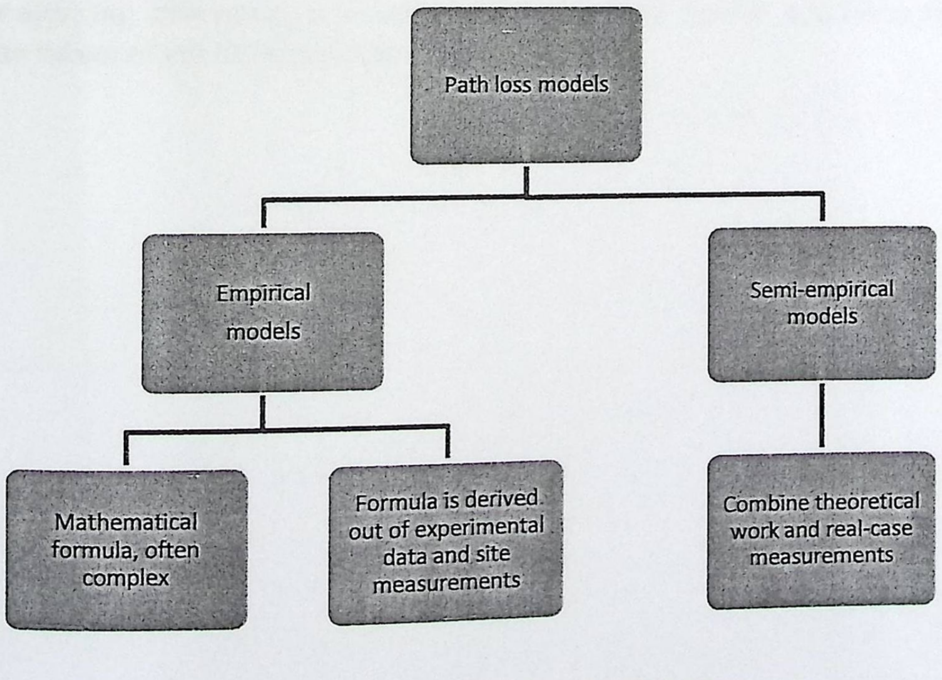
The rest of the values of the standard deviation between the readings recorded in the second floor and the readings recorded in the rest floors shown in the following Table:

Floor separation	μ	Standard deviation (σ)
2nd to 1st	-71.48	8.61
2nd to 2nd	-51.17	9.75
2nd to 3rd	-77.09	5.50
2nd to 4th	-91.13	5.06

Table (4.4): values of the standard deviation

4.5 Model Calculations

Many path loss models have been developed in order to calculate the average path loss (in dBm) and therefore, by knowledge of the transmitted power, the average received power at a certain distance, for the given frequency of the operating system , Path loss models [18] can be distinguished in two basic categories:



Fig(4.5): Path Loss Models Classifications.

The fundamental path loss model is the Free Space Model that predicts an inverse square dependence of the average received power versus distance between transmitter and receiver ,extensive research has developed a significant number of modified power-law models that try to take into account the complex nature of real life wireless channels.

As mentioned above ,the indoor propagation channel is a much more complex case than the outdoor environment, due to the increased number of obstacles, whose dimensions are close to the wavelength of the propagated electromagnetic wave, where the presence of multiple types of walls and floors add to the complexity of the calculations. As a result, various path loss models have been developed to describe the indoor channel and its multiplicative effects that cause the attenuation of a transmitted signal [19].

4.5.1 Same Floor Measurements

As we mentioned in chapter three , ITU is our adopted model in the two cases ,same floor and multiple floors measurements.

In the same floor measurements ,ITU model is:

$$P_{r\,(dBm)} = -23 - 10n\log_{10}(d) \qquad (3)$$

After applying this equation to our measurements(2nd to 2nd and 5th to 5th) and knowing the values of (n) the result was :

Point number	5^{th} to 5^{th} meaasurements	2^{nd} to 2^{nd} measurements	ITU model 5^{th} to 5^{th}	ITU model 2^{nd} to 2^{nd}

P1	-56	-55	-55.39	-60.75
P2	-59	-57	-50.11	-57.01
P3	-50	-55	-44.74	-49.76
P4	-59	-60	-53.00	-56.68
P5	-57	-57	-54.77	-56.37
p6	-62	-65	-57.90	-59.50
P7	-54	-60	-49.20	-45.95
P8	-46	-43	-46.22	-38.05
P9	-51	-42	-47.36	-45.37
P10	-55	-58	-51.52	-53.73
P11	-57	-60	-56.08	-60.08
P12	-51	-52	-52.58	-57.16
P13	-49	-47	-50.11	-54.63
P14	-37	-45	-47.03	-51.54
P15	-36	-40	-43.01	-47.57
P16	-36	-37	-37.68	-42.24
P17	-37	-33	-33.86	-36.20
P18	-39	-34	-38.15	-37.09
P19	-49	-47	-46.17	-44.87
P20	-57	-46	-51.15	-52.40
P21	-58	-59	-52.58	-52.80
P22	-60	-62	-54.09	-54.17
p23	-56	-60	-57	-49.53
		% error	7.92	9.99

Table(4.5) Same floor measurement and modeling.

As it can be seen, the ITU model with the varying power decay index corresponds rather well as compared to the measured data. The total of the 23 measurements provide an average error of 7.92 % for the fifth floor and 9.99% for the second floor measurements . As it can be seen, the ITU model with the varying power decay index corresponds rather well as compared to the measured data.

4.5.2. Multi-floor measurements

As mentioned The general form of the ITU model, equation (4)

$$L_{total} = 20\log_{10}(f) + N\log_{10}(d) + Lf(n) - 28\ \text{dB} \quad (4)$$

So in multi-floor the power received is

$$P_{r\,(dBm)} = -23 - 10n\log_{10}(d) + Lf(n) \quad (5)$$

After precise numerical tuning based on our measurements for floor loss coefficient Lf (n) we got:

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

Table(4.6): Floor loss coefficient.

So ITU-1 model becomes :

$$P_{r\,(dBm)} = -23 - 10n\log_{10}(d) - 5n \quad (6) \quad \text{(One floor separation)}$$

And ITU-2 model becomes :

$$P_{r\,(dBm)} = -23 - 10n\log_{10}(d) - 18(n+1) \quad (7) \quad \text{(Two floor separation)}$$

These equation applied to our measurements and the relative error was calculated in each case as shown in the following table :

2nd to 1st	ITU1 Lf(n)=5n	2nd to 3rd	ITU1 Lf(n)=5n	5th to 4th	ITU1 Lf(n)=5n
-85	-79.47	-80	-72.06	-86	-78.75
-80	-74.70	-75	-67.71	-80	-71.29
-78	-66.19	-72	-59.34	-65	-64.58
-77	-74.29	-77	-67.33	-85	-75.31
-69	-73.90	-69	-66.97	-85	-77.85
-90	-77.85	-90	-70.60	-89	-82.47
-68	-62.38	-68	-55.02	-80	-70.07
-59	-56.65	-56	-46.36	-74	-66.31
-64	-61.85	-59	-54.36	-68	-67.7
-74	-70.70	-74	-63.92	-81	-79.77
-86	-78.60	-86	-71.28	-84	-73.22
-77	-74.89	-77	-67.88	-75	-74.72
-68	-71.77	-68	-64.95	-72	-71.29
-64	-68.16	-64	-61.39	-69	-67.25
-63	-63.92	-59	-56.84	-70	-62.72
-60	-59.28	-58	-50.86	-68	-58.14
-60	-55.75	-52	-44.42	-60	-56.04
-64	-56.17	-63	-45.37	-69	-58.47
-71	-61.41	-60	-53.80	-79	-66.25
-69	-69.14	-66	-62.38	-81	-72.7
-73	-69.60	-69	-62.83	-85	-74.72
-75	-71.22	-73	-64.42	-90	-76.88
-70	-65.95	-68	-59.09	-74	-72
%error	6.3		12		3.21

Table(4.7): one floor separation measurement and modeling

And ITU-2 model applied to the floors that have two floor separation and the result shown in table (4.8) :

2nd to 4th	ITU-2 Lf(n)=18(n+1)	5th to 3rd	ITU2 Lf(n)=18(n+1)
-95	-91.1527	-96	-102.34
-95	-89.8665	-94	-99.22
-94	-87.6101	-91	-96.82
-93	-89.7552	-94	-100.85
-94	-89.6512	-95	-101.95
-97	-90.7159	-97	-104.01
-87	-86.6326	-90	-98.74
-80	-85.2311	-93	-97.39
-89	-86.499	-93	-97.88
-90	-88.7964	-91	-99.98
-97	-90.9177	-93	-102.79
-92	-89.9152	-91	-100.6
-89	-89.0817	-89	-99.22
-90	-88.124	-90	-97.73
-89	-87.0253	-90	-96.25
-86	-85.8626	-86	-95.05
-82	-85.0228	-85	-94.59
-83	-85.1203	-88	-95.12
-87	-86.3894	-92	-97.37
-92	-88.3828	-95	-99.78
-91	-88.5044	-96	-100.6
-93	-88.9354	-95	-101.51
-90	-87.5476	-97	-96
%error	3.293805		7.46

Table(4.8): Two floor separation measurement and modeling.

4.6 IBWave™ Simulation

iBwave Design is an in-building design tool that lets wireless network operators, system integrators and equipment manufacturers bring strong, reliable wireless communications indoors, by automating network design and eliminating guesswork.

Because of its unavailability of the software for students and researchers locally, a consultant was asked from Jawwal Mobile Company to have a simulation for the two antennas installed in field, so we joined a private training classes to figure out the tasks of working on such software, consequently, simulation could be available after giving hand from the stuff of planning engineers in the section of planning in Hebron branch, because there were insufficient configuration that the software support for the 2.4GHz.

A prediction of the signal strength on the field is simulated in three cases, first with the presence of the access point in the second floor only, secondly with the access point on the fifth floor only, and the last one is with the effect of the both access points in two floors. The detailed charts for the simulation is found in the appendix(D).

4.7 Comparison between measured, modeled and simulated values

For each point in the field, a three values of signal strength is gained, which are the measured by Netstumbler™, the model and from the IbWave™ simulation, thus there is an opportunity to check and compare each value with the others, but it is must be known that the IbWave™ values is gained by a prediction indicated by color-wise scale so there is an uncertainty that reach to a value of (±2.5dBm) in some charts, and to (±5dBm) in others.

4.7.1 Same Floor Comparison:

The first thing we compared is the same floor measurements , 2nd to 2nd and 5th to 5th with the ITU-1 model and the Approximate values of ibwave ,the relative error for each method was calculated.

Second to second data comparison:

point	SSID	Slope distance	Measurement	Simulation	ITU-1Model
P1	WH-B-Floor 2	18.8	-55	-50	-60
P2	WH-B-Floor 2	14.06	-57	-45	-57
P3	WH-B-Floor 2	8	-55	-53	-49
P4	WH-B-Floor 2	13.7	-60	-57	-56
P5	WH-B-Floor 2	13.37	-57	-58	-56
p6	WH-B-Floor 2	17.06	-65	-66	-59
P7	WH-B-Floor 2	5.95	-60	-48	-45
P8	WH-B-Floor 2	3.22	-43	-48	-38
P9	WH-B-Floor 2	5.69	-42	-45	-45
P10	WH-B-Floor 2	10.89	-58	-50	-53
P11	WH-B-Floor 2	17.84	-60	-52	-60
P12	WH-B-Floor 2	14.22	-52	-43	-57
P13	WH-B-Floor 2	11.68	-47	-42	-54
P14	WH-B-Floor 2	9.19	-45	-42	-51
P15	WH-B-Floor 2	6.75	-40	-41	-47
P16	WH-B-Floor 2	4.46	-37	-40	-42
P17	WH-B-Floor 2	2.79	-33	-40	-36
P18	WH-B-Floor 2	2.99	-34	-40	-37
P19	WH-B-Floor 2	5.47	-47	-43	-44
P20	WH-B-Floor 2	9.82	-46	-45	-52
P21	WH-B-Floor 2	10.13	-59	-52	-52
P22	WH-B-Floor 2	11.27	-62	-55	-54
P23	WH-B-Floor 2	7.86	-60	-57	-49
			Relative error	10.04	9.99

Table (4.9): 2nd to 2nd measured, simulated and modeled values

The figure bellow shows the measured, simulated, and modeled values related to the 2nd to 2nd floor:

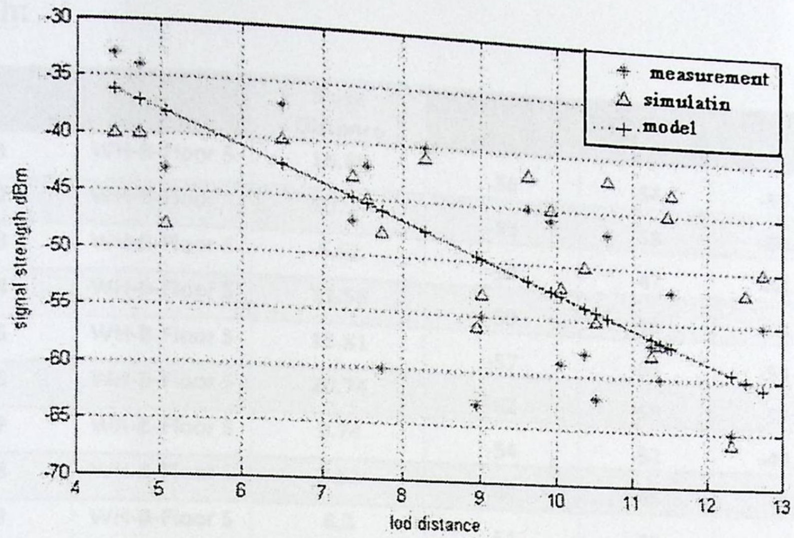


Fig.(4.6): 2nd to 2nd signal strength versus log distance (m).

Fifth to fifth:

point	SSID	Slope Distance	Signal	Simulation	ITU-1Model
P1	WH-B-Floor 5	16.68	-56	-54	-55.39
P2	WH-B-Floor 5	10.54	-59	-58	-50.11
P3	WH-B-Floor 5	6.61	-50	-47	-44.74
P4	WH-B-Floor 5	13.56	-59	-48	-53.00
P5	WH-B-Floor 5	15.81	-57	-55	-54.77
p6	WH-B-Floor 5	20.74	-62	-58	-57.90
P7	WH-B-Floor 5	9.74	-54	-52	-49.20
P8	WH-B-Floor 5	7.52	-46	-45	-46.22
P9	WH-B-Floor 5	8.3	-51	-53	-47.36
P10	WH-B-Floor 5	11.92	-55	-53	-51.52
P11	WH-B-Floor 5	17.71	-57	-55	-56.08
P12	WH-B-Floor 5	13.07	-51	-49	-52.58
P13	WH-B-Floor 5	10.54	-49	-47	-50.11
P14	WH-B-Floor 5	8.07	-37	-40	-47.03
P15	WH-B-Floor 5	5.69	-36	-40	-43.01
P16	WH-B-Floor 5	3.58	-36	-40	-37.68
P17	WH-B-Floor 5	2.57	-37	-40	-33.86
P18	WH-B-Floor 5	3.73	-39	-42	-38.15
P19	WH-B-Floor 5	7.49	-49	-47	-46.17
P20	WH-B-Floor 5	11.54	-57	-56	-51.15
P21	WH-B-Floor 5	13.07	-58	-57	-52.58
P22	WH-B-Floor 5	14.9	-60	-58	-54.09
p23	WH-B-Floor 5	3.79	-56	-57	-38.33
			Relative error	5.38	8.95

Table (4.10): signal strength, simulation, and model in fifth to fifth floor.

The figure bellow shows the measured, simulated, and modeled related to the 5th to 5th floor

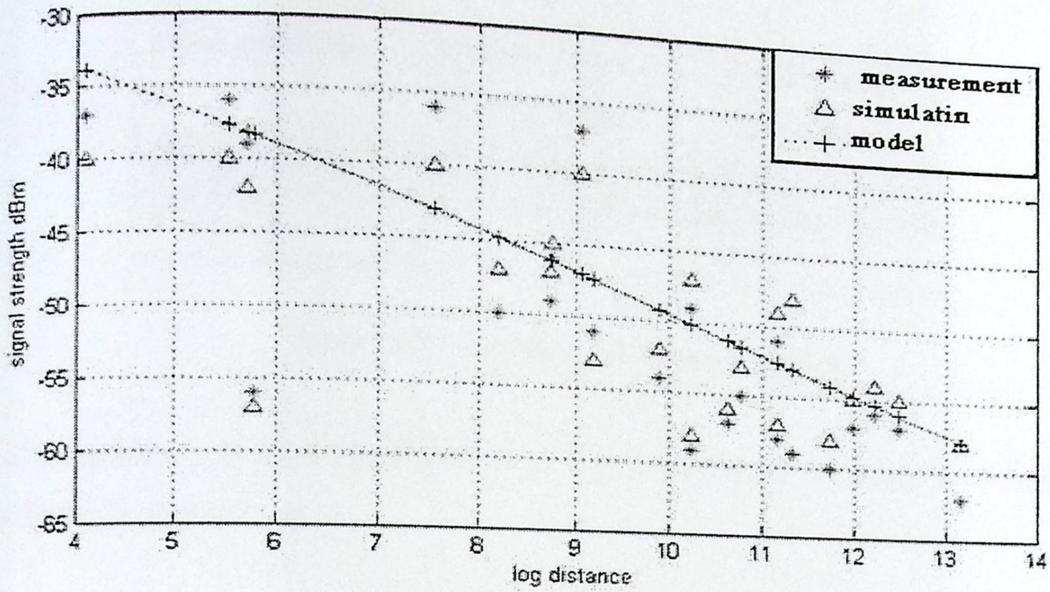


Fig.(4.7): 5th to 5th signal strength versus log distance.

4.7.2 Multiple Floor Comparison:

The other related tables that compare the measured ,simulated ,and valued and it's related error in details are shown in appendix C ,here are the summery of this comparison.

4.7.2.1 One floor separation comparison

Floor separation	Relative error (ITU-2 model)	Relative error (Simulation)
2nd to 1st	6.39	5.63
2nd to 3rd	12.08	8.69
5th to 4th	8.31	5.25

Table (4.11): One floor separation comparison.

4.7.2.2 Two floor separation comparison

Floor separation	Relative error (ITU-3 model)	Relative error (Simulation)
2nd to 4th	3.39	4.71
5th to 3rd	7.46	5.06

Table (4.12): Two floor separation comparison.

the plot of comparison between the measured ,simulated ,and modeled values in multiple floor case are shown in appendix E

4.7.2.2 Two floor separation comparison

Floor separation	Relative error (ITU-3 model)	Relative error (Simulation)
2^{nd} to 4^{th}	3.39	[illegible]
5^{th} to 3^{rd}	7.46	[illegible]

Table (4.12): Two floor separation comparison

the plot of comparison between the measured ,simulated and modeled values [illegible]

case are shown in appendix E

Chapter 5

5

Measurements and Data Analysis for 900 MHz Frequency

5.1 Introduction

5.2 Building Structure and location

5.3 Measurement Software

5.4 Measurement Plan

5.5 Data Collection

5.6 Model Calculations

5.7 Comparison Between Measured, Modeled and Simulated Values

5.8 Comparison between 900 MHz and 2.4 GHz

5.9 Result discussion

Chapter Five

Measurements and Data Analysis for 900 MHz Frequency

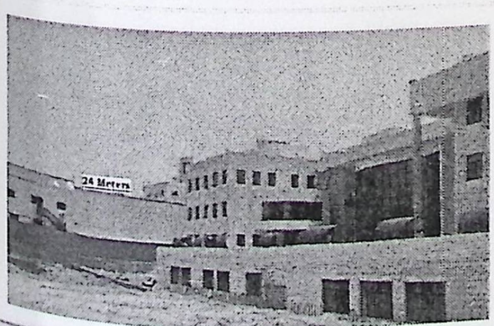
5.1 Introduction

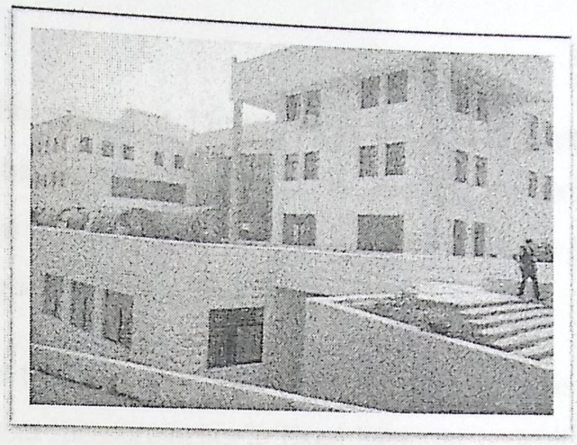
This chapter presents a site-specific validation of the ITU indoor path loss model at 900 MHz .Based on measurements acquired in a recent experiment for a GSM indoor environment. since it is works between 900MHz to 5 GHz, we are in position to provide values for the model's parameters that concern specifically this frequency band.

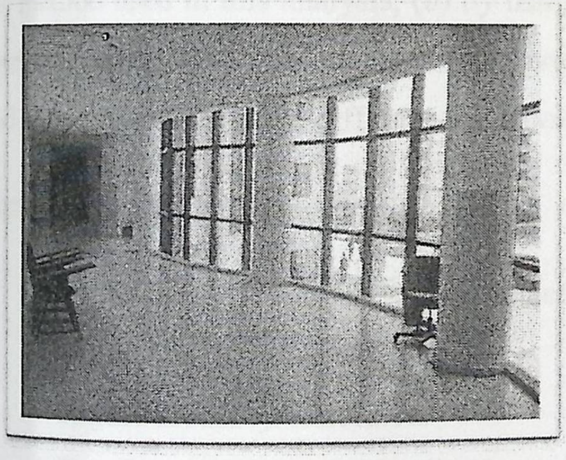
5.2 Building Structure and Location

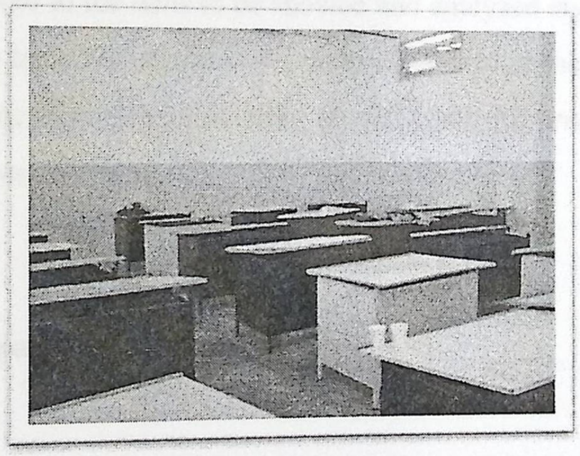
First of all a study of the building location and structure was done, measurement also done at the College of Engineering and Technology (Building C), The building location is at Wadi Al-Haria in Hebron. It's a three story-building with ground floor, a sketch of each floor is shown in the appendix G.

The following pictures shows shot for the building including the serving microcell location with respect to the building, and the internal space distribution in the offices, architectural laboratories, survey laboratories, and service rooms: like w.c., j.c. and kitchenettes. That the pictures indicate many of these details.









5.3. Measurement Software

5.3.1 TEMS Investigation

Terrestrial Ecosystem Monitoring Site abbreviated by TEMS is a software used to predict the indoor radio signal the Tems tool is used. Tems has many functions such as detecting the serving cells and display the serving line and showing the sites in map windows,etc In our project we are interested in two functions: detecting and measuring the signal strength of the serving cells.

To obtain the measurements from Tems there are two ways ;(a) by using mini tems installed on Sony Ericson k 850i mobile to get the different measurements in fixed locations or while moving ,these measurements stored as a logfiles then moved to the tems to be showed and analyzed and this is the method used in this analysis, (b) by using the tems installed on the laptop connected to the mobile then measuring the signal strength in a certain location or by following specific path we provided it and showing the results in different ways (values or contours).

Tems has many advantages:

- It measures continuously, not affected by parameter settings.
- Great sensitivity (-117 dBm).
- Higher accuracy/calibrated.
- Can detect multi path in radio channels.
- Measure on any ARFCN.

Type of information that can provide:

- Air interface measurements (GSM and WCDMA).
- Data service measurements.
- Network configuration parameters.
- Cell data.
- Positioning data.

Measuring The Signal Strength Using TEMS Mobile

while measuring the signal strength using the mobile TEMS, firstley the software was showing all serving cells, but the desired cell was one of them it is the microcell near C Building (12B), so the TEMS is locked to recive signal from (12B) only, then recording the measurment on each point is taken to be saved on logfile.

5.3.2 IBwave

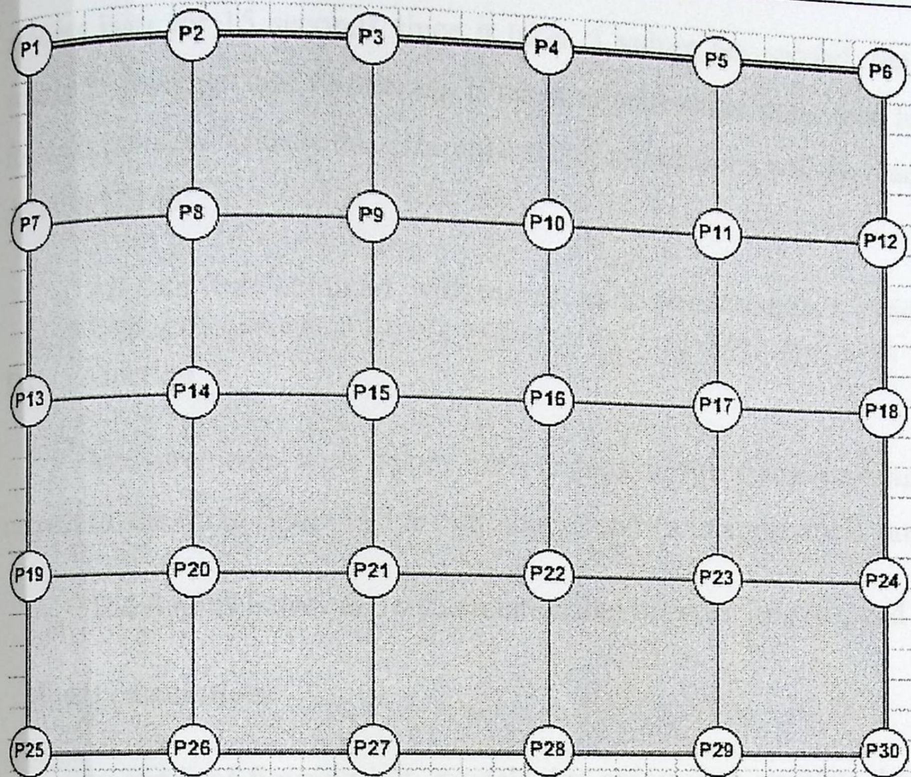
As used in the simulation of WLAN,IBWave was used in simulating GSM in this part. Case here includes three story-simulation with transmitted power of -36 dBm coming from a 24 m apart from microcell that located in the eastern corner outside the building.

5.4 Measurement plan

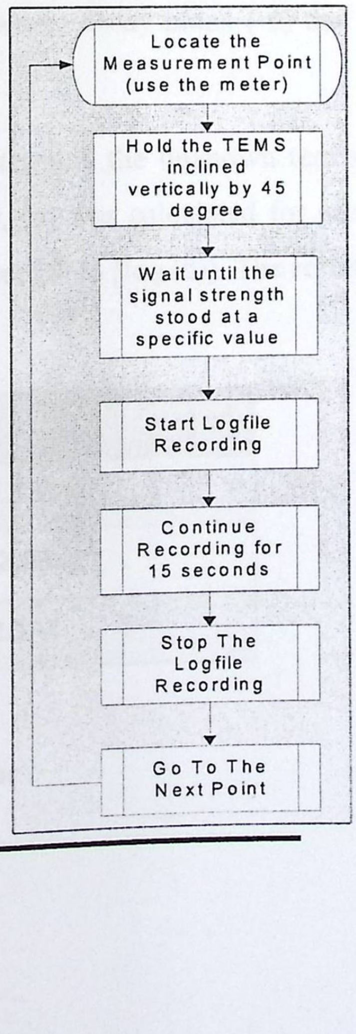
Here, GSM measurement is more complicated than one in the WLAN work, so work was more accurate since it needs more time-spending procedure, it is must be known that the transmitter was outside the building proposed.

Our strategy in measurement based on the technique of grid plan, that is each floor was divided into (3*3 m) for each grid unit, which was done by AutoCAD™, and numbering was arranged from the nearest points to the microcell and traveling apart. All above is translated by charts and plans in appendix G.

Distance between microcell and grid points were determined using AutoCAD™ software. The following figure illustrates a virtual grid plan with the lines of distance measurements.



The grid unit area was chosen (3*3m) in order to comply with the building geometry so as to have points on all the spaces inside,and that interval is much sufficient to observe the variation of the signal, as a gross this number of points will be enough to do the desired calculations.



After that, TEMS is hold on the point at level of 20cm for the points facing the cell (LOS), whereas other points were hold at a level to 120cm, because the transmitter is outside the building, the points facing the microcell (LOS) with presence of windows, it was measured at level of 20 cm to put the outer walls on consideration, that was one of the problems we faced because the transmitter is outside the building.

TEMS handset should be adjusted 45 degree upon horizon, in order to receive the vertical and horizontal polarization. Then wait for 5 seconds before recording till the signal remains stable, then recording the logfile is started. This process lasts for 15 seconds since it takes 5 values per second, the resulting values for each point equals 75 readings that its average is taken to start calculation, then logfile is ended and same is done for next point.as a result the data needed for calculations will be ready for use after it is delivered to desktop TEMS.

All data were obtained with respect to no pedestrian flow inside the building.

5.5. Data collection

Measurements were taken with respect to the signal coming from the outer microcell with respect to the three floors inside building, as shown in appendix B, and log file in the attached CD.

The figures below show the relationship between [log (d)] and the signal strength:

5.6. Model calculations

. as result of figuring out models that are used to simulate the indoor environment, whether in WLAN 2.4 GHz or GSM 900 MHz, and as mentioned in chapter 3, ITU model is the referred model in analyzing results obtained, and as conclusion for chapter 3. ITU model is a simple, applicable describer for the results. Supremely it takes in consideration the power decay index (n) that briefly describes the indoor environment.

Before the application of the model, it is important to determine the unknown terms in the model formula, which can be found from the read data, so firstly, (n) was calculated for each floor which represents the slope of the relationship between the signal strength to [log (d)]. The resulting n's are indicated in the table (5.1):

Floor number	Path loss exponent n (measured)
1st floor	1.831
2nd floor	2.08
3rd floor	2.148

Table 5.1: n values for each floor

Also it is important to determine the standard deviation of the readings recorded in each floor, these values are indicated in the table 5.2

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

Table 5.2. the value of the standard deviation for each floor

After that ITU formula was applied in the following form

Pr (dBm)= 5 - 10n log10 (d). Eq(5.1)

In the case studied, the loss penetration of the outer-wall must be put into consideration in the ITU model, which equals 20.19 dB[1]. So the model form will be as follows :

Pr (dBm)= 5 - 10n log10 (d). Eq(5.2)

The relative error between the measured values and the model values is shown In Table (5.3)

floor	relative error
First floor	17.12
Second floor	17
Third floor	14.57

Table(5.3): relative error between measured ,modeled values

It is obvious that relative error values are large to compare the model results with the measured values, so the resulting values of the model don't reflect the accurate measurements practically done. But after dealing with standard deviation and applying it to the model the results appear in appindex B, then the relative error was calculated, and the results are indicated in Table (5.4), and form of the ITU formula become

$$P_{r\,(dBm)} = 5 - 10n\log_{10}(d) - \sigma \qquad Eq(5.3)$$

Floor number	relative error
1st floor	11.48
2nd floor	14.24
3rd floor	12.97

Table (5.4):Relative error with respect to the standard deviation found

It is clear that the error value decreased apparently after applying the standard deviation in the formula, and results become more precise about (3-4)%

5.7 comparison between measured, modeled and simulated values

For each point in the field, a three values of signal strength is gained, which are the measured by TEMS, the model and from the IbWave™ simulation, thus there is an a good opportunity to check and compare each value with the others, but it is must be known that the IbWave™ values is gained by a prediction indicated by color-wise scale so there is an uncertainty that reach to a value of (±2.5dBm) in some charts, and to (±5dBm) in others. Also the microcell located outside the building ,and it is expected that the error will be increase , The figures bellow show the measured, simulated, and modeled values related to the 1st ,2nd,3rd floor respectively :

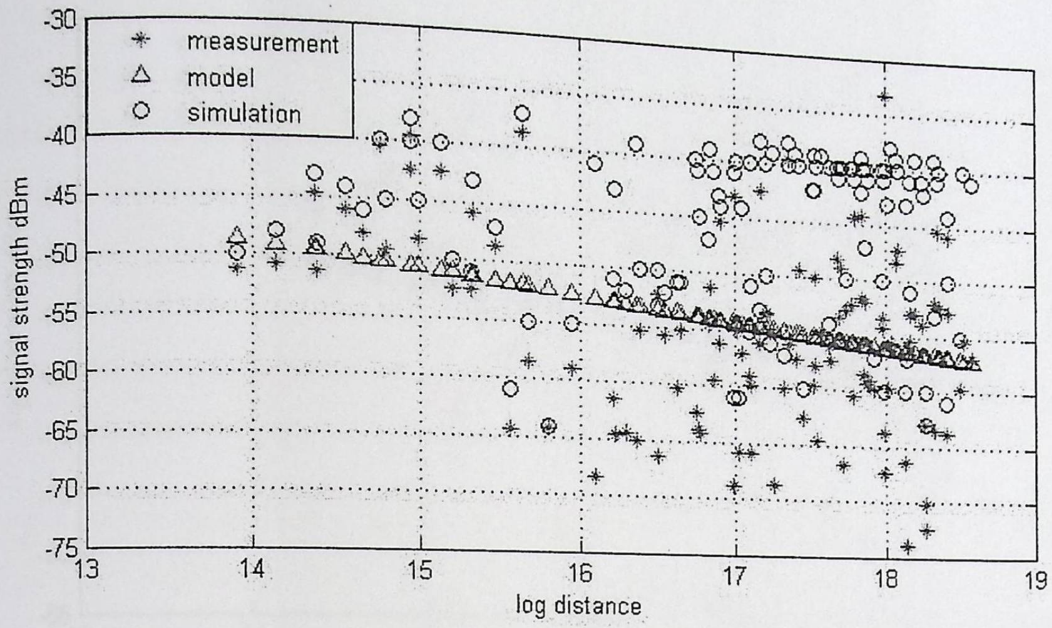


Fig (5.1):1st floor comparison

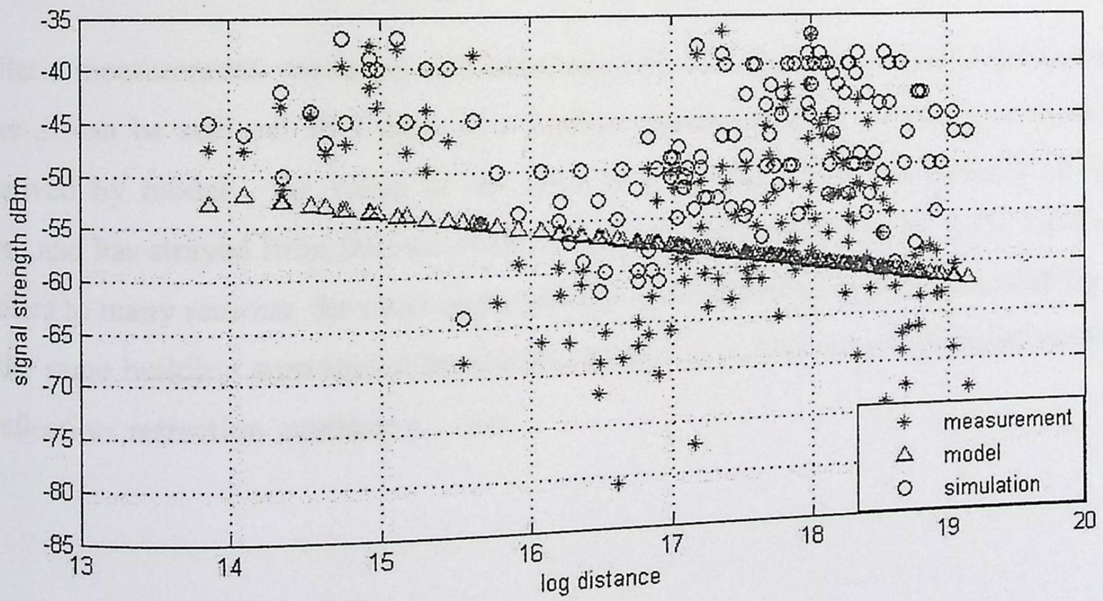


Fig (5.2):2nd floor comparison

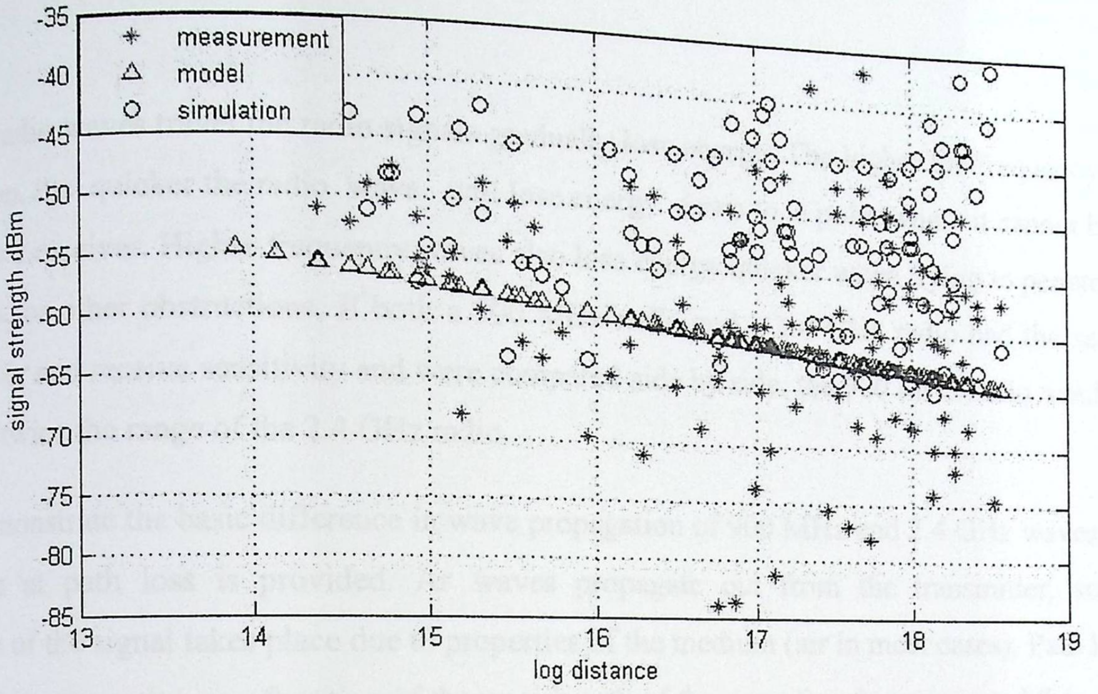


Fig (5.3):3rd floor comparison

After a measurement, modeling and simulating process ,and drawing the relationship between each other ,it can be noticed that there is a relative affinity between the values measured and the values derived by model , the value of the error in the comparison were greatest in the case of simulation ,and has strayed from the rest of the measured and modeled values with error reached 17 %, this refers to many reasons, the most important that the transmitter is located outside the building , As it is the same building surrounded by buildings and this is what causes propagation mechanisms such as reflection ,refraction ,scattering ….etc

5.8 Comparison between 900 MHz and 2.4 GHz

As radio waves travel the radio signals gradually lose energy. The higher the frequency of transmission, the quicker the radio wave will lose energy down to a point where it cannot be detected by a receiver. Higher frequency waves also lose energy quicker when trying to penetrate walls, trees, or other obstructions. If both a 900 MHz radio and a 2.4 GHz radio had the same output power and receive sensitivity and were compared side by side, the 900 MHz radio would get almost twice the range of the 2.4 GHz radio.

To demonstrate the basic difference in wave propagation of 900 MHz and 2.4 GHz waves, a quick look at path loss is provided. As waves propagate out from the transmitter, some attenuation of the signal takes place due to properties of the medium (air in most cases). Path loss describes this attenuation as a function of the wavelength of the operating frequency and the distance between the transmitter and receiver

Path loss exponent factor was compared between the two frequencies , In 2.4 GHz frequency n reached 4 while it 2.14 in 900 MHz, as the frequency increase path loss increase and the penetration loss increase ,so n increase, and this is what already proved in our measurements .

5.9 Result discussion

ITU model has been modified and the floor penetration loss added to its equation to fit the measurements resulting two cases ,same floor and multiple floor through precise numerical tuning , The same ITU model was adopted in building C and applied it to the measurements recorded for each floor .also standard deviation was determined and added to the model equation ,so lower error was obtained ,and became approximately represent the power distribution inside the building after the path loss exponent factor and the standard deviation were determined for each floor based on the outer serving microcell

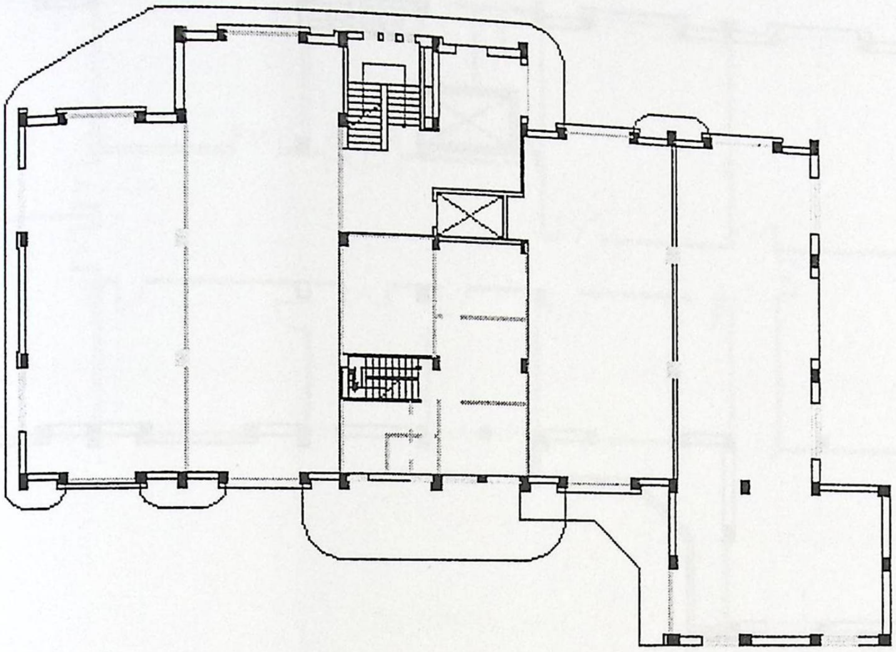
For each point in the field, a three values of signal strength is gained, which are measured by nets tumbler in WLAN or TEMS in GSM, the model is from the IbWave™ simulation. and compare these result with each other .

Path loss exponent was calculated for two different indoor environments and different frequencies and comparing it depending on the environment and the frequency .

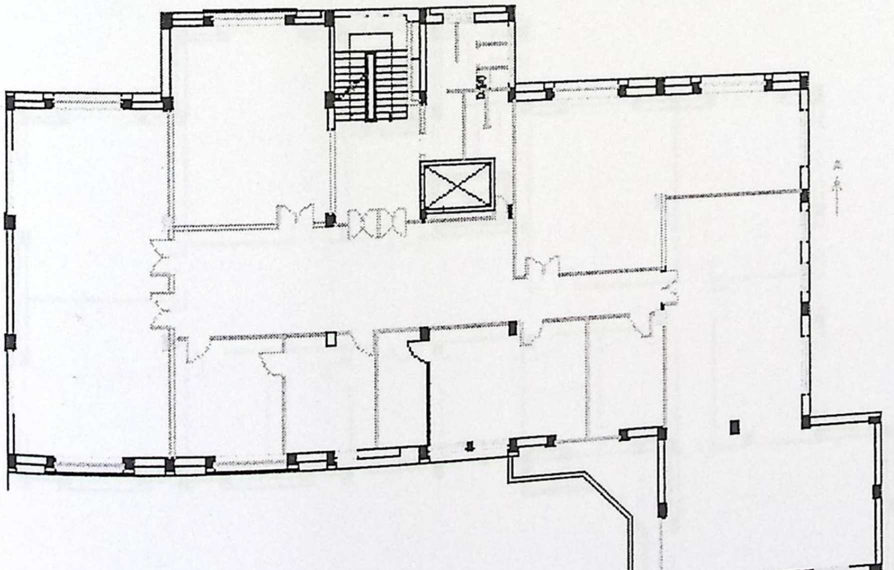
In WLAN case dead spots determined by the simulation and measurements

The value of the standard deviation also determined and it's compared to the local operator criteria .

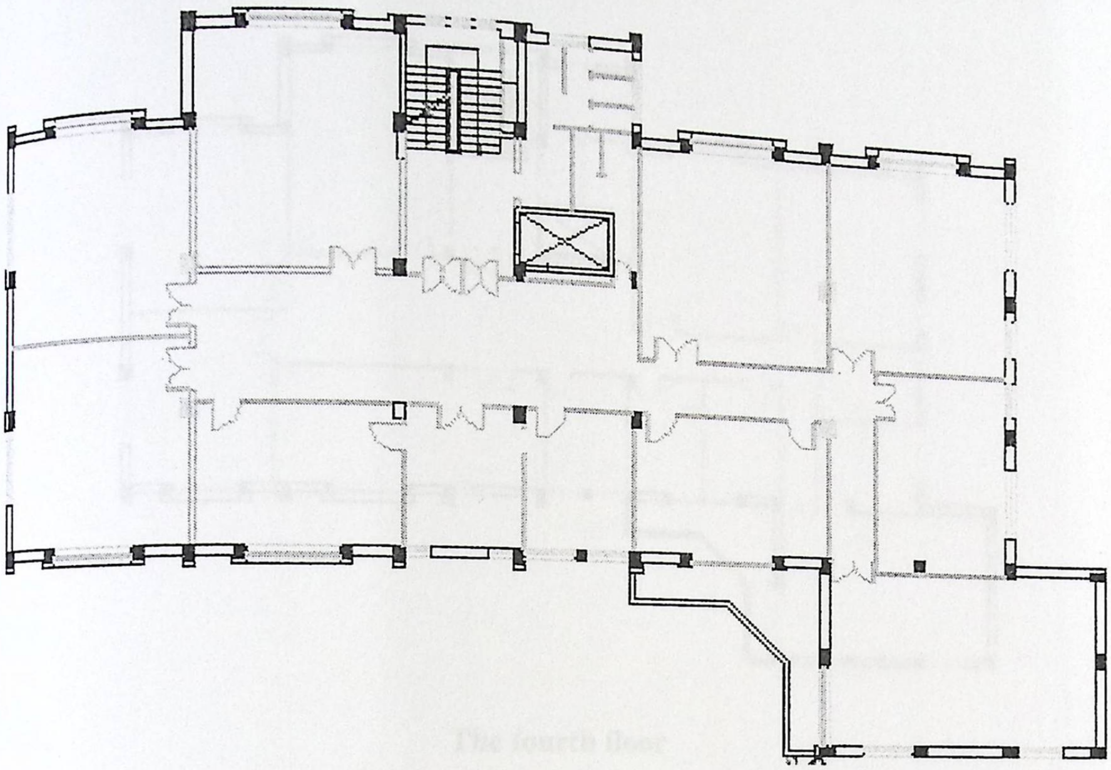
Appendix A



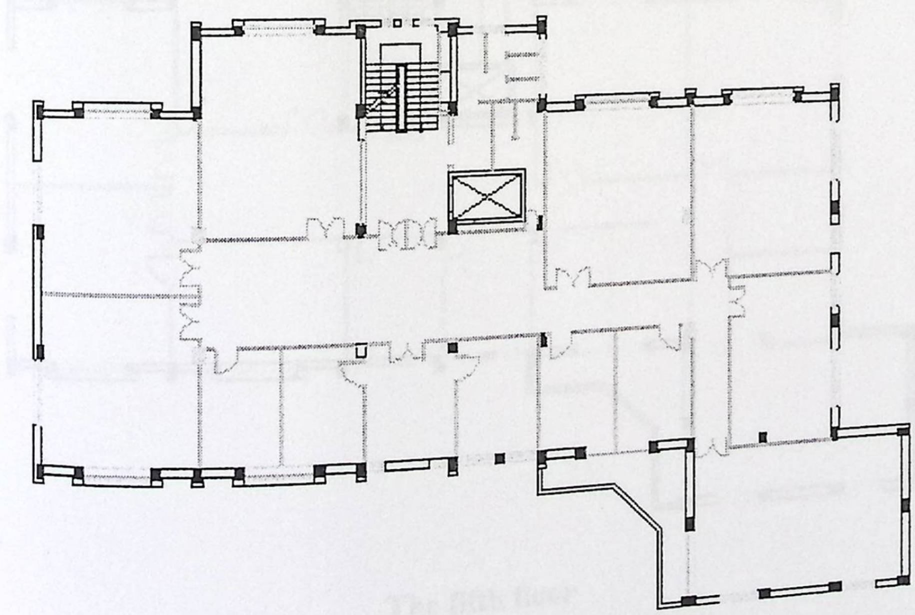
The ground floor



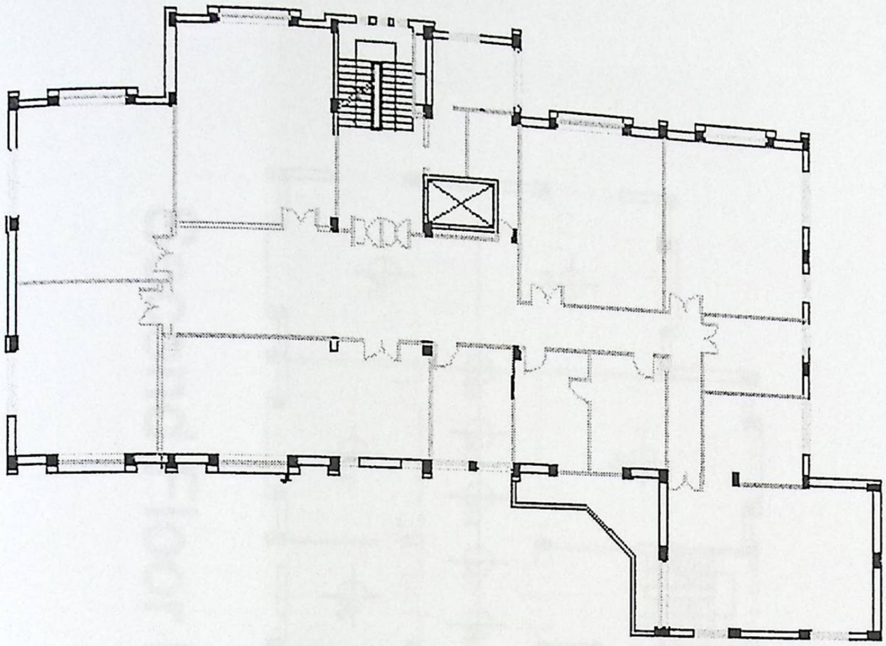
The first Floor



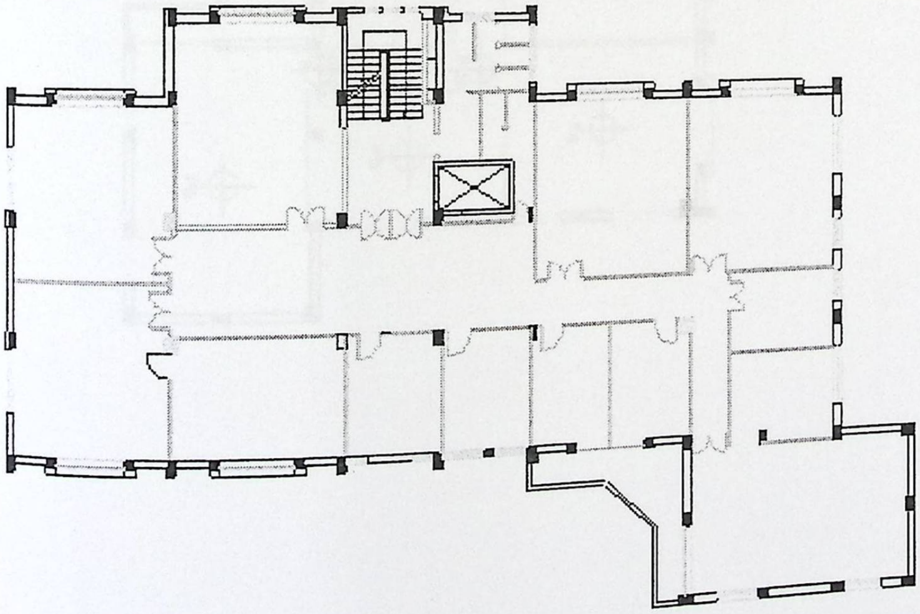
The second floor



The third floor

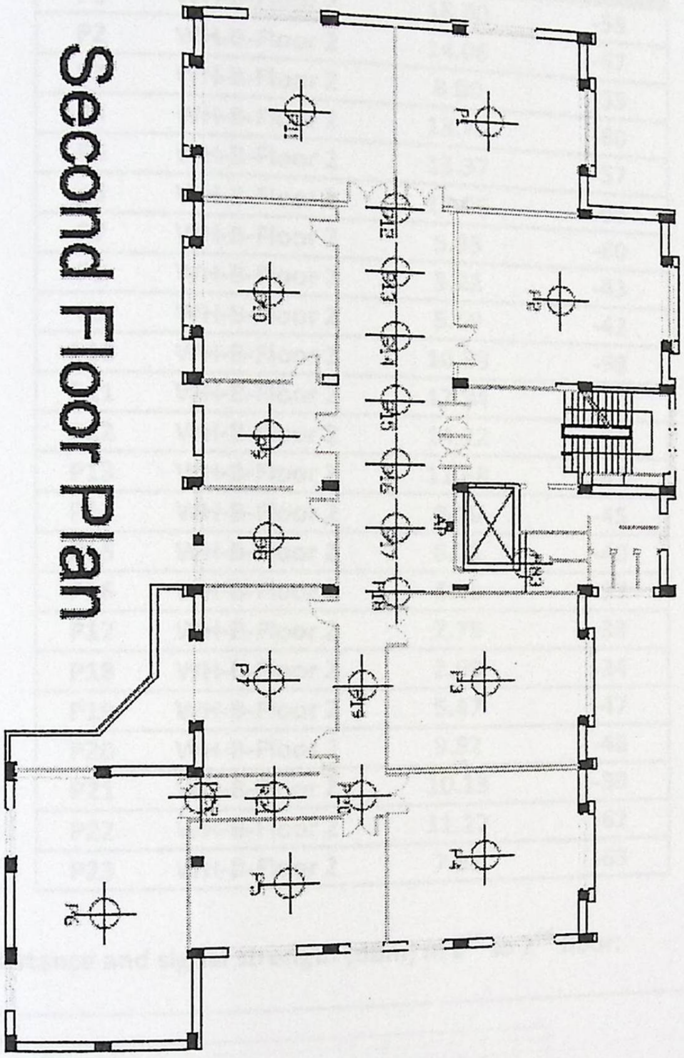


The fourth floor



The fifth floor

Appendix B



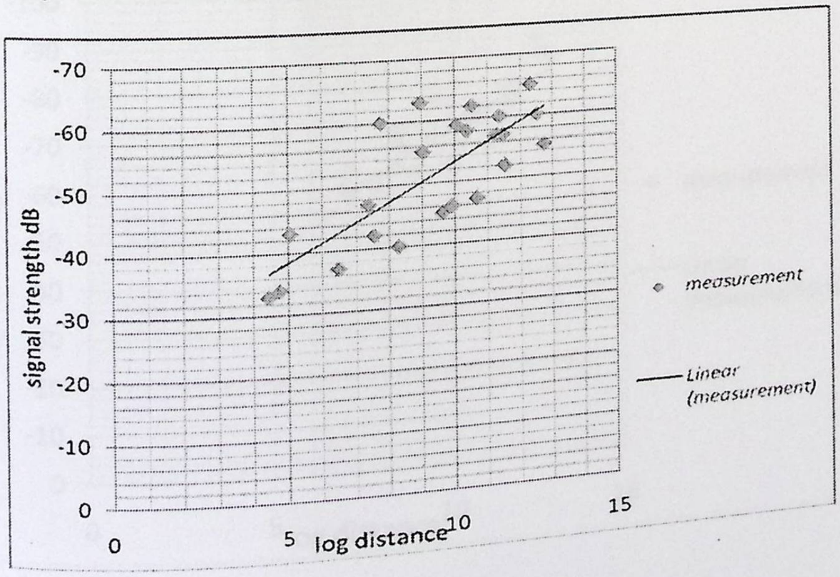
Second Floor Plan

Appendix C

- Tables and graphs related to the second floor access point:

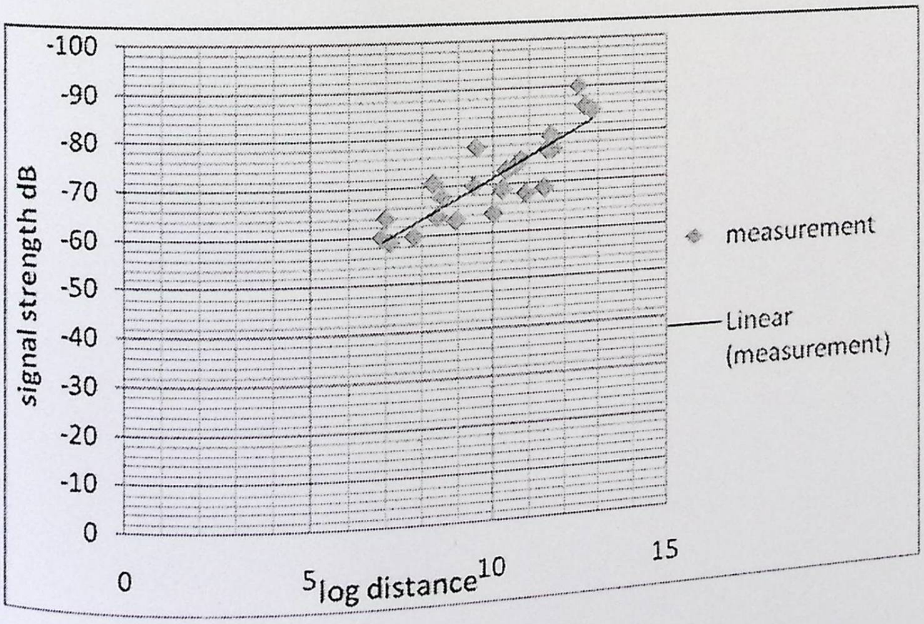
point	SSID	2^{nd} to 2^{nd} slope distance	signal strength
P1	WH-B-Floor 2	18.80	-55
P2	WH-B-Floor 2	14.06	-57
P3	WH-B-Floor 2	8.00	-55
P4	WH-B-Floor 2	13.70	-60
P5	WH-B-Floor 2	13.37	-57
p6	WH-B-Floor 2	17.06	-65
P7	WH-B-Floor 2	5.95	-60
P8	WH-B-Floor 2	3.22	-43
P9	WH-B-Floor 2	5.69	-42
P10	WH-B-Floor 2	10.89	-58
P11	WH-B-Floor 2	17.84	-60
P12	WH-B-Floor 2	14.22	-52
P13	WH-B-Floor 2	11.68	-47
P14	WH-B-Floor 2	9.19	-45
P15	WH-B-Floor 2	6.75	-40
P16	WH-B-Floor 2	4.46	-37
P17	WH-B-Floor 2	2.79	-33
P18	WH-B-Floor 2	2.99	-34
P19	WH-B-Floor 2	5.47	-47
P20	WH-B-Floor 2	9.82	-46
P21	WH-B-Floor 2	10.13	-59
P22	WH-B-Floor 2	11.27	-62
P23	WH-B-Floor 2	7.86	-63

Relationship between log distance and signal strength (dBm) in 2^{nd} to 2^{nd} floor:



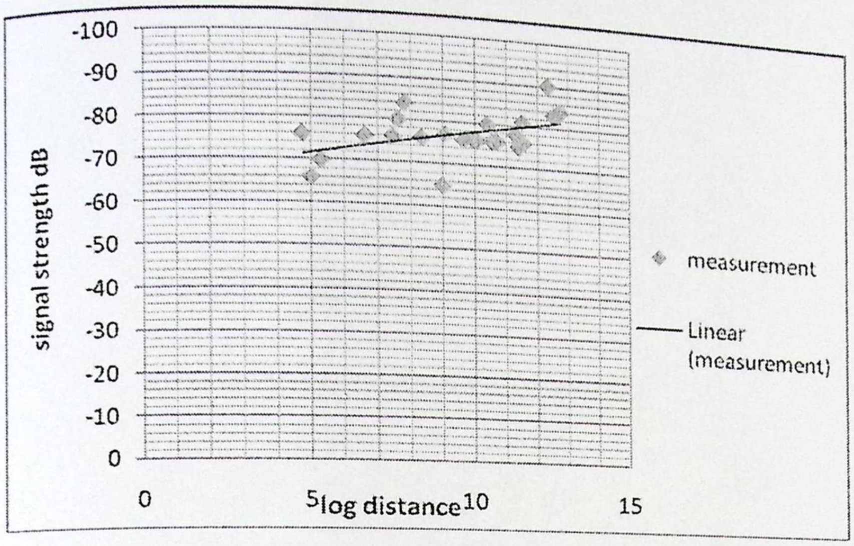
point	SSID	2nd to 1st slope distance	signal
P1	WH-B-Floor 2	19.23538666	-85
P2	WH-B-Floor 2	14.63087489	-80
P3	WH-B-Floor 2	8.970646576	-78
P4	WH-B-Floor 2	14.2867806	-77
P5	WH-B-Floor 2	13.97206499	-69
P6	WH-B-Floor 2	17.5329005	-90
P7	WH-B-Floor 2	7.206587264	-68
P8	WH-B-Floor 2	5.184920443	-59
P9	WH-B-Floor 2	6.990350492	-64
P10	WH-B-Floor 2	11.62475376	-74
P11	WH-B-Floor 2	18.30034153	-86
P12	WH-B-Floor 2	14.78404884	-77
P13	WH-B-Floor 2	12.36343803	-68
P14	WH-B-Floor 2	10.04353026	-64
P15	WH-B-Floor 2	7.875239679	-63
P16	WH-B-Floor 2	6.031658147	-60
P17	WH-B-Floor 2	4.925708071	-60
P18	WH-B-Floor 2	5.045879507	-64
P19	WH-B-Floor 2	6.816993472	-71
P20	WH-B-Floor 2	10.62685748	-69
P21	WH-B-Floor 2	10.91169098	-73
P22	WH-B-Floor 2	11.9792529	-75
P23	WH-B-Floor 2	8.847604195	-70

- Relationship between log distance and signal strength (dBm) in 2nd to 1st floor:



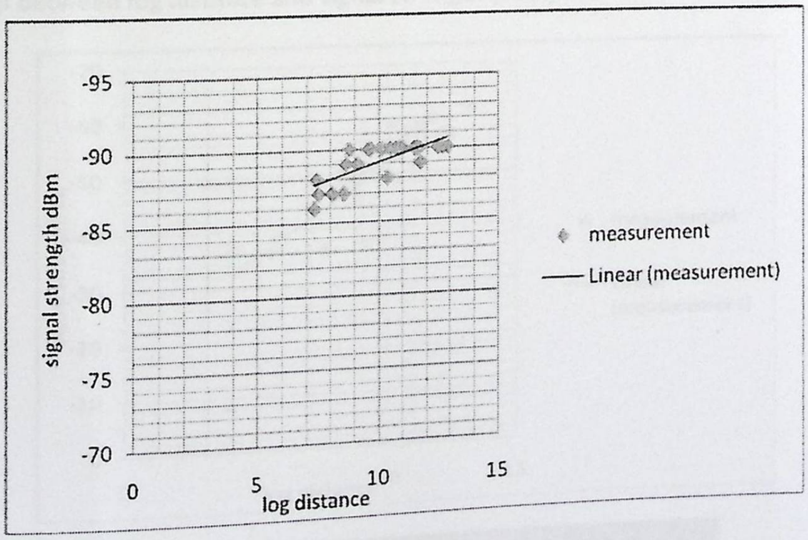
2nd to 3rd			
point	SSID	Slope distance	signal
P1	WH-B-Floor 2	18.83242151	-84
P2	WH-B-Floor 2	14.09689682	-81
P3	WH-B-Floor 2	8.070470866	-77
P4	WH-B-Floor 2	13.73943594	-75
P5	WH-B-Floor 2	13.41188279	-78
P6	WH-B-Floor 2	17.08983909	-90
P7	WH-B-Floor 2	6.049371868	-84
P8	WH-B-Floor 2	3.397557947	-70
P9	WH-B-Floor 2	5.79007772	-80
P10	WH-B-Floor 2	10.94508566	-80
P11	WH-B-Floor 2	17.87631114	-83
P12	WH-B-Floor 2	14.25580934	-76
P13	WH-B-Floor 2	11.72666193	-76
P14	WH-B-Floor 2	9.248378236	-76
P15	WH-B-Floor 2	6.832232432	-76
P16	WH-B-Floor 2	4.58703608	-76
P17	WH-B-Floor 2	2.987072145	-76
P18	WH-B-Floor 2	3.181336197	-66
P19	WH-B-Floor 2	5.579551953	-76
P20	WH-B-Floor 2	9.878770166	-76
P21	WH-B-Floor 2	10.18454712	-76
P22	WH-B-Floor 2	11.32088777	-76
P23	WH-B-Floor 2	7.933479691	-65

Relationship between log distance and signal strength (dBm) in 2nd to 3rd floor:



point	SSID	2nd TO 4th	
		slope distance	signal
P1	WH-B-Floor 2	19.35200506	-90
P2	WH-B-Floor 2	14.78385944	-90
P3	WH-B-Floor 2	9.21805294	-90
P4	WH-B-Floor 2	14.44341026	-90
P5	WH-B-Floor 2	14.13218313	-90
p6	WH-B-Floor 2	17.66076442	-90
P7	WH-B-Floor 2	7.512316554	-90
P8	WH-B-Floor 2	5.602088896	-87
P9	WH-B-Floor 2	7.30513518	-89
P10	WH-B-Floor 2	11.8167212	-90
P11	WH-B-Floor 2	18.4228798	-90
P12	WH-B-Floor 2	14.93546451	-89
P13	WH-B-Floor 2	12.54410619	-90
P14	WH-B-Floor 2	10.26511081	-90
P15	WH-B-Floor 2	8.155942619	-89
P16	WH-B-Floor 2	6.393817326	-87
P17	WH-B-Floor 2	5.363077475	-86
P18	WH-B-Floor 2	5.473655086	-88
P19	WH-B-Floor 2	7.139425747	-87
P20	WH-B-Floor 2	10.83651697	-88
P21	WH-B-Floor 2	11.11597949	-90
P22	WH-B-Floor 2	12.16562781	-90
P23	WH-B-Floor 2	9.098356995	-90

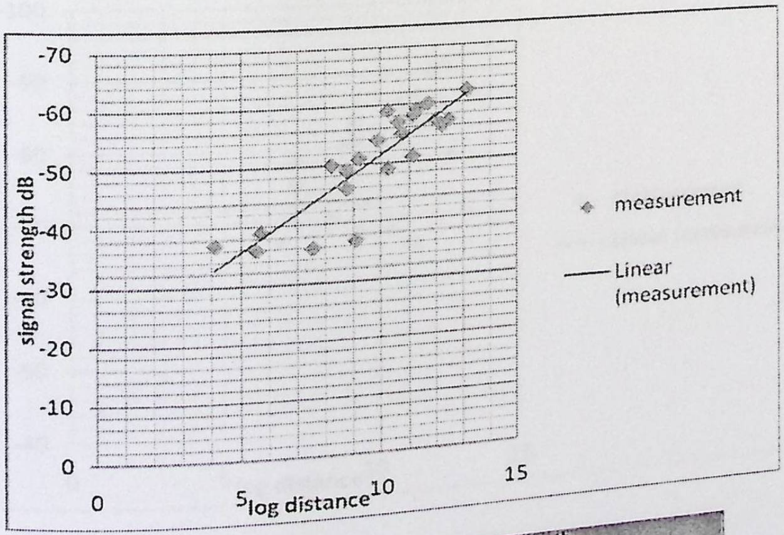
Relationship between log distance and signal strength (dBm) in 2nd to 4th floor:



- Tables and graphs related to the fifth floor access point:

point	SSID	5^{th} to 5^{th} slope distance	signal
P1	WH-B-Floor 5	16.68	-56
P2	WH-B-Floor 5	10.54	-59
P3	WH-B-Floor 5	6.61	-50
P4	WH-B-Floor 5	13.56	-59
P5	WH-B-Floor 5	15.81	-57
p6	WH-B-Floor 5	20.74	-62
P7	WH-B-Floor 5	9.74	-54
P8	WH-B-Floor 5	7.52	-46
P9	WH-B-Floor 5	8.3	-51
P10	WH-B-Floor 5	11.92	-55
P11	WH-B-Floor 5	17.71	-57
P12	WH-B-Floor 5	13.07	-51
P13	WH-B-Floor 5	10.54	-49
P14	WH-B-Floor 5	8.07	-37
P15	WH-B-Floor 5	5.69	-36
P16	WH-B-Floor 5	3.58	-36
P17	WH-B-Floor 5	2.57	-37
P18	WH-B-Floor 5	3.73	-39
P19	WH-B-Floor 5	7.49	-49
P20	WH-B-Floor 5	11.54	-57
P21	WH-B-Floor 5	13.07	-58
P22	WH-B-Floor 5	14.9	-60
P23	WH-B-Floor 5	3.79	-56

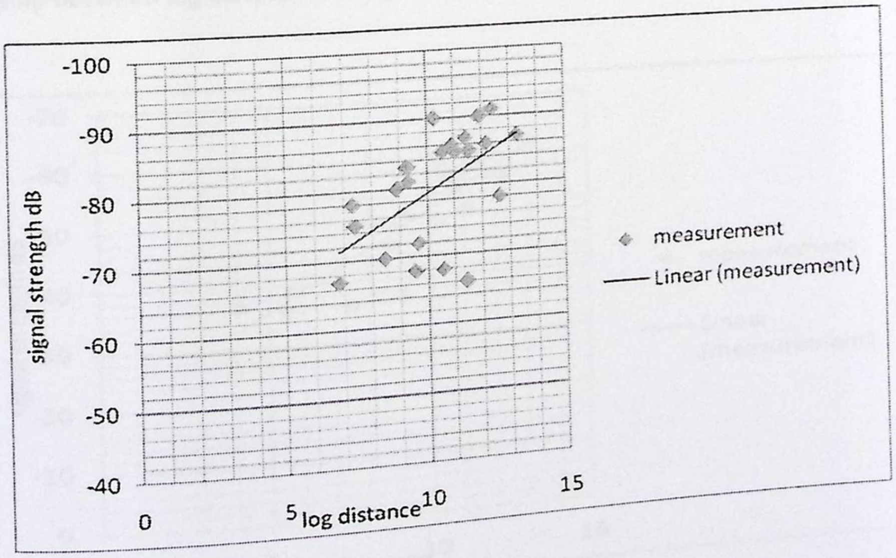
- Relationship between log distance and signal strength (dBm) in 5^{th} to 5^{th} floor:



5^{th} to 4^{th}

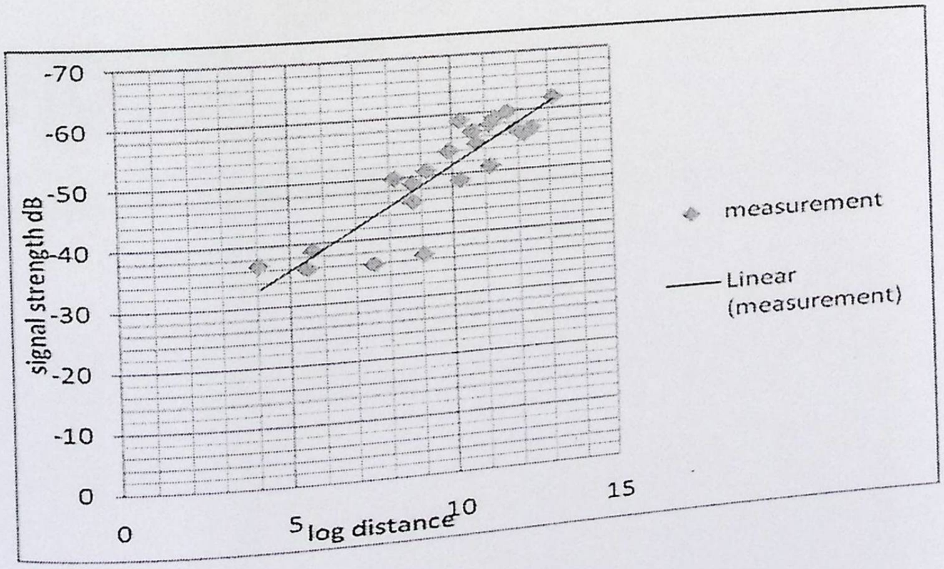
point	SSID	slope distance	signal
P1	WH-B-Floor 5	17.16	-91
P2	WH-B-Floor 5	11.30	-85
P3	WH-B-Floor 5	7.76	-80
P4	WH-B-Floor 5	14.15	-85
P5	WH-B-Floor 5	16.32	-86
p6	WH-B-Floor 5	21.13	-87
P7	WH-B-Floor 5	10.55	-90
P8	WH-B-Floor 5	8.55	-81
P9	WH-B-Floor 5	9.24	-72
P10	WH-B-Floor 5	18.17	-78
P11	WH-B-Floor 5	12.59	-85
P12	WH-B-Floor 5	13.69	-66
P13	WH-B-Floor 5	11.30	-68
P14	WH-B-Floor 5	9.03	-68
P15	WH-B-Floor 5	6.99	-70
P16	WH-B-Floor 5	5.41	-78
P17	WH-B-Floor 5	4.81	-67
P18	WH-B-Floor 5	5.51	-75
P19	WH-B-Floor 5	8.52	-83
P20	WH-B-Floor 5	12.23	-86
P21	WH-B-Floor 5	13.69	-87
P22	WH-B-Floor 5	15.45	-90

Relationship between log distance and signal strength (dBm) in 5th to 4th floor:



point	SSID	5th to 3rd slope distance	signal
P1	WH-B-Floor 5	18.09	-100
P2	WH-B-Floor 5	12.66	-100
P3	WH-B-Floor 5	9.63	-100
P4	WH-B-Floor 5	15.26	-100
P5	WH-B-Floor 5	17.29	-100
p6	WH-B-Floor 5	21.89	-100
P7	WH-B-Floor 5	11.99	-100
P8	WH-B-Floor 5	10.28	-100
P9	WH-B-Floor 5	10.86	-100
P10	WH-B-Floor 5	13.82	-100
P11	WH-B-Floor 5	19.05	-100
P12	WH-B-Floor 5	14.83	-100
P13	WH-B-Floor 5	12.66	-89
P14	WH-B-Floor 5	10.68	-90
P15	WH-B-Floor 5	9.02	-90
P16	WH-B-Floor 5	7.86	-86
P17	WH-B-Floor 5	7.46	-86
P18	WH-B-Floor 5	7.93	-88
P19	WH-B-Floor 5	10.25	-100
P20	WH-B-Floor 5	13.50	-100
P21	WH-B-Floor 5	14.83	-100
P22	WH-B-Floor 5	16.46	-100

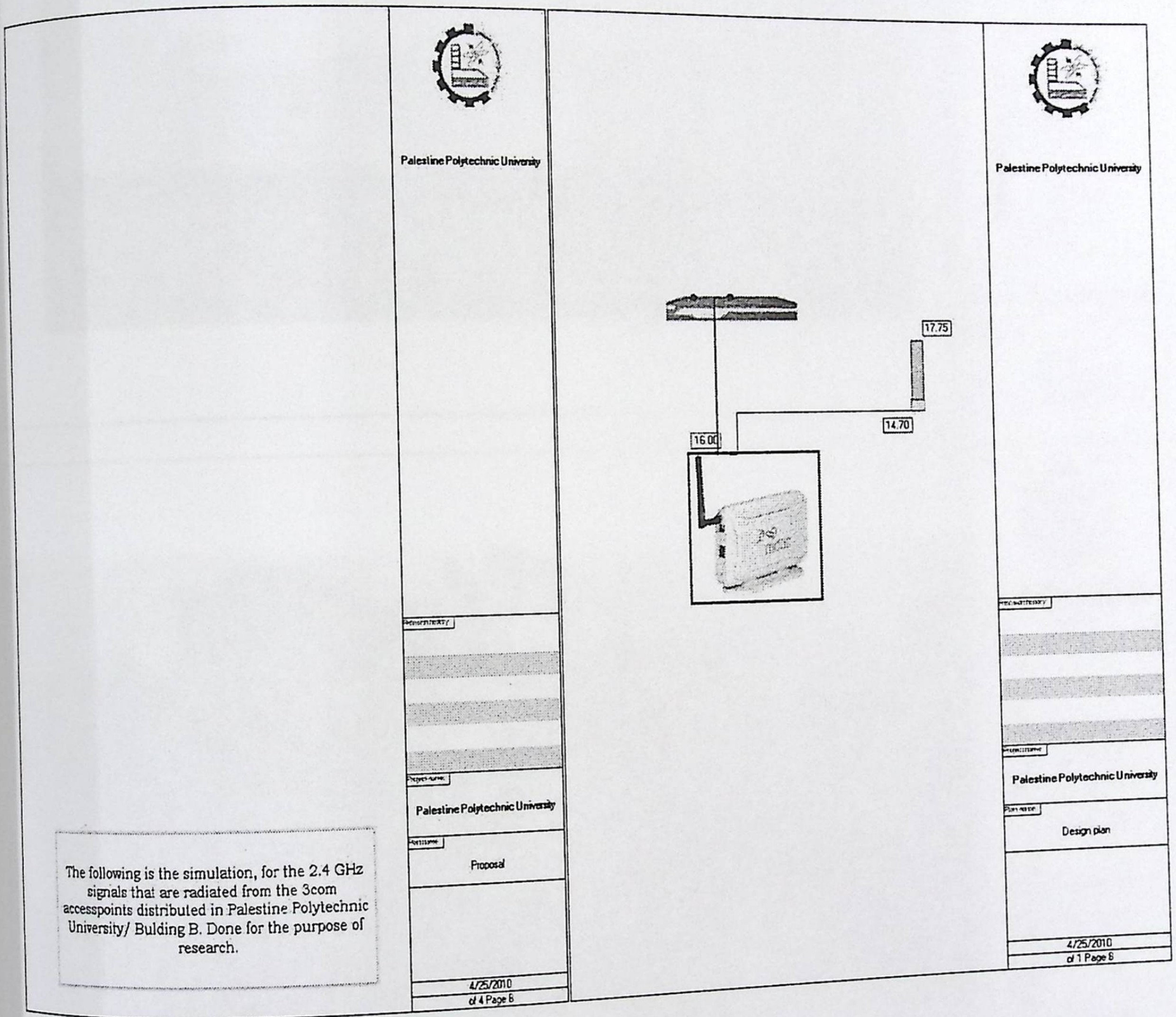
- **Relationship between log distance and signal strength (dBm) in 5th to 3rd floor:**

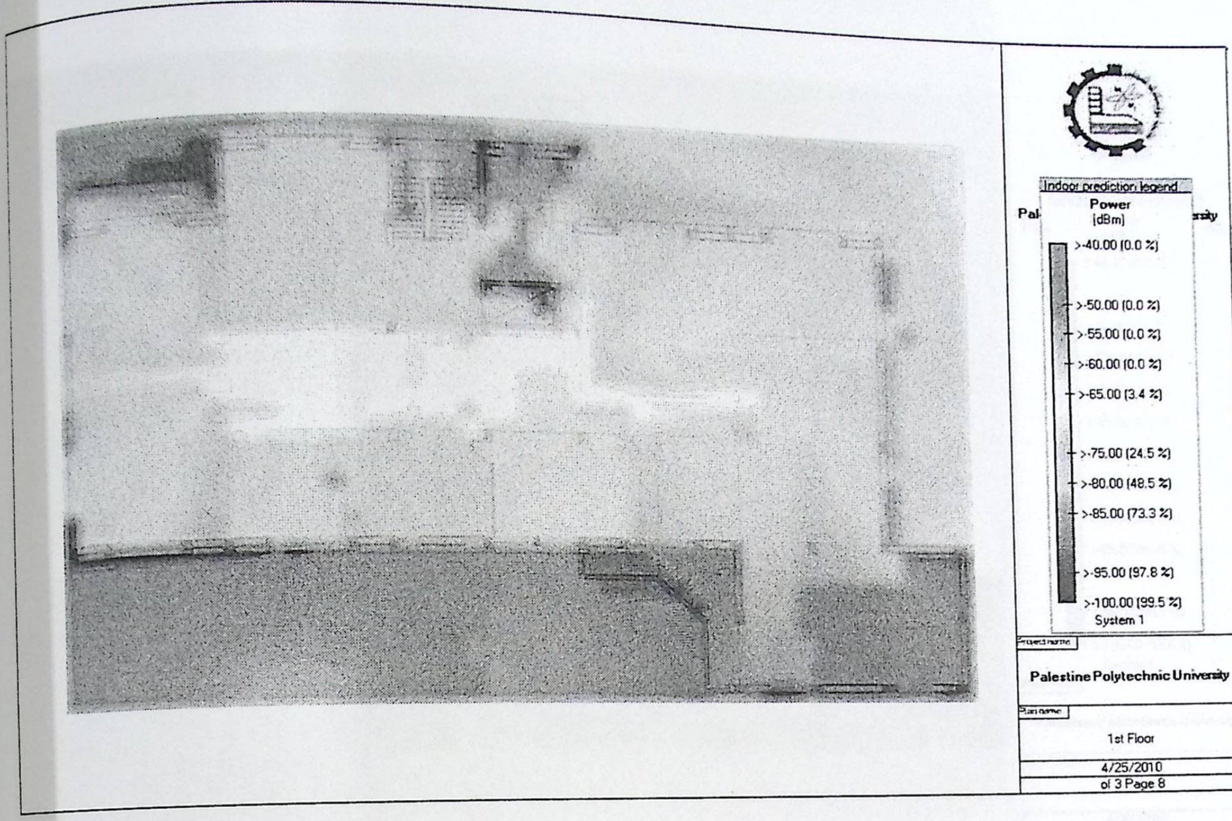


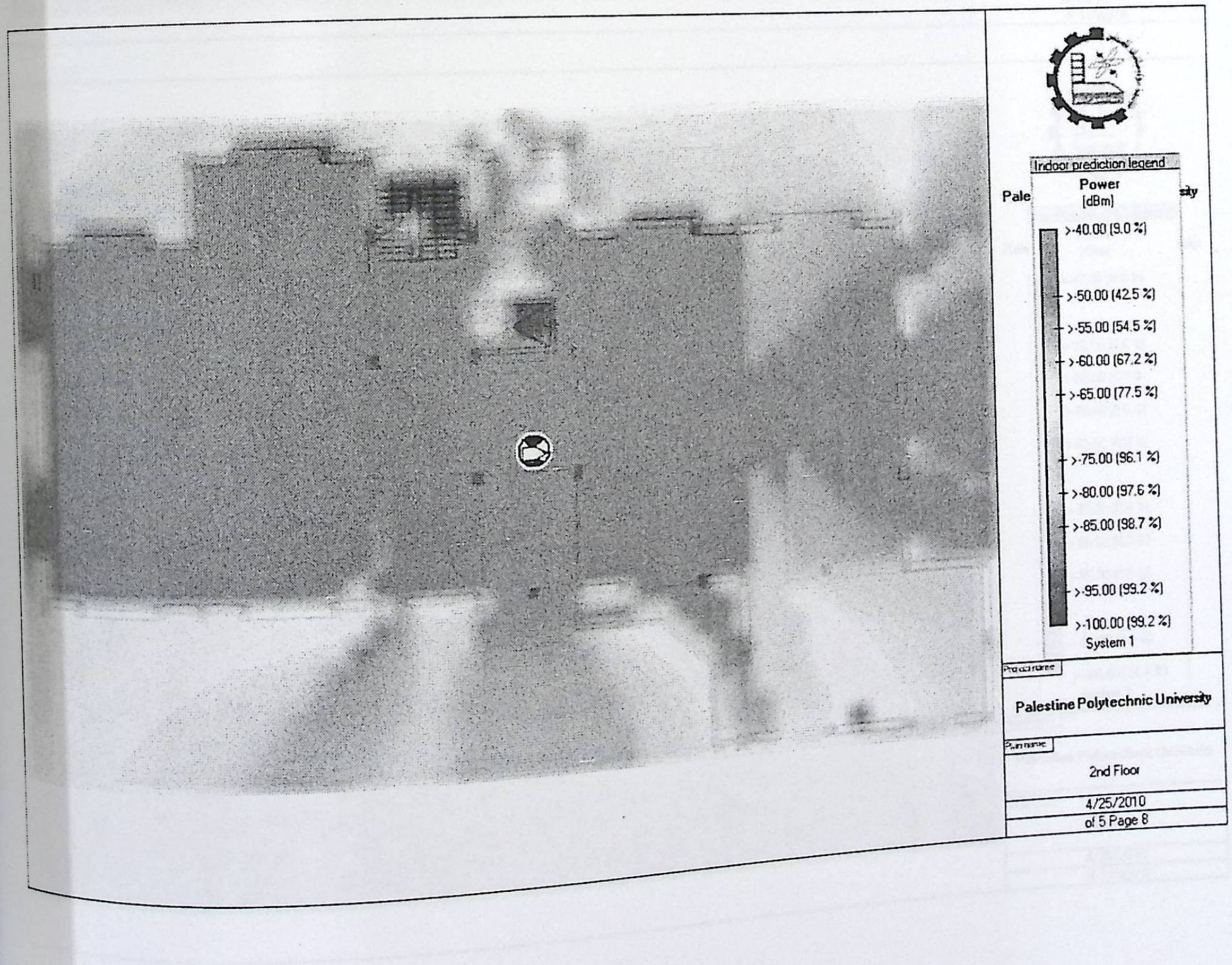
Appendix D

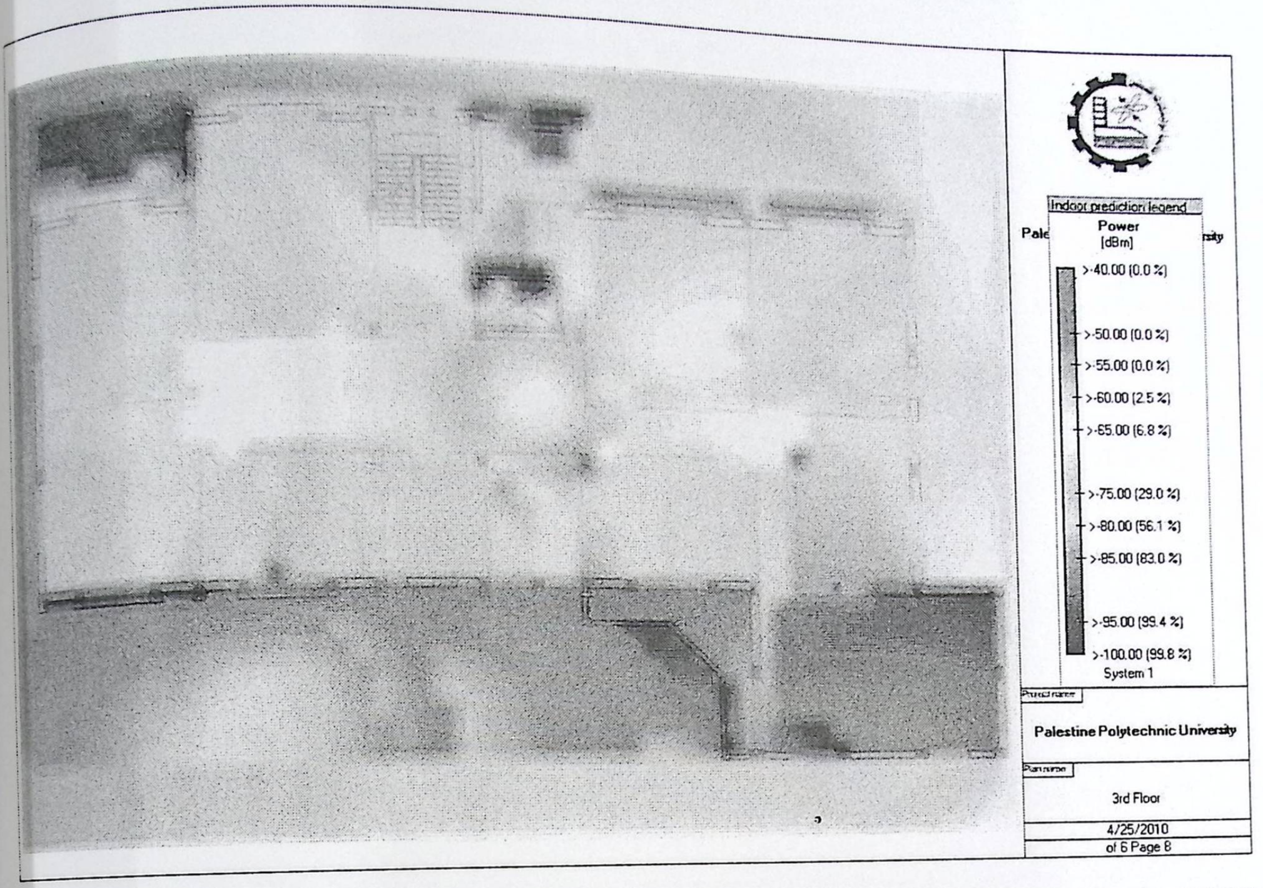
WLAN simulation

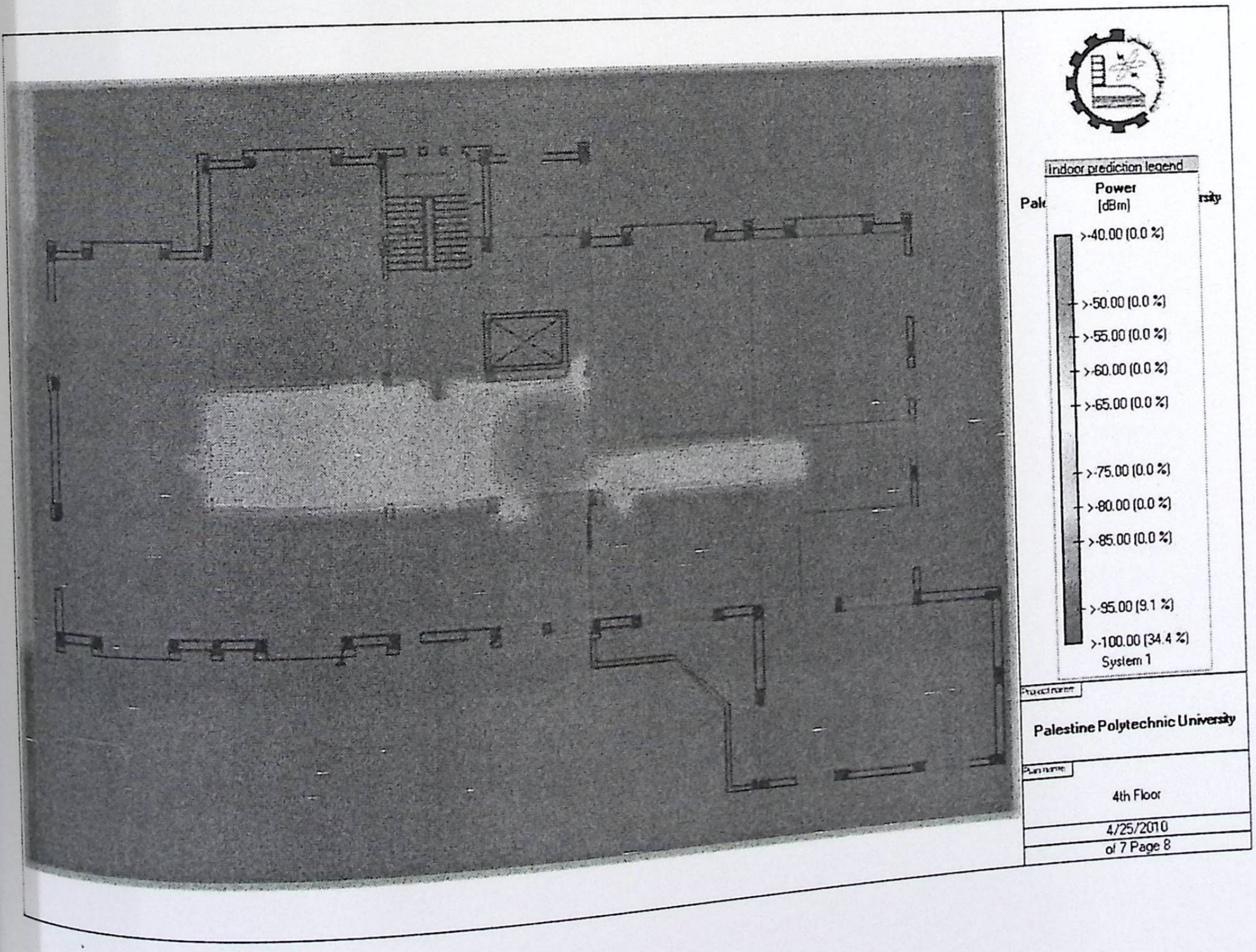
Antenna only in second floor

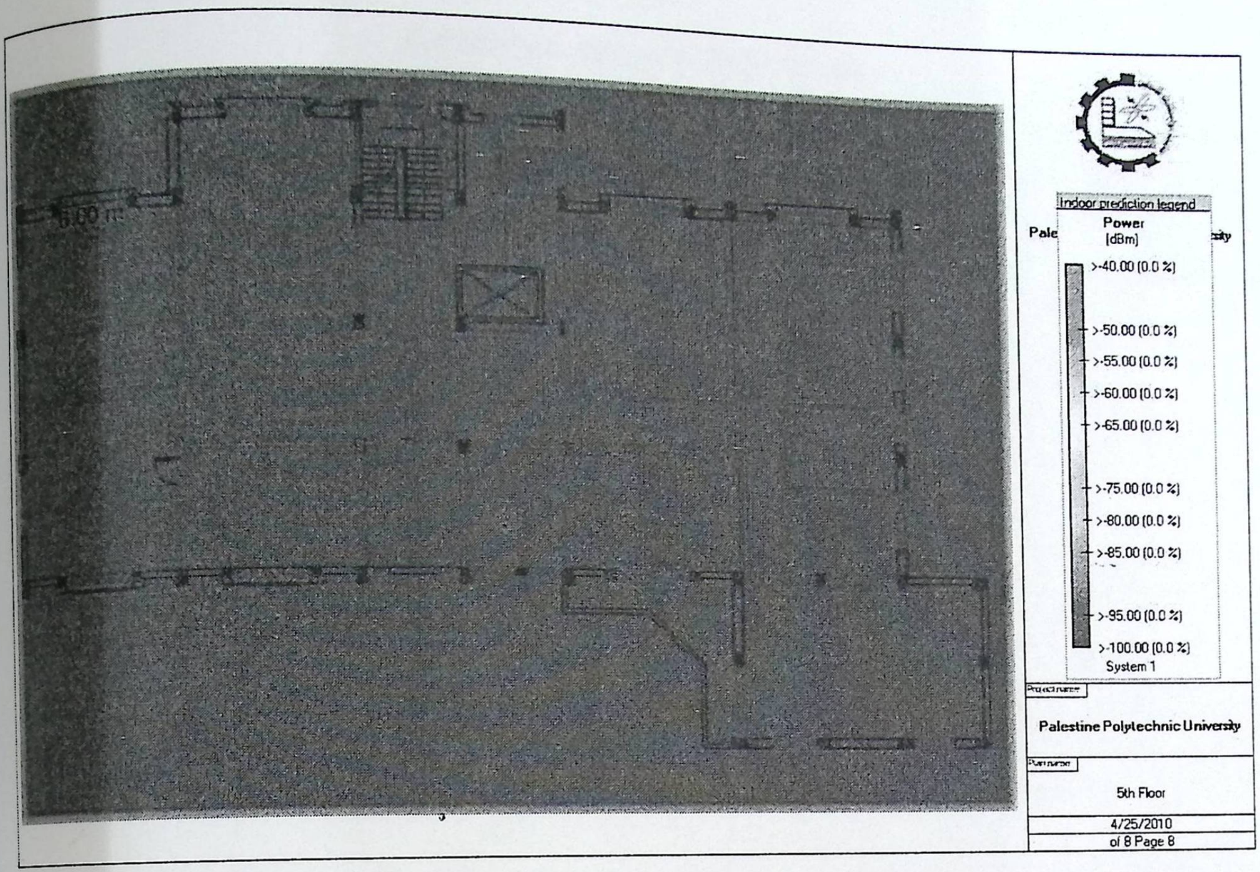



Indoor prediction legend
Power
[dBm]
>-40.00 [0.0 %]
>-50.00 [0.0 %]
>-55.00 [0.0 %]
>-60.00 [0.0 %]
>-65.00 [3.4 %]
>-75.00 [24.5 %]
>-80.00 [48.5 %]
>-85.00 [73.3 %]
>-95.00 [97.8 %]
>-100.00 [99.5 %]
System 1
Palestine Polytechnic University
1st Floor
4/25/2010
of 3 Page 8

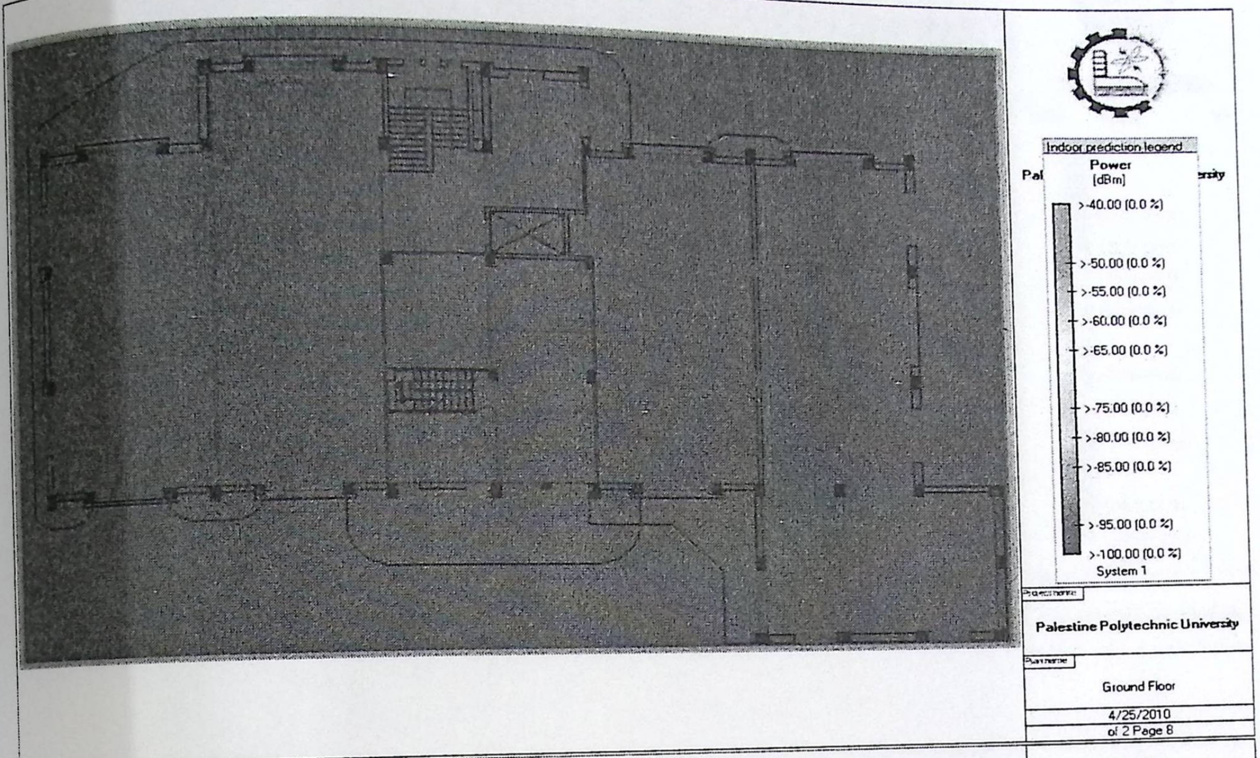

Indoor prediction legend
Power
[dBm]
>-40.00 [9.0 %]
>-50.00 [42.5 %]
>-55.00 [54.5 %]
>-60.00 [67.2 %]
>-65.00 [77.5 %]
>-75.00 [96.1 %]
>-80.00 [97.6 %]
>-85.00 [98.7 %]
>-95.00 [99.2 %]
>-100.00 [99.2 %]
System 1
Palestine Polytechnic University
2nd Floor
4/25/2010
of 5 Page 8

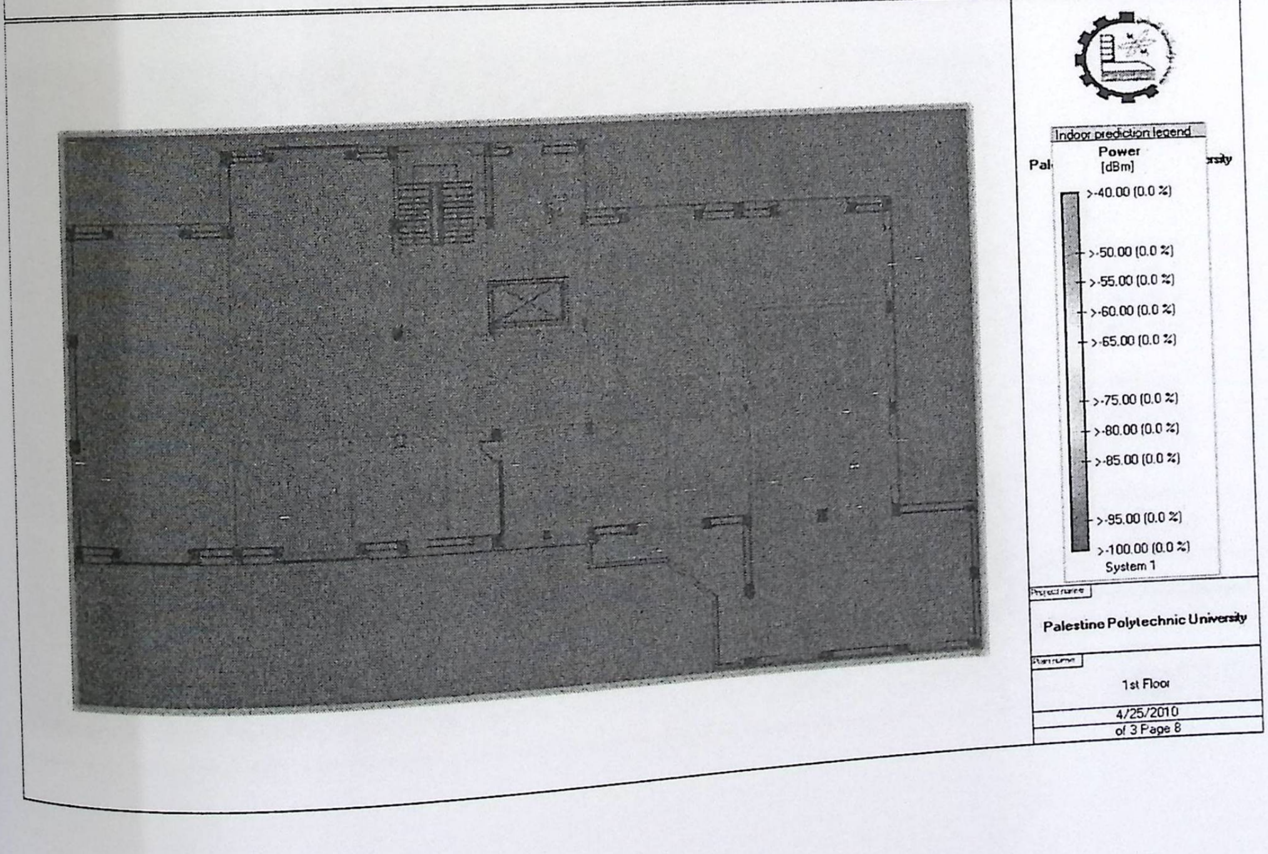

Indoor prediction legend
Power
[dBm]
>-40.00 (0.0 %)
>-50.00 (0.0 %)
>-55.00 (0.0 %)
>-60.00 (2.5 %)
>-65.00 (6.8 %)
>-75.00 (29.0 %)
>-80.00 (56.1 %)
>-85.00 (83.0 %)
>-95.00 (99.4 %)
>-100.00 (99.8 %)
System 1
Project name
Palestine Polytechnic University
Plan name
3rd Floor
4/25/2010
of 6 Page 8

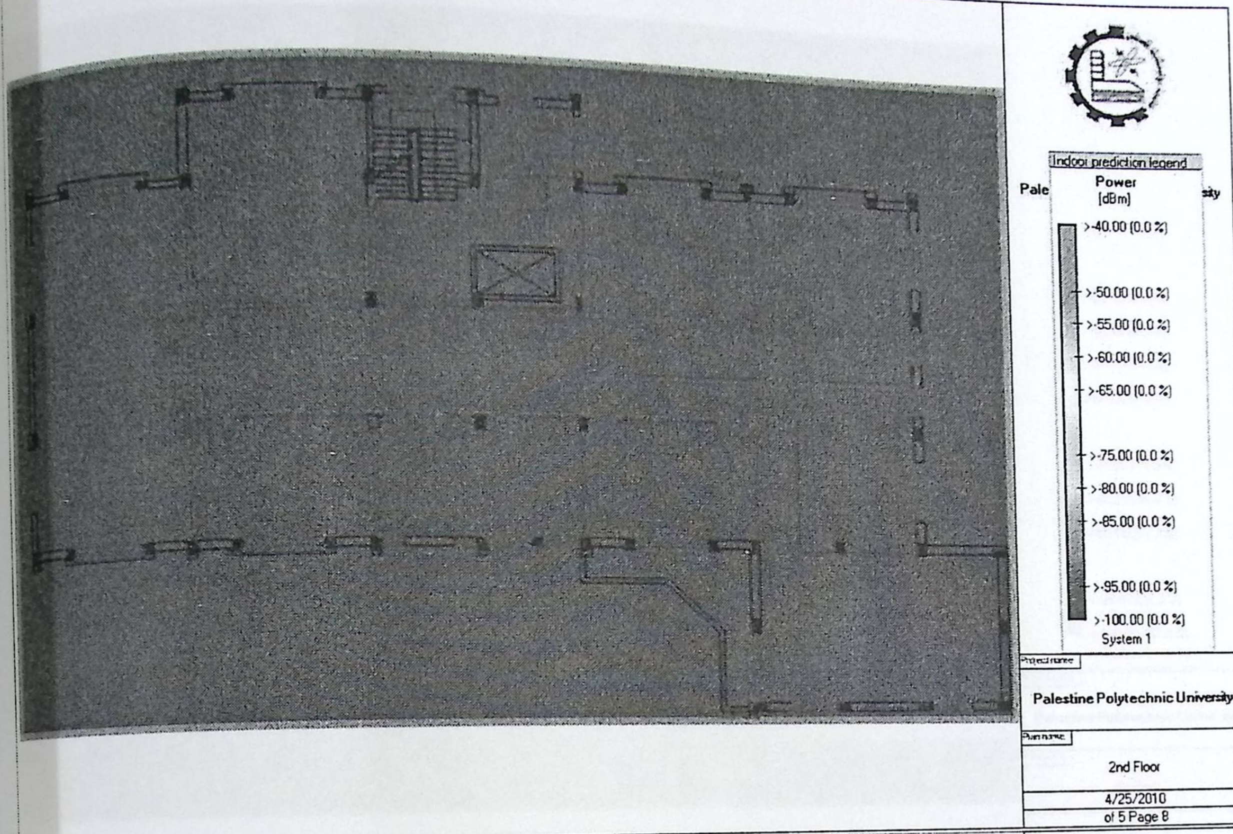

Indoor prediction legend
Power
[dBm]
>-40.00 (0.0 %)
>-50.00 (0.0 %)
>-55.00 (0.0 %)
>-60.00 (0.0 %)
>-65.00 (0.0 %)
>-75.00 (0.0 %)
>-80.00 (0.0 %)
>-85.00 (0.0 %)
>-95.00 (9.1 %)
>-100.00 (34.4 %)
System 1
Project name
Palestine Polytechnic University
Plan name
4th Floor
4/25/2010
of 7 Page 8

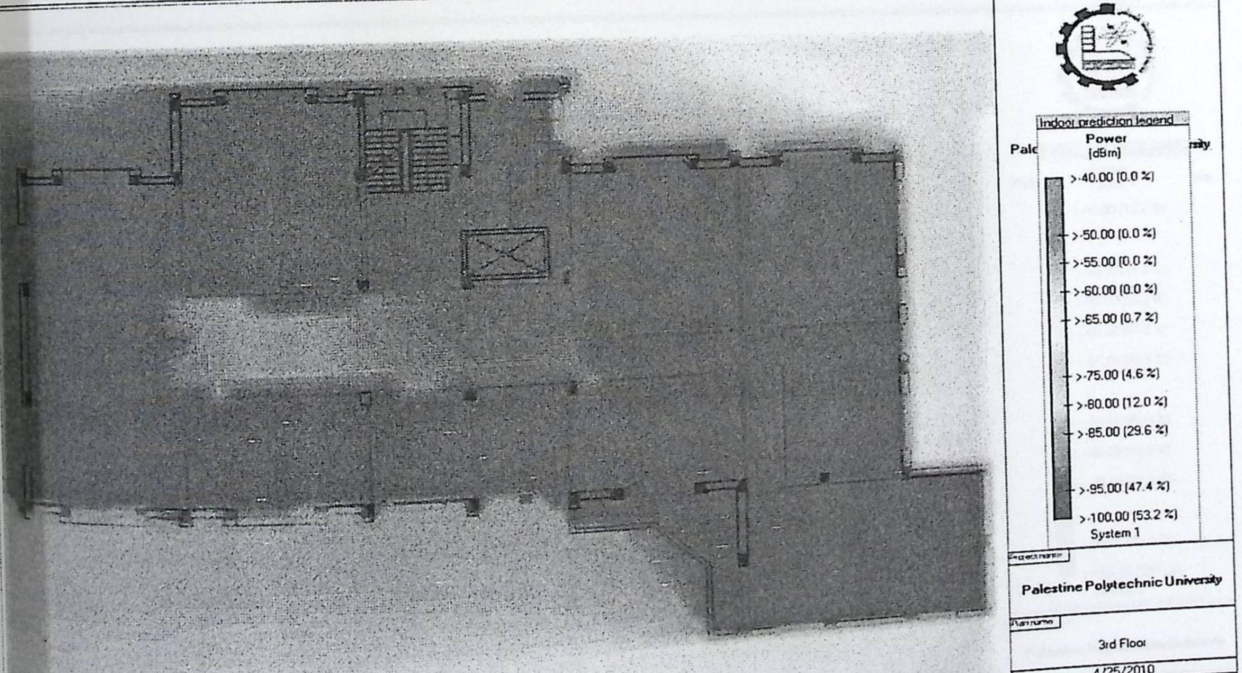

Indoor prediction legend
Power
[dBm]
>-40.00 (0.0 %)
>-50.00 (0.0 %)
>-55.00 (0.0 %)
>-60.00 (0.0 %)
>-65.00 (0.0 %)
>-75.00 (0.0 %)
>-80.00 (0.0 %)
>-85.00 (0.0 %)
>-95.00 (0.0 %)
>-100.00 (0.0 %)
System 1
Palestine Polytechnic University
5th Floor
4/25/2010
of 8 Page 8

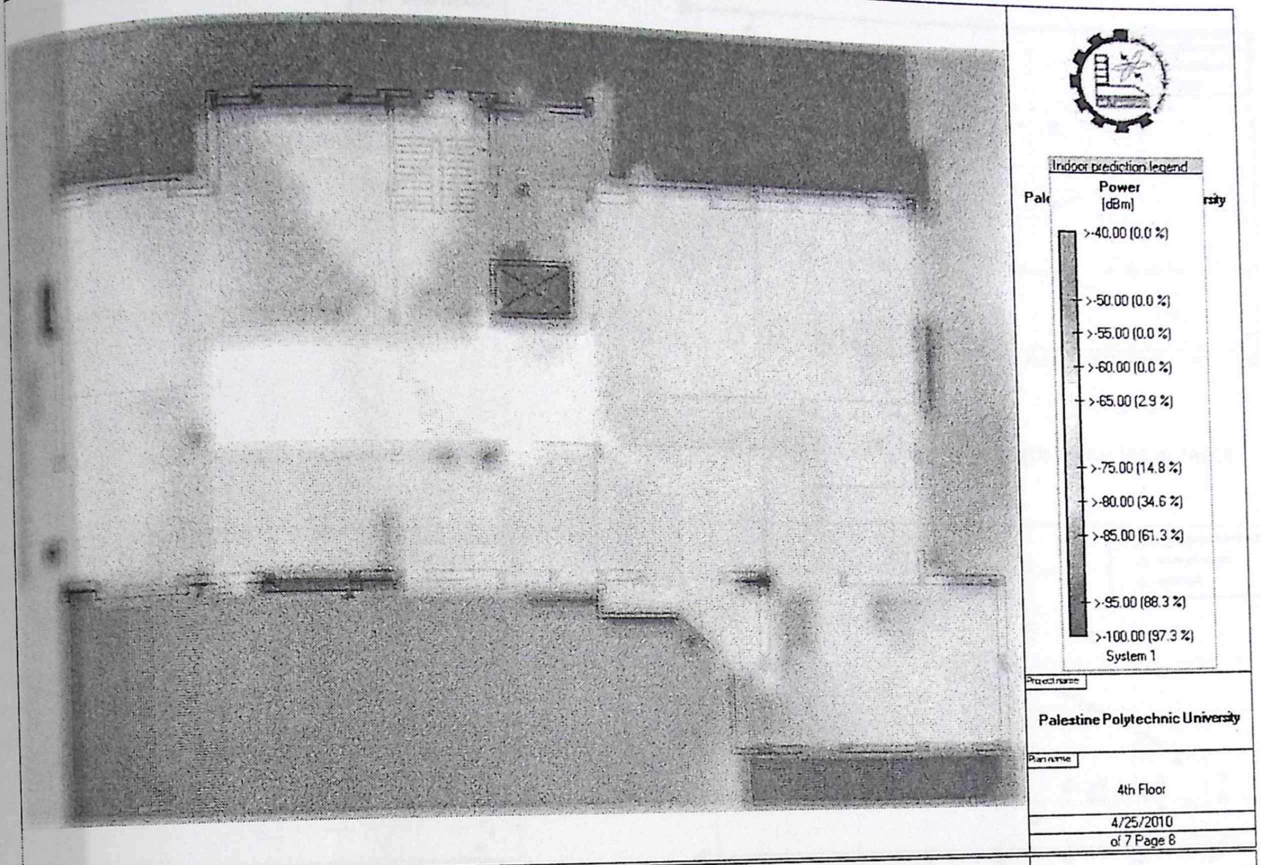
Antenna only in fifth floor

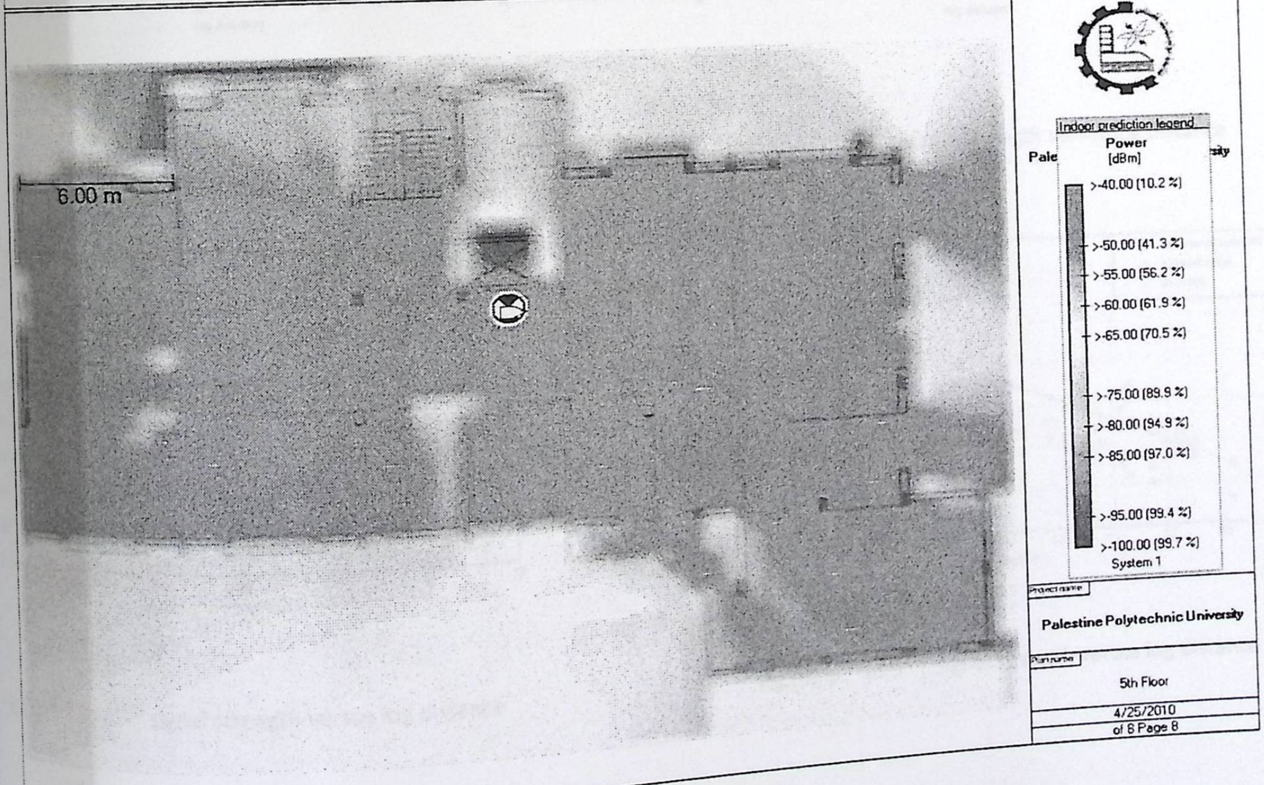





Indoor prediction legend
Power
[dBm]
>-40.00 (0.0 %)
>-50.00 (0.0 %)
>-55.00 (0.0 %)
>-60.00 (0.0 %)
>-65.00 (0.0 %)
>-75.00 (0.0 %)
>-80.00 (0.0 %)
>-85.00 (0.0 %)
>-95.00 (0.0 %)
>-100.00 (0.0 %)
System 1
Project name
Palestine Polytechnic University
Plan name
2nd Floor
4/25/2010
of 5 Page 8


Indoor prediction legend
Power
[dBm]
>-40.00 (0.0 %)
>-50.00 (0.0 %)
>-55.00 (0.0 %)
>-60.00 (0.0 %)
>-65.00 (0.7 %)
>-75.00 (4.6 %)
>-80.00 (12.0 %)
>-85.00 (29.6 %)
>-95.00 (47.4 %)
>-100.00 (53.2 %)
System 1
Project name
Palestine Polytechnic University
Plan name
3rd Floor
4/25/2010
of 6 Page 8


Indoor prediction legend
Power
[dBm]
>-40.00 (0.0 %)
>-50.00 (0.0 %)
>-55.00 (0.0 %)
>-60.00 (0.0 %)
>-65.00 (2.9 %)
>-75.00 (14.8 %)
>-80.00 (34.6 %)
>-85.00 (61.3 %)
>-95.00 (88.3 %)
>-100.00 (97.3 %)
System 1
Project name
Palestine Polytechnic University
Plan name
4th Floor
4/25/2010
of 7 Page 8


6.00 m
Indoor prediction legend
Power
[dBm]
>-40.00 (10.2 %)
>-50.00 (41.3 %)
>-55.00 (56.2 %)
>-60.00 (61.9 %)
>-65.00 (70.5 %)
>-75.00 (89.9 %)
>-80.00 (94.9 %)
>-85.00 (97.0 %)
>-95.00 (99.4 %)
>-100.00 (99.7 %)
System 1
Project name
Palestine Polytechnic University
Plan name
5th Floor
4/25/2010
of 8 Page 8

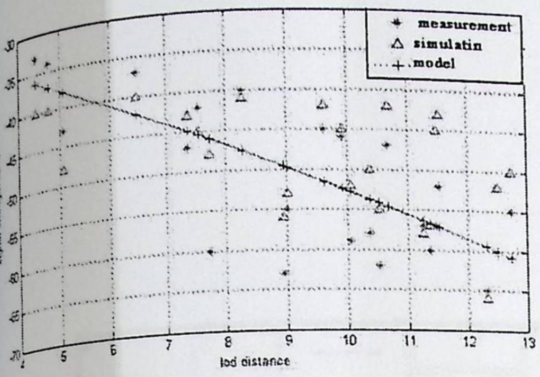


Fig.(1): 2nd to 2nd signal strength versus log distance

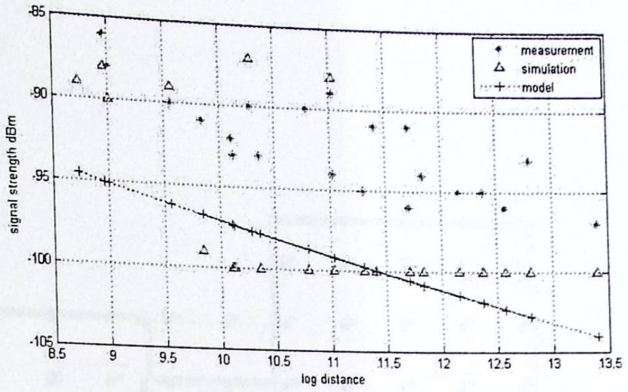


Fig.(2): 5th to 3rd signal strength versus log distance

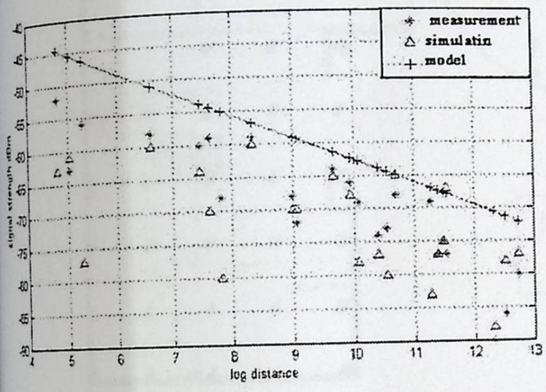


Fig.(3): 2nd to 3rd signal strength versus log distance

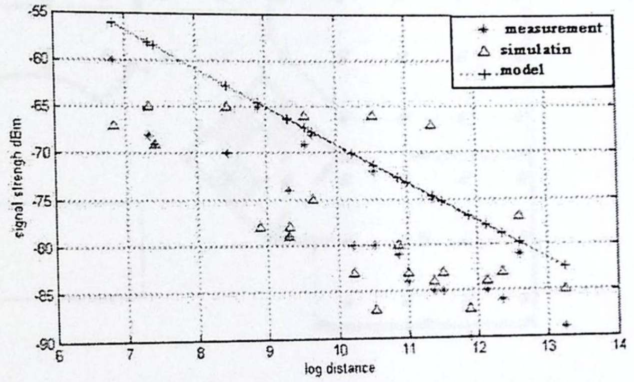


Fig.(4): 5th to 4th signal strength versus log distance

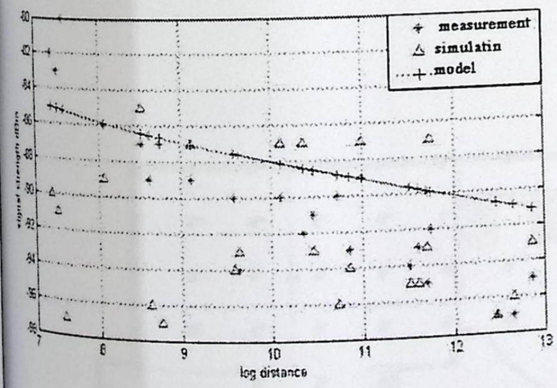


Fig.(5): 2nd to 4th signal strength versus log distance

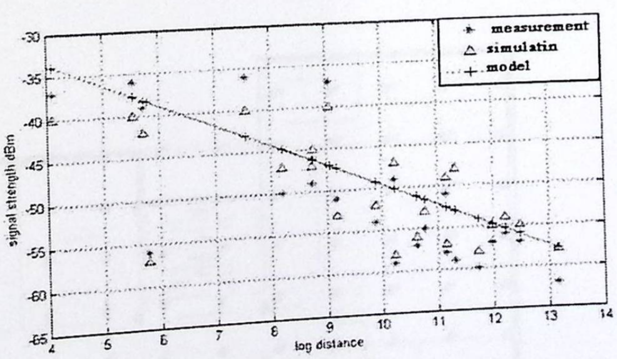
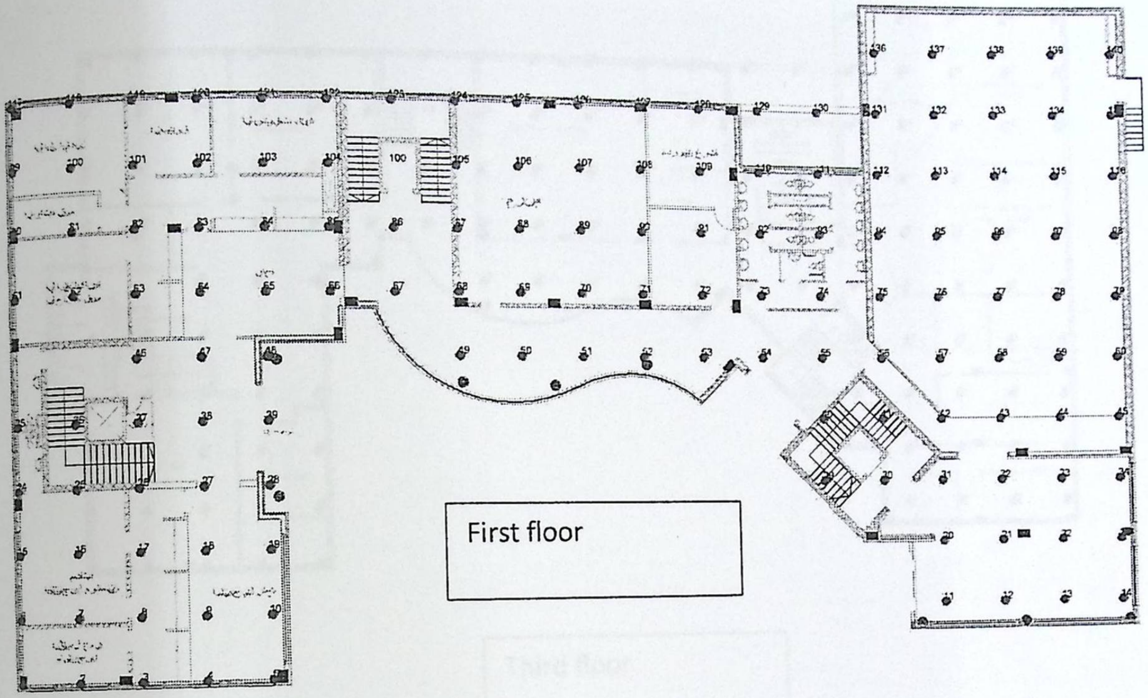
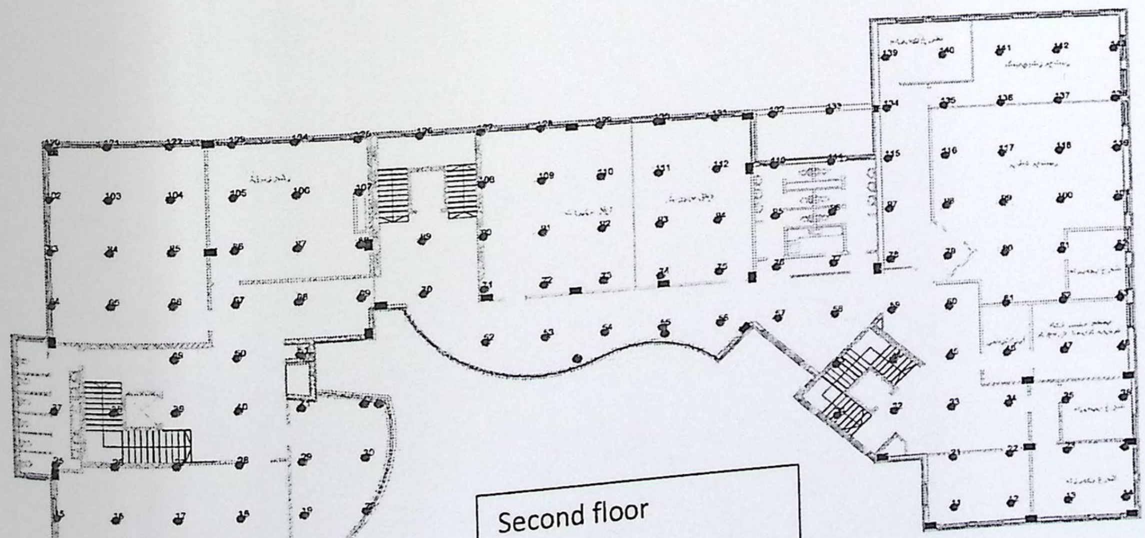


Fig.(6): 5th to 5th signal strength versus log distance

APPENDIX F
FIRST, SECOND AND THIRD FLOORS

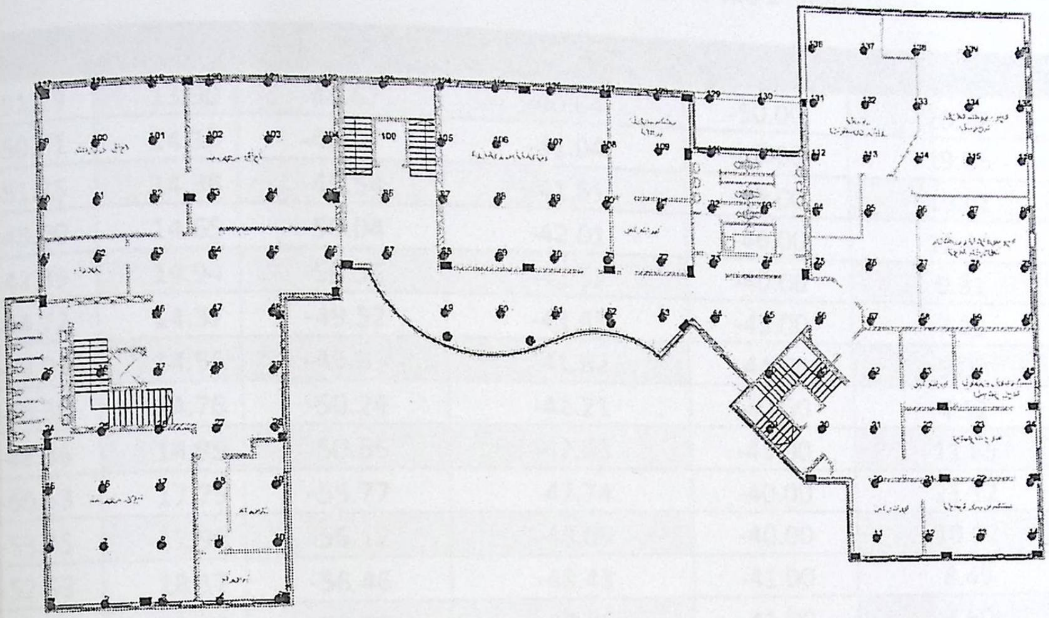


First floor



Second floor

APPENDIX F
FIRST, SECOND AND THIRD FLOORS



Third floor

Appendix G

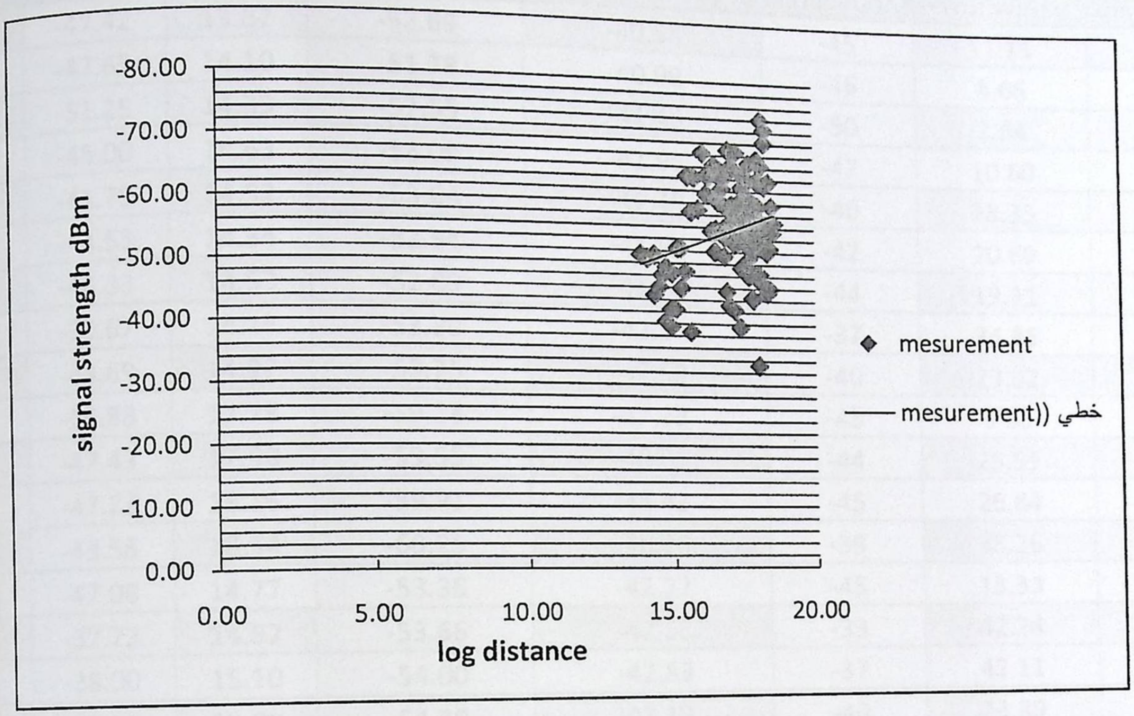
- **Measured, modeled, and simulated values related to the 1st floor :**

distance	signal	log d	model with σ	model without σ	simulation	error without σ	error with σ
24.57	-51.29	13.90	-48.67	-40.64	-50.00	20.77	5.12
25.86	-50.71	14.13	-49.07	-41.04	-48.00	19.06	3.23
27.41	-51.25	14.38	-49.54	-41.51	-49.00	19.01	3.35
29.19	-48.00	14.65	-50.04	-42.01	-46.00	12.49	4.24
31.16	-42.39	14.94	-50.55	-42.52	-40.00	0.31	19.25
27.36	-44.72	14.37	-49.52	-41.49	-43.00	7.23	10.73
28.52	-45.99	14.55	-49.85	-41.82	-44.00	9.07	8.39
29.94	-40.38	14.76	-50.24	-42.21	-40.00	4.52	24.41
31.57	-48.36	14.99	-50.66	-42.63	-45.00	11.85	4.75
60.10	-60.53	17.79	-55.77	-47.74	-40.00	21.12	7.86
62.81	-53.45	17.98	-56.12	-48.09	-40.00	10.02	5.00
65.56	-52.93	18.17	-56.46	-48.43	-41.00	8.49	6.68
68.33	-45.32	18.35	-56.79	-48.76	-41.00	7.60	25.32
30.15	-49.35	14.79	-50.29	-42.26	-45.00	14.37	1.91
31.22	-39.52	14.94	-50.57	-42.54	-38.00	7.64	27.96
32.52	-42.38	15.12	-50.89	-42.86	-40.00	1.14	20.09
34.04	-45.87	15.32	-51.26	-43.23	-43.00	5.77	11.74
61.42	-59.39	17.88	-55.95	-47.92	-40.00	19.31	5.79
64.13	-48.38	18.07	-56.29	-48.26	-39.00	0.25	16.35
66.79	-53.82	18.25	-56.61	-48.58	-41.00	9.74	5.18
69.52	-45.89	18.42	-56.93	-48.90	-44.00	6.56	24.06
33.05	-52.49	15.19	-51.02	-42.99	-50.00	18.10	2.80
33.99	-52.45	15.31	-51.24	-43.21	-51.00	17.61	2.30
35.19	-48.63	15.46	-51.52	-43.49	-47.00	10.57	5.94
36.58	-38.68	15.63	-51.83	-43.80	-37.00	13.23	33.99
57.77	-56.04	17.62	-55.46	-47.43	-54.00	15.36	1.03
60.29	-44.35	17.80	-55.80	-47.77	-41.00	7.70	25.80
62.86	-54.30	17.98	-56.13	-48.10	-50.00	11.41	3.38
65.47	-55.38	18.16	-56.45	-48.42	-51.00	12.56	1.94
68.11	-63.49	18.33	-56.77	-48.74	-53.00	23.24	10.59
70.78	-59.66	18.50	-57.07	-49.04	-55.00	17.79	4.33
35.91	-64.39	15.55	-51.68	-43.65	-61.00	32.21	19.74
36.90	-58.53	15.67	-51.90	-43.87	-55.00	25.05	11.33
37.91	-64.21	15.79	-52.11	-44.08	-64.00	31.35	18.84
39.23	-58.95	15.94	-52.38	-44.35	-55.00	24.76	11.14

59.46	-52.72	17.74	-55.69	-47.66	-50.00	9.60	5.63
61.93	-59.87	17.92	-56.01	-47.98	-57.00	19.86	6.45
64.43	-47.17	18.09	-56.33	-48.30	-40.00	2.39	19.41
66.96	-62.97	18.26	-56.63	-48.60	-42.00	22.82	10.07
69.56	-52.72	18.42	-56.94	-48.91	-50.00	7.23	8.00
72.16	-56.91	18.58	-57.23	-49.20	-41.00	13.55	0.56
40.66	-68.32	16.09	-52.67	-44.64	-41.00	34.66	22.91
41.85	-64.59	16.22	-52.90	-44.87	-43.00	30.54	18.10
43.26	-65.12	16.36	-53.16	-45.13	-39.00	30.70	18.36
48.25	-51.28	16.84	-54.03	-46.00	-39.00	10.30	5.36
50.27	-55.00	17.01	-54.35	-46.32	-40.00	15.77	1.17
52.30	-42.34	17.18	-54.67	-46.64	-38.00	10.15	29.12
54.47	-39.52	17.36	-54.99	-46.96	-38.00	18.83	39.15
56.64	-50.00	17.53	-55.30	-47.27	-39.00	5.46	10.60
58.92	-49.00	17.70	-55.62	-47.59	-40.00	2.89	13.50
61.24	-52.00	17.87	-55.92	-47.89	-47.00	7.90	7.54
63.64	-55.49	18.04	-56.23	-48.20	-38.00	13.14	1.34
66.08	-52.87	18.20	-56.53	-48.50	-39.00	8.27	6.92
68.08	-52.00	18.33	-56.76	-48.73	-39.00	6.28	9.16
68.58	-52.23	18.36	-56.82	-48.79	-40.00	6.58	8.80
71.10	-55.32	18.52	-57.11	-49.08	-40.00	11.28	3.23
41.75	-61.49	16.21	-52.88	-44.85	-51.00	27.07	14.01
42.52	-64.39	16.29	-53.02	-44.99	-52.00	30.13	17.65
43.44	-55.38	16.38	-53.19	-45.16	-50.00	18.45	3.95
44.60	-66.39	16.49	-53.40	-45.37	-53.00	31.66	19.56
45.90	-60.32	16.62	-53.63	-45.60	-51.00	24.40	11.09
47.40	-63.97	16.76	-53.89	-45.86	-41.00	28.31	15.76
48.97	-56.23	16.90	-54.15	-46.12	-43.00	17.98	3.70
50.71	-57.01	17.05	-54.42	-46.39	-44.00	18.63	4.55
52.56	-53.44	17.21	-54.71	-46.68	-40.00	12.66	2.37
54.48	-56.02	17.36	-54.99	-46.96	-40.00	16.16	1.83
56.55	-59.66	17.52	-55.29	-47.26	-42.00	20.79	7.33
58.68	-48.09	17.68	-55.58	-47.55	-40.00	1.11	15.59
60.81	-44.16	17.84	-55.87	-47.84	-39.00	8.32	26.50
63.13	-33.25	18.00	-56.16	-48.13	-40.00	44.78	68.93
44.64	-52.03	16.50	-53.41	-45.38	-50.00	12.78	2.66
45.11	-55.74	16.54	-53.49	-45.46	-52.00	18.43	4.03
46.26	-55.28	16.65	-53.69	-45.66	-51.00	17.40	2.87
47.34	-62.47	16.75	-53.88	-45.85	-40.00	26.61	13.75
48.55	-59.56	16.86	-54.08	-46.05	-41.00	22.69	9.20
49.96	-68.85	16.99	-54.30	-46.27	-61.00	32.79	21.13

51.46	-65.94	17.11	-54.54	-46.51	-40.00	29.47	17.29
53.13	-68.60	17.25	-54.79	-46.76	-39.00	31.83	20.13
54.90	-57.35	17.40	-55.05	-47.02	-39.00	18.00	4.00
56.77	-64.57	17.54	-55.32	-47.29	-40.00	26.76	14.32
58.74	-53.44	17.69	-55.59	-47.56	-41.00	11.01	4.02
60.78	-51.67	17.84	-55.86	-47.83	-42.00	7.42	8.12
62.91	-63.83	17.99	-56.14	-48.11	-60.00	24.63	12.05
65.09	-56.57	18.14	-56.41	-48.38	-43.00	14.48	0.29
47.56	-64.23	16.77	-53.91	-45.88	-45.00	28.56	16.06
48.24	-54.51	16.83	-54.03	-46.00	-47.00	15.61	0.88
49.09	-45.43	16.91	-54.17	-46.14	-44.00	1.54	19.22
50.11	-43.13	17.00	-54.33	-46.30	-41.00	7.34	25.95
51.28	-59.79	17.10	-54.51	-46.48	-51.00	22.25	8.82
52.60	-53.32	17.21	-54.71	-46.68	-50.00	12.44	2.62
55.62	-62.67	17.45	-55.16	-47.13	-60.00	24.80	11.98
57.31	-54.69	17.58	-55.40	-47.37	-39.00	13.39	1.29
59.11	-66.67	17.72	-55.64	-47.61	-40.00	28.58	16.54
60.99	-58.42	17.85	-55.89	-47.86	-40.00	18.07	4.33
62.97	-67.32	17.99	-56.14	-48.11	-41.00	28.53	16.60
65.01	-66.33	18.13	-56.40	-48.37	-60.00	27.08	14.97
67.15	-70.22	18.27	-56.65	-48.62	-63.00	30.75	19.32
50.50	-65.87	17.03	-54.39	-46.36	-61.00	29.62	17.43
51.14	-58.97	17.09	-54.49	-46.46	-55.00	21.22	7.60
51.95	-55.96	17.16	-54.61	-46.58	-53.00	16.75	2.40
52.90	-54.98	17.23	-54.76	-46.73	-56.00	15.01	0.40
54.01	-59.98	17.33	-54.92	-46.89	-57.00	21.82	8.43
55.27	-49.37	17.43	-55.11	-47.08	-40.00	4.65	11.61
56.65	-57.78	17.53	-55.30	-47.27	-42.00	18.18	4.29
58.13	-57.39	17.64	-55.51	-47.48	-40.00	17.27	3.28
59.78	-52.33	17.77	-55.73	-47.70	-40.00	8.84	6.50
61.49	-58.97	17.89	-55.96	-47.93	-41.00	18.73	5.12
63.31	-59.70	18.01	-56.19	-48.16	-43.00	19.33	5.88
65.22	-74.00	18.14	-56.42	-48.39	-57.00	34.60	23.75
67.21	-72.40	18.27	-56.66	-48.63	-60.00	32.83	21.74
69.26	-63.70	18.41	-56.90	-48.87	-61.00	23.27	10.67
					%ERROR	17.13	11.48
ST.DEV	8.01						

- **Relationship between log distance and signal strength (dBm) in the first floor:**



- **Measured, modeled, and simulated values related to the 2nd floor :**

distance	signal	log	model with σ	model without σ	simulation	error with σ	error without σ
24.39	-47.42	13.87	-52.69	-40.58	-45	11.11	14.44
25.69	-47.65	14.10	-51.78	-40.99	-46	8.66	13.98
27.25	-51.25	14.35	-52.55	-41.46	-50	2.54	19.11
29.04	-48.00	14.63	-53.09	-41.96	-47	10.60	12.58
31.02	-41.79	14.92	-53.64	-42.49	-40	28.35	1.66
27.19	-43.53	14.34	-52.54	-41.44	-42	20.69	4.80
28.36	-44.33	14.53	-52.89	-41.77	-44	19.31	5.76
29.79	-39.67	14.74	-53.30	-42.17	-37	34.36	6.29
31.43	-43.69	14.97	-53.75	-42.59	-40	23.02	2.52
60.03	-55.88	17.78	-59.18	-47.73	-45	5.90	14.58
62.74	-47.43	17.98	-59.55	-48.09	-44	25.55	1.38
65.49	-47.23	18.16	-59.91	-48.43	-45	26.84	2.53
68.26	-43.58	18.34	-60.25	-48.76	-39	38.26	11.88
30	-47.08	14.77	-53.36	-42.22	-45	13.33	10.32
31.08	-37.72	14.92	-53.66	-42.50	-39	42.24	12.67
32.38	-38.00	15.10	-54.00	-42.83	-37	42.11	12.71
33.91	-43.90	15.30	-54.39	-43.19	-40	23.89	1.60
61.35	-57.52	17.88	-59.36	-47.91	-40	3.20	16.71
64.06	-46.00	18.07	-59.72	-48.25	-39	29.83	4.89
66.72	-50.00	18.24	-60.06	-48.57	-49	20.13	2.85
69.46	-45.90	18.42	-60.40	-48.89	-43	31.59	6.52
32.91	-48.00	15.17	-54.14	-42.96	-45	12.78	10.51
33.86	-49.72	15.30	-54.37	-43.18	-46	9.37	13.14
35.06	-46.85	15.45	-54.67	-43.46	-40	16.68	7.24
36.46	-38.68	15.62	-55.00	-43.77	-45	42.18	13.16
57.69	-56.04	17.61	-58.84	-47.42	-40	5.01	15.38
60.22	-44.35	17.80	-59.20	-47.76	-43	33.48	7.68
62.79	-54.30	17.98	-59.55	-48.09	-39	9.68	11.43
65.4	-53.26	18.16	-59.90	-48.42	-41	12.46	9.10
68.04	-69.18	18.33	-60.23	-48.73	-41	12.94	29.56
70.72	-57.00	18.50	-60.55	-49.04	-44	6.23	13.97
35.78	-68.39	15.54	-54.84	-43.62	-64	19.82	36.22
36.78	-54.97	15.66	-55.07	-43.84	-55	0.18	20.24
37.79	-62.65	15.77	-55.30	-44.06	-50	11.74	29.68
39.12	-58.95	15.92	-55.59	-44.33	-54	5.71	24.80
59.38	-52.72	17.74	-59.09	-47.65	-50	12.08	9.62
61.86	-59.87	17.91	-59.43	-47.97	-55	0.74	19.88

- **Measured, modeled, and simulated values related to the 2nd floor :**

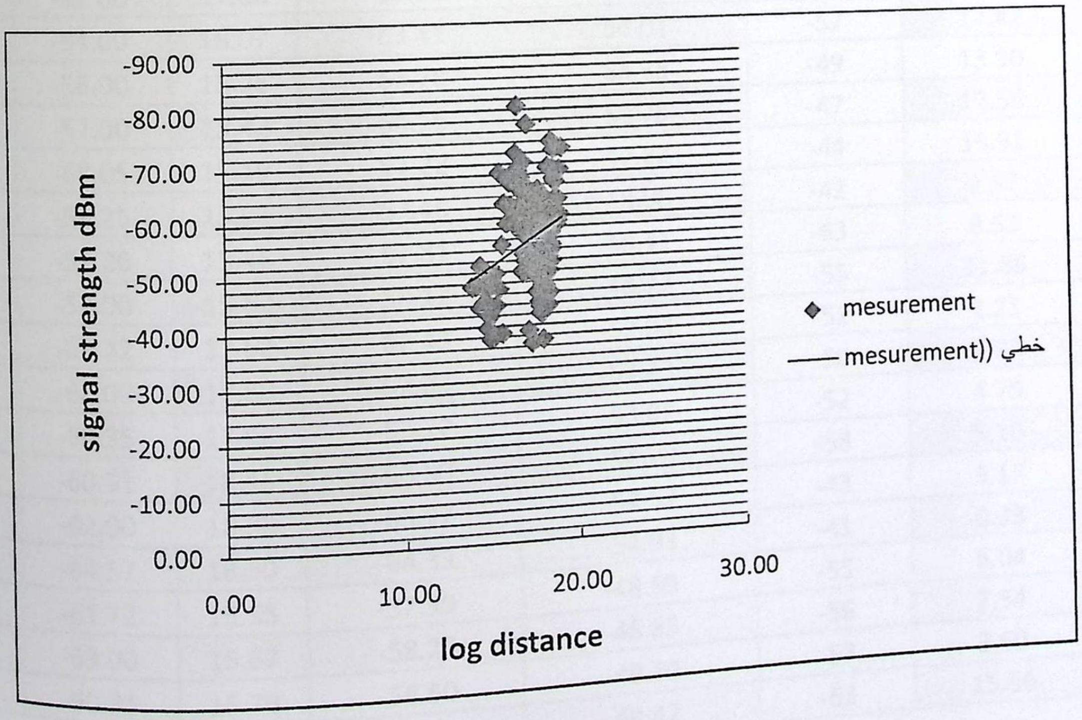
distance	signal	log	model with σ	model without σ	simulation	error with σ	error without σ
24.39	-47.42	13.87	-52.69	-40.58	-45	11.11	14.44
25.69	-47.65	14.10	-51.78	-40.99	-46	8.66	13.98
27.25	-51.25	14.35	-52.55	-41.46	-50	2.54	19.11
29.04	-48.00	14.63	-53.09	-41.96	-47	10.60	12.58
31.02	-41.79	14.92	-53.64	-42.49	-40	28.35	1.66
27.19	-43.53	14.34	-52.54	-41.44	-42	20.69	4.80
28.36	-44.33	14.53	-52.89	-41.77	-44	19.31	5.76
29.79	-39.67	14.74	-53.30	-42.17	-37	34.36	6.29
31.43	-43.69	14.97	-53.75	-42.59	-40	23.02	2.52
60.03	-55.88	17.78	-59.18	-47.73	-45	5.90	14.58
62.74	-47.43	17.98	-59.55	-48.09	-44	25.55	1.38
65.49	-47.23	18.16	-59.91	-48.43	-45	26.84	2.53
68.26	-43.58	18.34	-60.25	-48.76	-39	38.26	11.88
30	-47.08	14.77	-53.36	-42.22	-45	13.33	10.32
31.08	-37.72	14.92	-53.66	-42.50	-39	42.24	12.67
32.38	-38.00	15.10	-54.00	-42.83	-37	42.11	12.71
33.91	-43.90	15.30	-54.39	-43.19	-40	23.89	1.60
61.35	-57.52	17.88	-59.36	-47.91	-40	3.20	16.71
64.06	-46.00	18.07	-59.72	-48.25	-39	29.83	4.89
66.72	-50.00	18.24	-60.06	-48.57	-49	20.13	2.85
69.46	-45.90	18.42	-60.40	-48.89	-43	31.59	6.52
32.91	-48.00	15.17	-54.14	-42.96	-45	12.78	10.51
33.86	-49.72	15.30	-54.37	-43.18	-46	9.37	13.14
35.06	-46.85	15.45	-54.67	-43.46	-40	16.68	7.24
36.46	-38.68	15.62	-55.00	-43.77	-45	42.18	13.16
57.69	-56.04	17.61	-58.84	-47.42	-40	5.01	15.38
60.22	-44.35	17.80	-59.20	-47.76	-43	33.48	7.68
62.79	-54.30	17.98	-59.55	-48.09	-39	9.68	11.43
65.4	-53.26	18.16	-59.90	-48.42	-41	12.46	9.10
68.04	-69.18	18.33	-60.23	-48.73	-41	12.94	29.56
70.72	-57.00	18.50	-60.55	-49.04	-44	6.23	13.97
35.78	-68.39	15.54	-54.84	-43.62	-64	19.82	36.22
36.78	-54.97	15.66	-55.07	-43.84	-55	0.18	20.24
37.79	-62.65	15.77	-55.30	-44.06	-50	11.74	29.68
39.12	-58.95	15.92	-55.59	-44.33	-54	5.71	24.80
59.38	-52.72	17.74	-59.09	-47.65	-50	12.08	9.62
61.86	-59.87	17.91	-59.43	-47.97	-55	0.74	19.88

64.36	-47.17	18.09	-59.76	-48.29	-40	26.69	2.37
66.89	-62.97	18.25	-60.08	-48.59	-43	4.59	22.84
69.5	-50.00	18.42	-60.41	-48.90	-43	20.81	2.20
72.1	-51.82	18.58	-60.71	-49.19	-44	17.17	5.07
40.55	-66.58	16.08	-55.89	-44.62	-50	16.06	32.99
41.74	-62.10	16.21	-56.13	-44.85	-53	9.62	27.79
43.16	-61.22	16.35	-56.41	-45.11	-50	7.86	26.31
48.16	-50.00	16.83	-57.33	-45.98	-47	14.66	8.03
50.18	-52.00	17.01	-57.67	-46.31	-49	10.91	10.94
52.21	-39.00	17.18	-58.01	-46.62	-38	48.73	19.55
54.39	-36.66	17.36	-58.35	-46.95	-39	59.16	28.07
56.56	-50.00	17.53	-58.68	-47.26	-49	17.36	5.48
58.84	-49.00	17.70	-59.01	-47.58	-47	20.43	2.91
61.17	-52.00	17.87	-59.33	-47.88	-50	14.11	7.92
63.57	-55.49	18.03	-59.66	-48.19	-40	7.52	13.15
66.01	-52.87	18.20	-59.97	-48.49	-42	13.44	8.28
68.01	-52.00	18.33	-60.22	-48.73	-50	15.81	6.30
68.51	-52.23	18.36	-60.29	-48.78	-49	15.43	6.59
71.04	-53.78	18.52	-60.59	-49.07	-51	12.66	8.75
41.64	-59.40	16.20	-56.11	-44.83	-55	5.55	24.54
42.41	-66.75	16.27	-56.26	-44.97	-57	15.71	32.63
43.34	-59.91	16.37	-56.44	-45.15	-59	5.78	24.65
44.5	-71.91	16.48	-56.67	-45.35	-53	21.20	36.93
45.8	-80.66	16.61	-56.91	-45.58	-55	29.45	43.49
47.3	-64.97	16.75	-57.18	-45.84	-61	11.99	29.44
48.88	-53.23	16.89	-57.45	-46.10	-50	7.94	13.39
50.62	-50.01	17.04	-57.75	-46.38	-48	15.46	7.27
52.47	-51.44	17.20	-58.05	-46.66	-49	12.84	9.29
54.4	-50.02	17.36	-58.35	-46.95	-47	16.66	6.13
56.47	-58.66	17.52	-58.66	-47.25	-55	0.00	19.46
58.6	-46.09	17.68	-58.97	-47.54	-44	27.97	3.16
60.74	-42.16	17.83	-59.28	-47.83	-40	40.58	13.43
63.06	-37.25	18.00	-59.59	-48.13	-37	59.99	29.21
65.39	-49.03	18.16	-59.89	-48.41	-47	22.16	1.25
67.77	-55.74	18.31	-60.19	-48.70	-50	7.99	12.63
70.2	-52.28	18.46	-60.49	-48.98	-49	15.71	6.31
72.67	-62.47	18.61	-60.78	-49.25	-60	2.70	21.15
75.12	-59.56	18.76	-61.06	-49.52	-58	2.52	16.86
44.54	-68.85	16.49	-56.67	-45.36	-62	17.69	34.12
45.01	-65.94	16.53	-56.76	-45.45	-60	13.92	31.08
46.16	-68.60	16.64	-56.97	-45.65	-50	16.95	33.46

47.24	-57.35	16.74	-57.17	-45.83	-52	0.32	20.09
48.46	-62.57	16.85	-57.38	-46.03	-60	8.29	26.43
49.87	-50.44	16.98	-57.62	-46.26	-49	14.23	8.29
51.37	-51.67	17.11	-57.87	-46.50	-50	12.01	10.01
53.05	-63.83	17.25	-58.14	-46.75	-53	8.91	26.75
54.82	-51.57	17.39	-58.42	-47.01	-40	13.27	8.84
56.69	-61.23	17.54	-58.70	-47.28	-54	4.14	22.78
58.66	-53.51	17.68	-58.98	-47.55	-50	10.23	11.13
60.71	-43.43	17.83	-59.27	-47.82	-40	36.46	10.10
62.84	-42.13	17.98	-59.56	-48.10	-40	41.36	14.15
65.02	-56.79	18.13	-59.85	-48.37	-53	5.39	14.82
67.29	-53.32	18.28	-60.13	-48.64	-40	12.78	8.77
69.61	-62.67	18.43	-60.42	-48.91	-53	3.59	21.95
71.97	-54.69	18.57	-60.70	-49.18	-40	10.98	10.08
74.24	-66.67	18.71	-60.96	-49.42	-47	8.56	25.87
76.83	-58.42	18.86	-61.25	-49.70	-50	4.84	14.93
47.47	-67.32	16.76	-57.21	-45.87	-60	15.02	31.86
48.15	-66.33	16.83	-57.33	-45.98	-58	13.57	30.68
49	-70.22	16.90	-57.47	-46.12	-61	18.15	34.32
50.02	-65.87	16.99	-57.65	-46.28	-51	12.49	29.74
51.19	-58.97	17.09	-57.84	-46.47	-51	1.92	21.21
52.51	-55.96	17.20	-58.05	-46.67	-50	3.75	16.59
55.54	-54.98	17.45	-58.52	-47.12	-47	6.45	14.30
57.23	-59.98	17.58	-58.78	-47.35	-40	2.01	21.05
59.03	-49.37	17.71	-59.04	-47.60	-42	19.57	3.59
60.92	-57.78	17.85	-59.30	-47.85	-50	2.63	17.18
62.9	-52.39	17.99	-59.57	-48.11	-45	13.70	8.18
64.94	-45.33	18.13	-59.84	-48.36	-40	32.00	6.68
67.08	-57.97	18.27	-60.11	-48.62	-53	3.68	16.14
69.27	-59.70	18.41	-60.38	-48.87	-50	1.14	18.13
71.52	-74.00	18.54	-60.65	-49.13	-39	18.05	33.61
73.82	-72.40	18.68	-60.91	-49.38	-50	15.87	31.80
76.18	-58.70	18.82	-61.17	-49.63	-43	4.22	15.45
78.57	-63.21	18.95	-61.43	-49.87	-50	2.80	21.10
50.41	-58.98	17.03	-57.71	-46.35	-55	2.15	21.42
51.05	-61.02	17.08	-57.82	-46.45	-52	5.24	23.88
51.86	-77.23	17.15	-57.95	-46.57	-54	24.97	39.70
52.81	-60.55	17.23	-58.10	-46.72	-53	4.04	22.85
53.93	-61.00	17.32	-58.28	-46.88	-53	4.46	23.14
55.19	-63.18	17.42	-58.47	-47.07	-54	7.45	25.50
56.57	-60.43	17.53	-58.68	-47.26	-43	2.90	21.79

58.05	-61.21	17.64	-58.90	-47.47	-57	3.79	22.45
59.7	-65.00	17.76	-59.13	-47.69	-52	9.03	26.63
61.42	-60.48	17.88	-59.37	-47.92	-40	1.83	20.77
63.24	-58.67	18.01	-59.61	-48.15	-42	1.60	17.94
65.15	-53.23	18.14	-59.86	-48.38	-50	12.46	9.11
67.14	-55.32	18.27	-60.12	-48.62	-40	8.66	12.11
69.2	-59.43	18.40	-60.37	-48.86	-55	1.58	17.78
71.31	-61.13	18.53	-60.62	-49.10	-57	0.84	19.68
73.51	-67.08	18.66	-60.88	-49.34	-40	9.25	26.44
75.75	-63.44	18.79	-61.13	-49.58	-43	3.64	21.84
77.97	-58.98	18.92	-61.37	-49.81	-45	4.05	15.54
80.39	-60.34	19.05	-61.63	-50.06	-47	2.13	17.04
73.42	-68.92	18.66	-60.87	-49.33	-40	11.69	28.42
75.56	-66.42	18.78	-61.11	-49.56	-43	8.00	25.38
77.75	-63.36	18.91	-61.35	-49.79	-55	3.18	21.42
79.98	-68.65	19.03	-61.58	-50.01	-45	10.29	27.14
82.27	-72.66	19.15	-61.82	-50.24	-47	14.91	30.85
ST. DEV.	5.07				% ERROR	14.24	17.00

- ***Relationship between log distance and signal strength (dBm) in the second floor:***



58.05	-61.21	17.64	-58.90
59.7	-65.00	17.76	-59.13
61.42	-60.48	17.88	-59.37
63.24	-58.67	18.01	-59.61
65.15	-53.23	18.14	-59.86
67.14	-55.32	18.27	-60.12
69.2	-59.43	18.40	-60.37
71.31	-61.13	18.53	-60.62
73.51	-67.08	18.66	-60.88
75.75	-63.44	18.79	-61.13
77.97	-58.98	18.92	-61.37
80.39	-60.34	19.05	-61.63
73.42	-68.92	18.66	-60.87
75.56	-66.42	18.78	-61.11
77.75	-63.36	18.91	-61.35
79.98	-68.65	19.03	-61.58
82.27	-72.66	19.15	-61.82
ST. DEV.			

						Error without σ
				-40	27.83	5.82
				-55	22.76	5.90
				-57	29.02	7.16
					14.47	4.73
					9.96	8.28
				-41	8.58	9.82
				-43	6.92	11.08
				-48	11.53	7.09
				-54	1.63	15.19
				-50	4.56	12.65
				-57	13.94	3.12
				-48	12.02	4.64
				-45	16.83	0.44
			-54.60	-43	14.28	2.51
	14.79	-56.36	-46.96	-48	18.96	0.88
	14.94	-56.69	-47.29	-43	2.95	14.12
	15.12	-57.07	-47.67	-54	0.95	15.67
			-48.10	-51	18.68	0.72
-50.15	15.51	-57.90	-48.50	-45	15.45	3.29
-52.00	17.88	-63.00	-53.60	-50	21.16	3.08
-54.00	18.07	-63.41	-54.01	-57	17.42	0.01
-56.00	18.25	-63.78	-54.38	-49	13.90	2.88
-57.00	18.42	-64.16	-54.76	-47	12.56	3.93
-68.05	15.19	-57.22	-47.82	-44	15.91	29.72
-59.25	15.31	-57.48	-48.08	-42	2.97	18.84
-53.26	15.46	-57.81	-48.41	-63	8.53	9.11
-52.00	15.63	-58.17	-48.77	-55	11.86	6.21
-63.22	17.62	-62.43	-53.03	-52	1.25	16.12
-60.00	17.80	-62.83	-53.43	-50	4.72	10.95
-60.35	17.98	-63.22	-53.82	-52	4.75	10.82
-60.51	18.16	-63.60	-54.20	-58	5.10	10.43
-62.00	18.33	-63.97	-54.57	-43	3.17	11.99
-64.57	18.50	-64.33	-54.93	-41	0.38	14.93
-61.72	15.55	-57.99	-48.59	-55	6.04	21.27
-63.00	15.67	-58.25	-48.85	-56	7.54	22.46
-60.81	15.79	-58.50	-49.10	-57	3.80	19.26
-69.66	15.94	-58.82	-49.42	-63	15.56	29.05

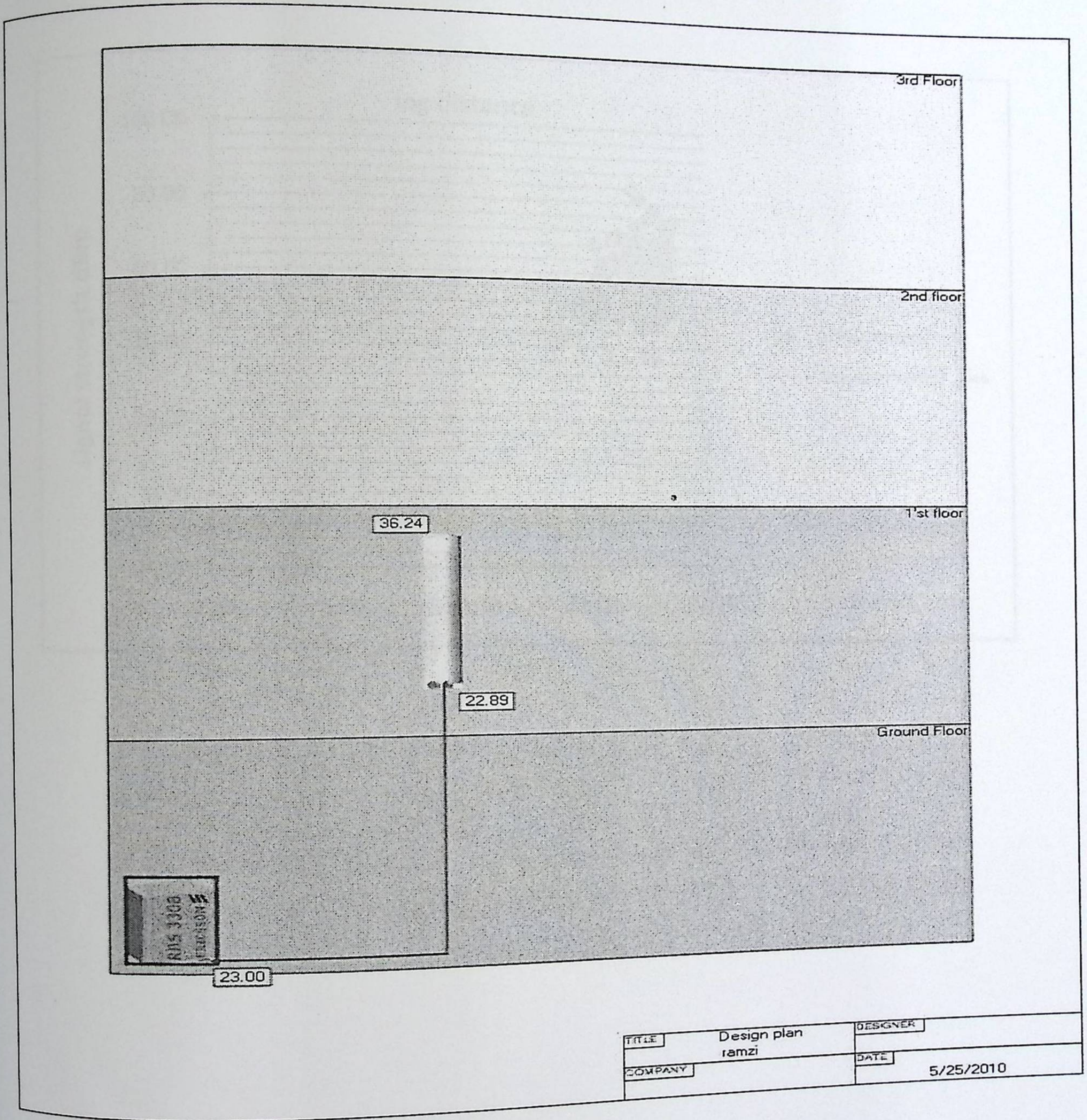
- **Measured, modeled, and simulated values related to the 3rd floor :**

Distance	Signal	Log d	Model with σ	Model without σ	Simulation	Error with σ	Error without σ
24.57	-42.58	13.90	-54.46	-45.06	-41	27.89	5.82
25.86	-43.00	14.13	-54.93	-45.53	-42	27.76	5.90
27.41	-43.00	14.38	-55.48	-46.08	-42	29.02	7.16
29.19	-48.98	14.65	-56.06	-46.66	-51	14.47	4.73
31.16	-51.54	14.94	-56.67	-47.27	-57	9.96	8.28
27.36	-51.08	14.37	-55.46	-46.06	-41	8.58	9.82
28.52	-52.23	14.55	-55.85	-46.45	-43	6.92	11.08
29.94	-50.48	14.76	-56.30	-46.90	-48	11.53	7.09
31.57	-55.89	14.99	-56.80	-47.40	-54	1.63	15.19
32.64	-54.61	15.14	-57.11	-47.71	-50	4.56	12.65
60.10	-55.12	17.79	-62.80	-53.40	-57	13.94	3.12
62.81	-56.43	17.98	-63.21	-53.81	-48	12.02	4.64
65.56	-54.45	18.17	-63.61	-54.21	-45	16.83	0.44
68.33	-56.00	18.35	-64.00	-54.60	-43	14.28	2.51
30.15	-47.38	14.79	-56.36	-46.96	-48	18.96	0.88
31.22	-55.07	14.94	-56.69	-47.29	-43	2.95	14.12
32.52	-56.53	15.12	-57.07	-47.67	-54	0.95	15.67
34.04	-48.45	15.32	-57.50	-48.10	-51	18.68	0.72
35.54	-50.15	15.51	-57.90	-48.50	-45	15.45	3.29
61.42	-52.00	17.88	-63.00	-53.60	-50	21.16	3.08
64.13	-54.00	18.07	-63.41	-54.01	-57	17.42	0.01
66.79	-56.00	18.25	-63.78	-54.38	-49	13.90	2.88
69.52	-57.00	18.42	-64.16	-54.76	-47	12.56	3.93
33.05	-68.05	15.19	-57.22	-47.82	-44	15.91	29.72
33.99	-59.25	15.31	-57.48	-48.08	-42	2.97	18.84
35.19	-53.26	15.46	-57.81	-48.41	-63	8.53	9.11
36.58	-52.00	15.63	-58.17	-48.77	-55	11.86	6.21
57.77	-63.22	17.62	-62.43	-53.03	-52	1.25	16.12
60.29	-60.00	17.80	-62.83	-53.43	-50	4.72	10.95
62.86	-60.35	17.98	-63.22	-53.82	-52	4.75	10.82
65.47	-60.51	18.16	-63.60	-54.20	-58	5.10	10.43
68.11	-62.00	18.33	-63.97	-54.57	-43	3.17	11.99
70.78	-64.57	18.50	-64.33	-54.93	-41	0.38	14.93
35.91	-61.72	15.55	-57.99	-48.59	-55	6.04	21.27
36.90	-63.00	15.67	-58.25	-48.85	-56	7.54	22.46
37.91	-60.81	15.79	-58.50	-49.10	-57	3.80	19.26
39.23	-69.66	15.94	-58.82	-49.42	-63	15.56	29.05

59.46	-60.88	17.74	-62.70	-53.30	-59	2.99	12.45
61.93	-62.69	17.92	-63.08	-53.68	-61	0.62	14.37
64.43	-57.00	18.09	-63.45	-54.05	-53	11.31	5.18
66.96	-57.96	18.26	-63.81	-54.41	-57	10.09	6.12
69.56	-58.16	18.42	-64.16	-54.76	-63	10.32	5.84
72.16	-57.00	18.58	-64.51	-55.11	-61	13.17	3.32
40.66	-64.35	16.09	-59.16	-49.76	-45	8.07	22.68
41.85	-48.00	16.22	-59.42	-50.02	-52	23.80	4.22
43.26	-48.67	16.36	-59.73	-50.33	-53	22.72	3.41
48.25	-49.59	16.84	-60.75	-51.35	-54	22.52	3.56
50.27	-46.00	17.01	-61.13	-51.73	-53	32.90	12.47
52.30	-46.39	17.18	-61.50	-52.10	-51	32.57	12.31
54.47	-38.47	17.36	-61.88	-52.48	-59	60.88	36.44
56.64	-47.10	17.53	-62.25	-52.85	-45	32.17	12.21
58.92	-36.88	17.70	-62.61	-53.21	-45	69.80	44.30
61.24	-49.59	17.87	-62.98	-53.58	-46	26.99	8.03
63.64	-63.62	18.04	-63.33	-53.93	-44	0.45	15.23
66.08	-67.09	18.20	-63.68	-54.28	-43	5.07	19.09
68.08	-49.42	18.33	-63.96	-54.56	-37	29.44	10.41
68.58	-68.21	18.36	-64.03	-54.63	-44	6.13	19.91
71.10	-74.57	18.52	-64.37	-54.97	-36	13.68	26.29
41.75	-61.67	16.21	-59.40	-50.00	-47	3.68	18.92
42.52	-71.00	16.29	-59.57	-50.17	-53	16.10	29.34
43.44	-59.98	16.38	-59.77	-50.37	-55	0.35	16.02
44.60	-65.06	16.49	-60.02	-50.62	-45	7.75	22.20
45.90	-60.58	16.62	-60.29	-50.89	-50	0.48	16.00
47.40	-64.29	16.76	-60.58	-51.18	-61	5.76	20.38
48.97	-60.25	16.90	-60.89	-51.49	-52	1.06	14.54
50.71	-59.54	17.05	-61.22	-51.82	-41	2.81	12.97
52.56	-57.28	17.21	-61.55	-52.15	-52	7.45	8.96
54.48	-59.45	17.36	-61.88	-52.48	-63	4.10	11.71
56.55	-49.34	17.52	-62.23	-52.83	-60	26.13	7.08
58.68	-47.28	17.68	-62.58	-53.18	-52	32.35	12.47
60.81	-46.12	17.84	-62.91	-53.51	-52	36.42	16.04
63.13	-48.87	18.00	-63.26	-53.86	-51	29.44	10.21
64.90	-50.39	18.12	-63.52	-54.12	-47	26.05	7.39
44.64	-52.56	16.50	-60.03	-50.63	-50	14.20	3.68
45.11	-58.00	16.54	-60.12	-50.72	-54	3.66	12.55
46.26	-68.57	16.65	-60.36	-50.96	-47	11.97	25.68
47.34	-84.01	16.75	-60.57	-51.17	-45	27.90	39.09
48.55	-83.66	16.86	-60.81	-51.41	-42	27.31	38.55

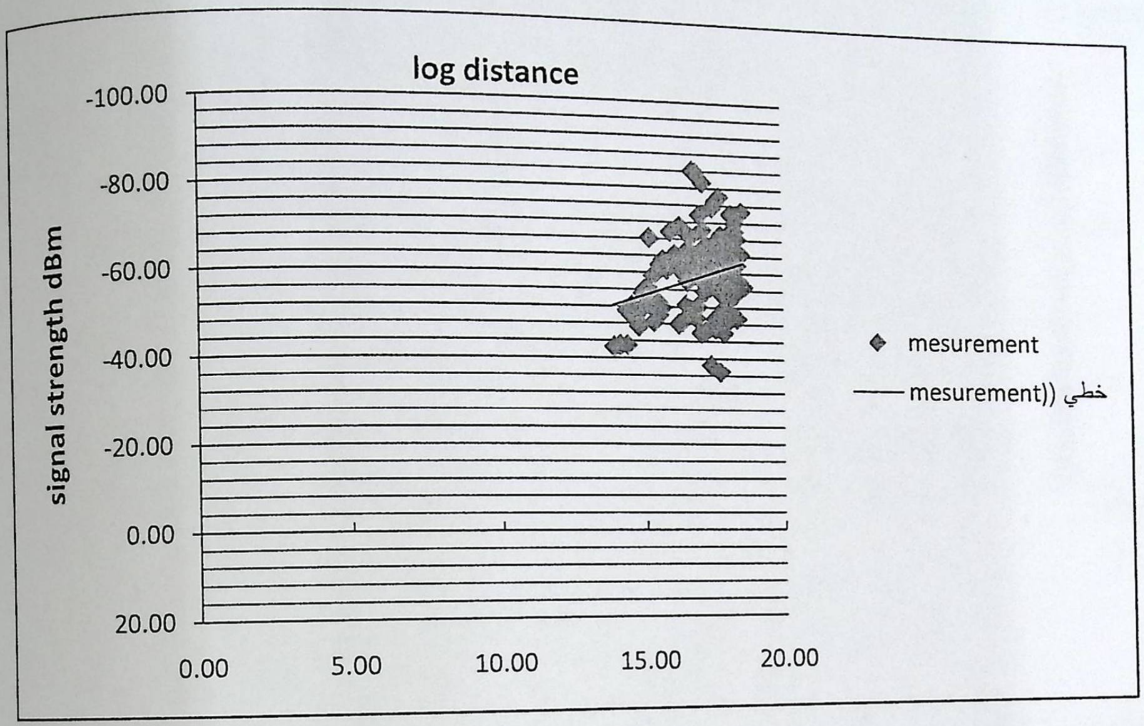
49.96	-73.71	16.99	-61.08	-51.68	-43	17.14	29.89
51.46	-81.28	17.11	-61.35	-51.95	-45	24.52	36.08
53.13	-66.33	17.25	-61.65	-52.25	-49	7.05	21.22
54.90	-61.62	17.40	-61.96	-52.56	-53	0.55	14.71
56.77	-58.13	17.54	-62.27	-52.87	-62	7.11	9.06
58.74	-50.00	17.69	-62.59	-53.19	-64	25.17	6.37
60.78	-49.15	17.84	-62.91	-53.51	-63	27.98	8.86
62.91	-55.56	17.99	-63.23	-53.83	-64	13.80	3.12
65.09	-60.44	18.14	-63.54	-54.14	-65	5.13	10.42
66.21	-61.02	18.21	-63.70	-54.30	-63	4.39	11.01
47.56	-62.18	16.77	-60.62	-51.22	-63	2.51	17.63
48.24	-59.70	16.83	-60.75	-51.35	-53	1.76	13.98
49.09	-52.17	16.91	-60.91	-51.51	-52	16.75	1.27
50.11	-59.45	17.00	-61.10	-51.70	-50	2.79	13.02
51.28	-61.43	17.10	-61.32	-51.92	-47	0.18	15.48
52.60	-61.64	17.21	-61.56	-52.16	-51	0.13	15.38
55.62	-75.57	17.45	-62.08	-52.68	-59	17.85	30.29
57.31	-76.88	17.58	-62.36	-52.96	-60	18.90	31.12
59.11	-78.10	17.72	-62.64	-53.24	-49	19.79	31.82
60.99	-57.10	17.85	-62.94	-53.54	-56	10.23	6.23
62.97	-67.99	17.99	-63.24	-53.84	-45	6.99	20.82
65.01	-74.06	18.13	-63.53	-54.13	-41	14.22	26.91
67.15	-70.01	18.27	-63.83	-54.43	-51	8.82	22.25
50.50	-65.35	17.03	-61.18	-51.78	-51	6.39	20.77
51.14	-70.31	17.09	-61.29	-51.89	-40	12.82	26.19
51.95	-55.65	17.16	-61.44	-52.04	-43	10.40	6.49
52.90	-59.27	17.23	-61.61	-52.21	-53	3.94	11.92
54.01	-61.46	17.33	-61.80	-52.40	-54	0.57	14.73
55.27	-62.78	17.43	-62.02	-52.62	-63	1.21	16.18
56.65	-65.34	17.53	-62.25	-52.85	-64	4.73	19.11
58.13	-67.98	17.64	-62.49	-53.09	-55	8.07	21.90
59.78	-68.98	17.77	-62.75	-53.35	-53	9.03	22.66
61.49	-67.23	17.89	-63.01	-53.61	-53	6.28	20.26
63.31	-68.20	18.01	-63.29	-53.89	-52	7.21	20.99
65.22	-70.00	18.14	-63.56	-54.16	-54	9.20	22.62
67.21	-71.92	18.27	-63.84	-54.44	-55	11.23	24.30
ST. DEV.					% ERROR	12.97	14.57

Appendex H

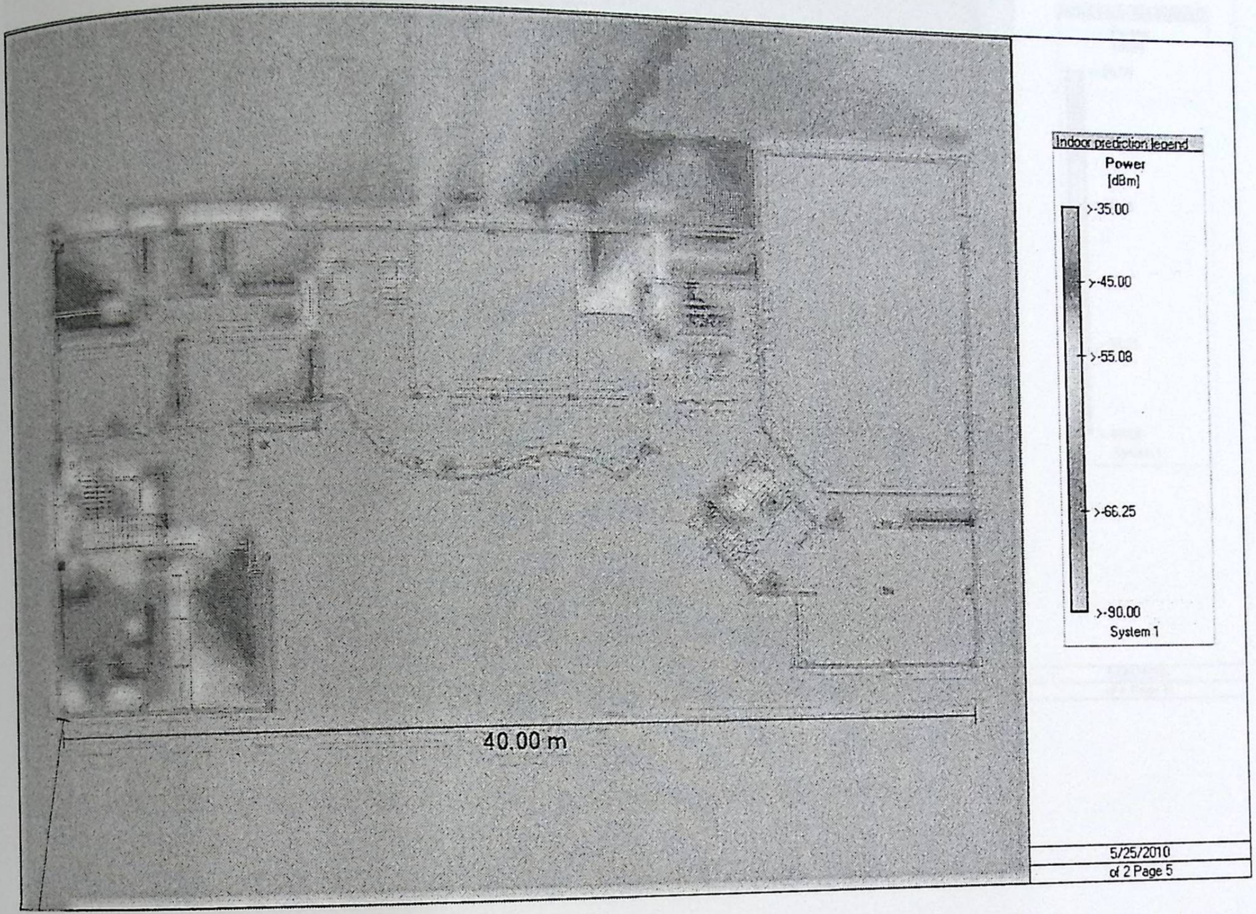


3rd Floor
2nd floor
1'st floor
Ground Floor
36.24
22.89
23.00
TITLE
Design plan
ramzi
DESIGNER
COMPANY
DATE
5/25/2010

- ***Relationship between log distance and signal strength (dBm) in the third floor:***

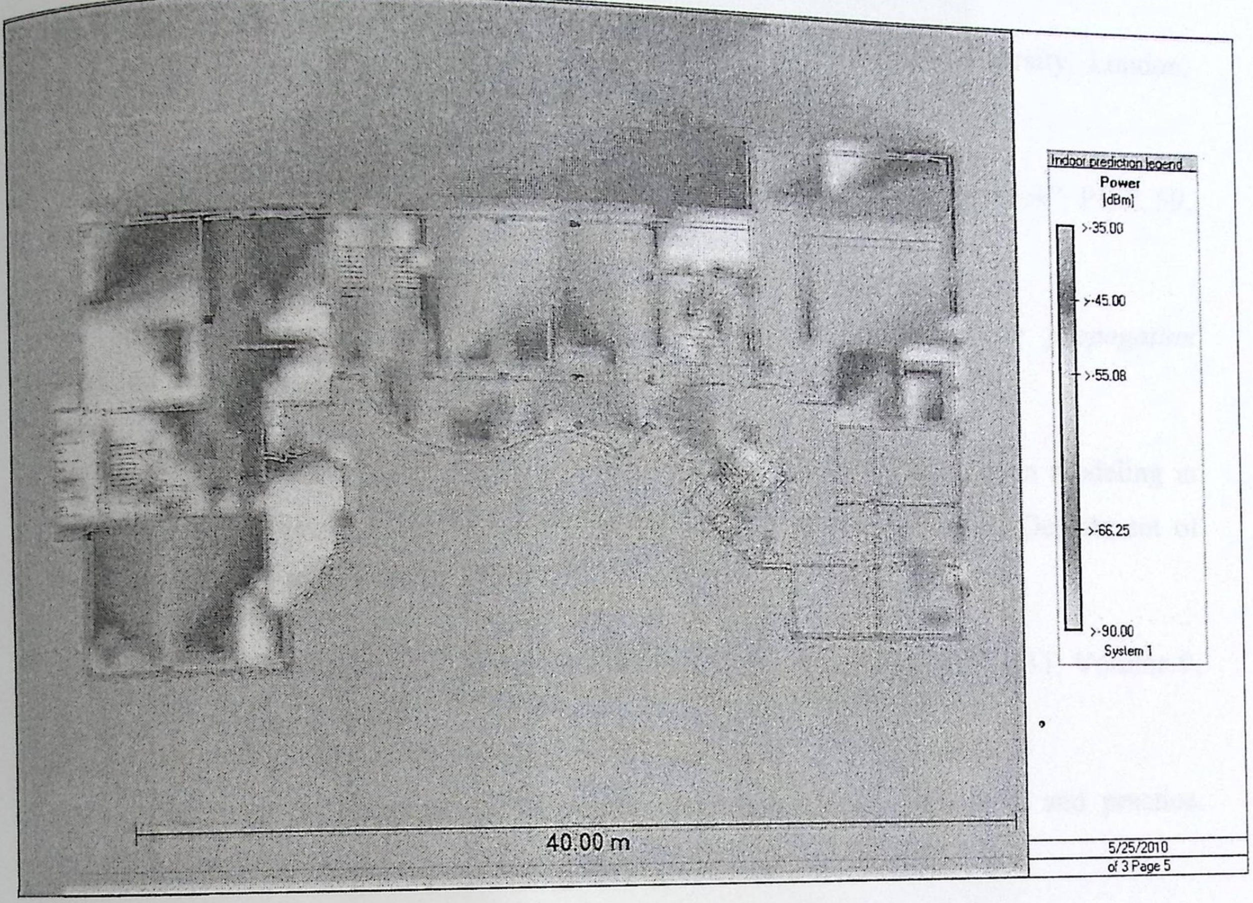


First Floor:


Indoor prediction legend
Power
[dBm]
>-35.00
>-45.00
>-55.08
>-66.25
>-90.00
System 1
40.00 m
5/25/2010
of 2 Page 5

Second floor

Third floor


Indoor prediction legend
Power
[dBm]
>-35.00
>-45.00
>-55.08
>-66.25
>-90.00
System 1
40.00 m
5/25/2010
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