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Bachelor Thesis

Graduation Project

Derivation of Measurement-based comparative models for indoor propagation at 2.4 GHz and 900 MHz frequency bands

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اسم المشروع

Derivation and Measurement of comparative models for indoor propagation at 2.4 GHz and 900 MHz frequency bands

أسماء الطلبة

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بناء على نظام كلية الهندسة و التكنولوجيا و إشراف و متابعة المشرف المباشر على المشروع وموافقة أعضاء اللجنة الممتحنة تم تقديم هذا المشروع إلى دائرة الهندسة الكهربائية وذلك للوفاء بمتطلبات درجة البكالوريوس في الهندسة تخصص هندسة الالكترونيات والاتصالات.

توقيع المشرف

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توقيع اللجنة الممتحنة

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توقيع رئيس الدائرة

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Abstract

Nowadays, wireless networks are widespread due to their mobility, simplicity and expandability. However, one of the most challenges that face wireless networks developers is the propagation loss which limits the coverage of these networks.

From this point, the need of modeling propagation loss of wireless signals shows up, as it provides a good impression and expectation about the coverage of the field strength of wireless signals. This was the main motivation for our project.

We are intending to come out with models for indoor propagation at 2.4 GHz and 900 MHz frequency bands by taking many measurements using HF60105 spectrum analyzer, in a sample of five large buildings, for the indoor penetration loss experienced by a signal transmitted from an external source. These models are for multiwall penetration loss and for the general indoor propagation loss. Analysis of data will enable comparison between the two frequency bands.

In our project, we use an external source instead of indoor access points of 2.4 GHz. This will enable adequate comparison with propagation loss at 900MHz for outdoor cellular base station. Additionally, we are intending to use new equipments and software which will give us new measurements for 900 MHz that will be compared with previous ones. The new data and analysis at 2.4 GHz will provide guidelines, as far as coverage is concerned, for cellular operators willing to operate a WiMAX network in the 2.5 GHz frequency band in the future.

المقترح

في الوقت الحاضر، انتشرت الشبكات اللاسلكية بشكل كبير وعلى نطاق واسع نظرا لبساطتها، والقدرة على تنقل الاجهزة فيها بالإضافة الى القدرة على توسيعها. ومع ذلك، واحدة من أكثر التحديات التي تواجه المطورين الشبكات اللاسلكية هو ضياع قوة الاشارة في الانتشار مما يحد من نطاق تغطية هذه الشبكات.

من هذه النقطة، ظهرت الحاجة الى ايجاد معادلات نموذجية تحدد كمية الفقد في الاشارات الاسلكية، حيث أن هذه المعادلات توفر انطباعا وتوقعا جيدين حول تغطية شدة المجال من الاشارات اللاسلكية. وكان هذا هو الدافع الرئيسي لمشروعنا.

نحن ننوي الخروج بمعادلات نموذجية لتحديد انتشار الاشارات اللاسلكية في الأماكن المغلقة على نطاقات التردد ٢.٤ غيغاهرتز و ٩٠٠ ميغاهيرتز من خلال اتخاذ العديد من القياسات باستخدام محلل الطيف HF60105 في عينة من خمسة مبان كبيرة لحساب الفقدان في الاشارة في عملية الاختراق الداخلي الذي يطرأ على إشارة لاسلكية تنتقل من مصدر خارجي . هذه المعادلات النموذجية هي لضياع القوة في الاشارة بسبب اختراق الاشارة لمجموعة من الجدران الداخلية بالاضافة الى الضياع الناتج عن الانتشار داخل الاماكن المغلقة بشكل عام. تحليل البيانات سيمكننا من المقارنة بين اثنين من نطاقات التردد.

في مشروعنا، نستخدم مصدر خارجي بدلا من نقاط الوصول داخل المباني والتي تعمل على تردد ٢.٤ غيغاهرتز. وسيمكننا هذا من عمل مقارنة مناسبة وكافية مع الخسارة الحاصلة لانتشار اشارات نقطة وصول شركة الهاتف المحمول على تردد MHZ٩٠٠ . بالإضافة إلى ذلك، فإننا ننوي استخدام معدات وبرمجيات جديدة والتي ستوفر لنا قياسات جديدة ل٩٠٠ ميغاهيرتز. ثم نقوم بمقارنتها مع سابقاتها. ستوفر البيانات والتحليلات الجديدة في ٢.٤ غيغاهرتز مبادئ توجيهية تتعلق بالتغطية لمشغلي الخليوي المستعدين لتشغيل شبكة واي ماكس في النطاق الترددي ٢.٥ غيغاهرتز مستقبلا.

Dedication

We dedicate this work

To our families

To our teachers

To our friends

To our beloved homeland Palestine

Acknowledgment

Our thankfulness is first and last to Allah who graced us with mind and knowledge.
We would like to give our great thanks to all who learned us over the years, to our parents and families who supported us and were beside us every time.
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1.1 Overview

Indoor propagation modeling is one of the main aspects that wireless networks planners seek to achieve, in order to estimate the coverage area for these networks. Many models have been developed, but since these models are mostly empirical, in other words they are based on measurements for specific scenarios and environment, there is a continuous need of new models due to the wide variations in environment and buildings structures around the world.

This project aims to come out with two models for indoor propagation loss at two frequency bands; 900 MHz and 2.4 GHz. To develop these models, a large set of measurements will be taken, by a spectrum analyzer, in a sample of five large multi-floored multi-wall buildings. Penetration loss for outer and inner walls will be taken in consideration, besides the general propagation loss that results from the transmitter separation and other factors related to wave propagation characteristics.

In this project, we will use an external source instead of indoor access points of 2.4 GHz. This will enable adequate comparison with propagation loss at 900MHz for outdoor cellular base station. Additionally, we are intending to use new equipments and software which will give us new measurements for 900 MHz that will be compared with previous ones. And for the data of 2.4 GHz, the study will provide guidelines, as far as coverage is concerned, for cellular operators willing to operate a WiMAX network in the 2.5 GHz frequency band in the future.

By the end of this project, two models will be developed for indoor propagation loss at 2.4 GHz and 900 MHz frequency bands. In addition, these two models will be compared by mathematical correlation.

1.2 Objectives:

- Deriving models for indoor propagation at 2.4 GHz and 900 MHz frequency bands.
- Deriving models for multiwall penetration loss at 2.4 GHz and 900 MHz frequency bands.
- Finding the correlation between the various models at the different frequencies.

1.3 Motivation

As we mentioned, modeling indoor propagation is an essential issue for wireless networks designers. The main motivation of our project is to come out with an indoor propagation model for the 2.4 GHz unlicensed frequency band that can give a good approximation for the characteristics of the 2.5 GHz licensed frequency band used in WiMAX technology. This model could be an important guidance for either cellular operators to estimate the coverage area for a WiMAX Network in the case that these operators tend to go for 3G.

Another motivation for this project is to generalize the obtained models, by the end of the project, for the investigated buildings on other similar buildings.

1.4 Methodology

At the level of pursuance of our project, we will follow the next procedure:

- Choosing a suitable building near to the sample of buildings in which measurements will be taken, for deploying the 2.4 GHz base station.
- Using AutoCAD schemes to distribute many points (around 100 points) in each floor in the buildings.
- Measuring the signal strength from the 2.4 GHz transmitter in all points by the use of the spectrum analyzer and laptop NIC cards. In each point about 150 readings will be recorded by the spectrum analyzer and saved as a log file on the laptop. For each point the average signal strength will be deduced and a plot could be obtained clarifying the signal strength variation with the number

of walls, after eliminating the effect of transmitter-receiver separation distance. By this technique we can deduce the relationship between the number of walls and the penetration loss.

- The previous step will be repeated to measure the signal strength from Al-Wataniya BTS operating in the 900 MHz frequency band.
- Obtain new models for the two frequency bands relying on the analysis of measurements.
- Comparing the two obtained models by mathematical correlation.

1.5 Equipment and technologies

In this section, we would like to introduce the equipment and technologies that we need to fulfill our project:

- Al-Wataniya base stations: The nearest base station to each building is to be chosen to measure the signal strength for the 900 MHz frequency band.
- Bullet M wireless radio : this is transmitter for the 2.4 GHz frequency band.
- ASA-2416 antenna: This antenna will be mounted on the Bullet M wireless radio.
- Spectrum Analyzer: this is the receiving tool that will take measurements for both frequency bands.
- Laptops: We will use laptops as receivers with their NIC cards for the 2.4 GHz, and we will use them also to utilize multiple necessary software.
- MCS Spectrum Analyzer (used with spectrum analyzer) : This software is to be used in accompany with the spectrum analyzer equipment to record readings.
- InSSIDer software (used for laptops NIC cards): By this software, the 2.4 GHz signal strength will be measured on laptops. Additionally, we will need it to determine on which channel of the 2.4 GHz frequency band, our transmitter should operate, to eliminate interference with other access points that could be in neighborhood.
- AutoCAD software: This software will be used to provide us with the essential schemes for all buildings in which we will take measurements.

1.6 Timeline

Lastly in this chapter, the following table clarifies the time schedule for the second semester 2012/2013

Table 1 Timeline

Task	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Collection of references														
2. Preparation of proposal														
3.Learning to use equipments and software														
4.Start measuring at 2.4 GHz (at least one floor)														
5.For the same floor at 900 MHz														
6.Start analysis and develop a preliminary model														
7.Writing report														
8.Delivery of report to supervisor for review														
9.Submission of report to department														

1.7 Costs

$0 budget.

We look forward to finishing our project at no cost.

Chapter 2

Literature Review

2.1 Introduction

2.2 Previous Studies

2.1 Introduction

Modeling indoor wave propagation is an essential issue to predict the behavior of the signal inside buildings, to come out with a suitable prediction of the coverage area of wireless networks. Many models have been developed to characterize wave propagation as function of frequency, distance and other environmental conditions.

The existing models can be classified in two classes: Empirical models which are developed according to measurements, and deterministic models that are based on electromagnetic wave propagation theory.

We can conclude the empirical models in two popular models: [1]

1- ITU indoor path loss model:

$$Ltotal = 20\log_{10} f + N\log_{10} d + Lf(n) - 28 \quad \text{eq. (2.1)}$$

Where

N is the distance power loss coefficient

f is the frequency in MHz

d is the distance in meters (d>1m)

$Lf(n)$ is the floor penetration loss factor

n is the number of floors between the transmitter and the receiver

2- Log-distance path loss model: which describes the path loss of a signal inside a building over distance, as follows:

$$Ltotal = PL(d0) + N\log_{10}\frac{d}{d0} + Xs \qquad \text{eq. (2.2)}$$

Where

PL (d0) is the path loss at the reference distance, usually taken as (theoretical) free space loss at 1m

N/10 is the path loss distance exponent

Xs is a Gaussian random variable with zero mean and standard deviation

Of s dB

A popular example of deterministic models is ray tracing which is based on the geometrical optics principles. Using this method, reflection and diffraction and the penetration for each ray can be calculated using electromagnetic theory. Although the accuracy of these models, they require heavy computational algorithms and they need a lot of time for processing.

2.1 Previous studies

We aim by the end of our project to develop a simple model describing indoor propagation at two different frequency bands, which are 900 MHz and 2.4 GHz.
Our first step was to make a literature research for previous studies and works about the topic concerned. And we came out with many papers that we are introducing in this chapter.

Study to characterize the indoor channel for 802.11 wireless local area networks at 2.4 GHz frequency was discussed. Extensive field strength measurements were carried out inside different buildings. Then, path loss exponents from Log-distance Path loss Model and standard deviations from Log-Normal Shadowing, which statistically described the path loss models for different Transmitter Receiver separations and scenarios, were determined. The Chi-square test statistic values for each access point were calculated to prove that the observed fading is a normal distribution at 5% significance level. Two access points were used and measurements were taken by a laptop with a wireless client adapter and NetStumbler software. Four different scenarios were considered for measurements: a closed corridor, an open corridor, a class-room and a computer lab. [2]

This study is useful in our project, since we can study the analytical method used to determine the equations that described the path loss for each scenario. The analysis of data was done in a number of steps; calculating the mean signal levels, calculating curve fitting using least squares method by the help of MATLAB curve fitting tool, evaluating path loss exponent 'n' by curve fitting, verifying normal distribution for the variation of loss, finding standard deviation, calculating chi square goodness-of-fit test and finally a comparison of the measured data with the two ray model. The results obtained for each scenario was as follows:

Table 2 Robert Akl and Dinesh Tummalas' study results

Scenario/Parameter	**Path loss exponent n**		**Standard deviation**		**Chi-square test statistic X^2**	
	AP1	**AP2**	**AP1**	**AP2**	**AP1**	**AP2**
Closed Corridor	1.572	1.58	3.9849	4.022	16.152	20.3699
Open Corridor	1.688	1.63	3.5773	3.2642	20.0012	27.6687
Classroom	1.258	1.263	3.7606	4.053	19.6687	20.1618
Computer LAB	1.447	1.428	3.7049	3.846	15.7022	18.1544

Table 2.1

The values of Chi-square were considered acceptable to prove that the observed fading is a normal distribution of 5% significance level.

In one of scientific papers related to our project titled was made to predict propagation models for wireless access point signals at 2.4 Ghz and with 100 mW power in two different buildings of Siddhant College of Engineering (Polytechnic Institute building and E &T/C floor) with two different numbers of floors in each. Results had to be recorded by wireless client adapter and one of: Netstumbler, Wirelessmon, and inSSIDer softwares installed on Toshiba laptop. Prediction on these models was based on Log- Distance, ITU Path Loss and AFC Models. Different results were found in the two buildings due to the construction materials and inner shape of them. Measurements which were taken were compared with the three existed models. And results showed that AFC model was the most accurate for such environment. [3]

The hand of help for our project which this study provides is the suitable way of creating new propagation models in respect to previous ones.

Another paper related to indoor propagation modeling at 2.4GHz has relied on several models which are the International Telecommunication Union (ITU) and the log-distance path loss model to find his own model.

The transmitter (AP) and receiver were in the same building, both on the same floor or on different floors. Practical measurements were taken by using a laptop equipped with the NETSTUMBLER 0.40 software to see the impression of walls and doors.

Several effects caused the attenuation in the wireless signal which has been taken into account in this paper, such as: path loss, shadowing and multipath. [4]

According to this paper, floor loss factor, in one floor scenario, is zero. Applying this value to the ITU-model, the path loss and received power is represented as:

$L = 39.6 + N \log_{10} d$ eq. (2.3)

$Pr = -3.6 - N \log_{10} d$ eq. (2.4)

For multi floor scenario, the floor penetration loss factor is 15+4(n-1). So the path loss equation becomes:

$L = 39.6 + N \log_{10} d + 15 + 4(n-1)$ eq. (2.5)

In the case of studying the shadowing deviation effects scenario based on Log-distance path model, the free space loss PL (do) for 2.4GHz system is 40 dB, so the path loss equation becomes:

L=40+Nlog (d) + Xs

In a study to characterize the indoor path loss at 914 MHz frequency was made [5], measurements were taken in different buildings, the path loss was determined by using log-distance model and the standard deviation and mean for the log normal fading. The transmitter is an AP with Omni-directional antenna that was located inside the building, and the receiver is laptop with adapter card. The path loss in a multi-floor environment was predicted by a mean path loss exponent that was function of the number of the floor between the transmitter and the receiver.

$$PL(d)[dB] = PL(d0)[dB] + 10\log_{10}\frac{d}{d0} + FAF[dB] \qquad eq.(2.6)$$

Where:

PL (d0): is path loss at 1 m reference

FAF: is the floor attenuation factor which is function of the number of floors and building type.

n: is path loss exponent

The results have shown that in an open plan building the path loss exponent is close to 2, and for buildings including many more obstruction between transmitter and receiver the path loss exponent is higher. In addition, the attenuation factors for cloth-covered plastic partitions was found to be equal to 1.39 dB/partition, while it was equal to 2.38 dB/wall for concrete partitions.

Results has shown that the error between measured and predicted path loss using simple path loss models is about 9 dB. Moreover, the results show that site-specific information can be used to predict path loss in buildings with many different obstructions separating the transmitter and receiver with a standard deviation of 5.8 dB.

Another study, by Dr. Eng Osama Ata and a research group at Palestine Polytechnic University [[6]], that discussed indoor propagation for two frequency bands 900 MHz and 2.4 GHz, in order to come out with a specific model based on ITU models. To accomplish their work, they made measurements in Palestine Polytechnic University buildings in addition to Al-Ahli Hospital building. Measurements were recorded by Laptops using NIC cards for the 2.4 GHz frequency band, where transmitters were located inside the specified buildings. Whereas, the used TEMs tools to record signal strength from Jawwal BTS operating in 900 MHz frequency band. The new presented model is an ITU modified model named "AMATA" model which has the following formula:

$$L = 20Log_{10}f\ (MHz) + 10nLog_{10}d + L_{outer} + \chi_{\alpha} - 28 \qquad \text{eq. (2.7)}$$

L : Path loss in dB units

f : The frequency in MHz

d : The distance in meters

L_{outer} : Penetration loss of outer wall

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

X_{α} (dB) = $0.0075\ K^4 - .018\ K^3 + 1.1\ K^2 + 2.9\ K$ (for 900 MHz frequency band) eq. (2.8)

X_{α} (dB) = $0.0032\ K^4 - 0.086\ K^3 - 0.17\ K^2 + 9.3\ K$ (for 2.4 GHz frequency band) eq. (2.9)

K = number of separated walls.

Our project will be mainly based on this study, since we are intending to deal mostly with the same sample of buildings, for which measurements were taken. We aim to develop an extended AMATA model for indoor propagation, because we are going to use different transmitter fo the 2.4 GHz frequency band which is the "Bullet" base station instead of access points. And the transmitter in our case will be externally located. In addition, we are going to use a spectrum analyzer as a receiver for both frequency bands, which are 2.4 GHz and 900 MHz. Moreover, we can depend on the analysis method applied in their study to develop our own models.

Chapter *3 Technologies and Methodology*

3.1 Introduction

3.2 Technologies

3.3 Methodology

3.1 Introduction

Modeling Indoor propagation is different from modeling outdoor propagation, since the environment inside buildings varies widely from one scenario to another. In addition, indoor environment has more harsh and unexpected effects on signals, due to the variety of buildings layouts, buildings structures, the inner partitions, furniture, and even people existence inside buildings.

For our scenario, a sample of five large multi-floored buildings, which are categorized as institutional buildings, will be investigated to come out with empirical models to describe indoor propagation in these buildings and these models can be generalized over wide range of buildings with approximate type and conditions.

In this chapter we are going to introduce the equipments and software we are intending to use in our project, and we are going to describe the methodology that we will follow in collecting measurements and analyzing these measurements to come out with results that will pave the way for developing the new models for indoor propagation for two frequency bands, which are 2.4 GHz unlicensed frequency band and GSM 900 MHz frequency band.

3.2 Technologies:

In this section we are going to introduce the equipments and software needed to fulfill our project. The equipments are as mentioned below:

1. **Bullet M wireless radio:**

Bullet M is the latest version of the popular Ubiquity Bullet. It is a wireless radio for the frequency 2.4GHz, with an integrated Type N RF connector that can be directly plugged into any Antenna, to create a powerful and robust outdoor Access Point.

The amount of power that could be supplied to the antenna can reach up to 600mW. The Bullet M is ideal for long-distance links, capable of 100Mbps over multi-km distances.

Bullet M eliminates the need to use RF cables and requires no special antenna or tools to install.

There is a special software used for Bullet M wireless radio called "air OS", it is an intuitive, versatile and highly developed technology. It is exceptionally intuitive and was designed to require no training to operate.That enables hi-performance outdoor multipoint networking.

Figure 1 Bullet M wireless radio

2. ASA-2416 Antenna:

ASA-2416 is the antenna that we use in our project, which is designed for the 2.4GHz ISM bands. It provides superb performance in IEEE 802.11b, 802.11g, 802.11n Wireless LAN, Bluetooth, and Wireless Video Systems.

Important features of ASA-2416 Antenna

- High performance.
- Light weight.
- Operate in all weather conditions
- In accordance with customer needs to change the color or features.

Specifications:

- VSWR is less than or equal 1.5
- Gain 13 – 16 dB
- Beam width: H: 45-120°
- Polarization vertical.
- Power handing 50 watt.
- Impedance 50 ohms.
- Connectors N- female.
- Dimension: (500 ×110) mm× mm.
- Weight 2.03 kg.

Figure 2 ASA -2416 Antenna

3. Spectrum Analyzer "Spectran HW V4 / FW BETA41":

This type of spectrum analyzer is a high-frequency measurement tool used to take measurements of the wireless signal in dBm that is generated from the base station. We use it in our project to measure a wireless signal from the base station on 900MHz and 2.4GHz frequency band.

The range of Frequencies that are supported by the Spectrum Analyzer are from 30MHz to 9GHz. It supports three types of demodulation: amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM).

There are two ways to manually set the frequency range: the center frequency that Gives us the frequency at which the signal has the maximum power, and the frequency range width (span) which adjusts the width of the sweep. We can operate the spectrum analyzer either with the optionally available Omni LOG antenna or with the professional Hyper LOG antenna.

This device contains :

1- Hyper LOG measurement antenna

2- SMA cable 1m

3- Battery charger / power supply with 4 adapters

4- SMA tool

5- SMA adapter

6- Registration card

MCS Spectrum Analyzer (used with spectrum analyzer): This software installed to a laptop to be used to transfer and record the measurements on the laptop as log files.

Figure 3 Spectrum Analyzer

4. InSSIDer software:

It's a Wi-Fi network scanner software for Microsoft Windows and Apple Macintosh from MetaGeek, LLC[7].It received a 2008 Infoworld Bossie Award for "Best of open source software in networking".[8]

The purpose of using this software in our project is scanning 2.4 GHz frequency band channels in order to see available channels and Wi-Fi networks on them. Since our ASA Antenna is operating at 2.4 GHz and our model will be based on 2.4 GHz measurements, an empty channel is needed to make our antenna operating on.

5. AutoCAD software:

A software application for computer-aided design (CAD) and drafting. The software supports both 2D and 3D formats. The software is developed and sold by Autodesk, Inc[9].

This software will be used to provide us with the essential schemes for all buildings in which we will take measurements. It will be also used to calculate the distance between outside source (base station) and specific points where measurements will be taken.

3.3 Methodology:

The procedure of this project is divided into two main parts:

I- Taking Measurements:

Taking measurements in the sample of buildings by the following procedure:

- Specify one Base Station of Al-Wataniya Cellular Operator as a transmitter in the 900MHz frequency band, and determine the frequency on which this BS operates, its coordinates by Google Earth and its transmitting power.
- Deploy the "Bullet M" Base station , which operates in the 2.4 GHz frequency band, on a suitable location, near to the investigated buildings and at a known distance. In order to avoid interference from other access points operating in the same frequency band, we need to specify one suitable channel of eleven Wi-Fi channels. This can be done by using the inSSIDer software which shows all networks and channels they operate on. Before the go, the transmitting power should be determined by programming the base station.
- For each building to be investigated, we should have the AutoCAD charts for each floor, in order to determine points in which measurements will be taken. We will need about 100 points in each floor to have more accurate results.
- In each point, we will use the HF60105 spectrum analyzer to measure the signal power. A sum of 150 readings will be taken in each point and saved into a log file on the laptop.

II- Measurements Analysis:

After recording measurements for the whole sample of buildings, and finding the average signal power from the recorded data for each point, all points will be classified according to the number of walls separation between the transmitter and the receiver.

Based on the ITU indoor path loss model, which is expressed in the formula 3.1, we can develop a new model for indoor propagation taking in consideration the penetration loss of inner walls.

$$L = 20\log(f) + Nlog(d) + P_f(n) - 28 \quad \text{eq. (3.1)}$$

Where:

L = the total path loss in dB decibel (dB).

f = Frequency of transmission. Unit: megahertz (MHz).

d = Distance in meters

N = the distance power loss coefficient.

n = Number of floors between the transmitter and receiver.

$P_f(n)$ = the floor loss penetration factor.

Note: The distance power loss coefficient denoted by N is equal to 10n, where n is path loss exponent and equals 2 in free space.

In our scenario the floor loss is zero, since the transmitters are outside the buildings, and the wave is considered to be a plane wave on the building. Next, we have to compute the path loss exponent n, since it is different than in free space environment. We can achieve this, first by eliminating the effect of frequency and average penetration loss of the outer wall (Lout). The remaining loss is due to the distance power loss coefficient (10nlog d) and penetration loss through inner walls.

For the points with no wall separation between the transmitter and receiver, the loss is due to environment with zero loss due to inner walls.

Loss = Pt – Pr

Then for this point, L= 10 n log d = Pt – Pr

By using the best fit tool in MATLAB or other software, we can obtain the curve of Power loss versus 10 n log d. Then simply the path loss exponent is the slope of this curve.

For the rest of points with different number of walls separation, and varying distance, the distance from the transmitter to each point can be found using AutoCAD, depending on the coordinates of the transmitter. And by substituting the value of path loss exponent, we can develop the relationship between the number of walls and the penetration loss through walls, denoted L-walls, by using curve fitting with MATLAB or other software.

This analysis will be followed to develop two different models for both frequency bands, 2.4 GHz and 900 MHz frequency bands, since the expected loss due to inner walls, could be distinct somehow as the frequency of the signal is different.

The two models we are intending to develop will have the following formula:

$$L = 20\log_{10} f + 10n\log_{10} d + Lout + Lwalls - 28 \qquad \text{eq. (3.2)}$$

Lastly, we can deduce the variance between measured values and the values we obtain from the obtained models.

A mathematical correlation is to be made, for both models, that will help to develop models in other scenarios and different environmental conditions.

Chapter 4
Preliminary Measurements

4.1 Introduction

4.2 Measurements and analysis

4.3 Conclusion

4.1 Introduction

After the comprehension of the way of analyzing data to develop the wanted models, we were to take a sample of measurements for initial analysis. The initial analysis is for 900 MHz frequency band will give us an idea for the future work for the next semester.

4.2 Measurements and analysis

For a preliminary analysis, a sample of 39 measurements distributed in the fifth floor of the building B in PPU. For each point of 39, measurements were taken for the received power at the center frequency 944.784 MHz, by the use of HF60105 spectrum analyzer, and recorded in a log file on a laptop. From the log file for each point, about 150 readings was averaged to give us the average received power in each point.

Points are determined on an AutoCAD chart of the concerned floor, and after determining the coordinates of the Base station operating at a center frequency 944.784 MHz, we were able to find the transmitter receiver separation distance for each point.

The figure (4.1) shows AutoCAD chart with 70 points from which we chose a sample of 39 points.

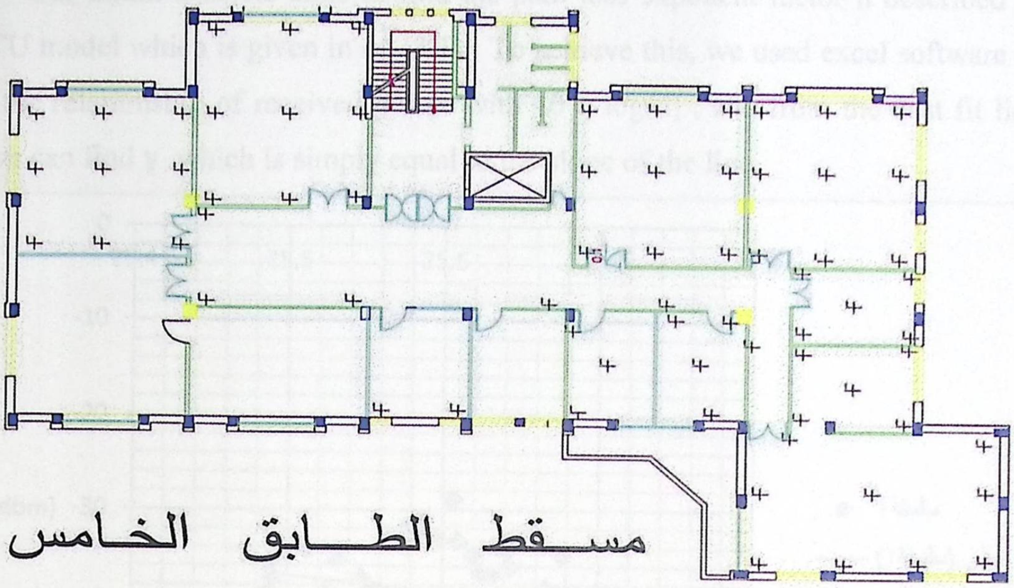


Figure 4 Building B- Fifth floor AutoCAD chart

Our initial analysis aims to find the path loss exponent factor n described in the ITU model which is given in eq (3.1) . To achieve this, we used excel software to draw the relationship of received power with 10 n log(d) , and from the best fit line tool we can find γ which is simply equal to the slope of the line.

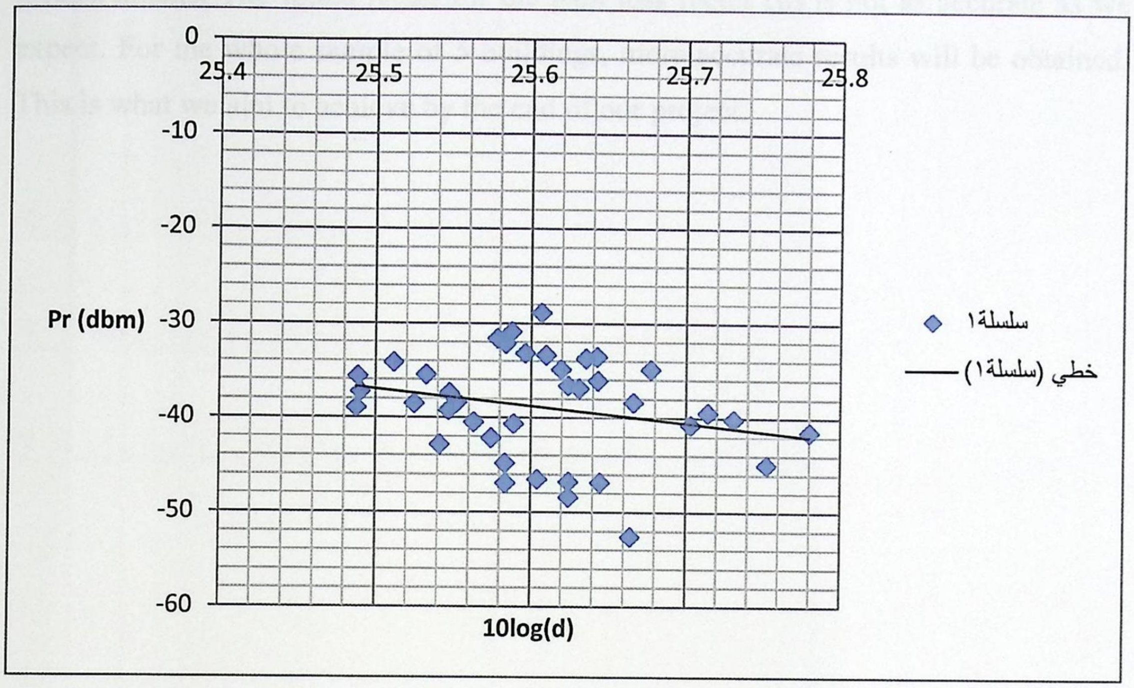


Figure 5 Power to 10logd scattering

Since the size of the chosen sample is not large enough, the obtained best fit line's slope was greater than expected.

Another method to find the exponent factor is done by calculation, based on the ITU model. The path loss exponent factor can be given by the following formula:

$n = (L - 20\log_{10} f + 28)/10\log_{10} d$ eq. (4.1)

We calculated n for each point, and then the average value was found to be equal to 2.124304829.

4.3 Conclusion

The analysis described previously was applied on a small sample of measurements. The found result for the path loss factor (n) is not as accurate as we expect. For the whole sample of 5 buildings, more accurate results will be obtained. This is what we aim to achieve by the end of our project.

Chapter 5
Measurements Collection

5.1 Introduction

5.2 Measurement Procedure at 900 MHz

5.3Measurement Procedure at 2.4 GHz

5.1 Introduction

As a continuation for the work that we started in the previous semester, we were to continue from the point we ended up with. In the previous chapter we presented a preliminary work with some measurements and we started to analyze the data we got in the fifth floor of building B, which is one of the sample of five buildings to be investigated.

In this chapter we will describe the procedure that we followed for collecting measurements in order to come up with the models we are intending to develop based on the analysis of these measurements.

The procedure of taking measurements is described for the two frequency bands in details in this chapter, and the results and analysis will be described and explained in the following chapters.

5.2 Measurement Procedure at 900 MHz:

- Buildings sample:
  1- B building: We have measured the received power values among five of its floors.
  2- B+ building: The received power was measured in four floors of the building.
  3- C building: we recorded the received power values in the first and second floors of this building.
  4- A building: we have measured the values of received power in three floors of this building.

We had to exclude Al-Ahli hospital building from the sample of buildings because a number of 900 MHz repeaters were deployed throughout the building.

A sample of one floor AutoCAD drawing for each building is attached to the report in appendix A.

- Locating the base station:

  For each building to be investigated, we had to choose the nearest cellular base station.

For buildings B and B+ we have chosen the base station located near to these buildings with the following parameters:-

1- The coordinates: latitude: 31°30'9.37"N, longitude: 35° 5'31.00"E
2- The transmitting power was 47 dBm
3- The frequency was 945 MHz

And for buildings A and C we chose the base station with the following parameters:

1- The coordinates: latitude: 31°30'33.06"N, longitude: 35° 5'29.46"E
2- The frequency was 947 MHz
3- The transmitting power was 57 dBm

- Technical Procedure:

  To measure the received power from the appropriate base station using the spectrum analyzer we followed the method described below:

  - Set up the spectrum analyzer with the appropriate parameters to start recording measurements.
  - The spectrum analyzer's parameters that we had to specify were the central frequency which was 945 MHz in buildings B and B+ case and 947 MHz in buildings C and A.

    Another important parameter was the frequency span that we chose to be 200 KHz which is the bandwidth of the channel in the GSM system.

  - In each point of measurement, we held the spectrum analyzer with an angle of 45 degrees to receive the maximum power and we directed it towards the base station. A sum of 150 readings were taken in 1 minute and saved to a log file, and the average of these readings was found.

- Outdoor Measurement:

  - Before taking measurements inside buildings, we had to determine the outdoor path loss exponent by taking measurements outside the buildings. This required going outside the university to record readings at certain distances from the base stations.

    Since the field nature wasn't favorable to take a large number of points, a few but sufficient points of measurement were taken on the top of some buildings around the university at different distances from the base stations near the four buildings (A, B, B+ and C).

    The results and analysis will be shown in the next chapter alongside the indoor measurement results and analysis.
  - In addition, for each building of the previously mentioned buildings, the signal strength was measured in several points on the outer side of the outer walls and on the opposite side from the inner side to determine the average penetration loss in these walls.

- Indoor Measurement:

  After the completion of the previous steps, we started taking measurements inside buildings, where the number of points in each floor was about ^0 to 100 points, except in few floors where the access to some offices and room was not available.

  The results and analysis for the sample of four buildings will be explained in the next chapter.

5.3Measurement Procedure at 2.4 GHz:

- Sample of buildings:
  1- B building: Because of the low location that we deployed the transmitter, power measurements couldn't be taken in the same floors of 900 MHz work, so we have measured the values of received power among four floors of the building.
  2- C building: For this building, the same two floors of 900 MHz measurements.
  3- A building: Three floors of this building are tested, and power measurements were taken across those floors.
  4- Al-Ahli building: power readings were measured in the three floors of the building.

  B+ building was excluded from the sample of buildings since we couldn't find a suitable and near location to deploy the transmitter.

- Technical Procedure:
  - The "Bullet M" wireless radio, which is the transmitter at 2.4 GHz frequency band, was programmed with the suitable parameters to work with before being mounted on the ASA-2416 antenna.
  - The wireless radio parameters that we had to specify are the followings:
    1- The channel among the fourteen 802.11 channels, and we chose channel 8
    2- The transmitting power which was set to maximum value of 20 dBm
  - The base station consisted of the wireless radio and the antenna was mounted at a near distance from each building, and at a suitable height to cover most of floors in each building. In some cases, tilting was necessary to cover higher floors.

- Indoor Measurement:
    - Since it was impossible to use the spectrum analyzer for measurement at 2.4 GHz, we used laptops to receive the Wi-Fi signal, and with the Vistumbler software we recorded the received power in log files.
    - We took measurements in the same points appointed for measurement at 900 MHz
    - In each point of measurement, a sum of 150 readings was taken and averaged.

The results and analysis for 2.4GHz measurement will be described in chapter 7

Chapter 6
GSM 900 MHz Results and Analysis

6.1 Introduction

6.2 Outdoor Measurement

6.3 Outer Wall Penetration Loss

6.4 Indoor Propagation

6.5 Multiwall Model

6.6 SRAB Model

6.7 Conclusion

6.1 Introduction:

In the previous chapter, we described the procedure of taking measurements at 900 MHz frequency band in the sample of five buildings. By following this procedure, we collected the necessary data outdoor and indoor in four buildings which are the PPU buildings (A,B,B+ and C) where it was quite impossible to measure in Al-Ahli hospital at 900 MHz, since there were a large number of repeaters distributed inside the building, so this building was excluded from measurement.

Now we are going to introduce the results and analysis for 900 MHz frequency band, and later we will finalize with the intended models for this band, which are the multiwall penetration loss model and the indoor propagation model.

6.2 Outdoor Measurement:

As a first step, we started collecting outdoor measurements around the investigated buildings. This was necessary to determine the outdoor path loss exponent (n) in the surrounding environment for each building. The calculation of the outdoor path loss exponent was needed for further analysis for the indoor analysis. We had two outdoor scenarios, buildings B and B+ scenario and buildings A and C scenario. This was because each two buildings in each scenario had a common base station and were in the same direction of the corresponding base station.

1. Buildings B and B+:

The following scatter plot clarifies the measurements taken for buildings B and B+. A number of measurements were taken at different distances from the base station, and we plotted the received power in dBm versus 10log (d) where d is the distance from the base station to the receiver in meters. The slope of the best fit linear line presents the value of the path loss exponent of the ITU model

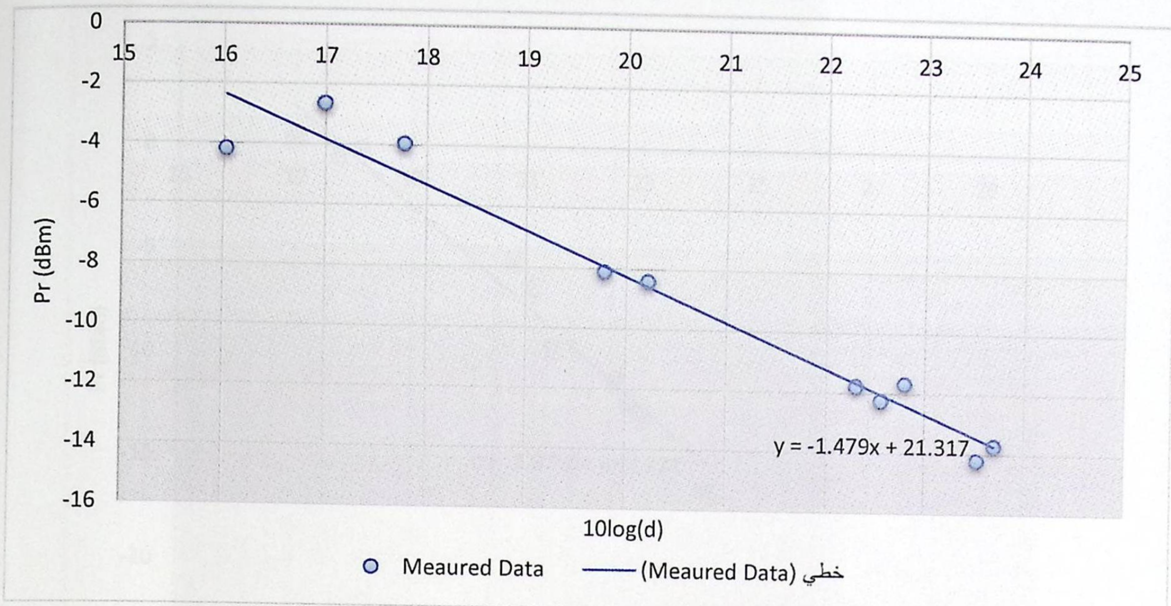


Figure 6: Outdoor measurements scatter for B and B+ buildings

From this figure, we can note that the slope of the linear best fit is about 1.5, which is the value of the path loss exponent. However, it's known that the free space path loss exponent equals two.

We can conclude that this decrease of the path loss exponent value below that one of the free space was due to some tunneling effect caused by the surrounding buildings which form some kind of corridor in which those two buildings are located.

This led us to investigate the path loss exponent in another path far away from these two buildings. The results were different, and the value of n increased significantly. The scatter below shows the measurements obtained for the second path, and shows the value of n which increased from 1.479 to 2.376.

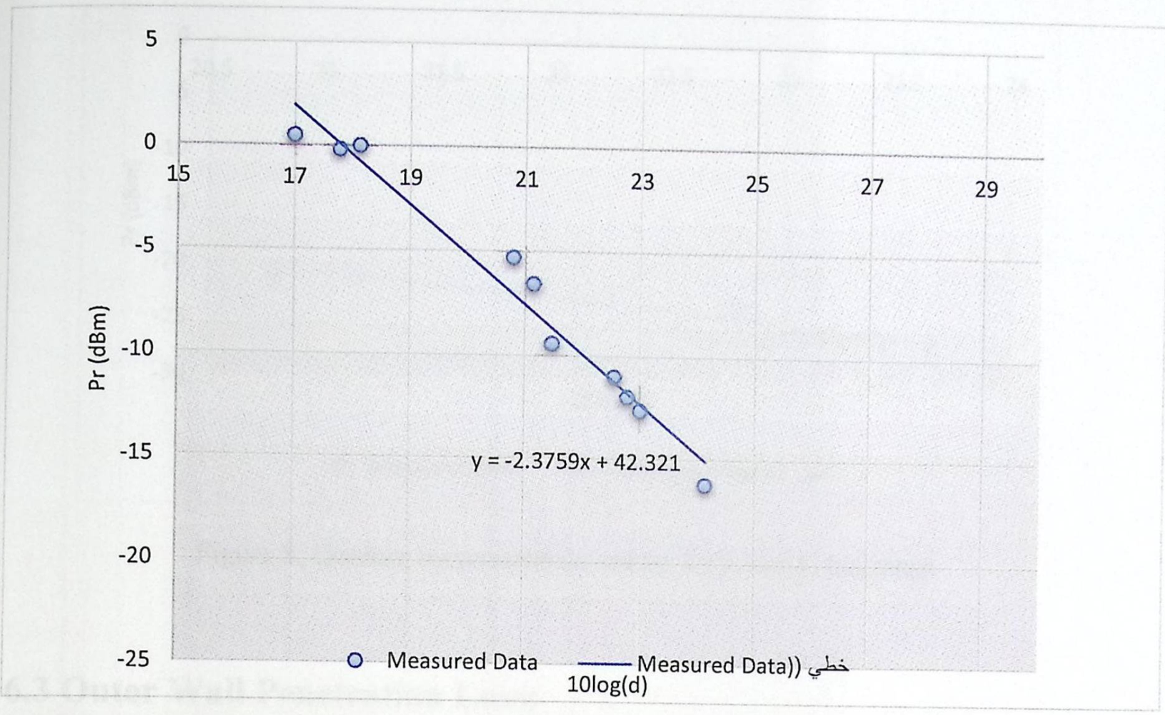


Figure 7: Outdoor measurements scatter for B and B+ buildings at the main beam path

For the indoor analysis in buildings B and B+, we were to use the calculated outdoor path loss exponent with the value of about 1.5, since we were concerned in the path in which these two buildings are located.

2. Buildings A and C:

Similarly to the work done for buildings B and B+, a set of measurements were taken for buildings A and C. The case here were distinct, where we got a value of n near to the known value for free space. The scatter plot below shows the measurements taken at different distances to acquire the needed results.

The slope of the best fit line equals 1.98 which is the corresponding value of the path loss exponent for the outdoor environment around A and C buildings.

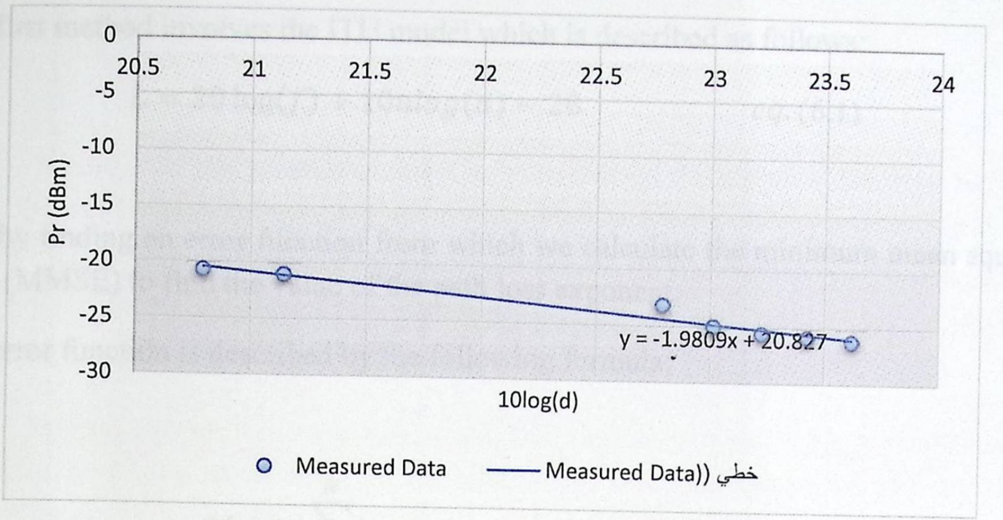


Figure 8: Outdoor measurements scatter for A and C buildings

6.3 Outer Wall Penetration Loss:

Before starting the indoor analysis, another important issue in which we were concerned was the penetration loss of the outer walls of all buildings. The procedure involved taking measurements on both sides of the outer wall of each building and calculating the average penetration loss to be used in the development of the multiwall penetration model at 900 MHz frequency band.

The average penetration loss of the outer wall for each building is shown in the following table:

Table 3 Outer wall penetration loss results

Building	Outer Wall Penetration Loss(dB)
A	12.37
B	11.88
B+	12.20
C	12.14

6.4 Indoor Propagation:

In this section, we are going to describe the indoor analysis done for the sample of four buildings. The analysis described in this section includes the calculation of the indoor path loss exponent by two different methods. The overall scatter plots for each building were attached in appendix e.

The first method involves the ITU model which is described as follows:

$$L = 20\log(f) + 10n\log(d) - 28 \qquad eq.(6.1)$$

and by finding an error function from which we calculate the minimum mean square error (MMSE) to find the value of the path loss exponent.

The error function is described by the following formula:

$$F(n) = \sum_{i=1}^{N} (L_{i(model)} - L_{i(measured)})^2 \qquad eq.(6.2)$$

Where:

$L_{i(model)}$ is the path loss in dB calculated from the ITU model

$L_{i(measured)}$ is the measured path loss in dB

N is the number of measurement points in each floor

When applying the ITU model to find $L_{i(model)}$,the path loss exponent n is unknown and needed to be found, but all other parameters are known. Whereas the measured path loss is calculated simply by subtracting the measured received power at a given point from the transmitted power of the corresponding BTS.

The second method of finding the indoor path loss exponent n is to plot a scatter of the received power at the measurement points versus 10log (d_0), where d_0 in the scattered plots is a reduced distance of the whole distance separation between the transmitter and receiver. This reduction of distance was taken in consideration since the behavior of the electromagnetic signal can't be considered stable in the near field. The reduction in distance was done in such a way to get the value of the slope of the mean line near to the value of the path loss exponent n derived by the MMSE method described earlier. This reduction of distance is considering an equivalent source to the original source with a new distance and new transmitting power. To verify this analysis, we calculated the received power (P_r(scatter)) from the equation of the best fit line of the scatter. Then we calculated the new transmitting power at the reduced distance d_0 as follows:

$$P_t = P_r(scatter) + 20\log(f) + 10n log(d_0) - 28 \quad \text{eq. (6.3)}$$

Where n in the above equation is the value of the slope of the best fit line. From the new transmitting power we could calculate the received power by applying the ITU model but with substituting d_0 instead of the whole distance. Then we plotted the calculated values for the ITU at the whole set of points side to side with the scatter of measured received power.

By this method we were able to calculate the indoor path loss exponent in all buildings, and now, let us describe and discuss the results obtained for each building separately.

1- Building B:

In this building, we measured the received power in five floors. For each floor we plotted the received power measured in dBm versus 10log (d_0). Here in this building, d_0 represents the distance to the equivalent source located at about 10 meters out of the building. The new calculated equivalent transmitting power was about 25 dBm.

The scatters of all floors are shown below, and from each scatter we found the equation that describes the received power and the slope of the best fit line that represents the measured indoor path loss exponent.

The following figure represents the scatter of readings measured in the first floor. We can note that the value of the slope of the linear line is about 2.36 which corresponds to the value of n in this floor.

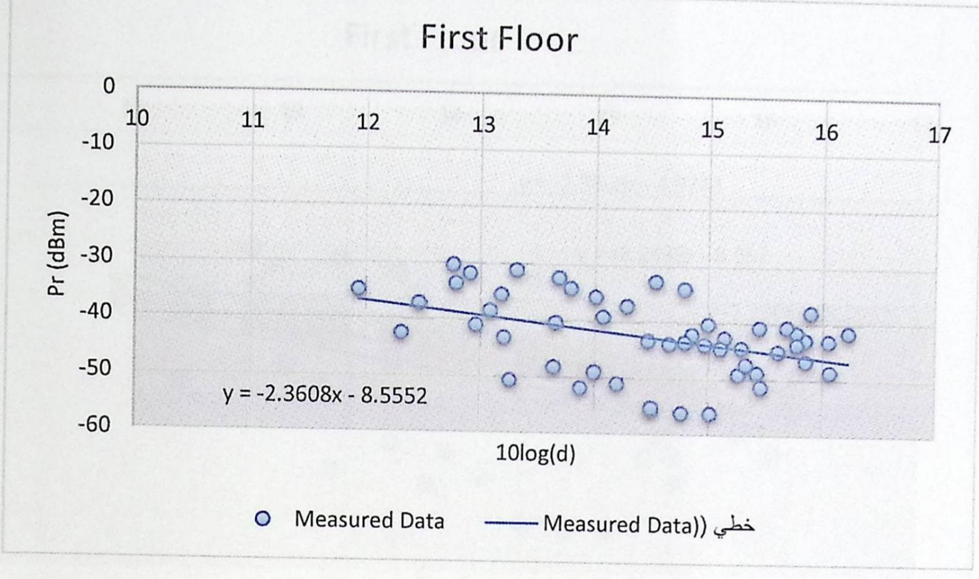


Figure 9: Scatter plot for the first floor of B building

The received power can be calculated through the linear equation shown on the figure, and which is described as:

$$P_r = -2.3608 * 10\log(d_0) - 8.5552 \qquad eq.(6.4)$$

When calculating the path loss exponent using MMSE method, we found that n=2.23.

The following figure shows the plots for both the measured data with the best fit line, and the ITU model when substituting the corresponding d_0 and the equivalent transmitted power:

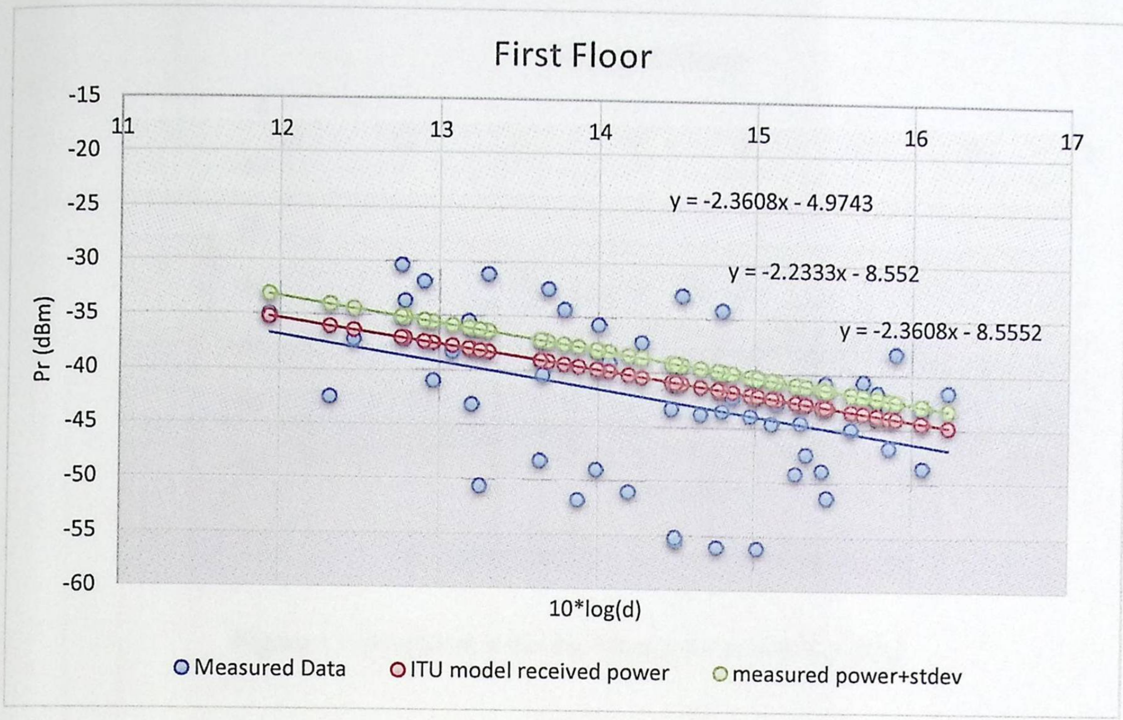


Figure 10: ITU and measured data plot at 900 MHz

The similar plots for all floors for the whole sample of building are attached in appendix B.

The same procedure was repeated for the rest of floors in this building, and the results are shown in the following figures, and the calculated values of n by the MMSE method are mentioned in the end of this section in table 6.2

Figure 11 shows the scatter plot for measurements of the 2^{nd} floor.

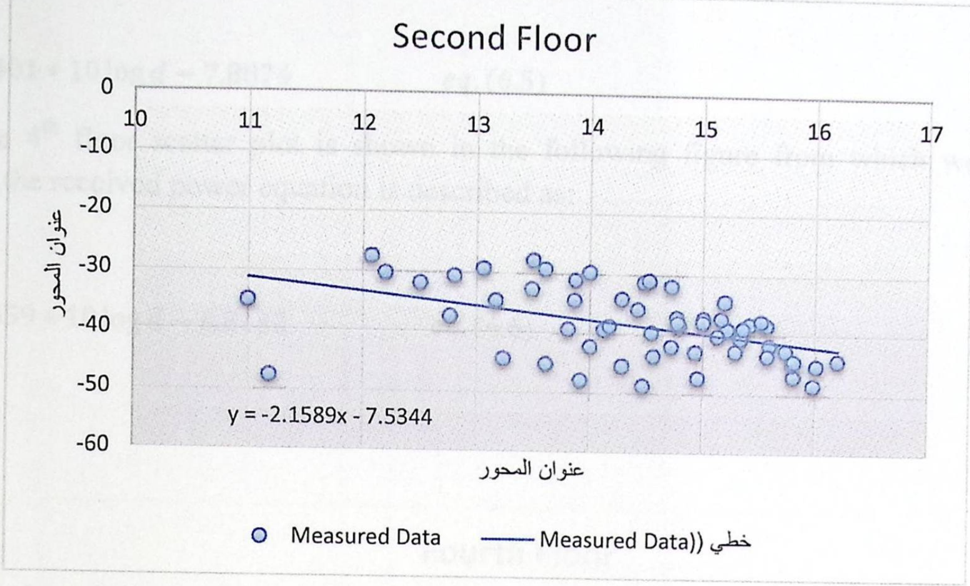


Figure 11: Scatter plot for the second floor of B building

For this floor the linear best fit equation is described as follows:

$$P_r = -2.1589 * 10 \log d - 7.5344 \qquad eq. 6.4$$

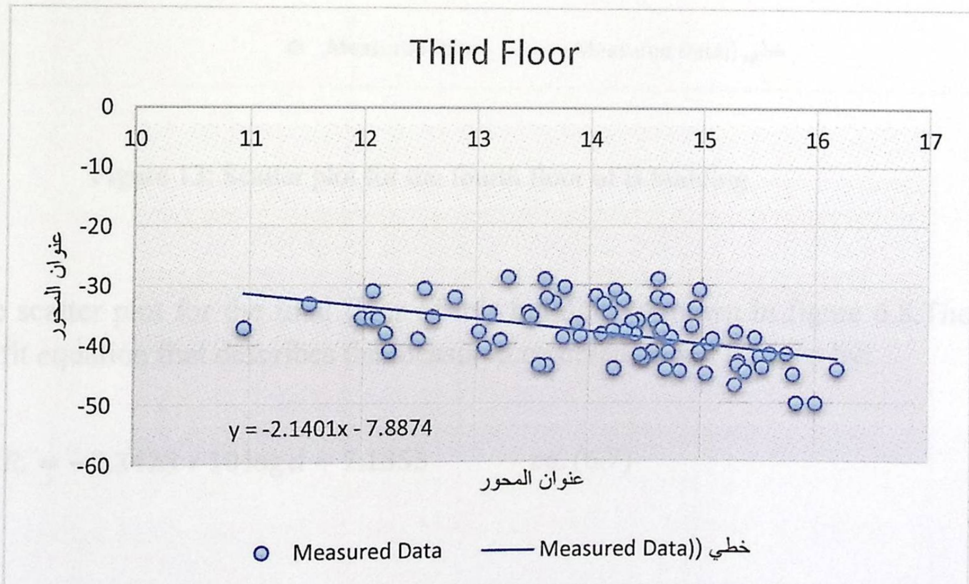


Figure 12: Scatter plot for the third floor of B building

The above figure shows the scattering of measurements taken in the 3rd floor, where the received power could be found through the following equation:

$$P_r = -2.1401 * 10\log d - 7.8874 \qquad eq.(6.5)$$

The 4th floor scatter plot is shown in the following figure from which we found that the received power equation is described as:

$$P_r = -2.2659 * 10\log d - 6.8132 \qquad eq.(6.6)$$

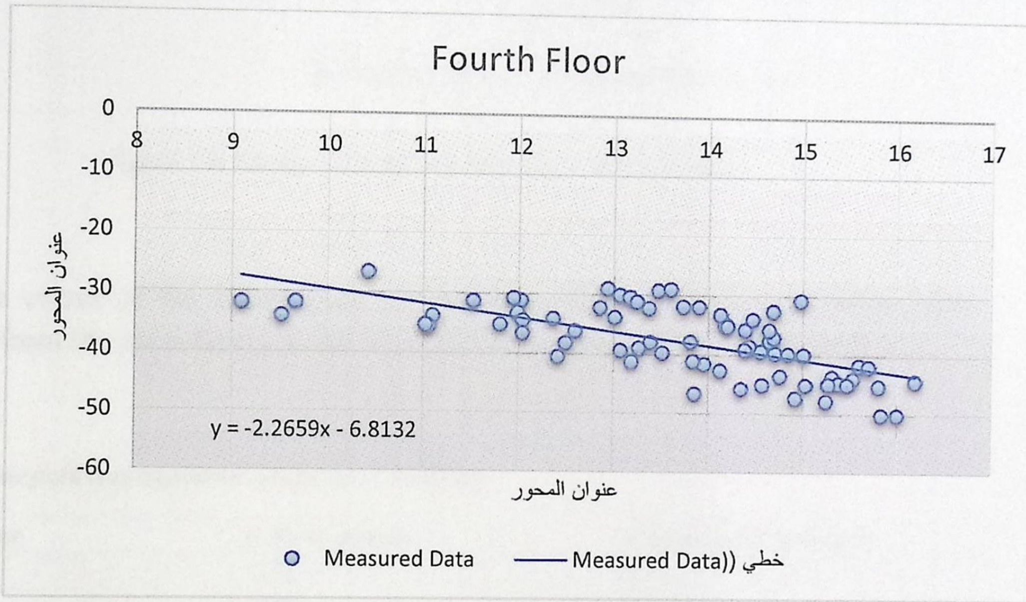


Figure 13: Scatter plot for the fourth floor of B building

The scatter plot for the final floor of this building is shown in figure 6.8.The linear best fit equation that describes the measured received power is given by:

$$P_r = -2.3423 * 10\log d - 7.1355 \qquad eq.(6.7)$$

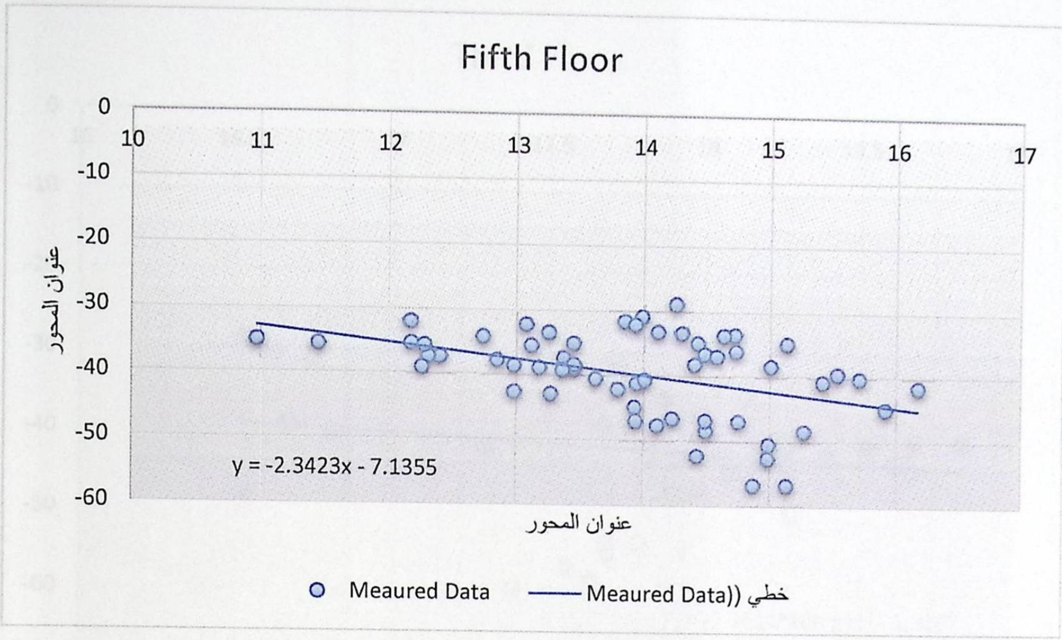


Figure 14: Scatter plot for the fifth floor of B building

The values of the indoor path loss exponent for each floor and which were calculated from the error function and from the scatter plots are shown in table 6.2 .

Table 4 Indoor path loss exponent results for B building

Floor number	n from scatter	n from error function
1	2.36	2.23
2	2.16	2.14
3	2.14	2.1
4	2.27	2.08
5	2.34	2.12
Average n	**2.254**	**2.134**

2- Building B+:

In this building we measured the received power in four different floors which are the 3rd,4th,5th and 6th floor. The transmitter in this case is the same for building B which is Wataniya BTS operating at 945 MHz and with a transmitting power of 47 dBm.

The scatter plots for all floors are shown below, and the values computed from the error functions are listed in table 6.3.

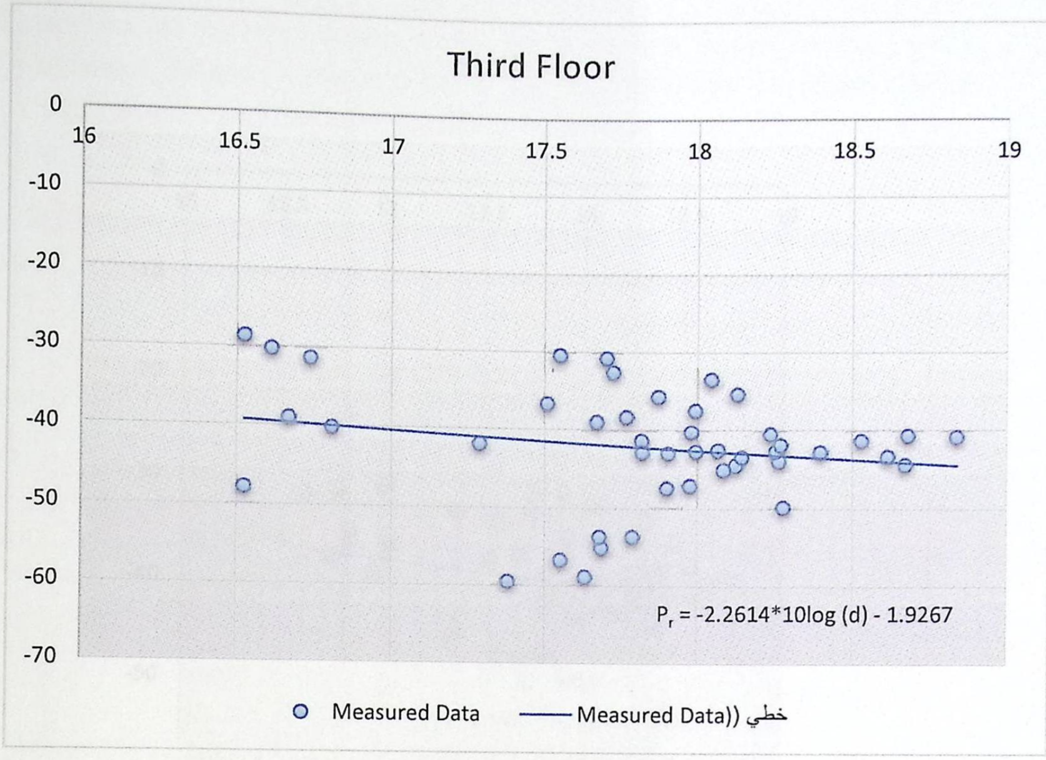


Figure 15: Scatter plot for the third floor of B+ building

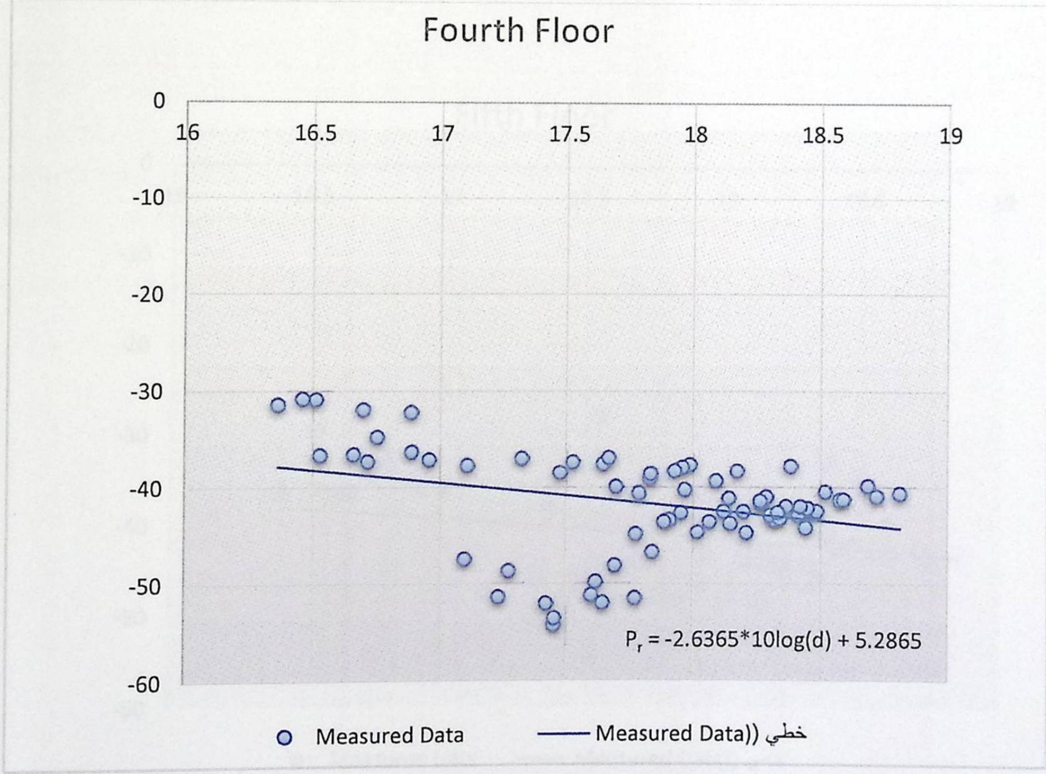


Figure 16: Scatter plot for the fourth floor of B+ building

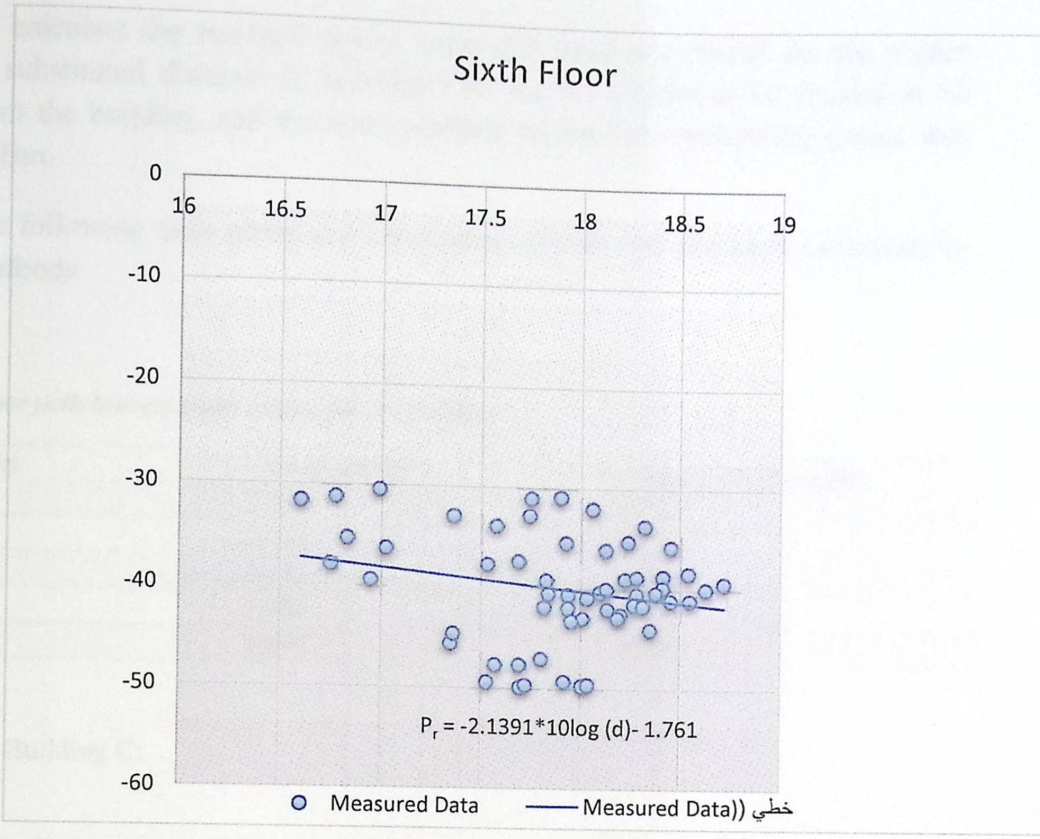


Figure 17: Scatter plot for the sixth floor of B+ building

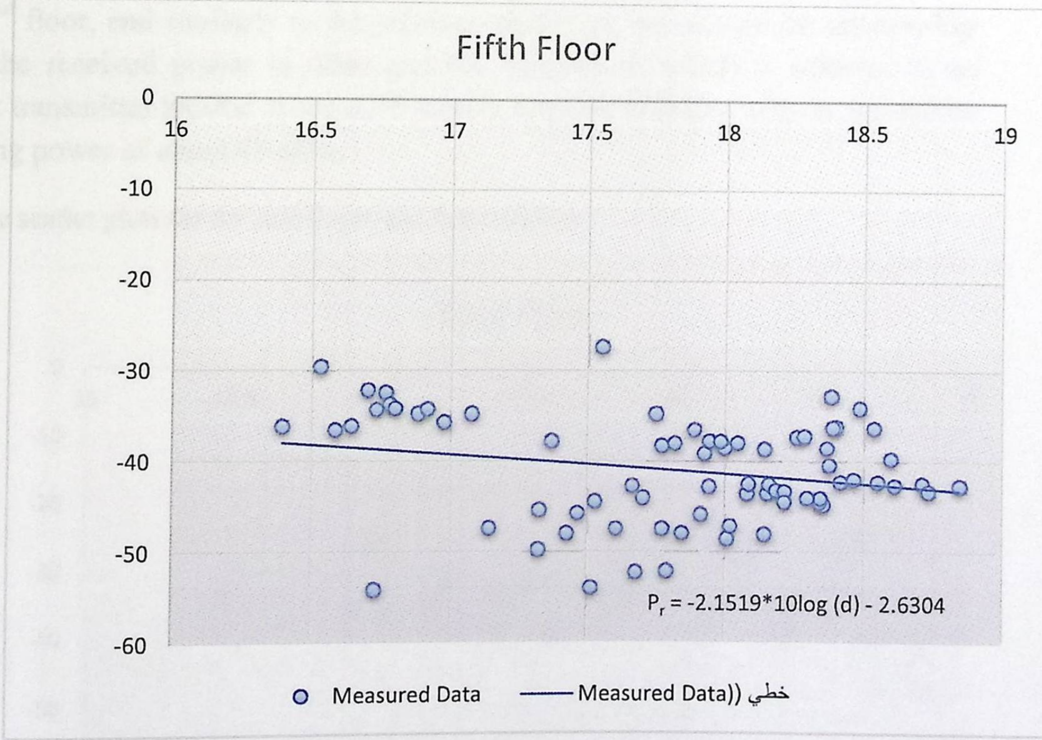


Figure 18: Scatter plot for the fifth floor of B+ building

To calculate the received power using the equations shown on the scatter plots, the substituted distance d_0 is referred to the transmitter to be located at 50 meters from the building, and the corresponding equivalent transmitting power was about 28 dBm.

The following table summarizes the values of path loss exponent calculated by the two methods

Table 5 Indoor path loss exponent results for B+ building

Floor number	n from scatter	n from error function
3	2.261	2.231
4	2.266	2.209
5	2.152	2.182
6	2.139	2.145
Average n	**2.297**	**2.192**

3- Building C:

In Building C, we have measured the received power of the second base station located near to buildings A and C, which operates at 947 MHz and the transmitting power was 57 dBm. The measurement included two floors; the 1st floor and the 2nd floor, and similarly to the previous buildings, we plotted the relationship between the received power in dBm and the distance d_0 which is referred to an equivalent transmitter located at about 45 meters from the building with an equivalent transmitting power of about 43 dBm.

The scatter plots for the two floors are shown below:

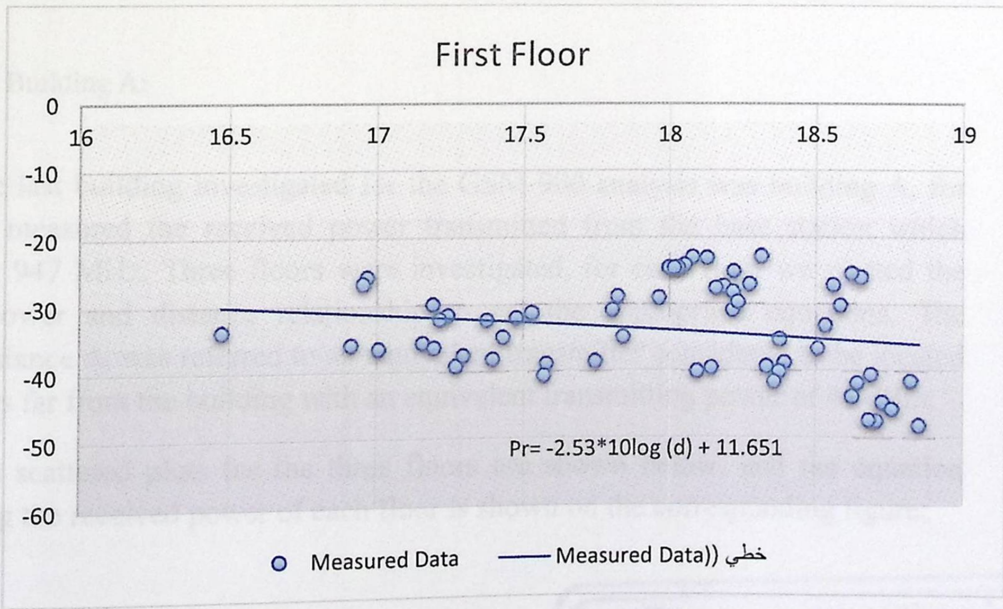


Figure 19: Scatter plot for the first floor of C building

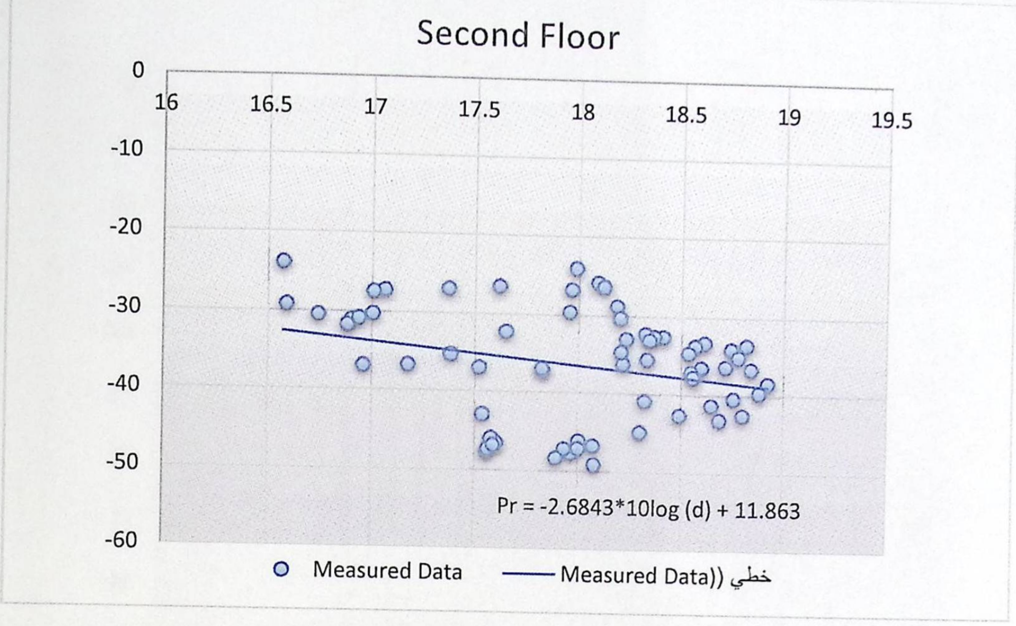


Figure 20: Scatter plot for the second floor of C building

In the following table, the values of the path loss exponent from both methods are shown:

Table 6 Indoor path loss exponent results for C building

Floor number	n from scatter	n from error function (ITU)
1	2.684	2.646
2	2.53	2.536
Average n	**2.607**	**2.591**

4- Building A:

The last building investigated for the GSM 900 analysis was building A, for which we measured the received power transmitted from the base station which operates at 947 MHz. Three floors were investigated, for each floor we plotted the received power and distance relationship to get the appropriate equations. The reduced distance d_0 was referred to an equivalent transmitter considered to be located at 25 meters far from the building with an equivalent transmitting power of 44 dBm.

The scattered plots for the three floors are shown below, and the equation representing the received power of each floor is shown on the corresponding figure:

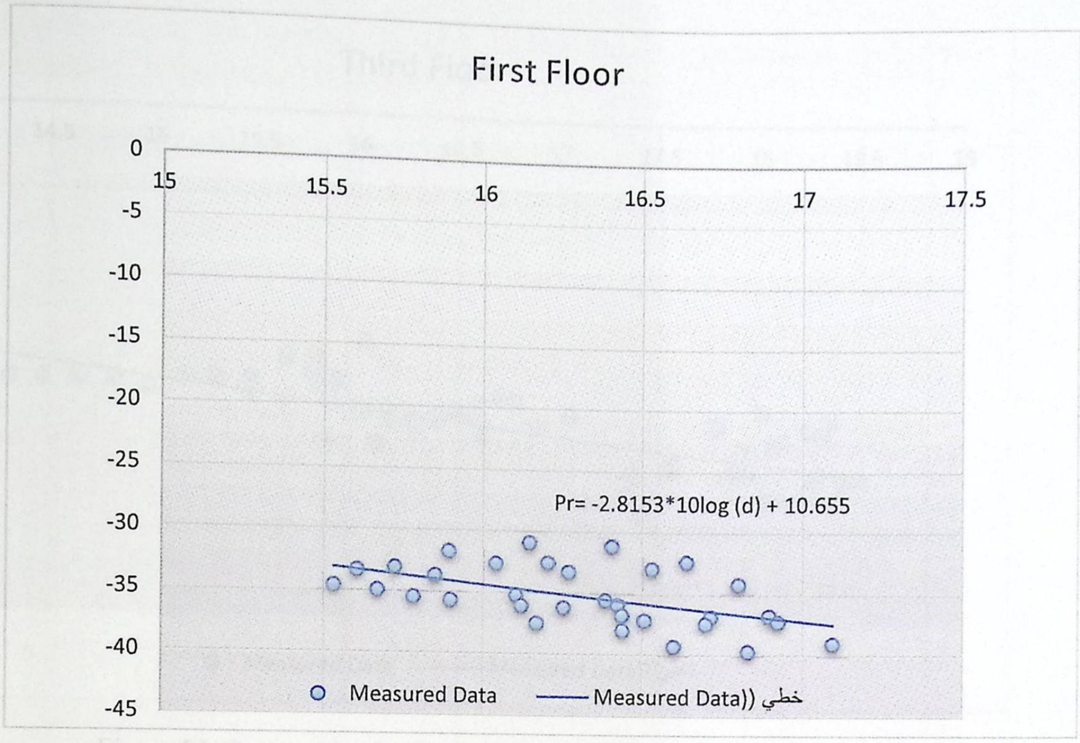


Figure 21: Scatter plot for the first floor of A building

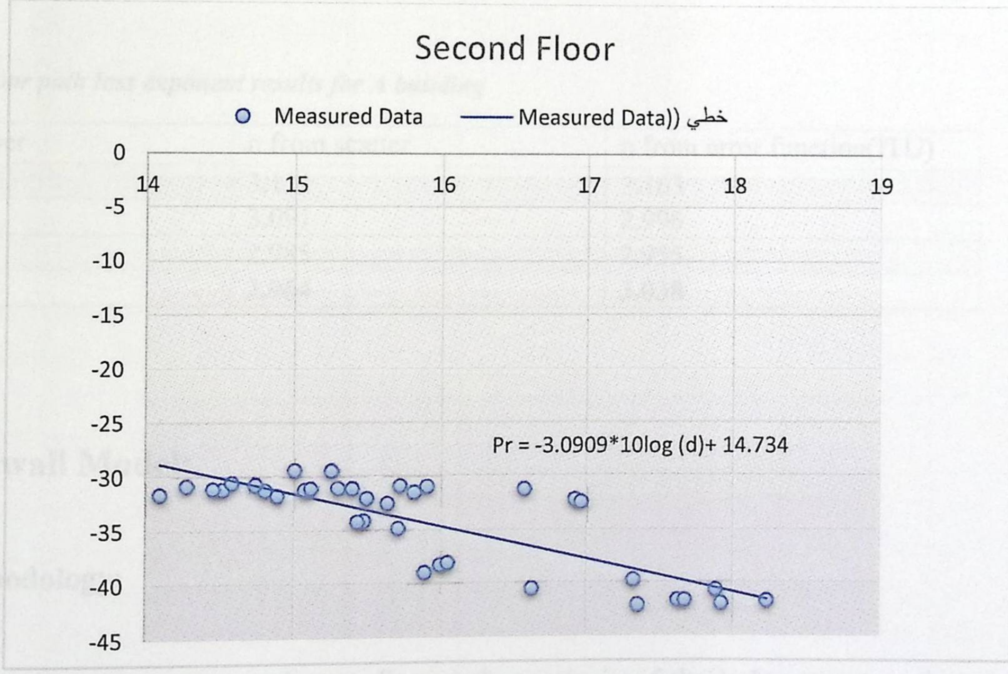


Figure 22: Scatter plot for the second floor of A building

The path loss exponent derived from the error function of the ITU is listed below besides the values of the slopes for the scattered plots:

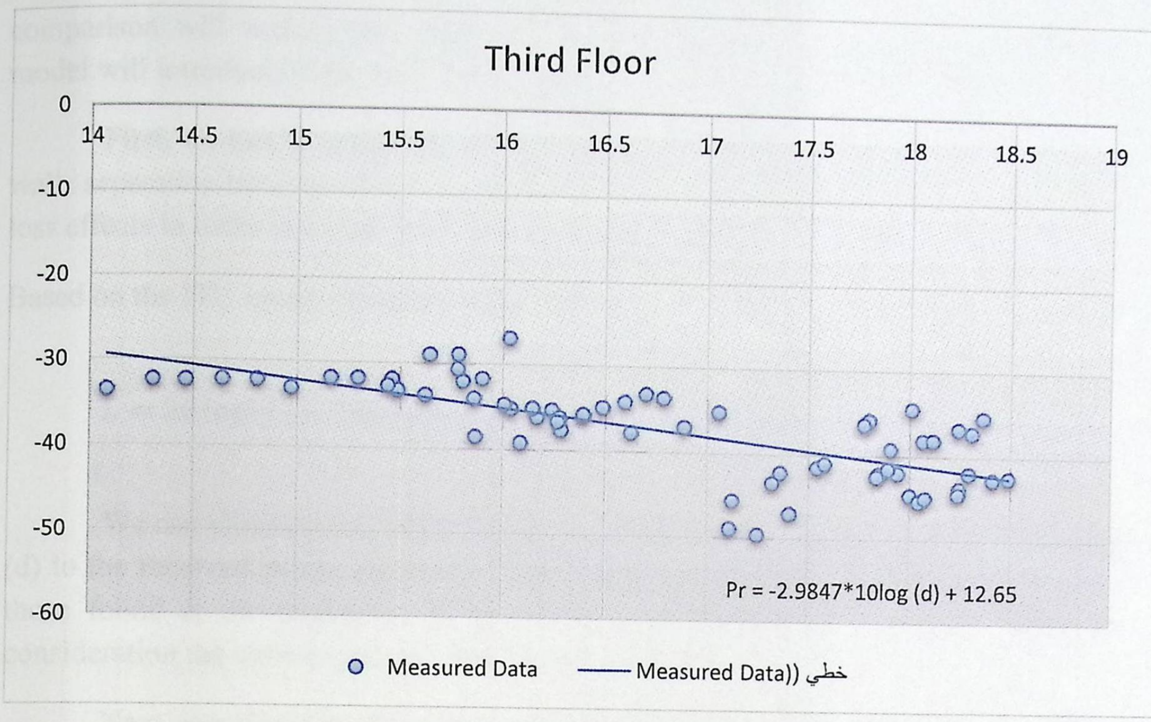


Figure 23: Scatter plot for the third floor of A building

Table 7 Indoor path loss exponent results for A building

Floor number	n from scatter	n from error function(ITU)
1	3.111	3.163
2	3.091	2.996
3	2.985	2.955
Average n	**2.964**	**3.038**

6.5Multiwall Model:

6.5.1 Methodology:

In this section we are going to discuss the analysis of the indoor propagation from another perspective, where we would like to evaluate the effect of the inner walls to come out with a multiwall penetration model that describes the penetration loss in respect to the number of walls separation between the transmitter and receiver. After developing the intended model which will be an extension of the ITU model, we will compare the developed model with the basic ITU model for which we discussed and derived the path loss exponent for all buildings in the previous section. The comparison will include the degree of improvement that the penetrated multiwall model will introduce to the basic ITU model.

First, we had to categorize all measurement points according to the number of walls separation between transmitter and receiver. Then, we had to eliminate all other loss effects in order to isolate the effect of internal walls.

Based on the ITU model described as bellow:

$$L = 20\log(f) + 10nlog(d) - 28 \qquad eq.(6.8)$$

We can eliminate the effect of free space loss by subtracting the term $10n_{out}\log(d)$ to the received power measured by the spectrum analyzer. The values of n_{out} are those found at the beginning of this chapter for outdoor environment, taking in consideration the corresponding value to each building.

Next, we eliminate the effect of frequency (20log (f)) and finally by adding 28, then the residual loss represents the indoor loss which is a composition of inner walls penetration loss and environmental loss. The environmental loss is consequent of the indoor environment that affects the signal in a way that is more severe and harsh than the outdoor environment. This indoor loss depends on the building structure, layout, partition, etc.

To separate the multiwall penetration loss from the environmental loss, we were to calculate the loss at points on which there were no inner walls separation. Since these points are not separated from the transmitter by any inner wall, then the inner walls penetration loss equals zero, and the residual loss after eliminating all other losses represents the indoor environmental effect. For the rest of points which were categorized depending on the number of inner walls standing between the transmitter and receiver, we had to subtract the environmental effect to come out with the multiwall penetration loss.

When coming out with the multiwall model penetration loss, we can process the data in a backward way by eliminating the effect of internal walls and to calculate a new path loss exponent other than n_{out} used in the previous analysis. The calculation of the new path loss exponent, called n_0, will introduce an improvement for the developed model since it represents the environmental effect separated from the walls effect. A set of samples of measurements taken in all buildings is attached in appendix C.

6.5.2 Multiwall Penetration Loss Results:

By following the previously discussed methodology, we obtained results from the investigated buildings. These results will be introduced for each building separately before showing the overall average multiwall penetration loss at 900 MHz

1- Building B:

The results of this building are shown in the table below, where we calculated the average multiwall penetration for each number of walls in five floors.

Table 8 walls penetration loss results for B building

Floor/walls	1 wall	2 walls	3 walls	4 walls	5 walls
1	3.07945676	7.987584	12.91618	18.08025	-
2	4.706525872	9.322028	12.49919	-	-
3	3.177220261	8.373357	15.00554	-	-
4	5.409357288	9.945564	17.81963	21.68638	-
5	4.516888366	11.76772	16.08996	20.28964	-
Avg. Loss(dB)	**4.452497947**	**9.852168**	**15.35358**	**20.01876**	-

2- Building B+:

The analysis of the measurement of this building led to the results shown in the table below. The average multiwall penetration loss was calculated for a number of walls up to five walls which occurred in the third floor of this building.

Table 9 walls penetration loss results for B+ building

Floor/walls	1 wall	2 walls	3 walls	4 walls	5 walls
3	4.713532	8.456675	13.68331	19.64394	24.06015
4	4.748507	8.40895	14.99771	18.17018	-
5	4.330898	9.026231	13.7778	18.93105	
6	4.795452	9.532927	14.46532	-	
Avg. Loss(dB)	**4.647097**	**8.856196**	**14.23104**	**18.91506**	**24.06015**

3- Building C:

For building C, the analysis involved two floors with a maximum wall separation of four walls in the second floor. Multiwall penetration loss was calculated for each floor and averaged as follows:

Table 10 walls penetration loss results for C building

Floor/walls	1 wall	2 walls	3 walls	4 walls	5 walls
1	5.839088	8.819164	15.28548	-	-
2	5.248818	7.22852	13.81936	18.30929	-
Avg. Loss(dB)	**5.543953**	**8.023842**	**14.55242**	**18.30929**	-

4- Building A:

The last building of the sample of investigation at the 900 MHz frequency band. Three walls were investigated and a maximum number of six walls was found in the first floor. The values for each floor and the average values are shown in the following table:

Table 11 walls penetration loss results for A building

Floor/walls	1 wall	2 walls	3 walls	4 walls	5 walls	6 walls
First floor	4.927102	8.264867	15.52634	19.48623	24.71808	32.50626
2nd floor	4.337263	10.78858	14.67766	18.49949	-	-
3rd floor	5.166541	9.94243	14.82801	19.18514	-	-
Avg. Loss(dB)	**4.810302**	**9.665294**	**15.01067**	**19.05695**	**24.71808**	**32.50626**

5- Average penetration loss for inner walls for the whole sample of buildings:

After calculating the multiwall penetration loss in each building and for each floor, and averaging the results for each building, we could find the overall average for the penetration loss through internal walls. The overall average for a number of walls going up to six walls is shown in table 12

Table 12 Average penetration loss for inner walls for all buildings

Number of walls	1 wall	2 walls	3 walls	4 walls	5 walls	6 walls
Average of Avgs. (dB)	**4.863462**	**9.099375**	**14.78693**	**19.07501**	**24.38912**	**32.50626**

After averaging the multiwall penetration loss, we calculated the variance about the average curve for each number of walls, and the results are shown in table 13

Table 13 variance about the average curve for each number of walls

Number of walls	**1 wall**	**2 walls**	**3 walls**	**4 walls**	**5 walls**	**6 walls**
Variance(dB)	**0.2272**	**0.700956**	**0.245055**	**0.500967**	**0.216433**	**-**

It is noticed that the maximum variance about the average curve occurs at a number of walls separation of two walls, whereas the minimum variance occurs at one wall. For the case of six walls we didn't calculate any variance since this value is obtained by averaging the penetration loss in one floor.

Moreover, for a given number of walls, we calculated the maximum difference between the overall average penetration loss and the obtained averages in different buildings, and we are showing the results in the table below:

Table 14 The values of maximum difference b/w average ang buildings results

Number of walls	**1 wall**	**2 walls**	**3 walls**	**4 walls**	**5 walls**	**6 walls**
Difference (dB)	**0.68049**	**1.07553**	**0.56665**	**0.94374**	**0.32896**	**-**

The table above shows the maximum differences calculated around the average curve, where the maximum differences at one wall and two walls were found in building C, at three and four walls in building B, whereas the difference at five walls is the same in both buildings A and B+ because the average at five walls was found only for those two buildings.

These results show that the measured values are within the measuring error of the spectrum analyzer which is about 1 dB.

The following figure shows the plots of the relationship between the number of walls and the loss due to the walls penetration for each building, in addition to the curve of the average penetration loss due to internal walls:

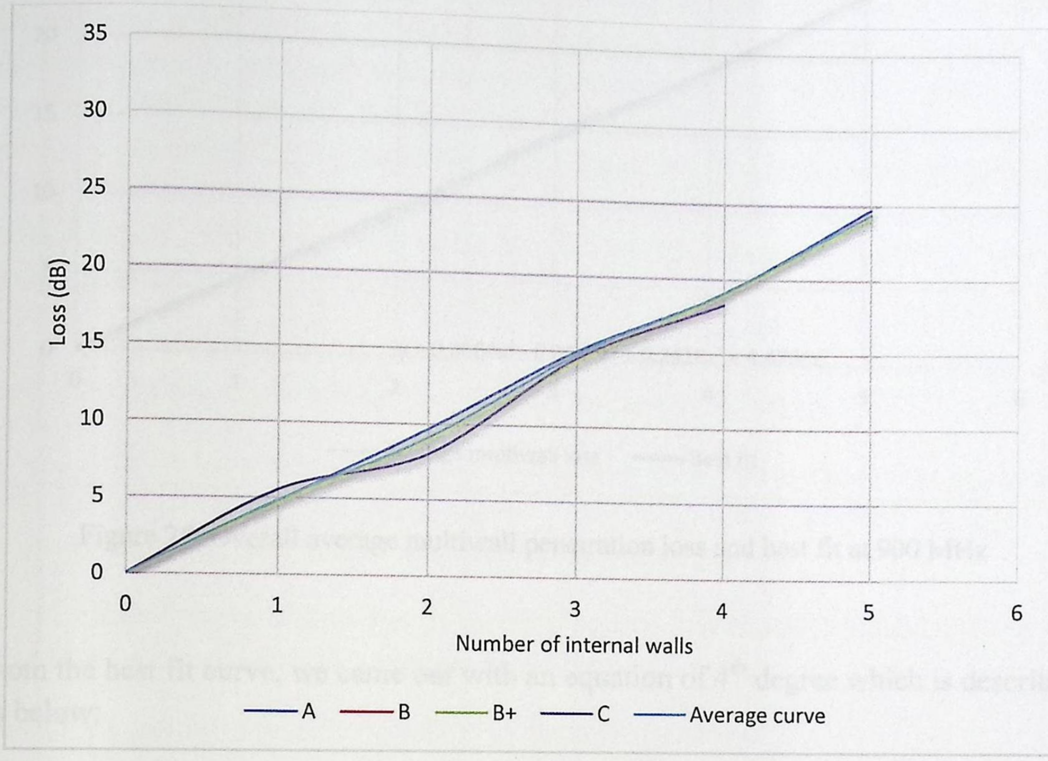


Figure 24: Average multiwall penetration loss for all buildings at 900 MHz

Now with these results of small variances, which confirms the similarity between the results obtained from the whole sample of buildings, we could find the best fit curve which gives us the equation that relates the multiwall penetration loss to the number of walls. However, since the value of penetration loss at six walls is deduced from few number of points and only in the first floor in building A, we ignored this value in the calculation of the multiwall penetration loss model, so it was more convenient to develop the model with a maximum number of 5 walls.

The average curve and the corresponding best fit curve are shown in the following figure:

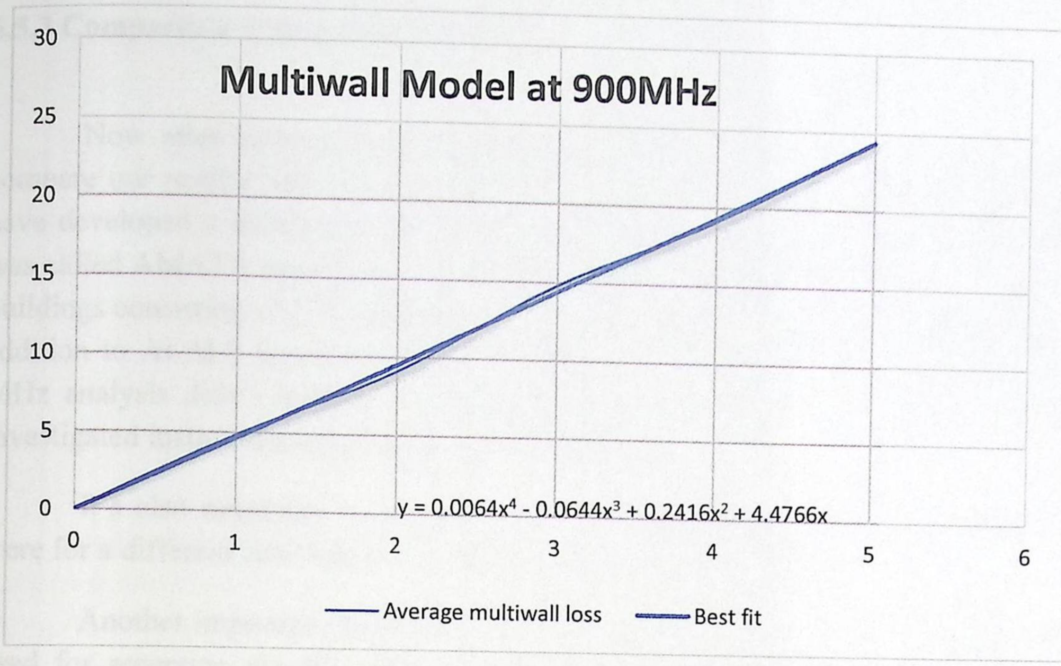


Figure 25: Overall average multiwall penetration loss and best fit at 900 MHz

From the best fit curve, we came out with an equation of 4th degree which is described as below:

$$L_{walls} = 0.0064x^4 - 0.0644x^3 + 0.2416x^2 + 4.4766x \qquad eq.(6.9)$$

where x is the number of inner walls.

Now, the total path loss can be described by the following formula:

$$L_{total} = 20\log(f) + 10n log(d) + L_{out} + L_{walls} - 28 \qquad \text{eq. (6.10)}$$

Where:

L_{total}: Total path loss in dB

f: Frequency in MHz

n: Path loss exponent

d: Distance in meters

L_{out}: Outer wall penetration loss in dB

L_{walls}: Multiwall penetration loss in dB

6.5.3 Comparison with previous studies:

Now after developing the multiwall model at 900 MHz, we would like to compare our results with a previously developed model by a group of students who have developed a multiwall model at the same frequency band. Their model, which was called AMATA model, was developed after taking measurements in a sample of buildings consisting of PPU buildings which are A, B and Abu Rumman buildings, in addition to Al-Ahli hospital building. Whereas our sample of buildings for the 900 MHz analysis didn't include Al-Ahli hospital or Abu Rumman buildings, and we investigated instead the buildings B+ and C in PPU.

It's also necessary to mention that their measurements taken in building A were for a different base station than the one we have dealt with.

Another important difference between their work and ours, was the equipment used for reception the 900 MHz signal. While we used a spectrum analyzer for measurement, they used TEMs measurement tool from Jawwal.

Despite these differences in developing our model and AMATA model, we have made a comparison for a number of walls up to 5 walls.

AMATA multiwall model is described by the formula below:

$$X\alpha\,(dB) = 0.0075\,K4 - 0.18\,K3 + 1.1\,K2 + 2.9\,K \qquad eq.(6.11)$$

Where K is the number of walls

This model is compared with our multiwall model derived in the previous section and described by the following formula:

$$L_{walls} = 0.0064x^4 - 0.0644x^3 + 0.2416x^2 + 4.4766x \qquad eq.(6.12)$$

Where x here is the number of walls separation.

We calculated the values obtained from both models for a number of walls up to 5 walls and we compared these values by finding the difference between the calculated value on each number of walls. The calculated values and the comparison are listed in the following table:

Table 15 Comparison between AMATA and SRAB models

Number of walls	L_{walls} from AMATA (dB)	L_{walls} from our model (dB)	Difference (dB)
1	3.8275	4.66044	0.83294
2	8.88	9.51064	0.63064
3	14.3475	14.40324	0.05574
4	19.6	19.35024	0.24976
5	24.1875	24.523	0.3355

From the previous table, we can note the great similarity between our multiwall model and AMATA model despite the use of different equipment for measuring the signal strength.

6.6 SRAB Model:

As we mentioned in the section of methodology, we would like to derive n_0 for the new model after eliminating the effect of walls at each point of measurement. This new path loss exponent represents the indoor loss without the internal walls effect.

After deriving n_0 in each floor we will represent the new extension of ITU model that takes in consideration, besides the indoor propagation, the multiwall penetration loss. And we will show the improvement that this new model, that we called SRAB model, will introduce to the basic ITU model.

1- Building B:

For this building, the next figures show the measured values side to side the modeled values of the received power. After the list of figures, we will show the values of n_0 for each floor beside the values of n derived for the ITU model. The improvement introduced by SRAB model is calculated as below:

$$Improvement\ Percentage = \frac{(\sigma ITU - \sigma SRAB)}{\sigma ITU} * 100\% \quad eq.(6.13)$$

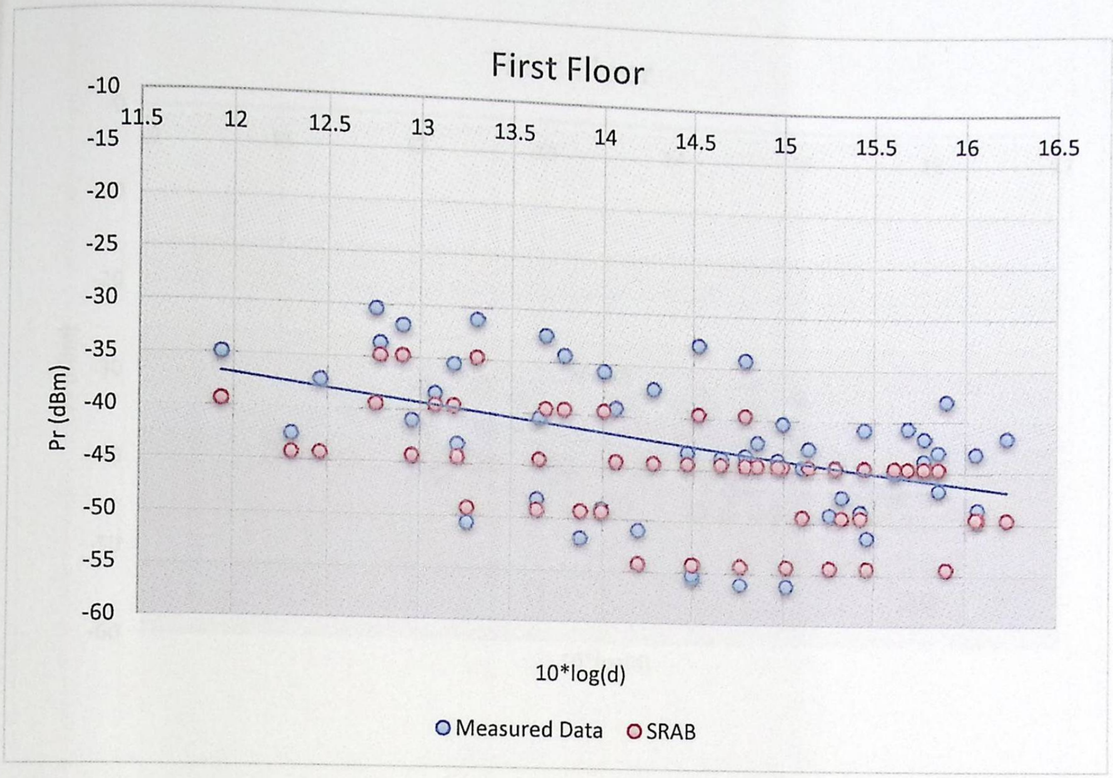


Figure 26: Measured and modeled data for building B first floor

Figure 27: Measured and modeled data for building B second floor

Figure 28: Measured and modeled data for building B third floor

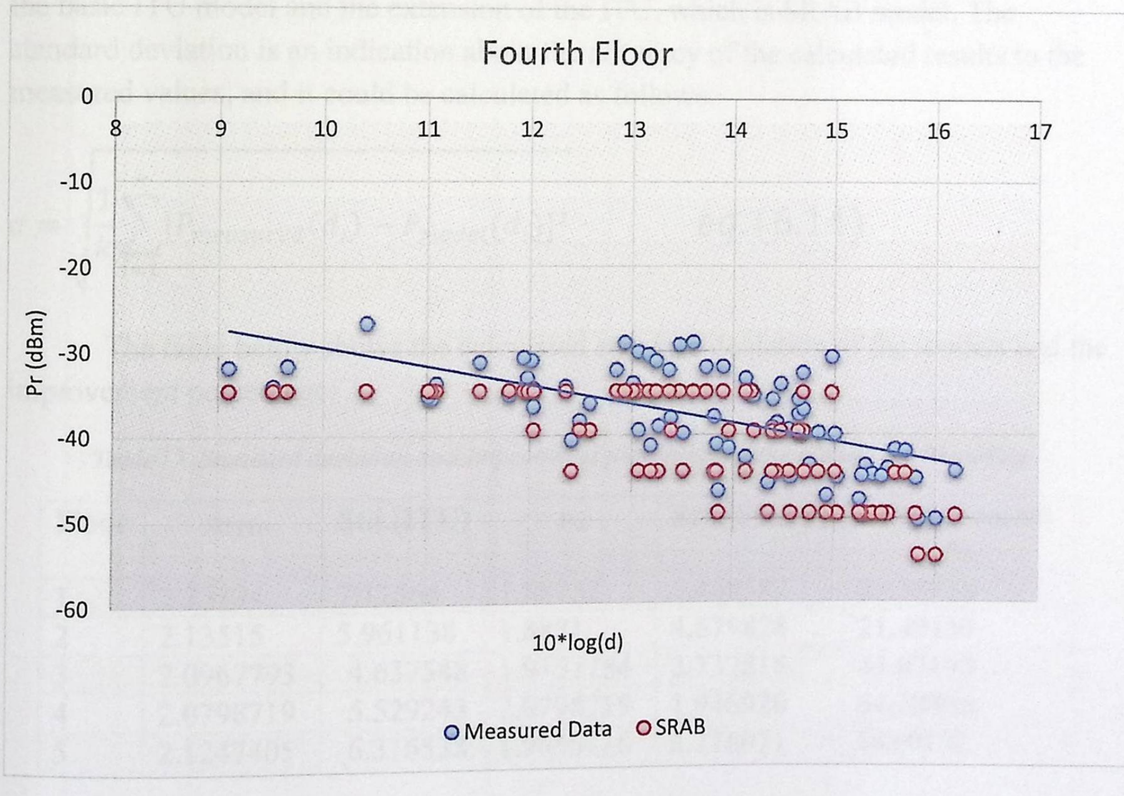


Figure 29: Measured and modeled data for building B fourth floor

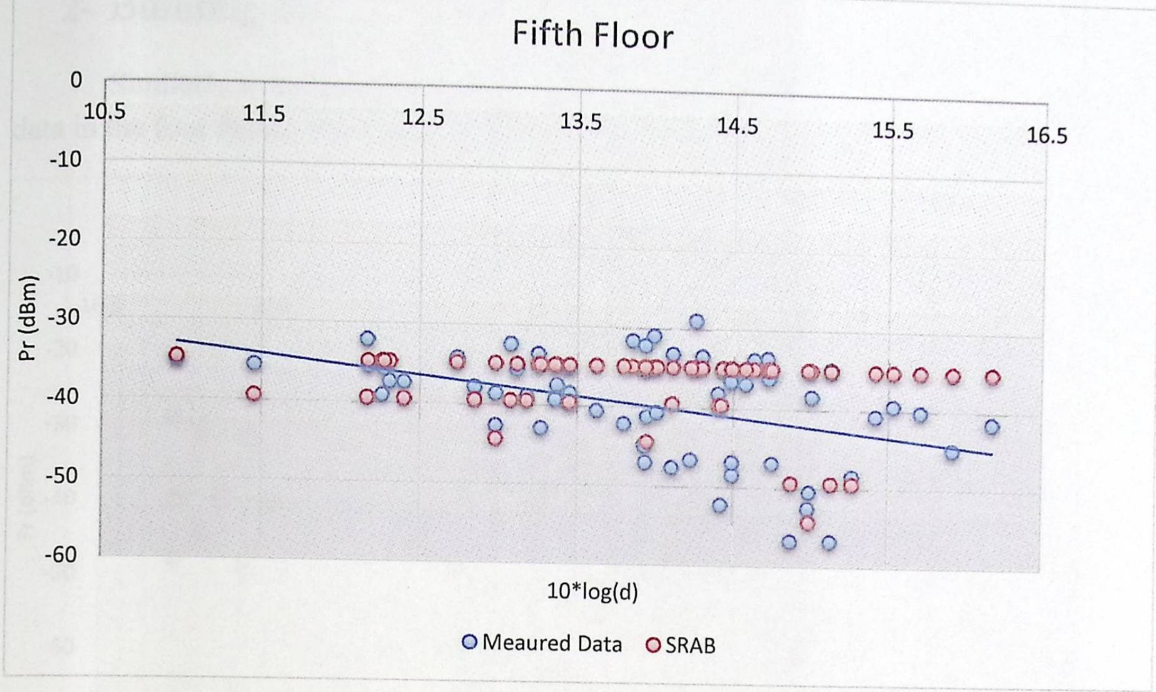


Figure 30: Measured and modeled data for building B fifth floor

Now we are going to show the results of standard deviation for both models, the basic ITU model and the extension of the ITU, which is SRAB model. The standard deviation is an indication about the accuracy of the calculated results to the measured values, and it could be calculated as follows:

$$\sigma = \sqrt{\frac{1}{k}\sum_{i=1}^{k}[P_{measured}(d_i) - P_{model}(d_i)]^2} \qquad eq.(6.14)$$

The table below shows the calculated standard deviation of the models and the improvement percentage:

Table ١٦ Standard deviation and Improvment percentage of the models for Bbuilding

Floor	$\mathbf{n_{ITU}}$	**Std.(ITU)**	$\mathbf{n_0}$	**Std.(SRAB)**	**Improvement %**
1	2.23334	7.12566	1.88752	5.459582	**23.38138**
2	2.13515	5.961138	1.8871	4.679828	**21.49439**
3	2.0967793	4.637548	1.9151784	2.732818	**41.07192**
4	2.0798719	5.529243	2.0798719	1.946926	**64.78856**
5	2.1247405	6.316538	1.9656416	6.276071	**18.60132**

We can note that SRAB model achieved about 65% of improvement in the 4th floor of building B

2- Building B+:

Similarly to building B, we have plotted the modeled values and the measured data in the four floors. The figure below show the obtained results:

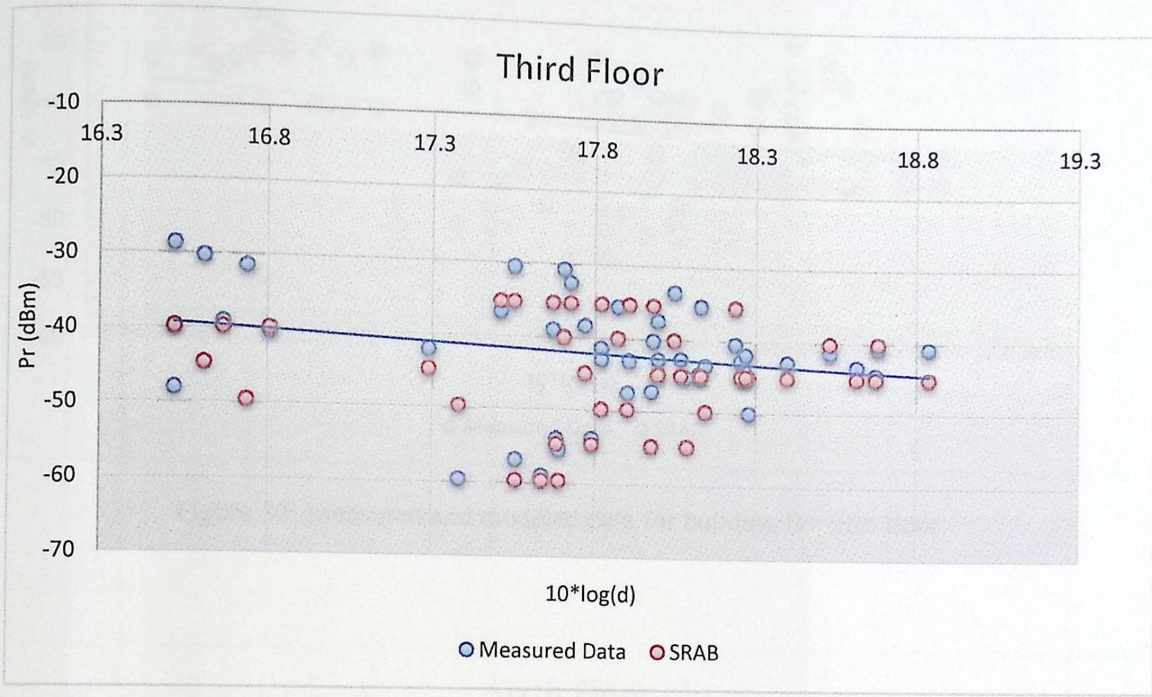


Figure 31: Measured and modeled data for building B+ third floor

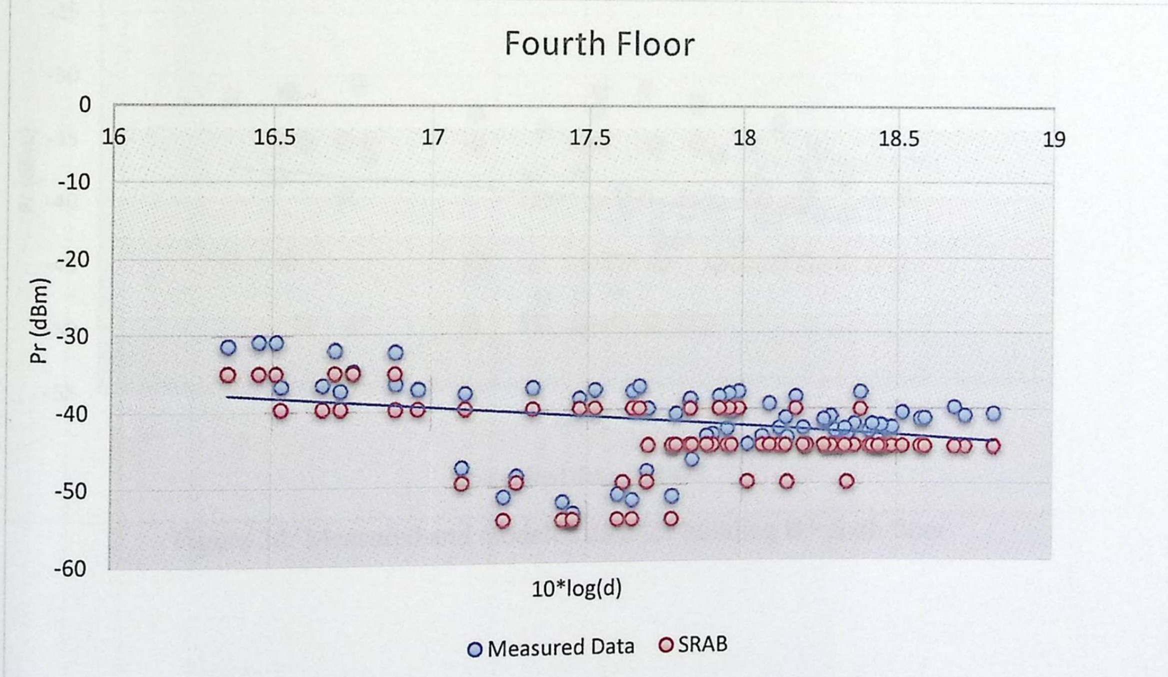


Figure 32: Measured and modeled data for building B+ fourth floor

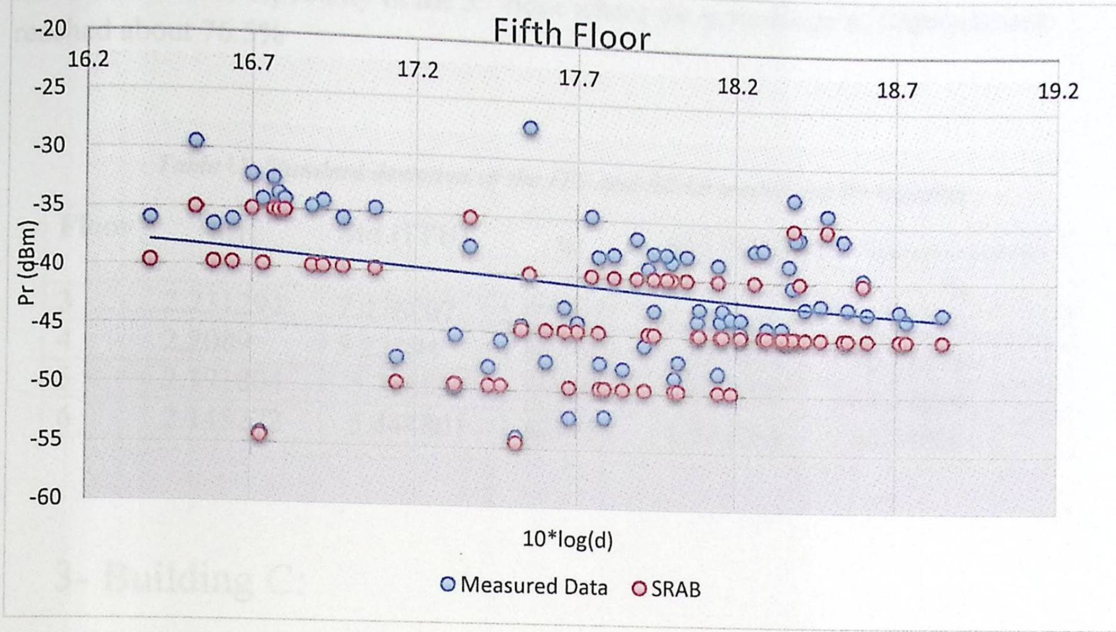


Figure 33: Measured and modeled data for building B+ fifth floor

Figure 34: Measured and modeled data for building B+ sixth floor

The comparison between the standard deviation of the ITU and SRAB models is illustrated in the table below, where we can note the high improvement that SRAB model introduces especially in the 3rd floor where the percentage of improvement reached about 76.5%

Table ١٧ Standard deviation of the ITU and SRAB models for B+ building

Floor	n_{ITU}	Std.(ITU)	n_0	Std.(SRAB)	Improvement %
3	2.231294	7.476007	1.873663	1.761148	**76.44266**
4	2.2089	5.22194	1.861147	1.549833	**70.32075**
5	2.191804	5.726532	1.859123	2.612395	**54.38086**
6	2.145272	5.444801	1.821757	1.974285	**63.74001**

3- Building C:

For the two floors of building C, we have also plotted the measured data with the modeled values versus the distance in logarithmic scale, and the figures are as shown below:

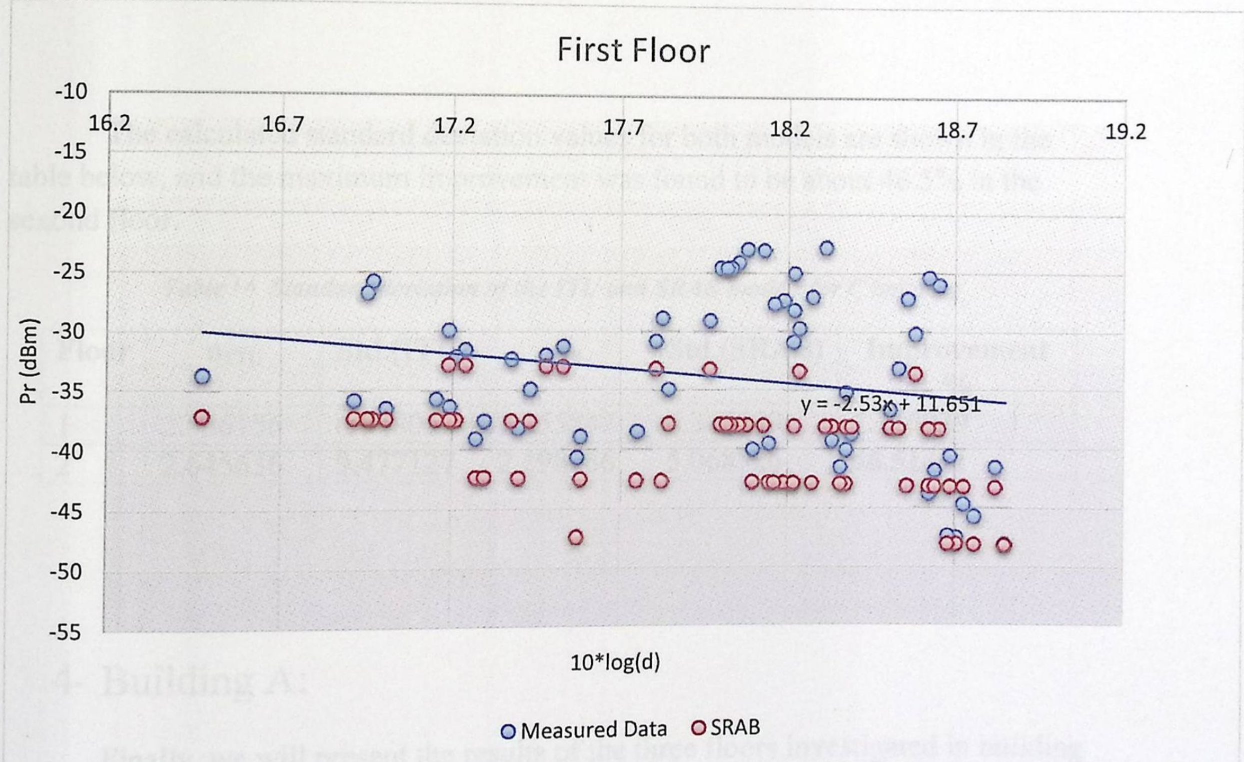


Figure 35: Measured and modeled data for building C first floor

Figure 36: Measured and modeled data for building C second floor

The calculated standard deviation values for both models are shown in the table below, and the maximum improvement was found to be about 46.5% in the sexond floor.

Table 18 Standard deviation of the ITU and SRAB models for C building

Floor	n_{ITU}	Std.(ITU)	n_0	Std.(SRAB)	Improvement %
1	2.536156	6.84805	2.255842	6.345339	**7.340939**
2	2.645636	9.477127	2.298786	5.068926	**46.51411**

4- Building A:

Finally, we will present the results of the three floors investigated in building A. The figures for this building are shown below:

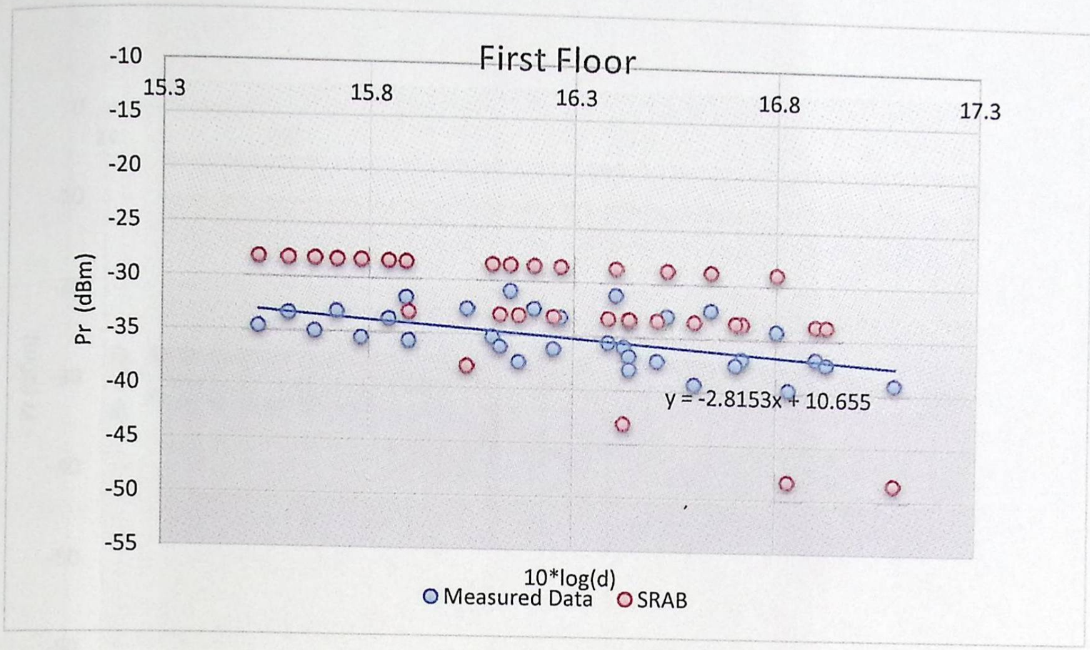


Figure 37: Measured and modeled data for building A first floor

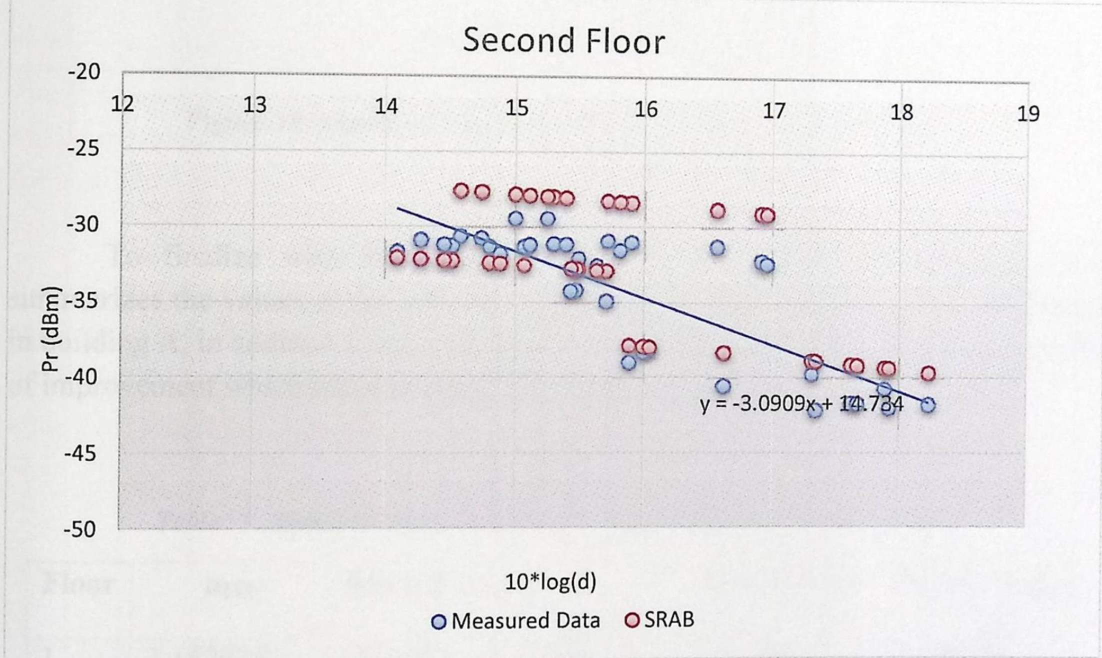


Figure 38: Measured and modeled data for building A second floor

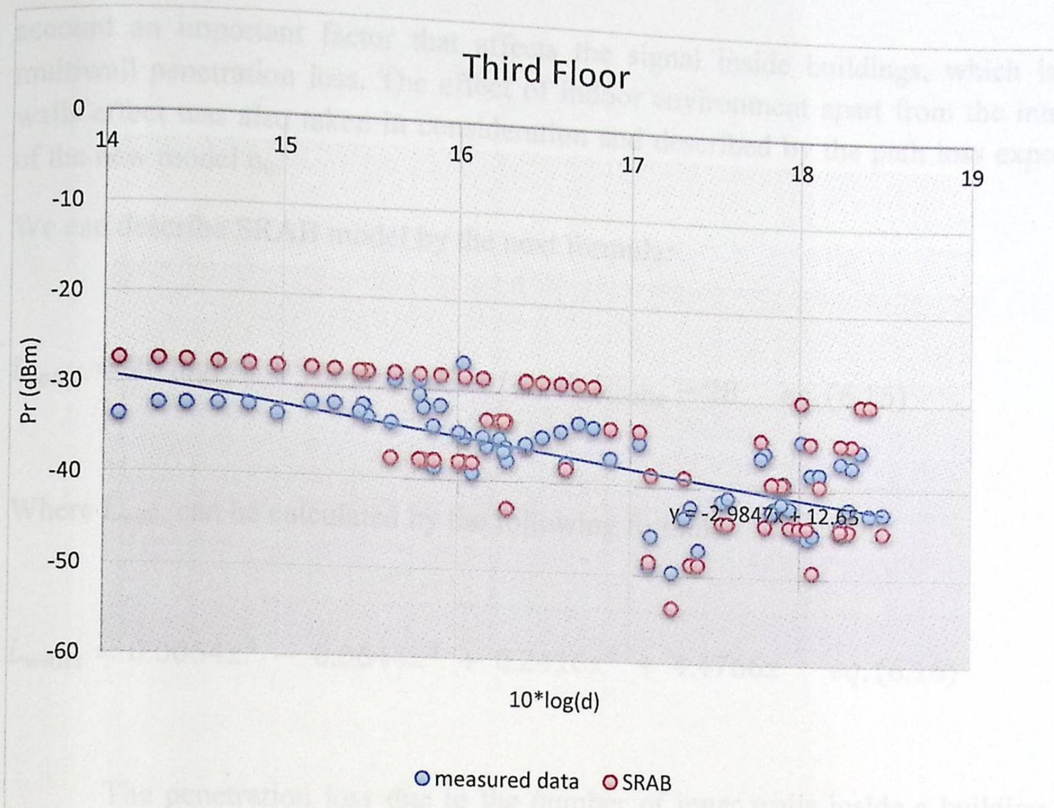


Figure 39: Measured and modeled data for building A third floor

To finalize with the analysis for GSM 900 MHz, the following table summarizes the values of the path loss exponent for ITU model and for SRAB model in building A, in addition to the standard deviation for both models and the percentage of improvement which reached about 63% in the second floor.

Table ۱۹ Standard deviation of the ITU and SRAB models for A building

Floor	n_{ITU}	Std.(ITU)	n_0	Std.(SRAB)	Improvement %
1	3.162716	6.28105	2.723415	5.083847	**19.06055**
2	2.995584292	4.83739	2.635838658	1.805694	**62.67214**
3	2.955399849	4.353223	2.630303	4.197426	**3.578877**

6.7 Conclusion:

From the previous analysis of the measurements collected at 900 MHz frequency band infour multi-floor buildings, we could come out with an extension model for the standard ITU model. This new model, called SARB model, takes into account an important factor that affects the signal inside buildings, which is the multiwall penetration loss. The effect of indoor environment apart from the internal walls effect was also taken in consideration and described by the path loss exponent of the new model n_0.

We can describe SRAB model by the next formula:

$$L_{total} = 20\log(f) + 10n_0 log(d) + L_{out} + L_{walls} - 28 \quad eq. (6.15)$$

Where L_{walls} can be calculated by the following formula:

$$L_{walls} = 0.0064x^4 - 0.0644x^3 + 0.2416x^2 + 4.4766x \quad eq. (6.16)$$

The penetration loss due to the number of inner walls inside a building was found by averaging the penetration loss in a number of floors in different buildings, where the maximum variance around the average curve was found to be about 0.7 dB for a number of walls equals 2 walls.

This extension of the ITU model introduced an improvement that reached about 76% in our sample of buildings. This model that describes the path loss at 900 MHz, and with the verification and validation of measurement and calculation, can be generalized for buildings and environment similar to the environment of investigation which led to the development of this model.

Chapter7

Wi-Fi 2.4 GHz Results and Analysis

7.1 Introduction:

In this chapter, we are going to discuss the second major part of our project, which is the analysis of measurement that have been collected at 2.4 GHz frequency band. We measured the received power of the 2.4 GHz transmitter by using laptops on which the Vistumbler software was installed. The collected data involved three of PPU buildings, which are A, B and C buildings, in addition to Al-Ahli hospital building. The workout of the analysis will lead us to develop models for the 2.4 GHz frequency band, exactly as for the 900 MHz frequency band. These models are for indoor propagation and for multiwall penetration loss. A comparison of models will be illustrated by the end of the chapter.

7.2 Outer Wall Penetration Loss:

In order to start the analysis of indoor propagation, we had to measure and calculate the value of outer wall penetration loss. This was done by taking a set of measurement on both sides of the outer wall of each building, and calculating the average difference between the outer and inner sides of the wall. The table below presents the results for the four buildings.

Table 20 Outer wall penetration loss at 2.4 GHz

Building	Outer Wall Penetration Loss(dB)
A	17.746
B	18.2035
Al-Ahli	22.7304
C	15.3377

7.3 Indoor Propagation

In this section, we are going to discuss the indoor propagation at 2.4 GHz in the sample of buildings. As we derived indoor propagation models at 900 MHz frequency band, we will follow the same procedure of analysis to come out with indoor propagation models at 2.4 GHz. The calculation of the path loss exponent was worked out for the whole sample of building for each investigated floor, by the two different methods described in chapter 6. The overall scatter plots for each building was attached in appendix e.

Now let us introduce the results obtained for each building separately in order to come out with the corresponding models.

1- Building B:

To take measurements in this building, the transmitter was deployed at about 25m away from the nearest wall of the building. After recording received power readings among four floors of this building, the value of indoor path loss exponent is calculated by MMSE method. Then a scatter plot was drawn between the received power measurements and 10log (d_0). Signal strength was detected and measured at the first four floors of the building. The values of path loss exponent derived from the error function were considered as reference, so we had to use a reduced distance in plotting the scattered plots for the measured power. In building B case, the equivalent transmitter was chosen to be at d_0 which equals 20m away from the building in the direction of 900MHz source.

Reducing the distance between the 2.4 GHz source and the building led to a change in the equivalent transmitted power. It had to change from 30 dBm at 25m to 27.6 at 20m. The results for the tested floors of this building are shown below:

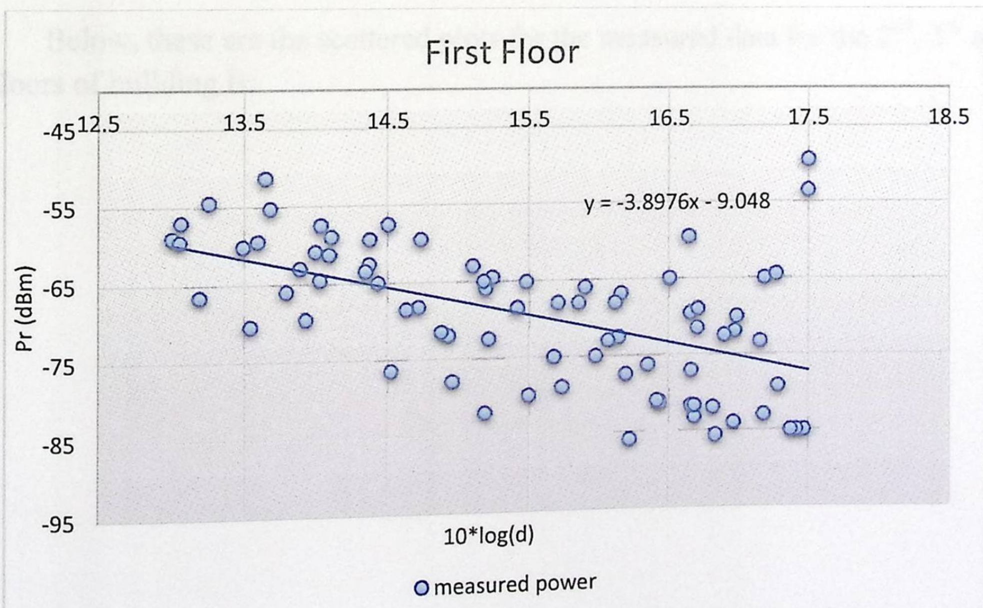


Figure 40: Recived power vs logarithmic distance building B first floor 2.4 GHz

We have plotted the ITU calculated values versus 10log (d_0) on the same plot of the measured data in order to verify the calculation of the path loss exponent. The figure below shows the two curves in addition to the curve of the measured data added to the corresponding standard deviation:

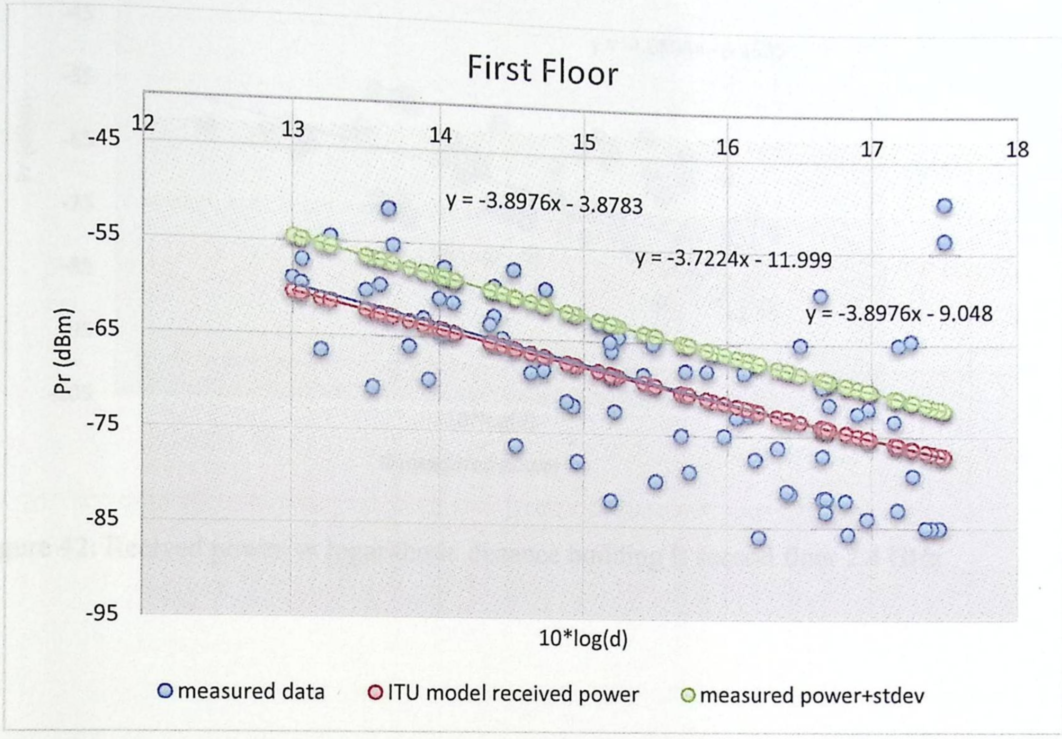


Figure 41: ITU and measured data plot at 2.4 GHz

The similar plots, that represent the ITU and the measured data for the rest of floors for the whole sample of buildings are attached in appendix B.

Below, these are the scattered plots for the measured data for the 2^{nd}, 3^{rd} and 4^{th} floors of building B:

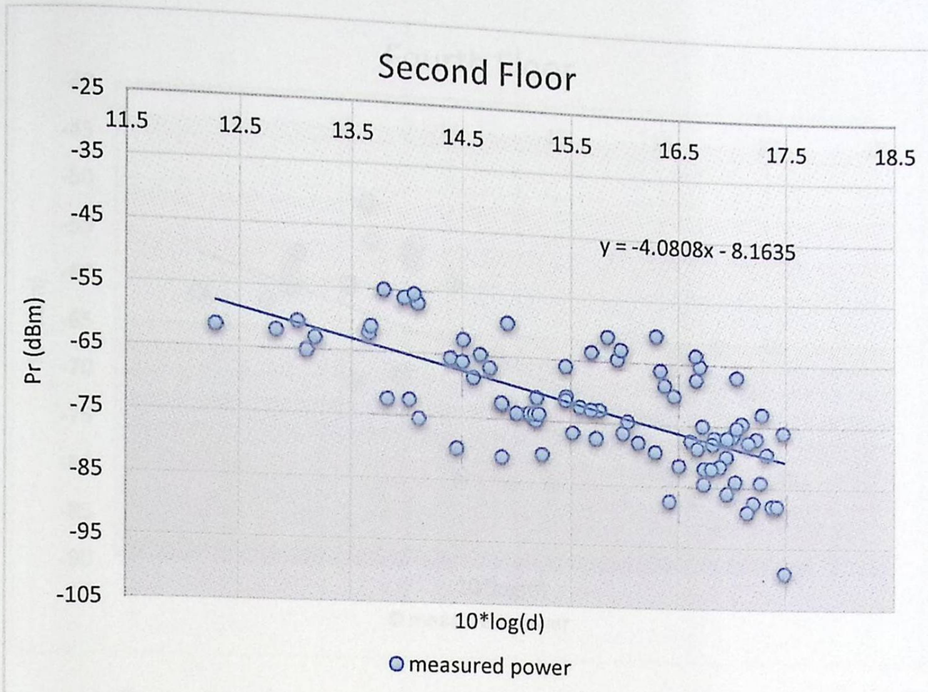


Figure 42: Recived power vs logarithmic distance building B second floor 2.4 GHz

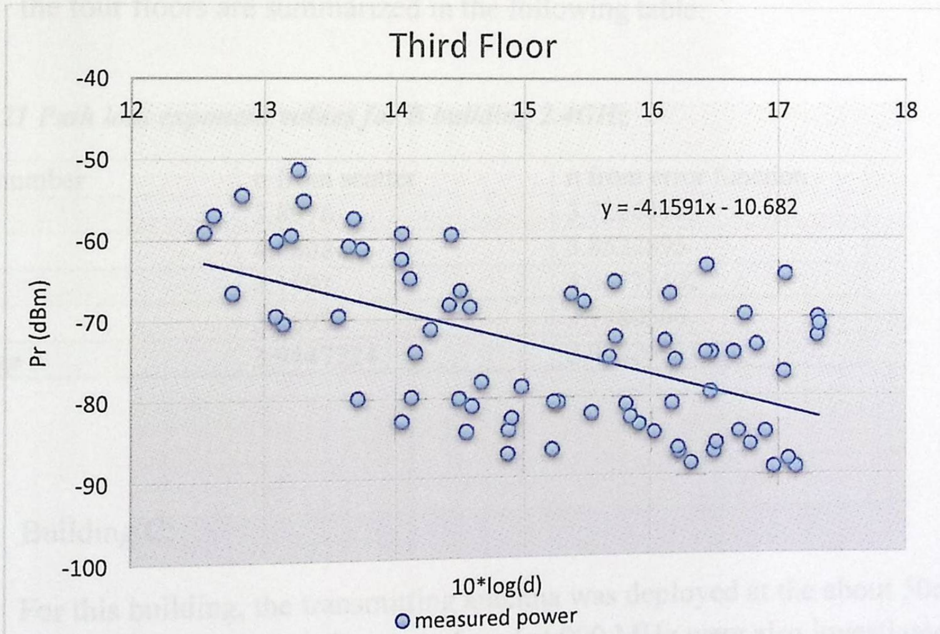


Figure 43: Recived power vs logarithmic distance building B third floor 2.4 GHz

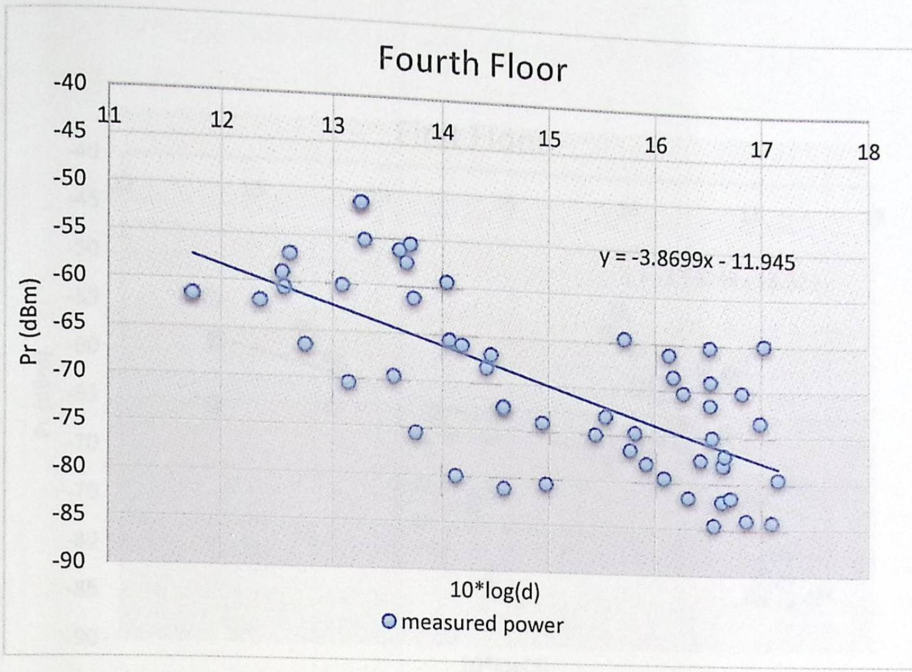


Figure 44: Recived power vs logarithmic distance building B fourth floor 2.4 GHz

The values of the path loss exponent calculated by the two methods for the four floors are summarized in the following table:

Table 21 Path loss exponent values for B building 2.4GHz

Floor number	n from scatter	n from error function
1	3.8976	3.72244983
2	4.0808	3.8522895
3	4.1591	4.00773402
4	3.8699	3.7980566
Average n	3.9447224	3.90226011

2- Building C:

For this building, the transmitting antenna was deployed at the about 50m to the north of the building. Both floors analyzed at 900 MHz were also investigated at 2.4 GHz. The same two ways of finding the value of indoor path loss exponent (MMSE and the scatter plot of measured power) were worked out for this building. Here, the equivalent distance for the transmitter was reduced to be 23m and the equivalent transmitted power was 26.5 dBm.

The results for the two floors of this building are shown in the following figures and the values of the path loss exponent are listed in table 7.3

Figure 45: Recived power vs logarithmic distance building C first floor 2.4 GHz

Figure 46: Recived power vs logarithmic distance building C second floor 2.4 GHz

The calculated values of the path loss exponent for this building are listed in the table below:

Table 22 Path loss exponent values for C building 2.4GHz

Floor number	n from scatter	n from error function
1	3.5624	3.51535
2	3.8677	3.714245
Average n	3.71505	3.614798

3- Building A:

As a continue to our work in analyzing indoor propagation, received power measurement in building A were recorded after deploying the transmitter at 35m from the building. The change on distance was to make the equivalent location of source about 10m which led to have an equivalent transmitted power about 18dbm.

The following figures and table show the results for building A floors:

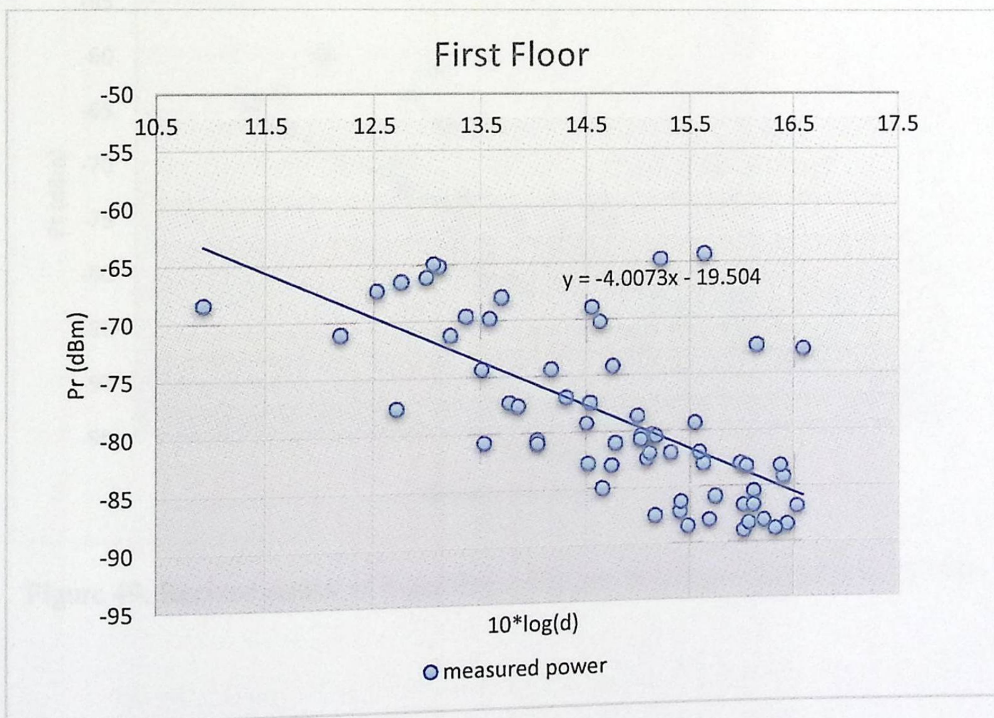


Figure 47: Recived power vs logarithmic distance building A first floor 2.4 GHz

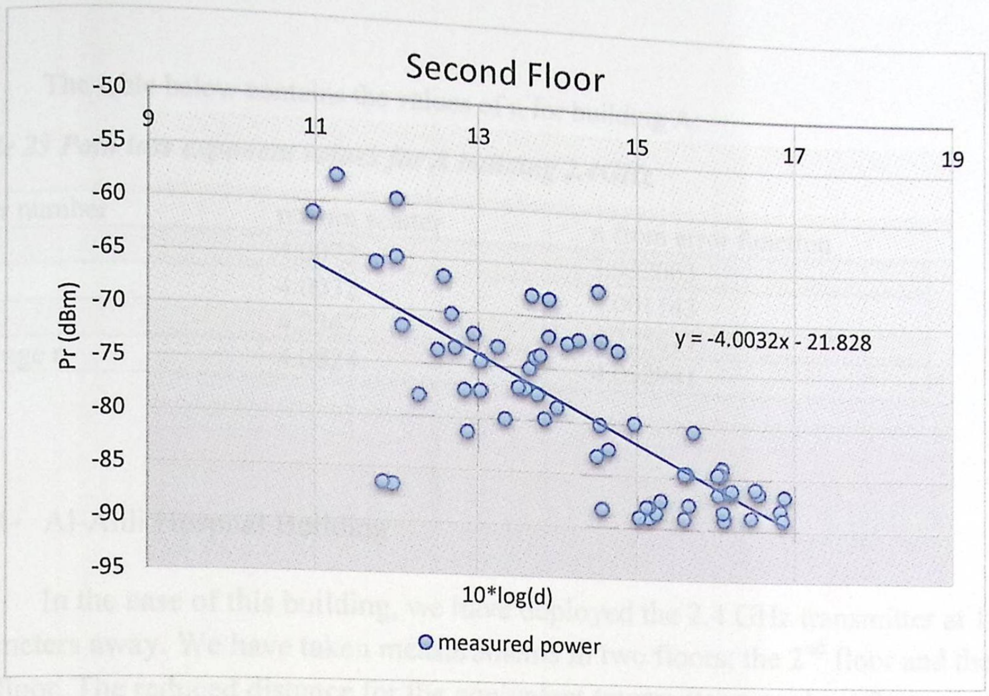


Figure 48: Recived power vs logarithmic distance building A second floor 2.4 GHz

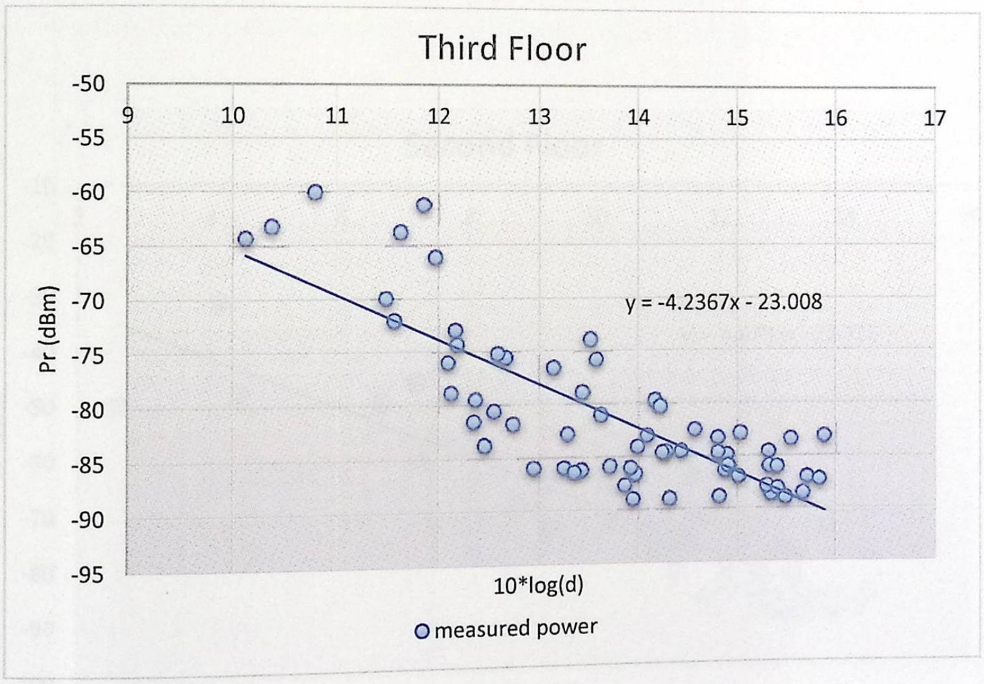


Figure 49: Recived power vs logarithmic distance building A third floor 2.4 GHz

The table below contains the values of n for building A:

Table 23 Path loss exponent values for A building 2.4GHz

Floor number	n from scatter	n from error function
1	4.0073	3.932063
2	4.0032	4.001143
3	4.2367	4.225617
Average n	4.0824	4.052941

4- Al-Ahli Hospital Building

In the case of this building, we have deployed the 2.4 GHz transmitter at 15 meters away. We have taken measurements in two floors; the 2nd floor and the 3rd floor. The reduced distance for the equivalent transmitter was about 2 meters from the building with an equivalent transmitted power of 17 dBm.

The scattered plots for this building are shown below:

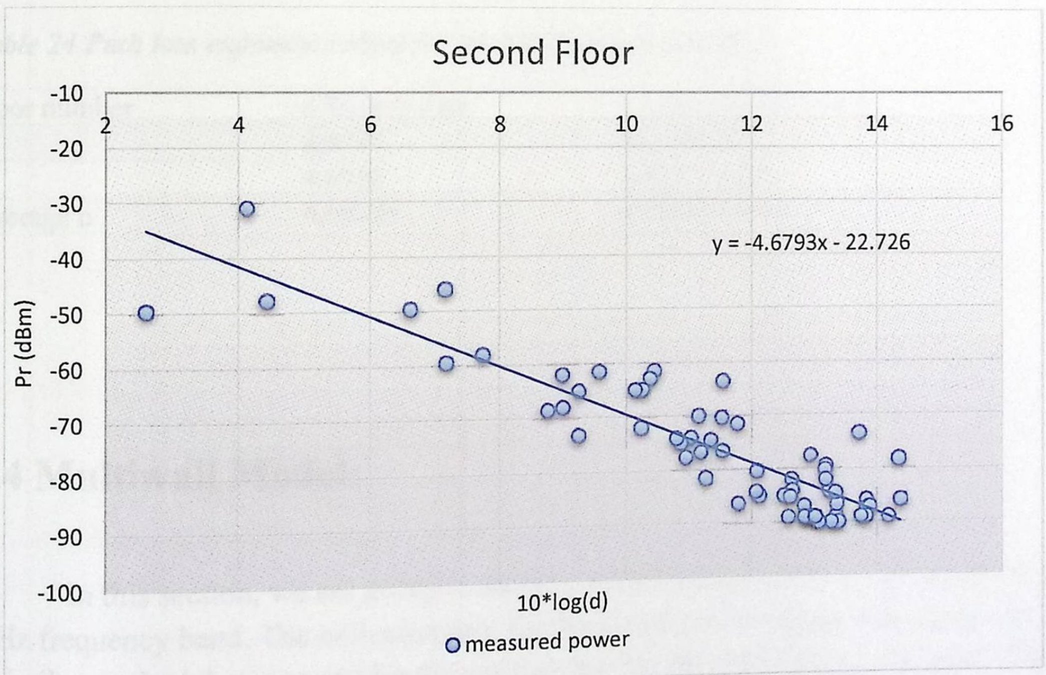


Figure 50: Recived power vs logarithmic distance building Al-Ahli second floor 2.4 GHz

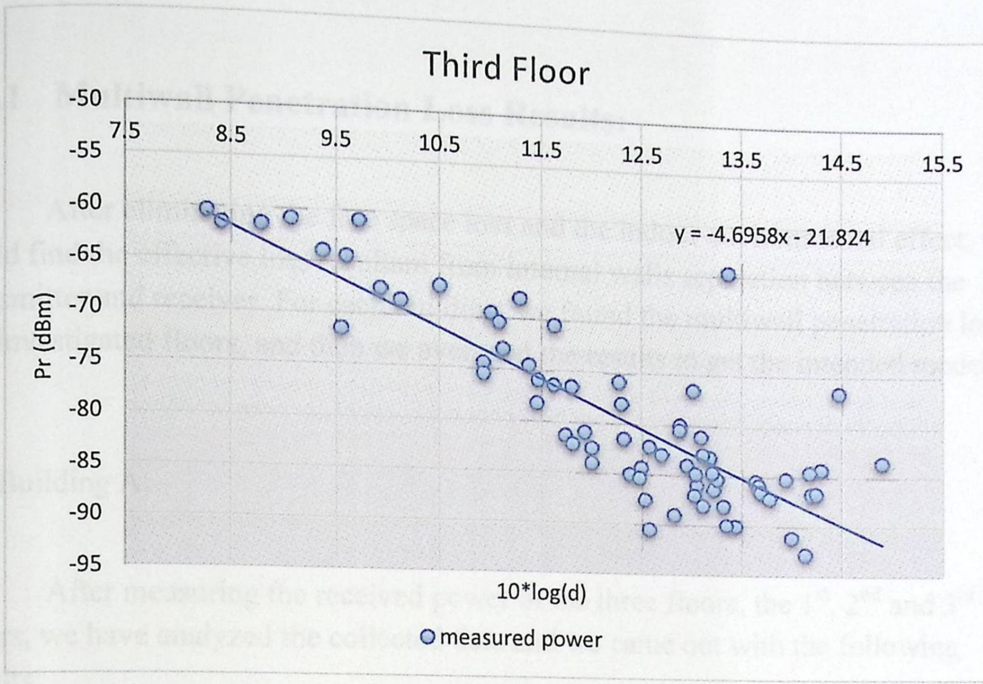


Figure 51: Recived power vs logarithmic distance building Al-Ahli third floor 2.4 GHz

We listed the path exponent values for Al-Ahli building in the following table:

Table 24 Path loss exponent values for Al-Ahli building 2.4GHz

Floor number	n from scatter	n from error function
2	4.6793	4.65585267
3	4.6958	4.635278465
Average n	4.68755	4.645565568

7.4 Multiwall Model:

In this section, we are going to derive a multiwall penetration loss model at 2.4 GHz frequency band. The collected data for the sample of buildings was processed in a similar method that we used for the analysis for the 900 MHz frequency band. Thus, we were able to find the effect of internal walls and their resultant penetration loss at 2.4 GHz. A set of samples of measurements taken in all buildings is attached in appendix D.

7.4.1 Multiwall Penetration Loss Results:

After eliminating the free space loss and the indoor environmental effect, we could find the effective loss resultant from internal walls separation between the transmitter and receiver. For each building, we found the multiwall penetration loss in the investigated floors, and then we averaged the results to get the intended model.

1- Building A:

After measuring the received power in the three floors, the 1st, 2nd and 3rd floors, we have analyzed the collected data and we came out with the following results:

Table 25 inner walls loss for A building 2.4 GHz

Floor/walls	1 wall	2 walls	3 walls	4 walls	5 walls
1	8.506185246	13.56483413	19.36332675	23.07296073	-
2	9.461210224	14.14616342	18.94024335	22.04255853	25.56209
3	8.563032565	14.74035932	19.53063052	22.82954158	25.40352
Avg. Loss(dB)	8.843476012	14.15045229	19.27807	22.64835	25.4828

2- Building B:

As we mentioned earlier in this chapter, we measured the signal strength in four floors of building B, which are the 1st, 2nd, 3rd and fourth floors. The following table shows the results for the internal walls penetration loss:

Table 26 inner walls loss for B building 2.4 GHz

Floor/walls	1 wall	2 walls	3 walls	4 walls
1	9.128802072	15.15737147	20.32661264	22.19303124
2	8.607258445	13.36442837	17.74474281	23.32623408
3	9.550270175	13.73641007	20.30462535	22.23052781
4	9.762069988	15.14340347	19.22888539	21.05098386

Avg. Loss(dB)	9.26210017	14.35040334	19.40122	22.20019

3- Building C:

For building C, the 1st and 2nd floors were investigated to find the penetration loss of internal walls. The obtained results are listed in the table below:

Table 27 inner walls loss for C building 2.4 GHz

Floor/walls	1 wall	2 walls	3 walls
1	8.886299722	14.94858684	21.22891353
2	9.321318983	15.3690818	22.2505281
Avg. Loss(dB)	9.103809353	15.15883432	21.73972

4- Al-Ahli:

The last building of this investigated sample at 2.4 GHz, was Al-Ahli hospital building. We measured the received power in two floors; the 2nd floor and the 3rd floor. The maximum number of walls separation between the transmitter and receiver was 5 walls, since the signal couldn't be detected after 5 walls.

The results of penetration loss on each number of walls are shown in the following table:

Table 28 inner walls loss for Al-Ahli building 2.4 GHz

Floor/walls	1 wall	2 walls	3 walls	4 walls	5 walls
2	7.911422034	15.43397789	21.24399813	24.27910031	27.30187
3	9.054213618	16.52449197	21.96182451	24.21949112	28.85512
Avg. Loss(dB)	8.482817826	15.97923493	21.60291	24.2493	28.07849

5- Average multiwall penetration loss in all buildings:

After finding the multiwall penetration loss in all floors for all buildings, we averaged the results to find the overall average loss. The results for the average multiwall penetration loss at each number of walls are listed in the table below:

*Table 29 5- **Average multiwall penetration loss in all buildings***

Number of walls	1 wall	2 walls	3 walls	4 walls	5 walls
Overall average loss (dB)	8.74746961	15.21124815	20.41917413	23.34267289	26.78065

From the resulted shown in the table above, we were able to plot the curve of average multiwall penetration loss at 2.4 GHz. The average curve is shown in the following figure:

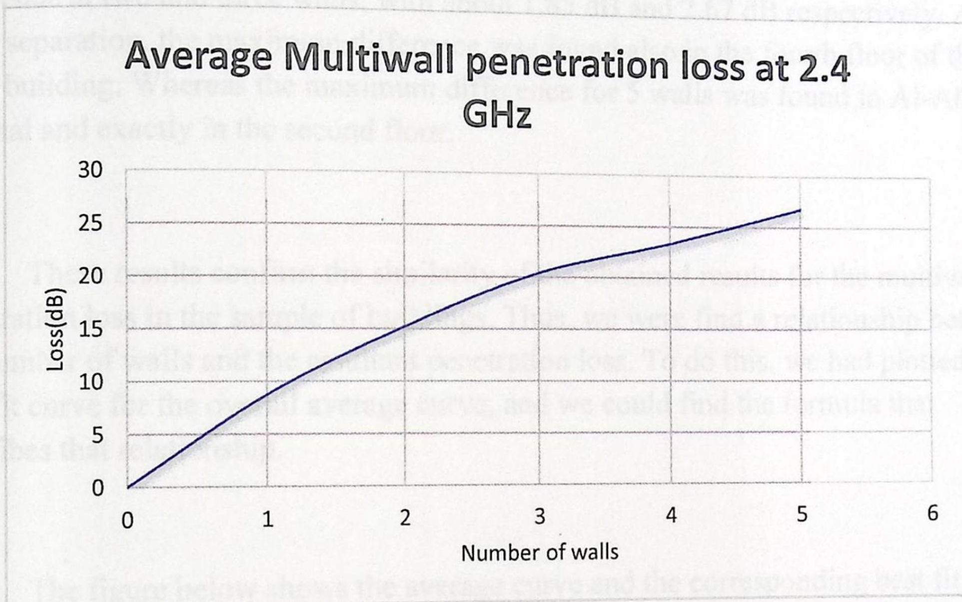


Figure 52: Average multiwall penetration loss at 2.4 GHz

We had also to calculate the variance about the average curve and the maximum difference between the overall average and the values found in each floor. The table below shows the values of calculated variance about the average curve. We notice that the maximum variance occurred at three walls separation with a value of about 2 dB.

Table 30 variance about the average curve 2.4GHz

Number of walls	1 wall	2 walls	3 walls	4 walls	5 walls
Variance(dB)	0.300041947	0.907523868	1.919015885	1.110032588	2.652153104

When calculating the difference between the average loss at each number of walls and the corresponding value in each floor we found that the maximum values of difference were as shown in the following table:

Table 31 differance from average walls loss for each floor 2.4 GHz

Number of walls	1 wall	2 walls	3 walls	4 walls	5 walls
Difference (dB)	1.014600377	1.846819785	2.674431318	2.291689026	2.074466319

The maximum difference at one wall was found to be about 1 dB in the fourth floor of building B. In the second floor of the same building occurred the maximum difference at two and three walls, with about 1.85 dB and 2.67 dB respectively. At 4 walls separation, the maximum difference was found also in the fourth floor of the same building. Whereas the maximum difference for 5 walls was found in Al-Ahli hospital and exactly in the second floor.

These results confirm the similarity of the obtained results for the multiwall penetration loss in the sample of buildings. Thus, we were find a relationship between the number of walls and the resultant penetration loss. To do this, we had plotted the best fit curve for the overall average curve, and we could find the formula that describes that relationship.

The figure below shows the average curve and the corresponding best fit curve:

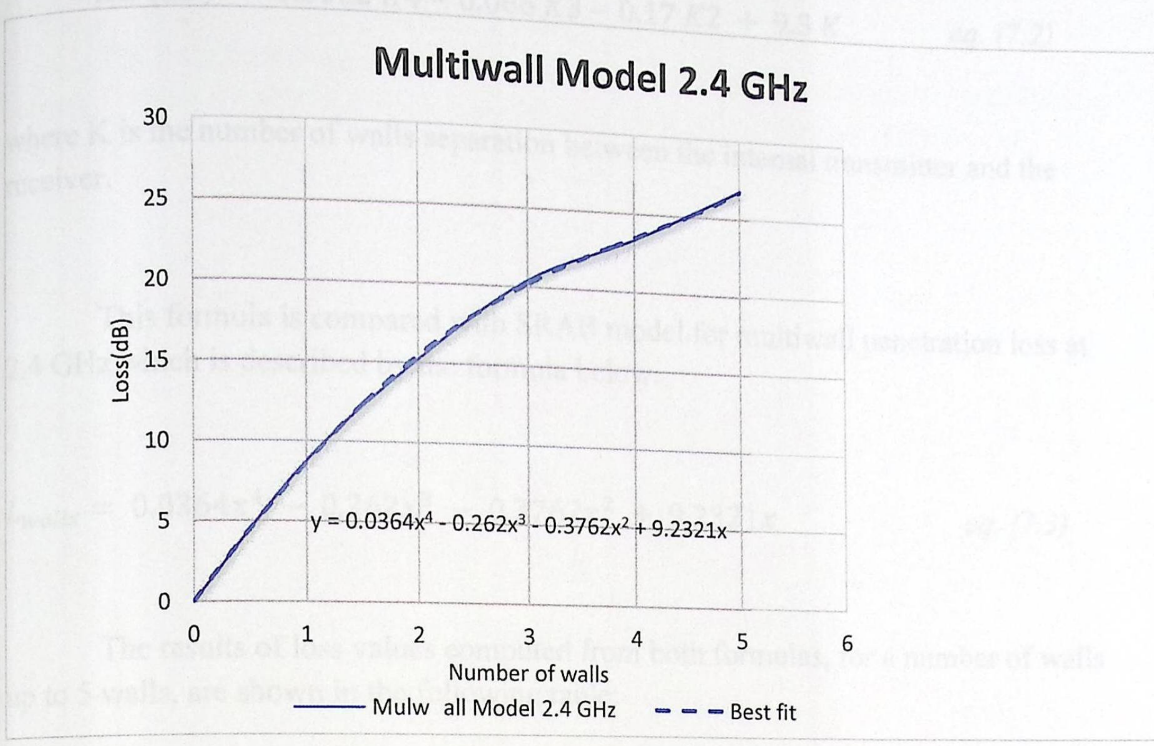


Figure 53: Average multiwall model at 2.4 GHz

From the above figure we found the relationship that relates the number of walls separation and the penetration loss. This relationship is described by the following formula:

$$L_{walls} = 0.0364x^4 - 0.262x^3 - 0.3762x^2 + 9.2321x \qquad eq.\ (7.1)$$

where x in this formula is the number of walls.

7.4.2 Comparison with AMATA model:

After the development of the multiwall penetration model at 2.4 GHz, we would like to compare this model with AMATA model for 2.4 GHz frequency band.

AMATA model at 2.4 GHz was developed for measurement taken for internal Wi-Fi transmitters located inside the investigated buildings. While we measured the received power of an external source at this frequency band. The following formula describes AMATA multiwall model for 2.4 GHz:

$$X\alpha\ (dB) = 0.0032\ K4 - 0.086\ K3 - 0.17\ K2 + 9.3\ K \qquad eq.\ (7.2)$$

where K is the number of walls separation between the internal transmitter and the receiver.

This formula is compared with SRAB model for multiwall penetration loss at 2.4 GHz which is described by the formula below:

$$L_{walls} = 0.0364x^4 - 0.262x^3 - 0.3762x^2 + 9.2321x \qquad eq.\ (7.3)$$

The results of loss values computed from both formulas, for a number of walls up to 5 walls, are shown in the following table:

Table 32 Multiwall comparison b/w AMATA and SRAB 2.4 GHz

Number of walls	L_{walls} from AMATA (dB)	L_{walls} from SRAB model (dB)	Difference (dB)
1	9.0472	8.6303	0.4169
2	17.2832	15.4458	1.8374
3	24.3072	20.1849	4.1223
4	29.7952	23.4596	6.3356
5	33.5	26.7555	6.7445

We notice that the difference between the two models can reach up to about 6.75 dB at 5 walls separation. We can say that this high difference is due to the use of an external transmitter instead of internal one for the measurement of our model.

7.5 SRAB Model:

In this section, results of calculating values of n0 after eliminating the internal walls effect and the extended ITU model for each floor of the sample buildings are shown with necessary tables and plots.

1- Building B:

The next figures show the measured values verses the modeled values of the received power for this building,. The value of n0 is shown then after the lest of scatters.

Figure 54: Measured and modeled values for building B first floor 2.4 GHz

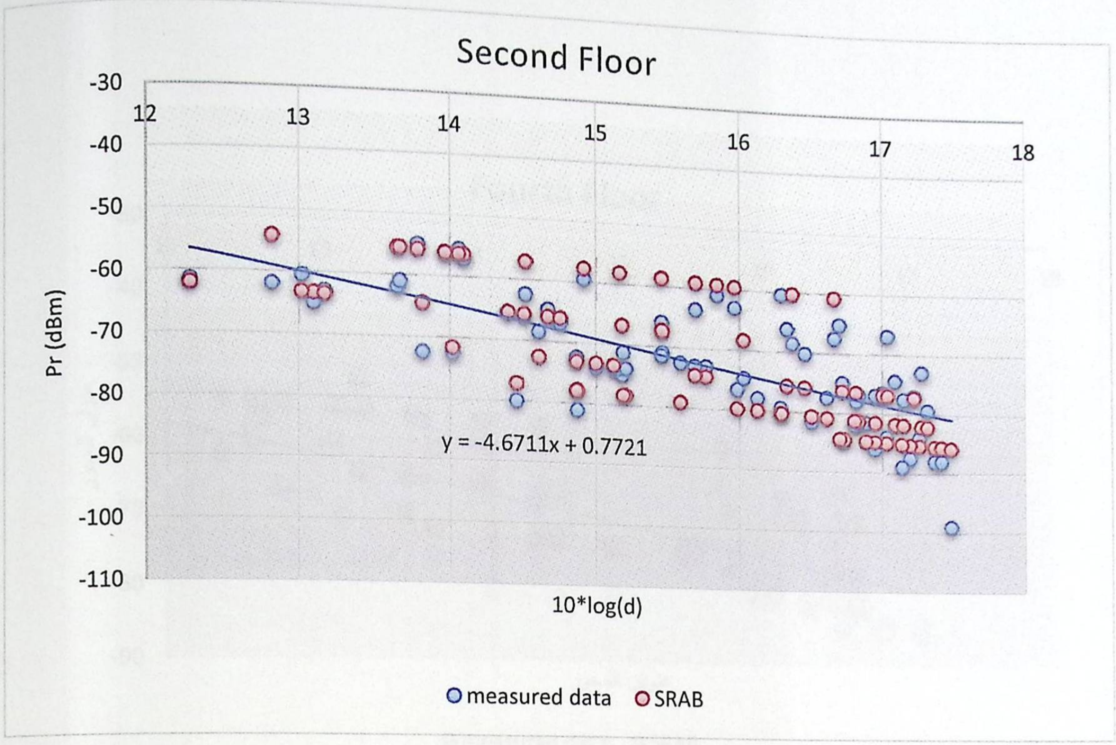


Figure 55: Measured and modeled values for building B second floor 2.4 GHz

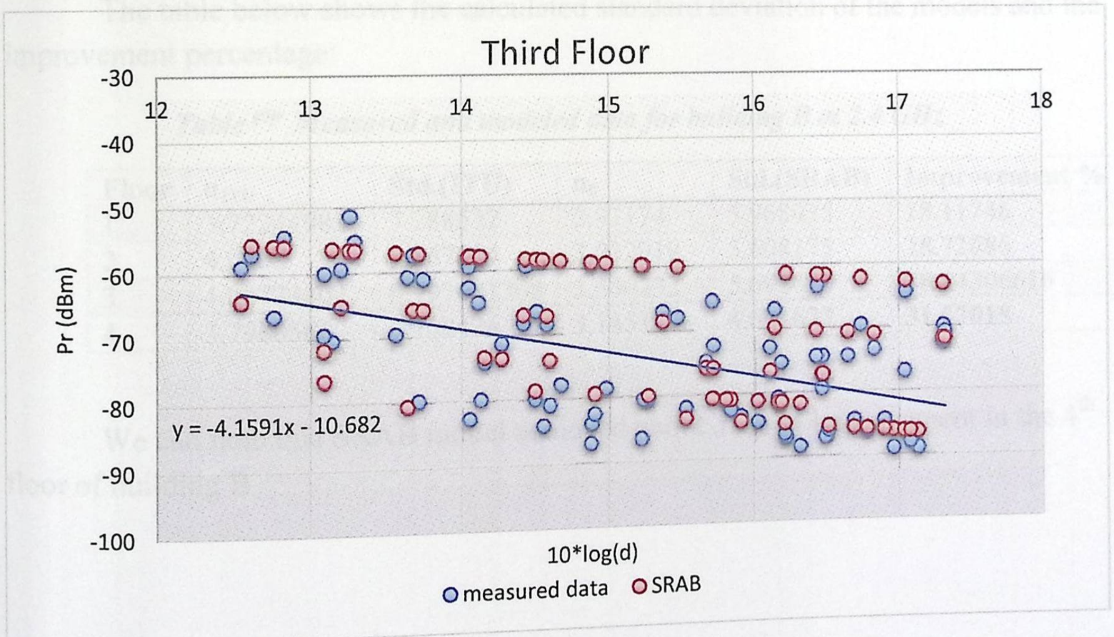


Figure 56: Measured and modeled values for building B third floor 2.4 GHz

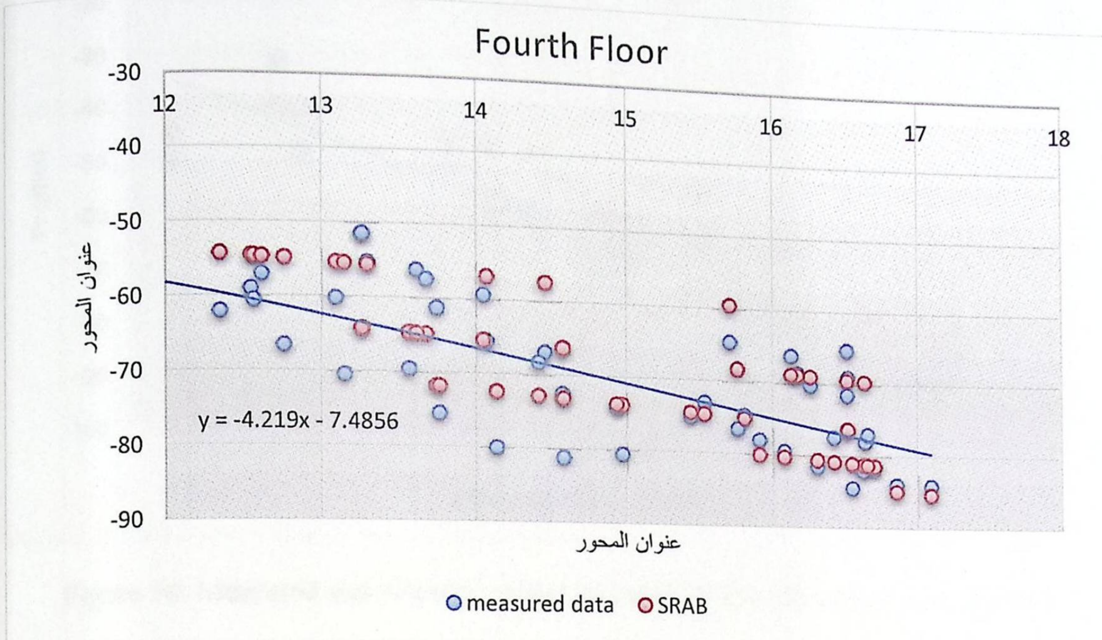


Figure 57: Measured and modeled values for building B fourth floor 2.4 GHz

The table below shows the calculated standard deviation of the models and the improvement percentage:

Table ٣٣ Measured and modeled data for building B at 2.4 GHz

Floor	n_{ITU}	Std.(ITU)	n_0	Std.(SRAB)	Improvement %
1	3.72244983	7.288532	2.97174	5.968035	**18.11746**
2	4.0808	7.867904	3.032919	5.608175	**28.72086**
3	4.00773402	6.997081308	3.360232	5.692611	**18.64306616**
4	3.7980566	6.768426	3.145123	4.631623	**31.57015**

We can note that SRAB model achieved about 31% of improvement in the 4th floor of building B

2- Building Al-Ahli:

We have plotted the modeled values and the measured data in two floors. The figure below show the obtained results:

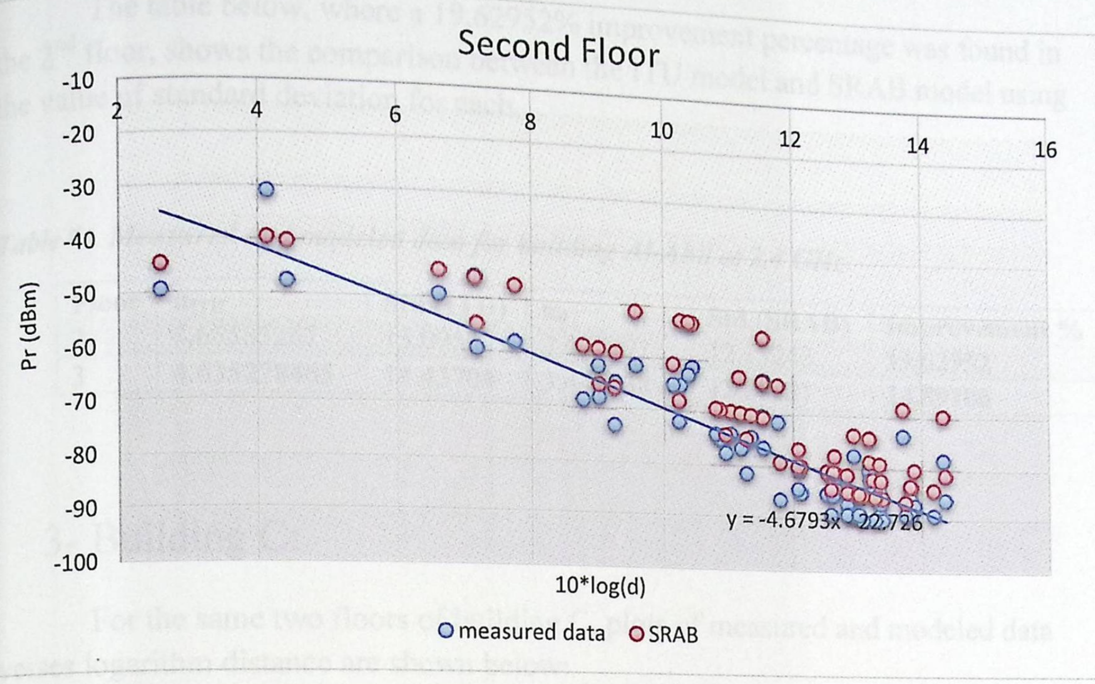


Figure 58: Measured and modeled values for building Al-Ahli second floor 2.4 GHz

Figure 59: Measured and modeled values for building Al-Ahli third floor 2.4 GHz

The table below, where a 19.62952% improvement percentage was found in the 2nd floor, shows the comparison between the ITU model and SRAB model using the value of standard deviation for each.

*Table ٣٤ **Measured and modeled data for building Al-Ahli at 2.4 GHz***

Floor	$\mathbf{n_{ITU}}$	**Std.(ITU)**	$\mathbf{n_0}$	**Std.(SRAB)**	**Improvement %**
2	4.65585267	15.09562	3.477291	12.13243	**19.62952**
3	4.635278465	14.43704	3.446038	12.28721	**14.89106**

3- Building C:

For the same two floors of building C, plots of measured and modeled data verses logarithm distance are shown below:

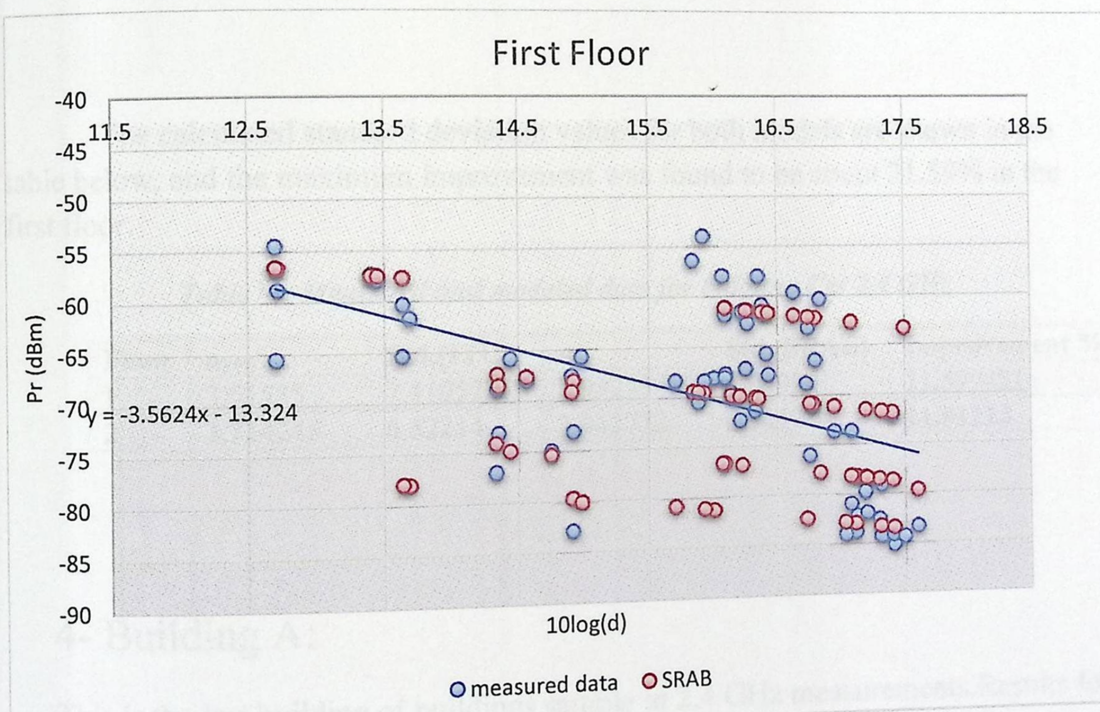


Figure 60: Measured and modeled values for building C first floor 2.4 GHz

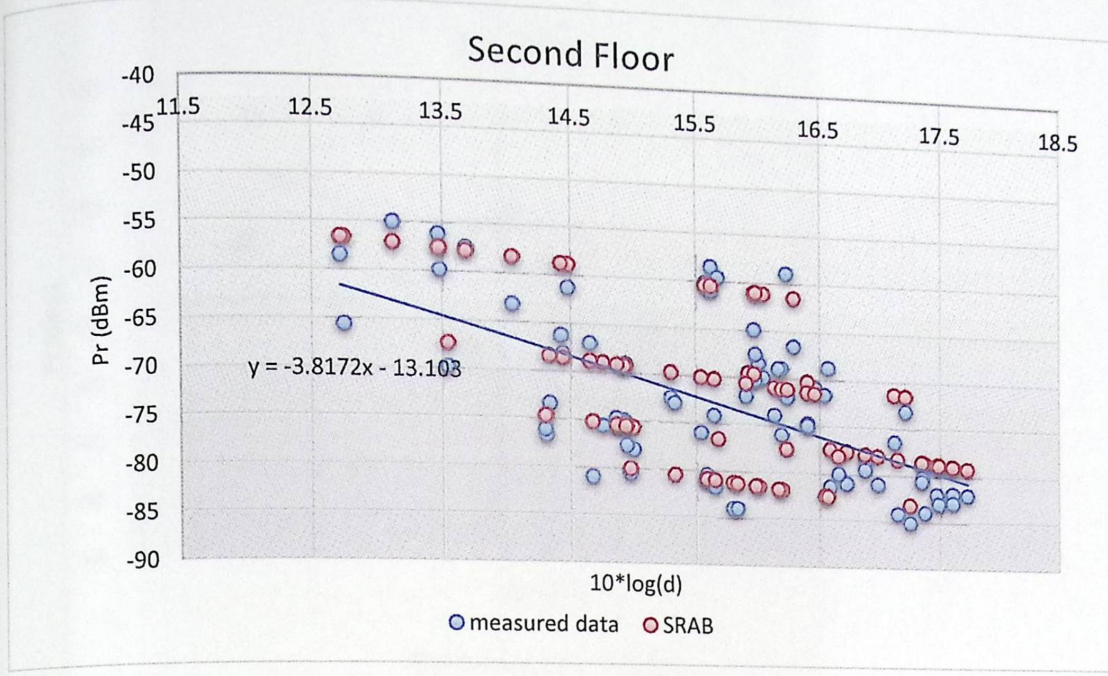


Figure 61: Measured and modeled values for building C second floor 2.4 GHz

The calculated standard deviation values for both models are shown in the table below, and the maximum improvement was found to be about 21.59% in the first floor.

Table ٣٥ Measured and modeled data for building Cat 2.4 GHz

Floor	n_{ITU}	Std.(ITU)	n_0	Std.(SRAB)	Improvement %
1	3.51535	7.41052286	2.932594	5.809891	**21.599451**
2	3.714245	6.52214	3.042772	5.745214	**11.91213**

4- Building A:

This is the last building of buildings sample in 2.4 GHz measurements.Results for this building are shown below:

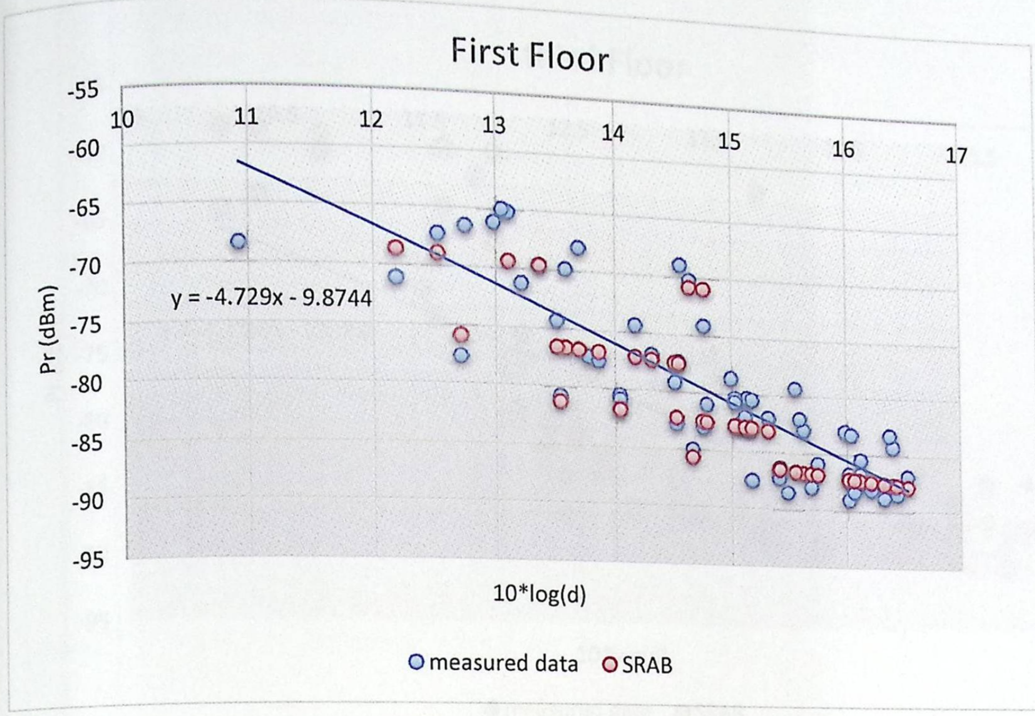


Figure 62: Measured and modeled values for building A first floor 2.4 GHz

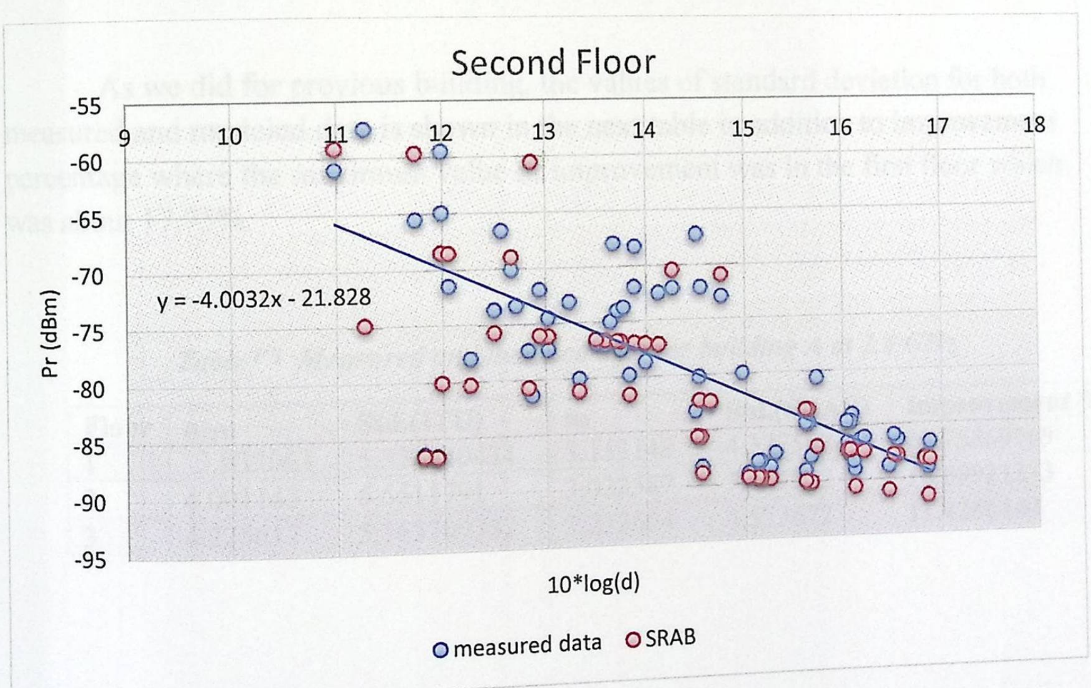


Figure 63: Measured and modeled values for building A second floor 2.4 GHz

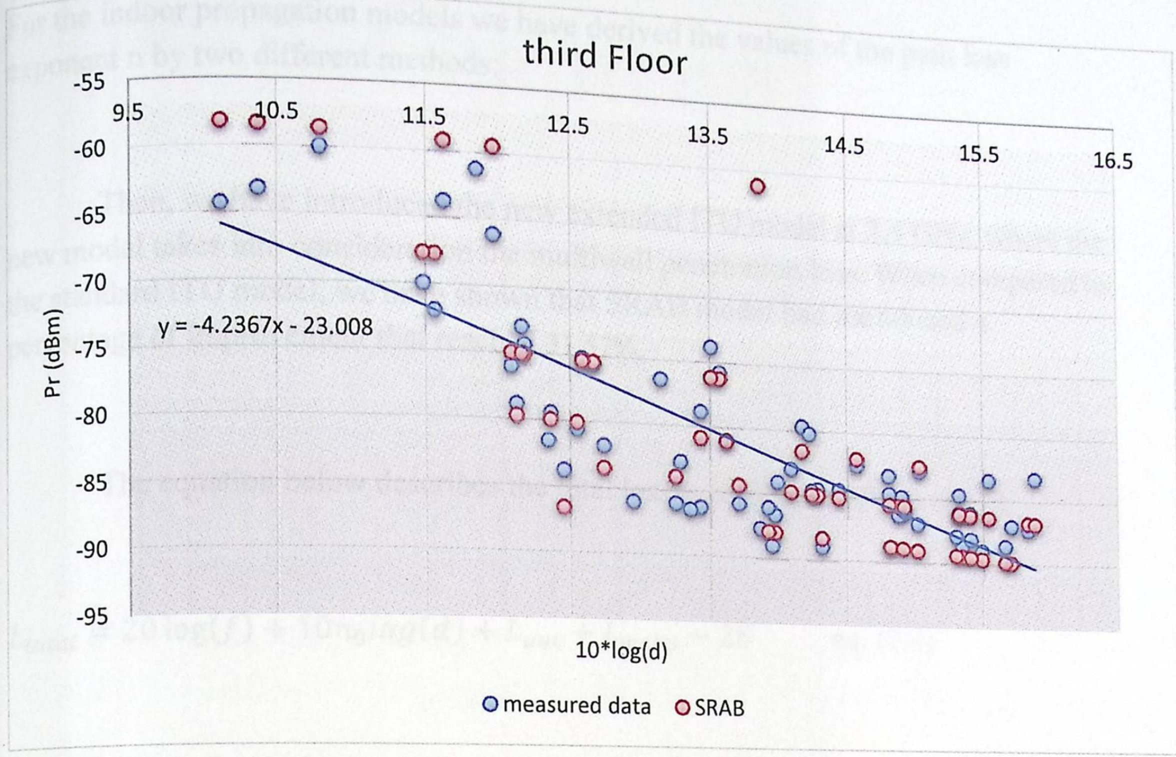


Figure 64: Measured and modeled values for building A third floor 2.4 GHz

As we did for previous building, the values of standard deviation for both measured and modeled data is shown in the next table in addition to improvement percentage where the maximum value of improvement was in the first floor which was about 17.75%.

Table ٣٦ Measured and modeled data for building A at 2.4 GHz

Floor	n_{ITU}	Std.(ITU)	n_0	Std.(SRAB)	Improvement %
1	3.932063	5.322640434	3.153148	4.377568	**17.75569769**
2	4.001143	6.5511791	3.022587	5.444737	**16.88921273**
3	4.225617	5.163709352	3.233604	4.573672	**11.4266144**

7.6 Conclusion:

In this chapter we have discussed the analysis of the measurement for the 2.4 GHz frequency band taken in four different buildings. This analysis was made to develop models for the indoor propagation at 2.4 GHz as it was discussed in section 3.

For the indoor propagation models we have derived the values of the path loss exponent n by two different methods.

Then, we have introduced the new extended ITU model at 2.4 GHz, where the new model takes into consideration the multiwall penetration loss. When compared to the standard ITU model, we have shown that SRAB model had introduced a percentage of improvement that reached 31.57%.

The equation below describes the total loss according to SRAB model:

$$L_{total} = 20\log(f) + 10n_0 log(d) + L_{out} + L_{walls} - 28 \qquad \text{eq. (7.4)}$$

Where L_{walls} at 2.4 GHz is calculated throughout the following formula:

$$L_{walls} = 0.0364x^4 - 0.262x^3 - 0.3762x^2 + 9.2321x \qquad \text{eq. (7.5)}$$

Chapter 8

Correlation and Conclusion

8.1 Introduction

8.2 SRAB Model

8.3 Indoor Propagation Models Correlation

8.4 Conclusion

8.1 Introduction:

So far in this thesis, we have introduced an analysis for indoor propagation of wireless signals at two frequency bands, which are 900 MHz and 2.4 GHz frequency bands. The analysis was worked out for measurements taken in different buildings in PPU and in Al-Ahli hospital building in Hebron. This analysis led to the development of indoor propagation models and penetrated multiwall models at both frequency bands.

An extension of the ITU model was carried out, by taking in consideration the effect of the internal partition walls made of bricks. Hence, the new model introduced an improvement to the standard ITU model and thus it has increased the accuracy of predicting the signal strength.

The sample of buildings consisted of different multi-floor multi-wall buildings, for which the structure and layout is widely common in our country. Therefore, these models can be applied for buildings with similar structure and construction.

8.2 SRAB model:

The multiwall penetration model developed for both frequency bands can be described by the following formula:

$$L_{total} = 20\log(f) + 10n_0 log(d) + L_{out} + L_{walls} - 28 \qquad \text{eq. (8.1)}$$

where L_{walls} is the penetration loss due to internal partition walls that can be calculated by two different formulas according the frequency of operation of the transmitter. The two formulas are listed below For 2.4 GHz and 900 MHz :

$$L_{walls} = 0.0364x^4 - 0.262x^3 - 0.3762x^2 + 9.2321x \qquad \text{eq. (8.2)}$$

$$L_{walls} = 0.0064x^4 - 0.0644x^3 + 0.2416x^2 + 4.4766x \qquad \text{eq. (8.3)}$$

This extension of the ITU model, since it has taken into account the effect of inner walls, it has introduced and improvement to the standard ITU model.

8.3 Indoor Propagation Correlation:

Earlier in the previous chapters, we have derived indoor propagation models floor by floor, by finding the path loss exponent for the ITU model and also finding the equations for scattered plots.

Here in this section, we are going to show the plots for the buildings A, B and C for the measurements at the two frequency bands. For each building, a plot containing the set of measurements at the two frequency band is plotted. The figures below show the collected data for these buildings:

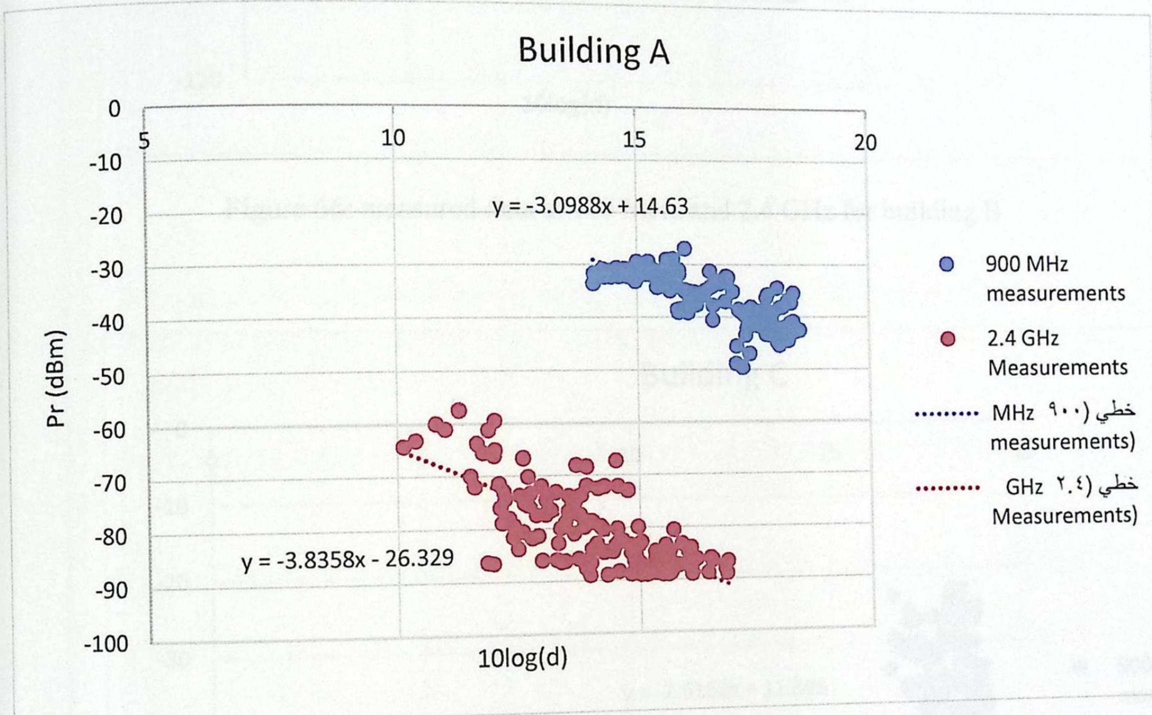


Figure 65: measured data at 900 MHz and 2.4 GHz for building A

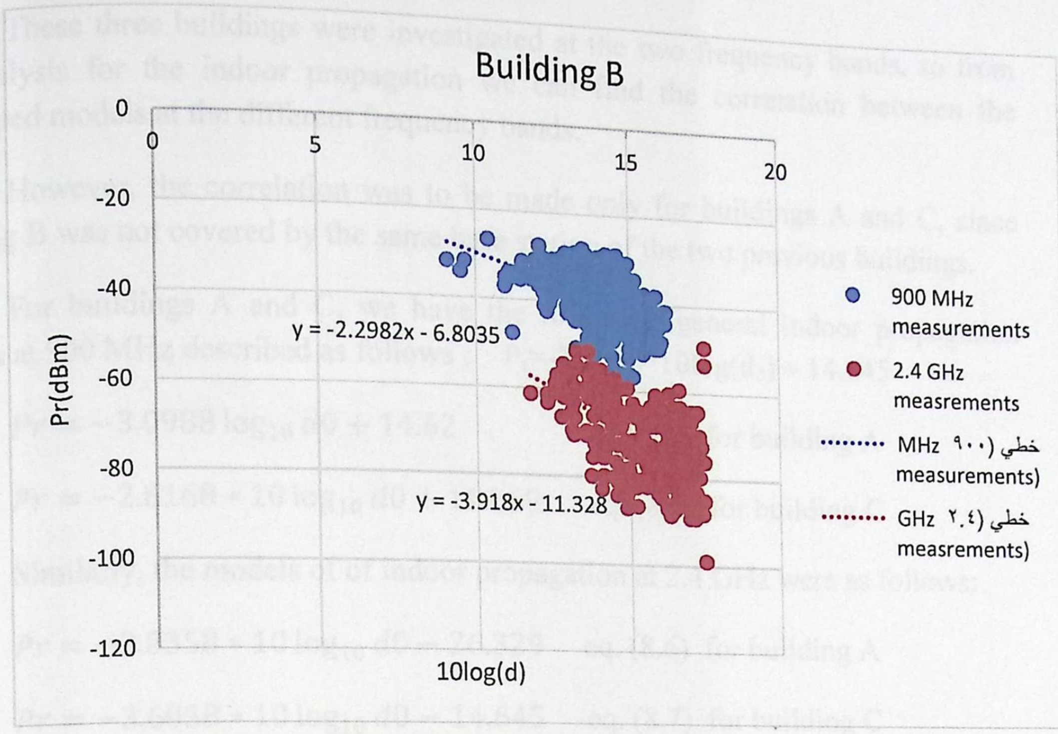


Figure 66: measured data at 900 MHz and 2.4 GHz for building B

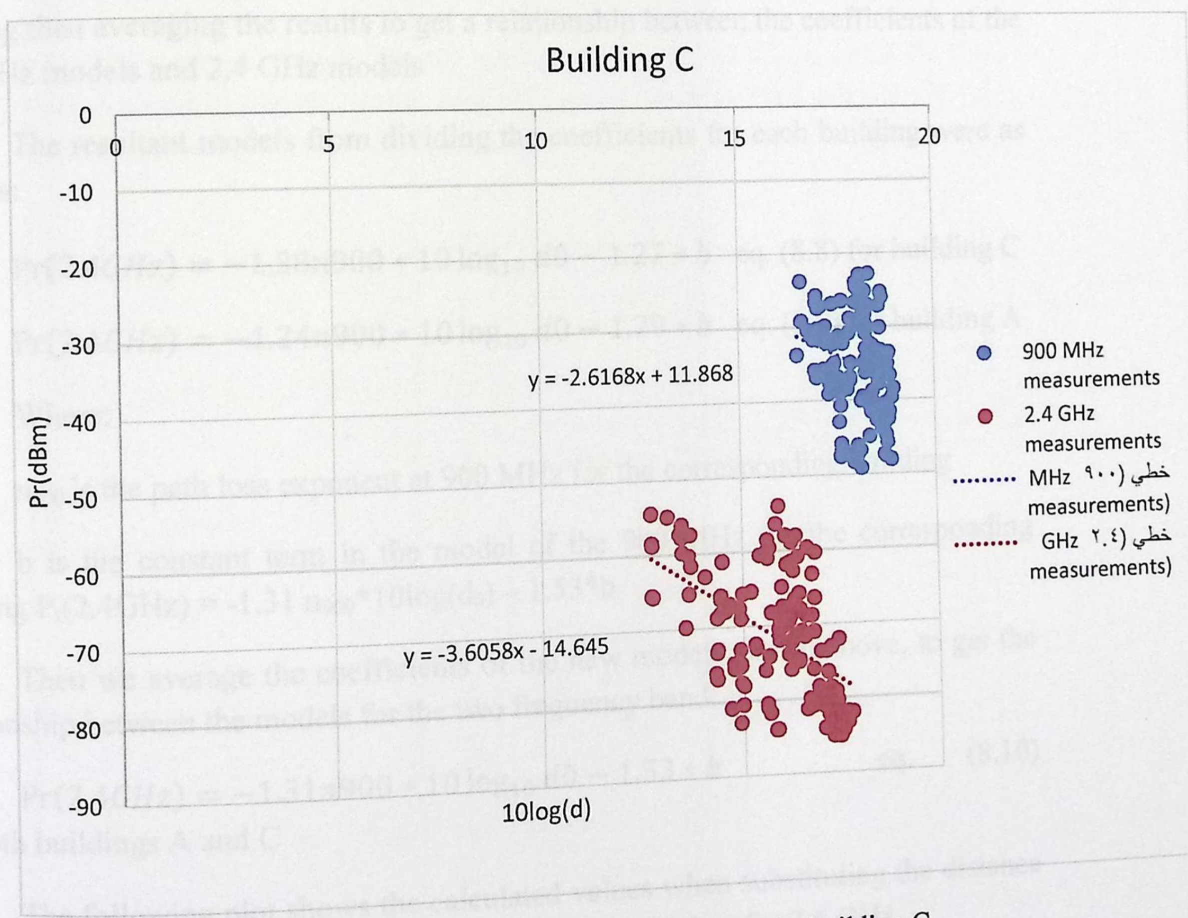


Figure 67: measured data at 900 MHz and 2.4 GHz for building C

These three buildings were investigated at the two frequency bands, so from the analysis for the indoor propagation we can find the correlation between the developed models at the different frequency bands.

However, the correlation was to be made only for buildings A and C, since building B was not covered by the same base station of the two previous buildings.

For buildings A and C, we have the following general indoor propagation models at 900 MHz described as follows : P_r=-3.6058*10log(d_0) – 14.645

$Pr = -3.0988 \log_{10} d0 + 14.62$ eq. (8.4) for building A

$Pr = -2.6168 * 10 \log_{10} d0 + 11.868$ eq. (8.5) for building C

Similarly, the models of of indoor propagation at 2.4 GHz were as follows:

$Pr = -3.8358 * 10 \log_{10} d0 - 26.329$ eq. (8.6) for building A

$Pr = -3.6058 * 10 \log_{10} d0 - 14.645$ eq. (8.7) for building C

The correlation is found by dividing the coefficients of each model for each building then averaging the results to get a relationship between the coefficients of the 900 MHz models and 2.4 GHz models

The resultant models from dividing the coefficients for each building were as follows:

$\text{Pr}(2.4GHz) = -1.38n900 * 10 \log_{10} d0 - 1.27 * b$ eq. (8.8) for building C

$\text{Pr}(2.4GHz) = -1.24n900 * 10 \log_{10} d0 - 1.79 * b$ eq. (8.9) for building A

Where:

n_{900} is the path loss exponent at 900 MHz for the corresponding building

b is the constant term in the model of the 900 MHz for the corresponding building P_r(2.4GHz) = -1.31 n_{900}*10log(d_0) – 1.53*b

Then we average the coefficients of the new models shown above, to get the relationship between the models for the two frequency band:

$$\text{Pr}(2.4GHz) = -1.31n900 * 10 \log_{10} d0 - 1.53 * b \quad \text{eq. (8.10)}$$

for both buildings A and C

The following plot shows the calculated values when substituting the distance d_0 and n_{900} of the building A side to side of the measured data for 2.4 GHz

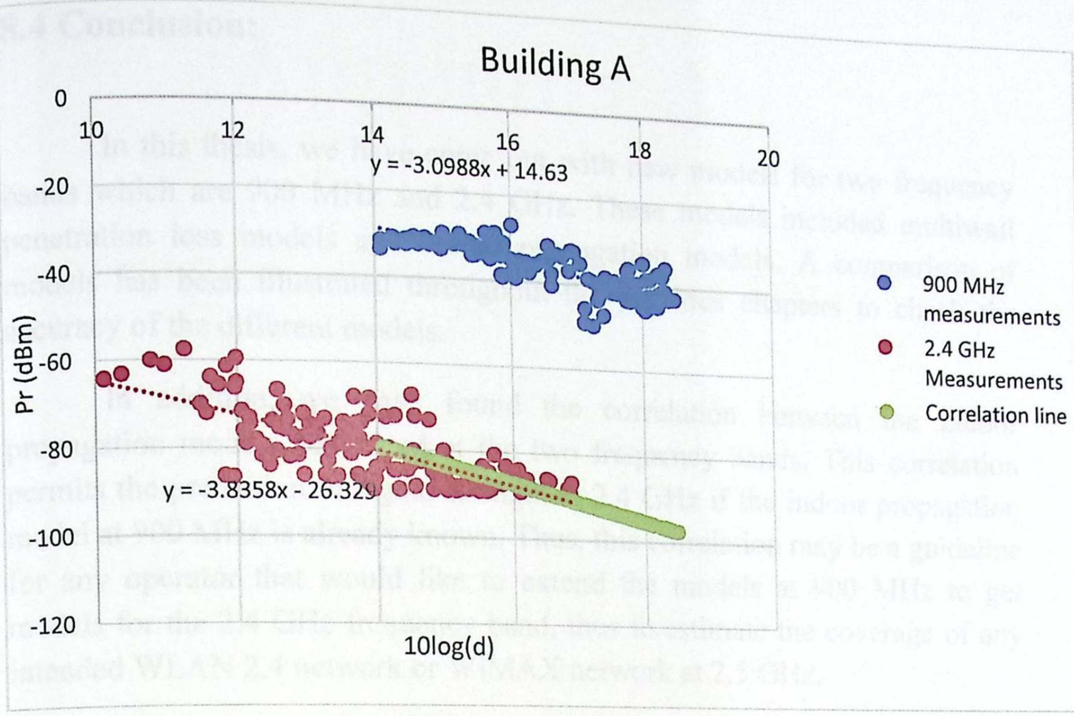


Figure 68: measured data at 900 MHz and 2.4 GHz and calculated 2.4 GHz data for building A

Similarly we have plotted the calculated values for building C, and the figure below shows a the line parallel to the best fit line of the measured data at 2.4 GHz, which confirms the validation of correlation between the two frequency bands.

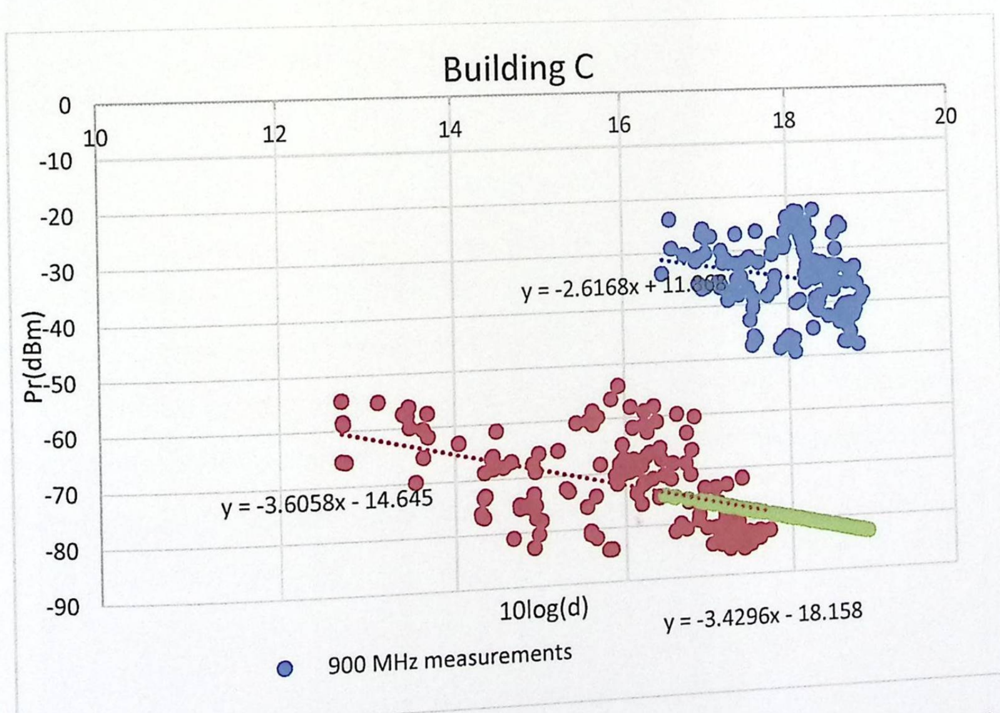


Figure 68: measured data at 900 MHz and 2.4 GHz and calculated 2.4 GHz data for building C

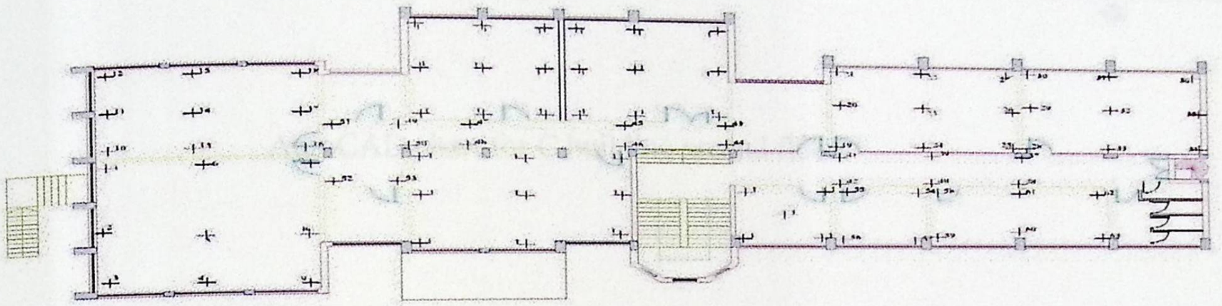
8.4 Conclusion:

In this thesis, we have come out with new models for two frequency bands which are 900 MHz and 2.4 GHz. These models included multiwall penetration loss models and indoor propagation models. A comparison of models has been illustrated throughout the previous chapters to check the accuracy of the different models.

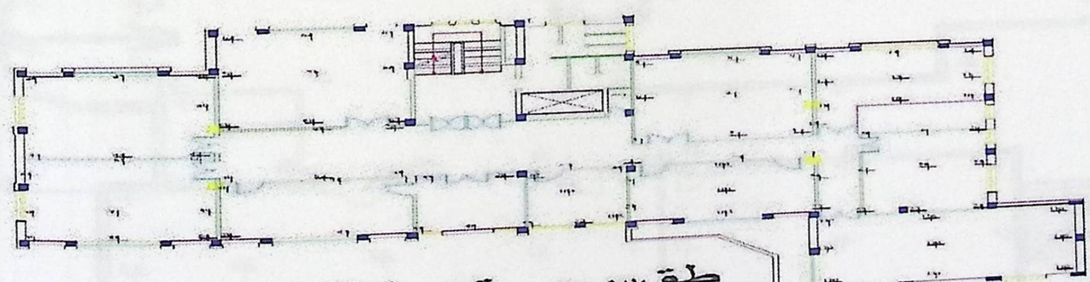
In addition, we have found the correlation between the indoor propagation models developed at the two frequency bands. This correlation permits the prediction of signal strength at 2.4 GHz if the indoor propagation model at 900 MHz is already known. Thus, this correlation may be a guideline for any operator that would like to extend the models at 900 MHz to get models for the 2.4 GHz frequency band, thus to estimate the coverage of any intended WLAN 2.4 network or WiMAX network at 2.5 GHz.

Appendix A

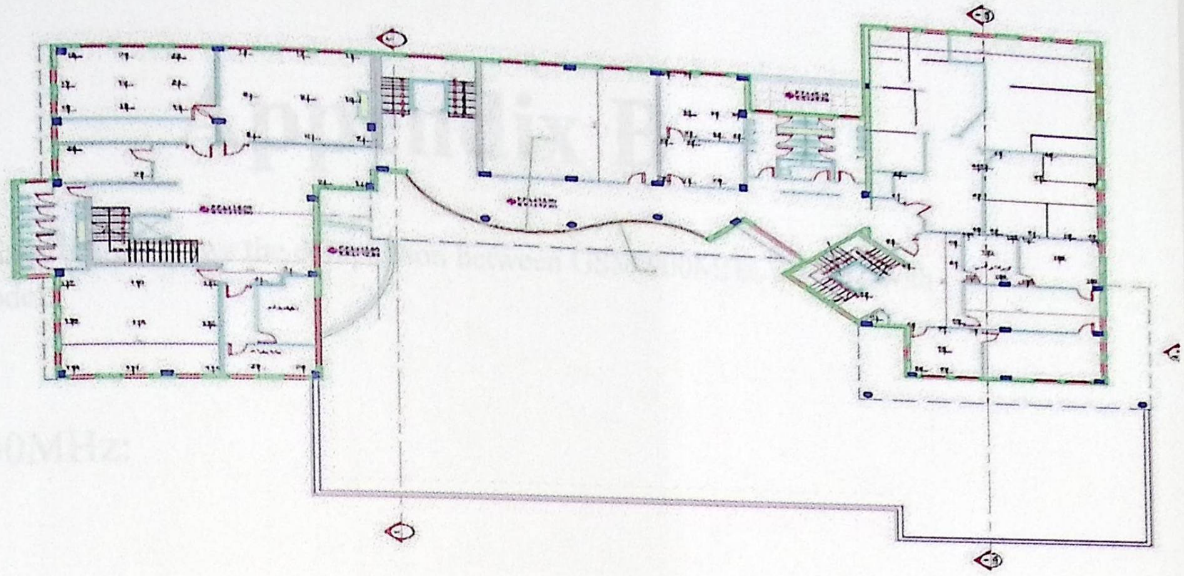
The following charts are shows the sample of one floor AutoCAD drawing for each building:



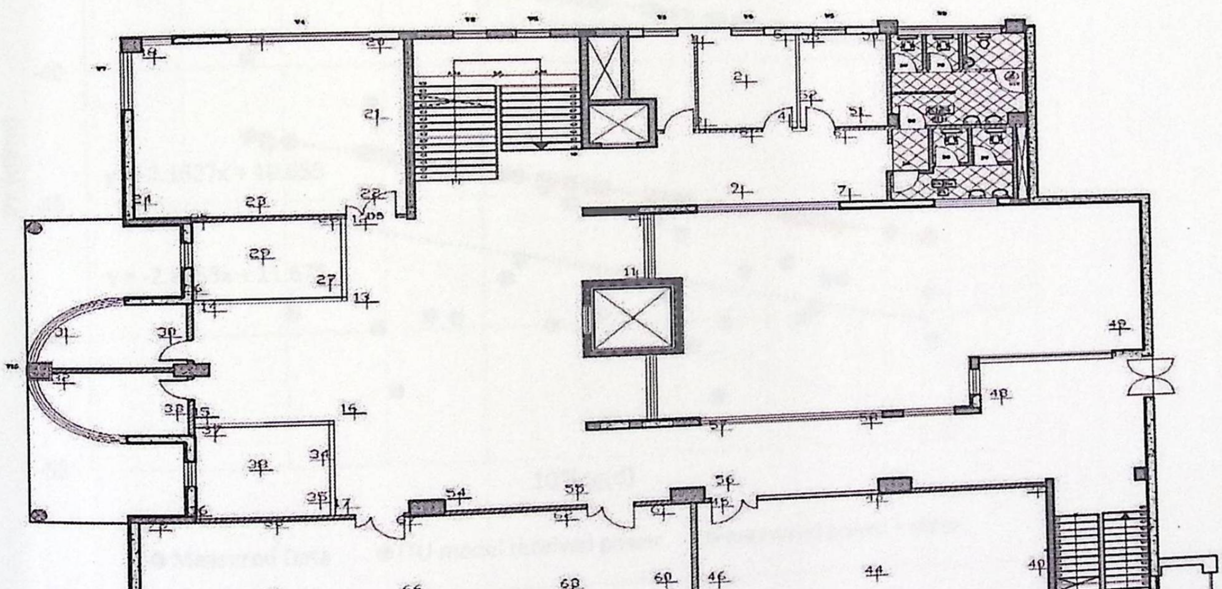
AutoCAD chart for A building third floor



AutoCAD chart for B building third floor



AutoCAD chart for C building second floor



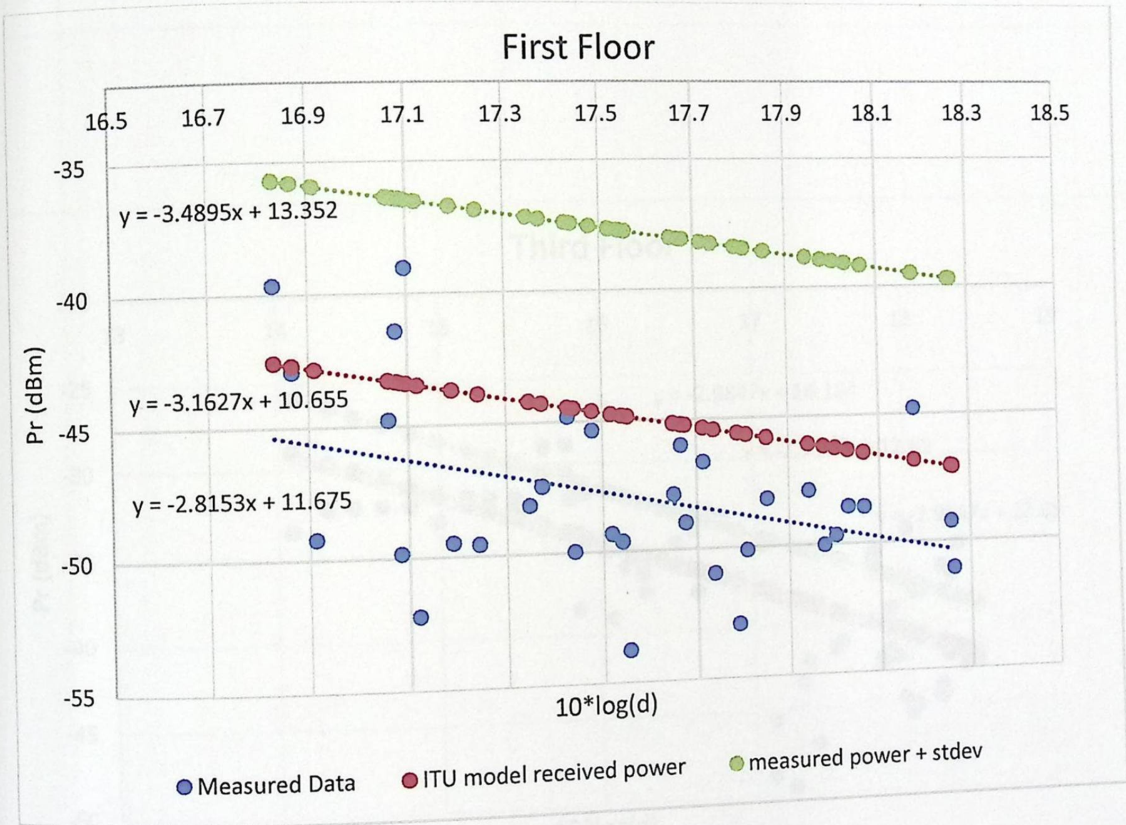
AutoCAD chart for B+ building sixth floor

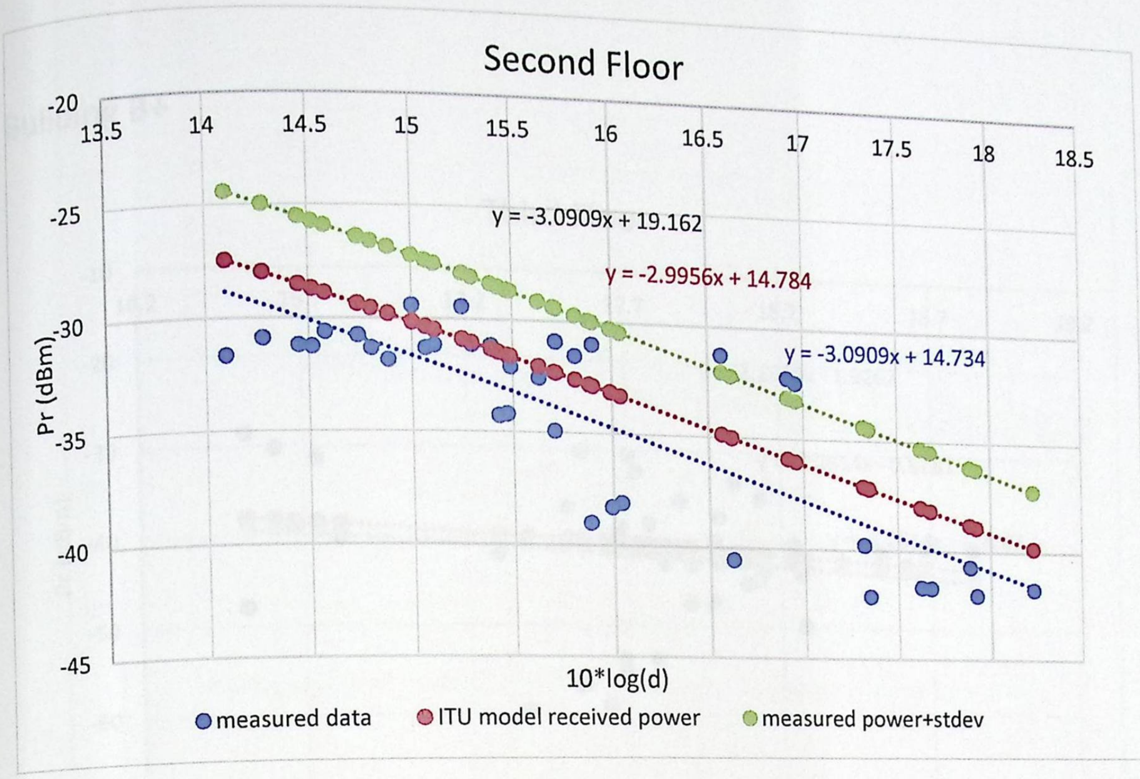
Appendix B

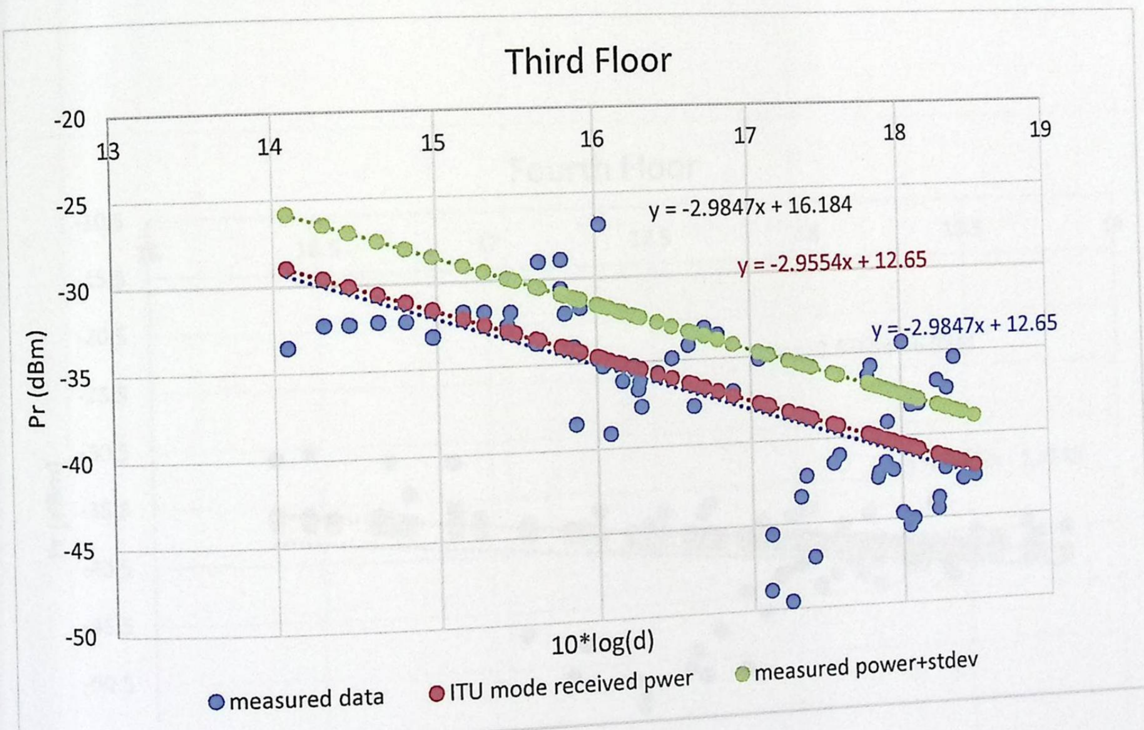
The following figures shows the comparison between GSM 900MHz, 2.4GHZ with the ITU model:

GSM 900MHz:

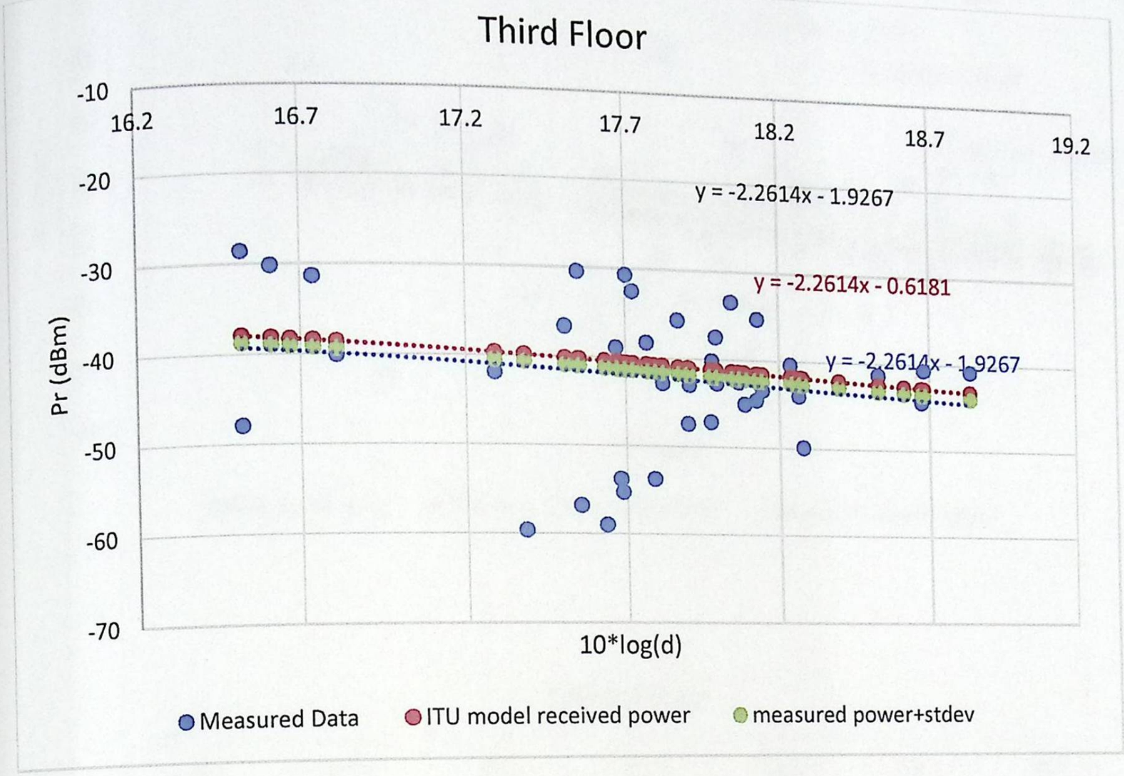
Building A



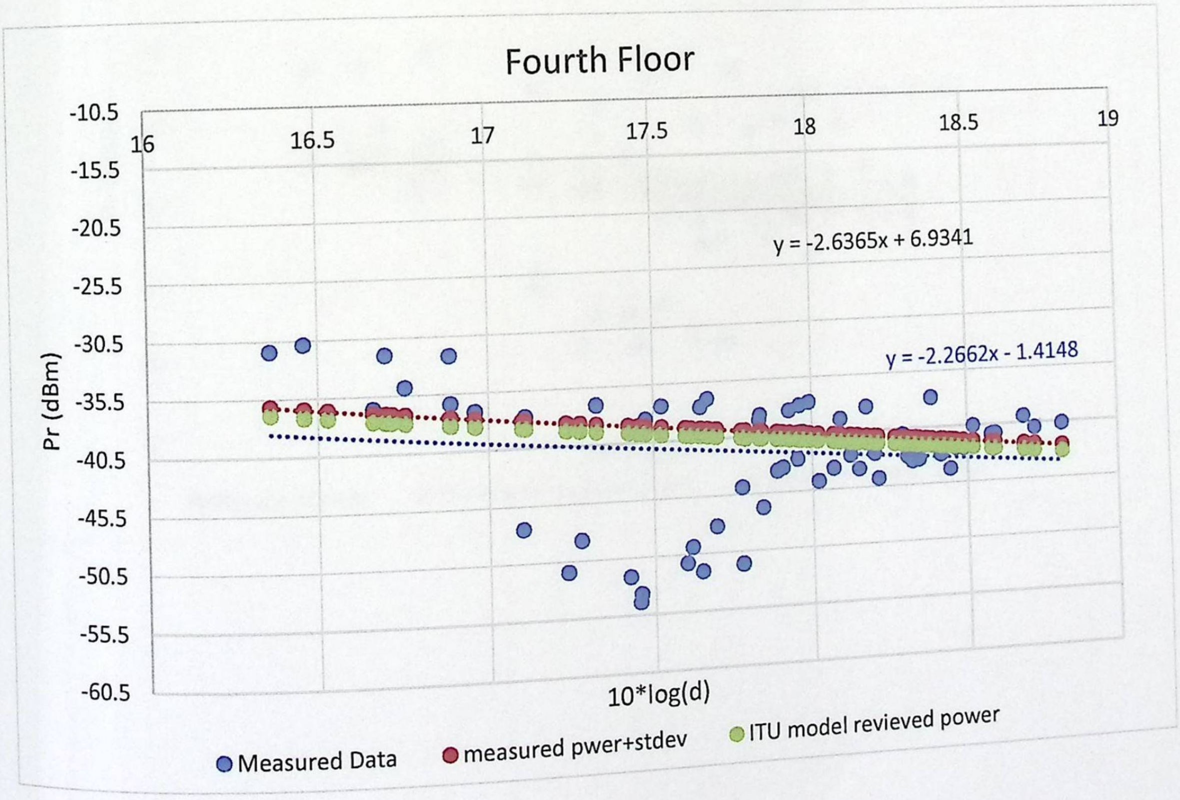

Second Floor
-20
-25
-30
-35
-40
-45
13.5
14
14.5
15
15.5
16
16.5
17
17.5
18
18.5
y = -3.0909x + 19.162
y = -2.9956x + 14.784
y = -3.0909x + 14.734
Pr (dBm)
10*log(d)
measured data
ITU model received power
measured power+stdev


Third Floor
-20
-25
-30
-35
-40
-45
-50
13
14
15
16
17
18
19
y = -2.9847x + 16.184
y = -2.9554x + 12.65
y = -2.9847x + 12.65
Pr (dBm)
10*log(d)
measured data
ITU mode received pwer
measured power+stdev

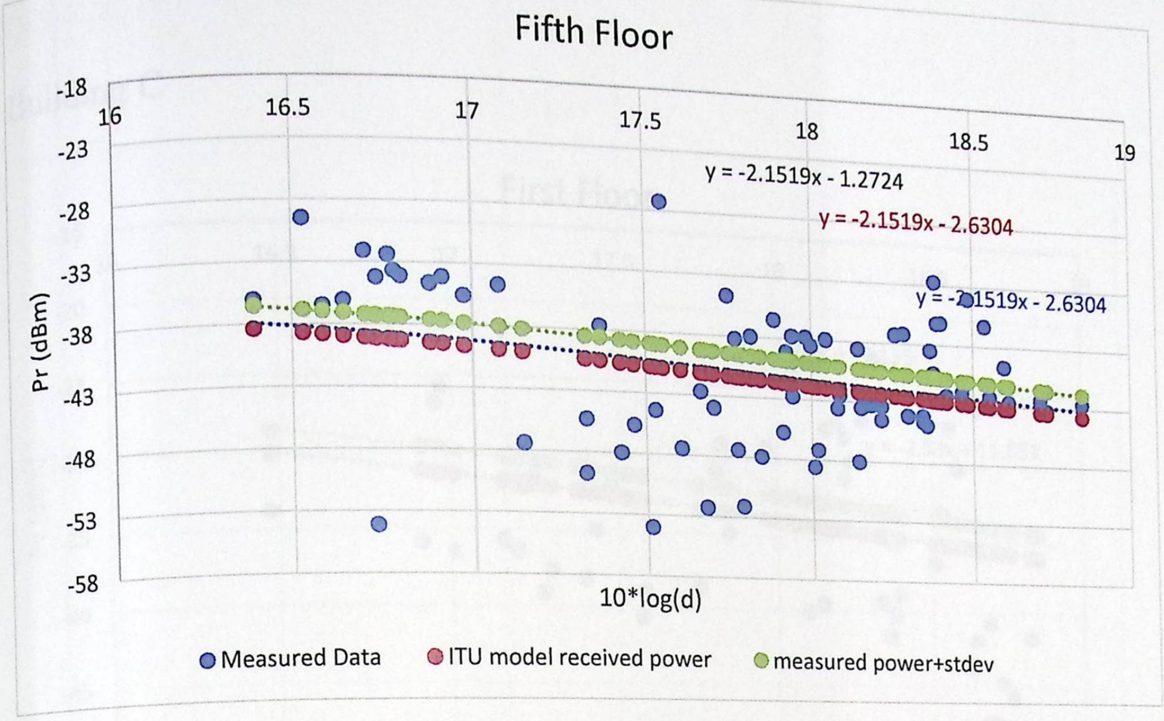
Building B+

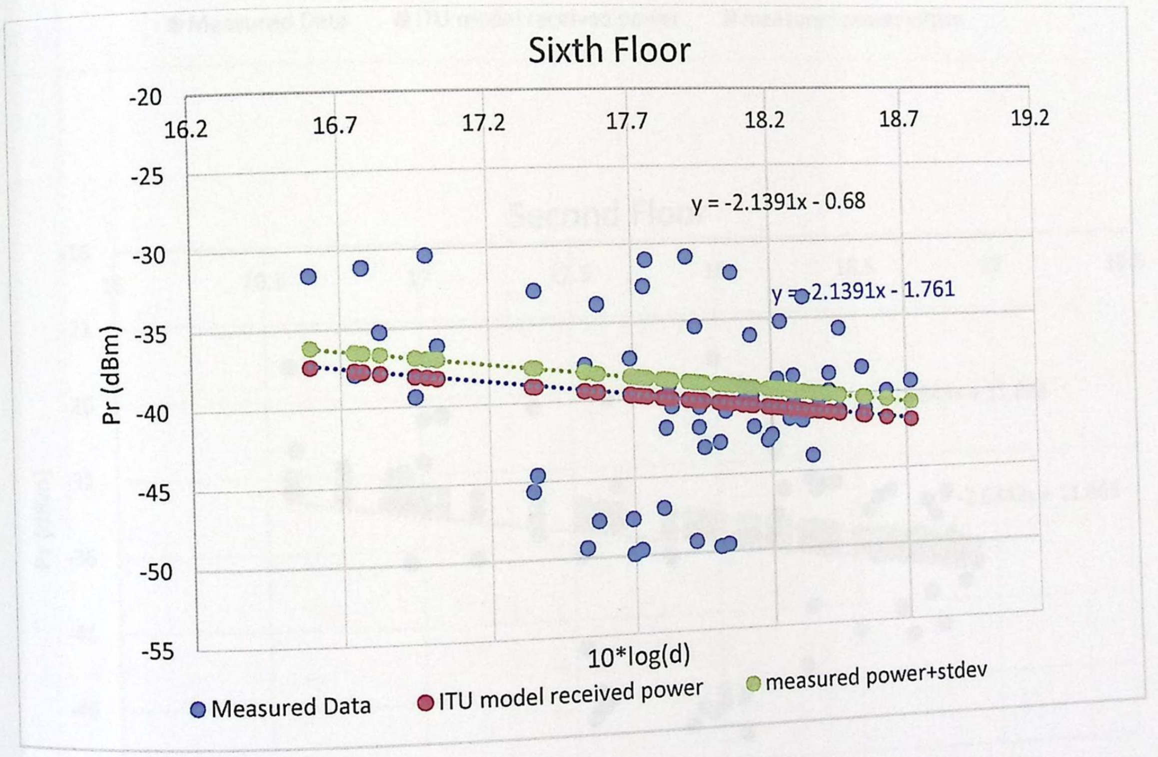


Third Floor
-10
-20
-30
-40
-50
-60
-70
16.2
16.7
17.2
17.7
18.2
18.7
19.2
Pr (dBm)
10*log(d)
y = -2.2614x - 1.9267
y = -2.2614x - 0.6181
y = -2.2614x - 1.9267
Measured Data
ITU model received power
measured power+stdev

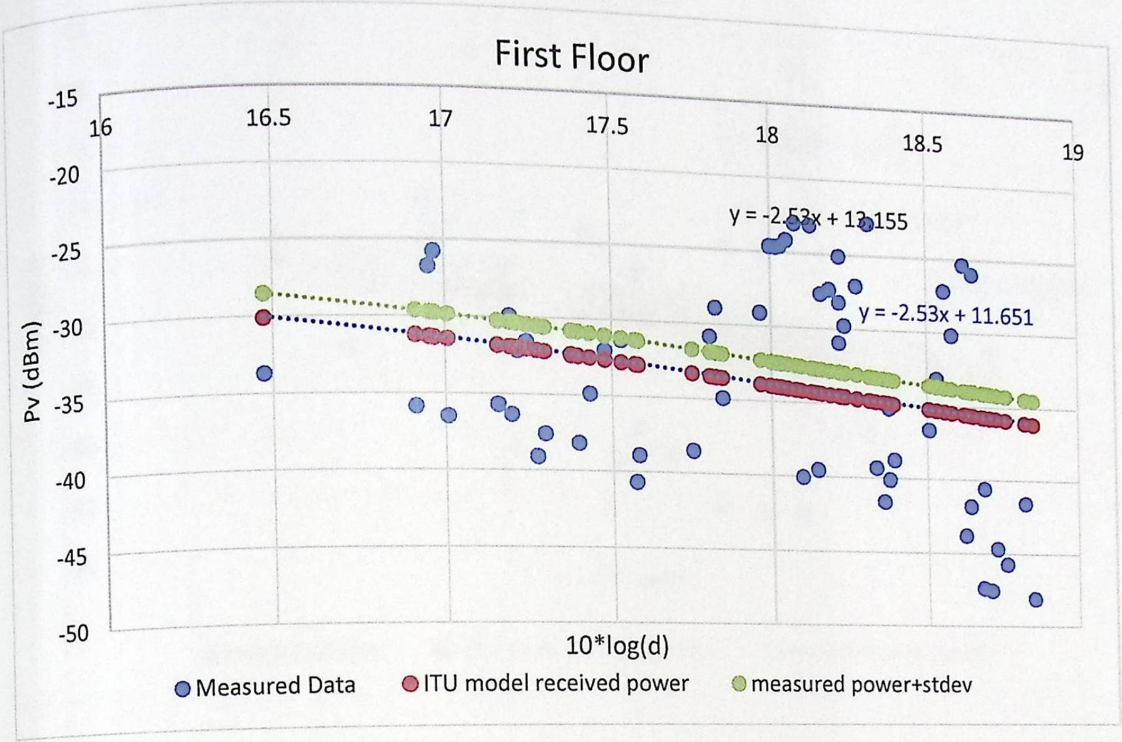


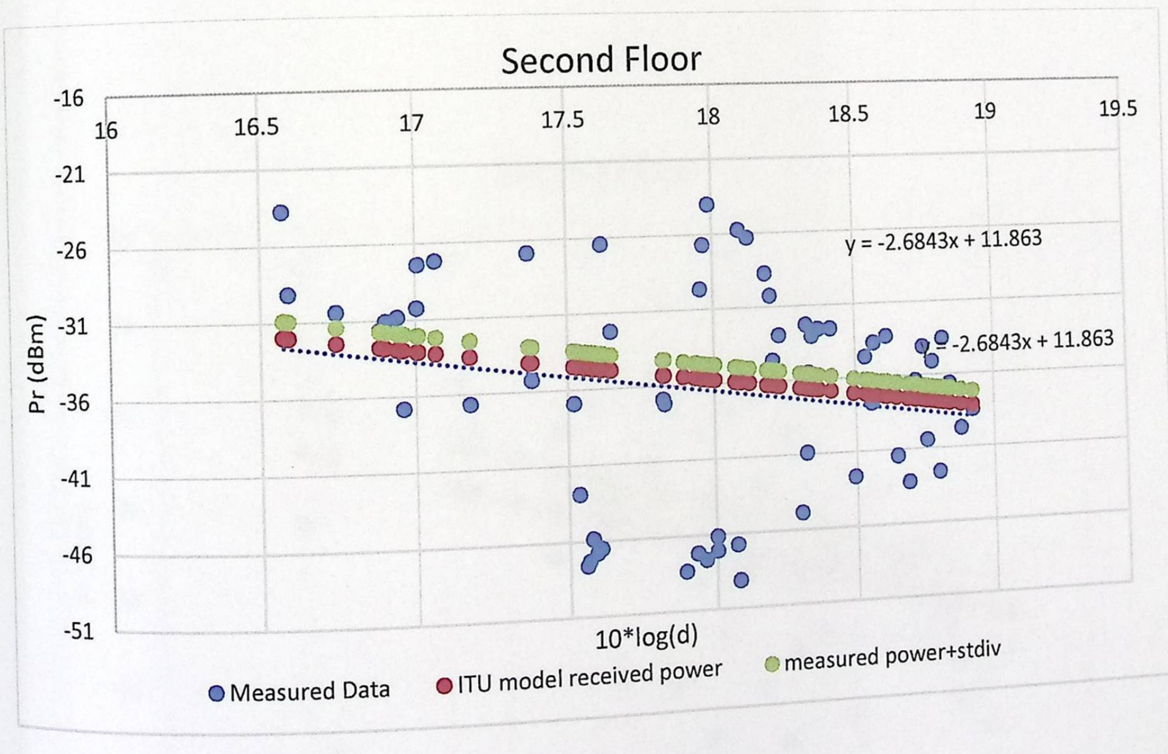
Fourth Floor
-10.5
-15.5
-20.5
-25.5
-30.5
-35.5
-40.5
-45.5
-50.5
-55.5
-60.5
16
16.5
17
17.5
18
18.5
19
Pr (dBm)
10*log(d)
y = -2.6365x + 6.9341
y = -2.2662x - 1.4148
Measured Data
measured pwer+stdev
ITU model revieved power


Fifth Floor
y = -2.1519x - 1.2724
y = -2.1519x - 2.6304
y = -2.1519x - 2.6304
Pr (dBm)
10*log(d)
Measured Data
ITU model received power
measured power+stdev

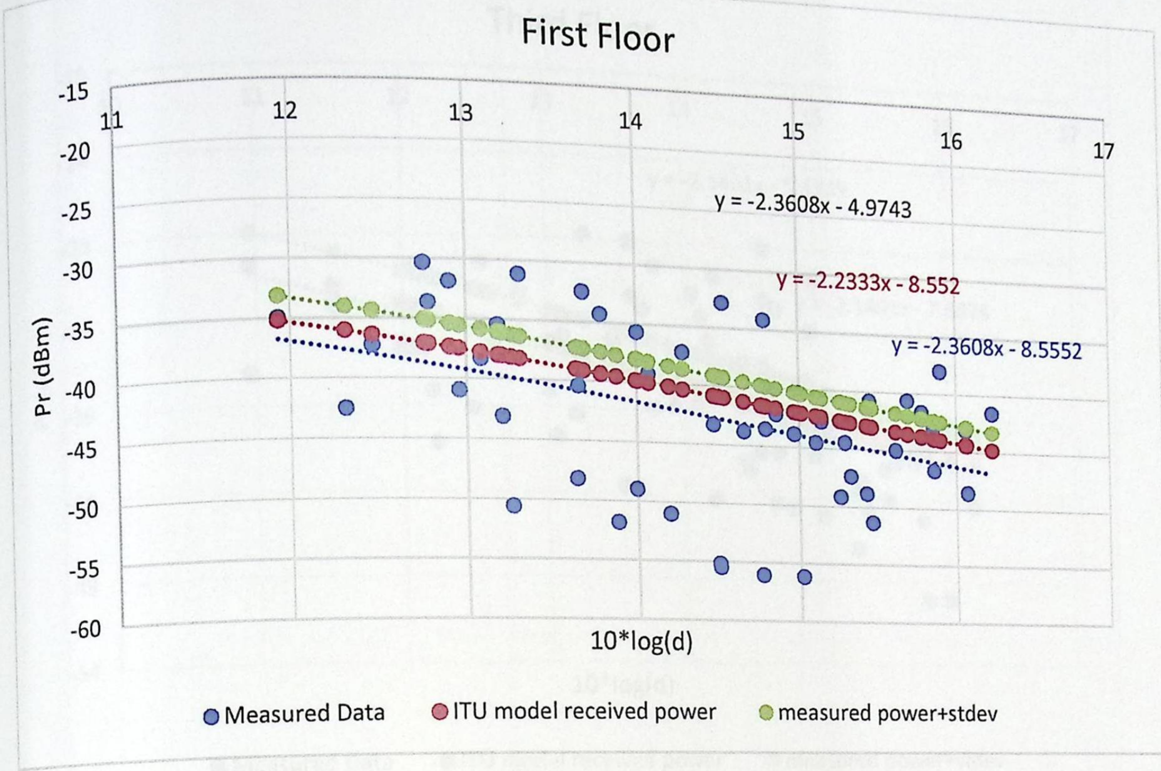

Sixth Floor
y = -2.1391x - 0.68
y = -2.1391x - 1.761
Pr (dBm)
10*log(d)
Measured Data
ITU model received power
measured power+stdev

Building C

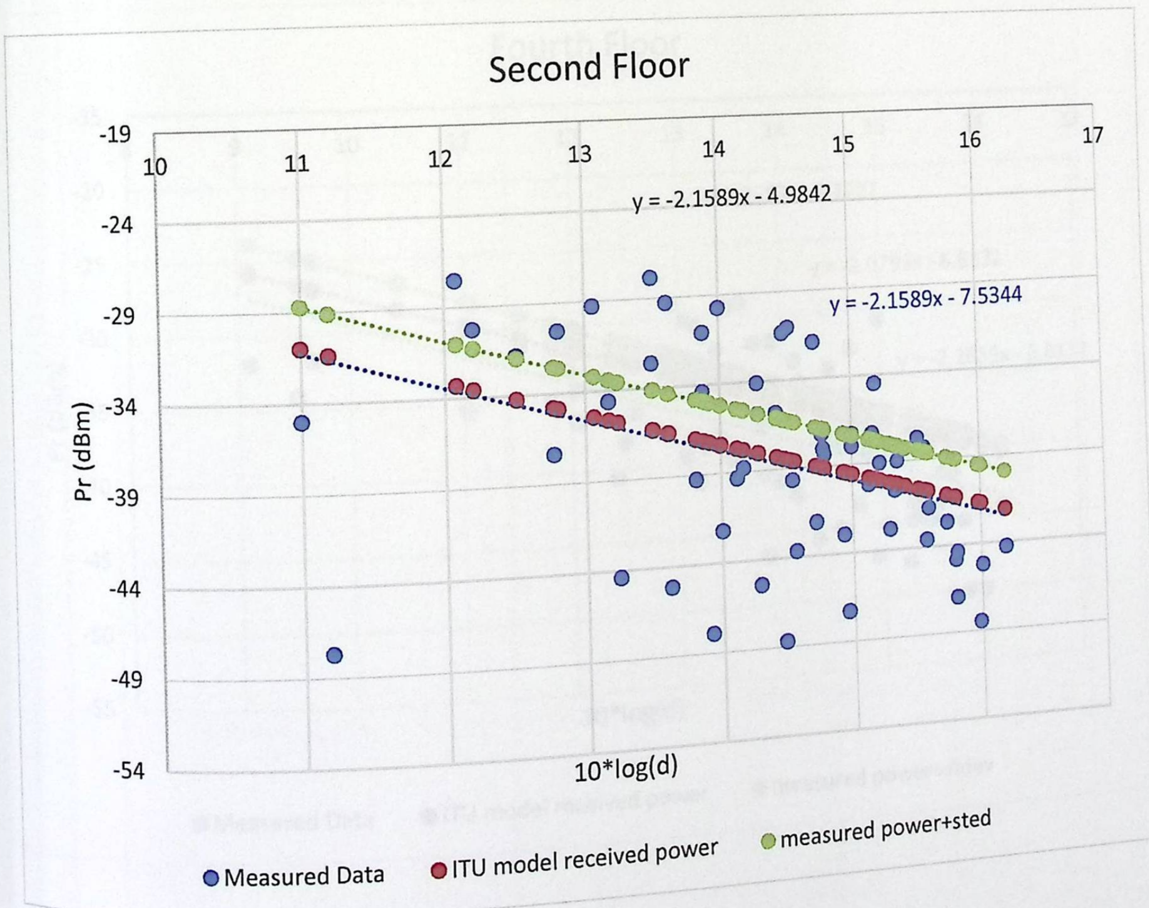

First Floor
-15
-20
-25
-30
-35
-40
-45
-50
16
16.5
17
17.5
18
18.5
19
Pv (dBm)
y = -2.53x + 13.155
y = -2.53x + 11.651
10*log(d)
Measured Data
ITU model received power
measured power+stdev


Second Floor
-16
-21
-26
-31
-36
-41
-46
-51
16
16.5
17
17.5
18
18.5
19
19.5
Pr (dBm)
y = -2.6843x + 11.863
-2.6843x + 11.863
10*log(d)
Measured Data
ITU model received power
measured power+stdiv

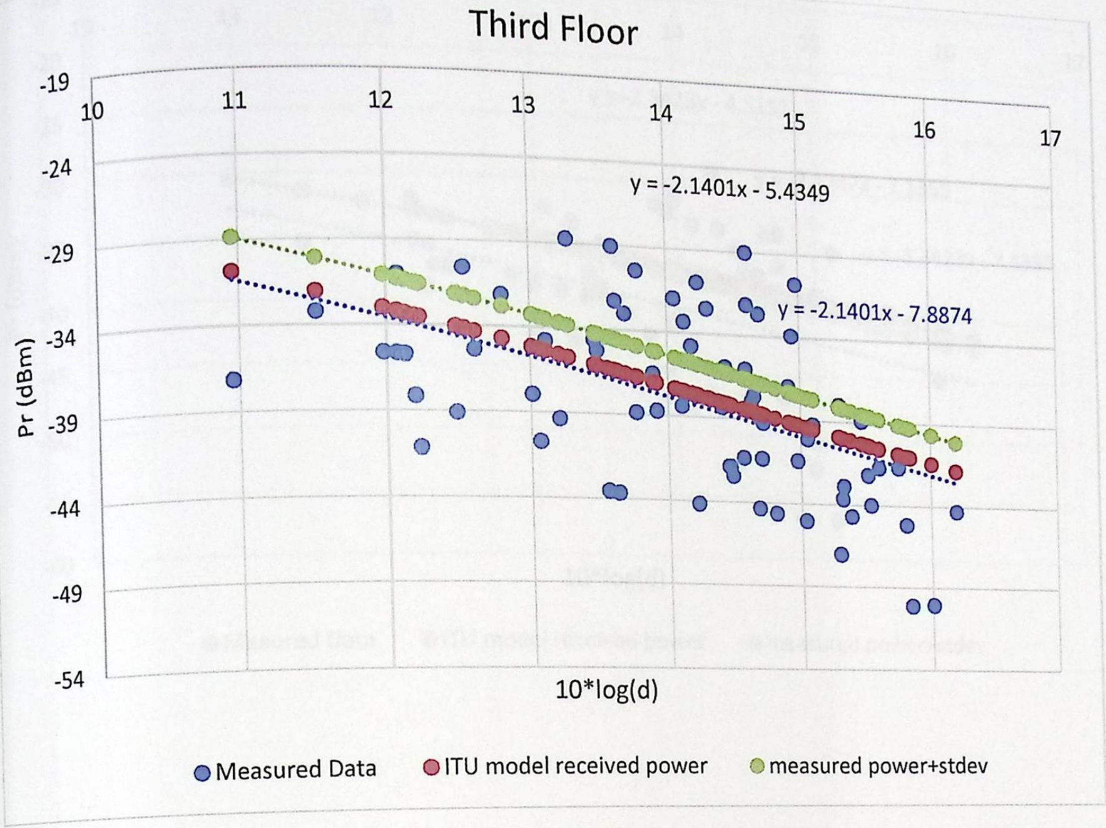
Building B

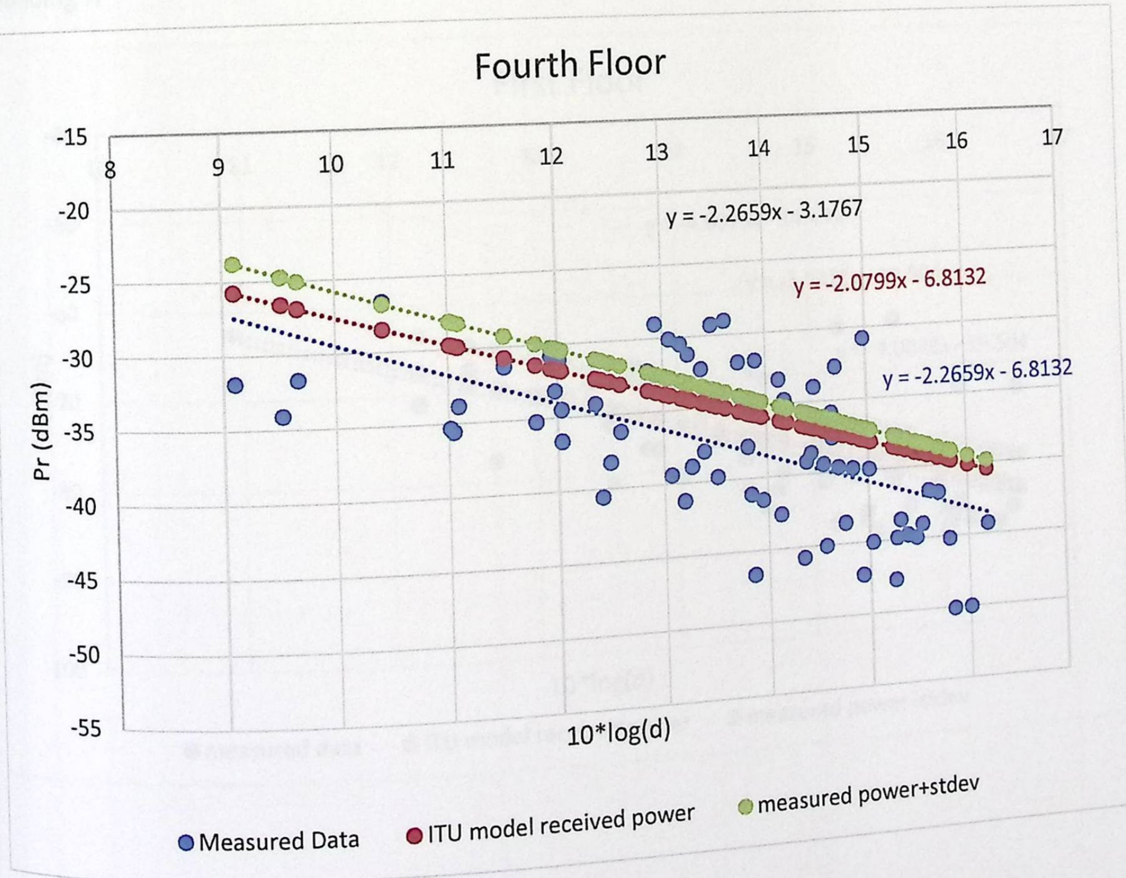


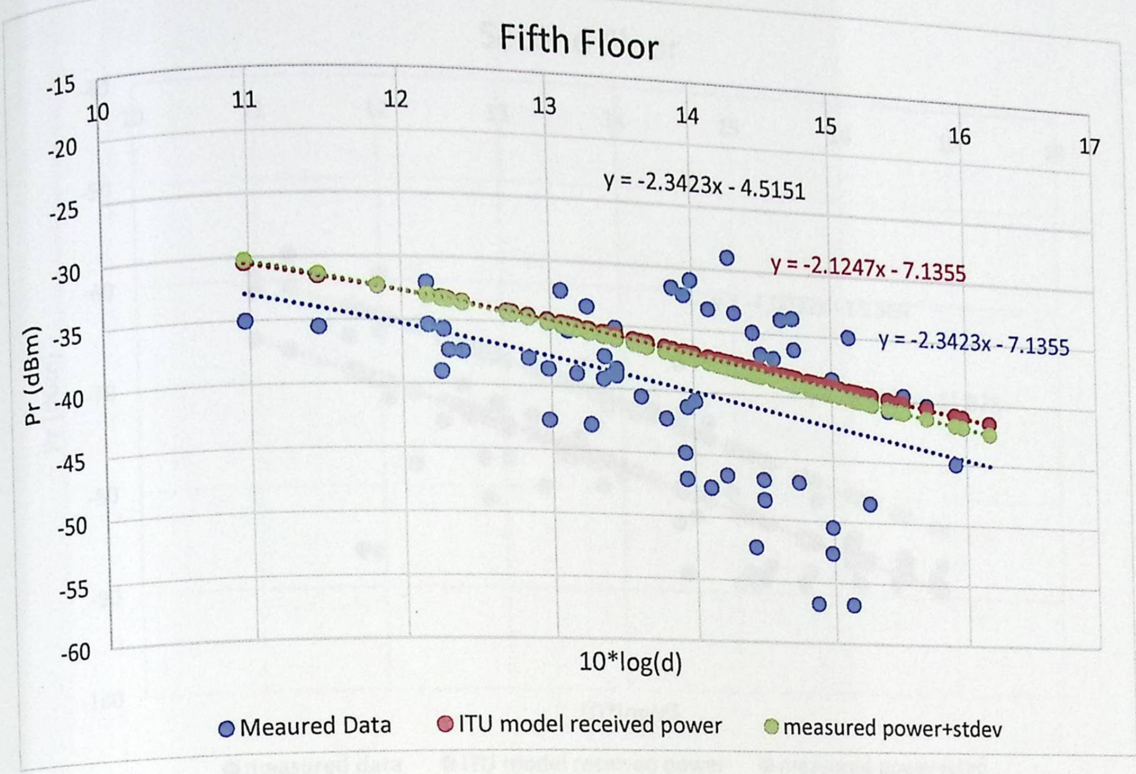
First Floor
y = -2.3608x - 4.9743
y = -2.2333x - 8.552
y = -2.3608x - 8.5552
Pr (dBm)
10*log(d)
Measured Data
ITU model received power
measured power+stdev



Second Floor
y = -2.1589x - 4.9842
y = -2.1589x - 7.5344
Pr (dBm)
10*log(d)
Measured Data
ITU model received power
measured power+sted


Third Floor
y = -2.1401x - 5.4349
y = -2.1401x - 7.8874
Pr (dBm)
10*log(d)
Measured Data
ITU model received power
measured power+stdev


Fourth Floor
y = -2.2659x - 3.1767
y = -2.0799x - 6.8132
y = -2.2659x - 6.8132
Pr (dBm)
10*log(d)
Measured Data
ITU model received power
measured power+stdev



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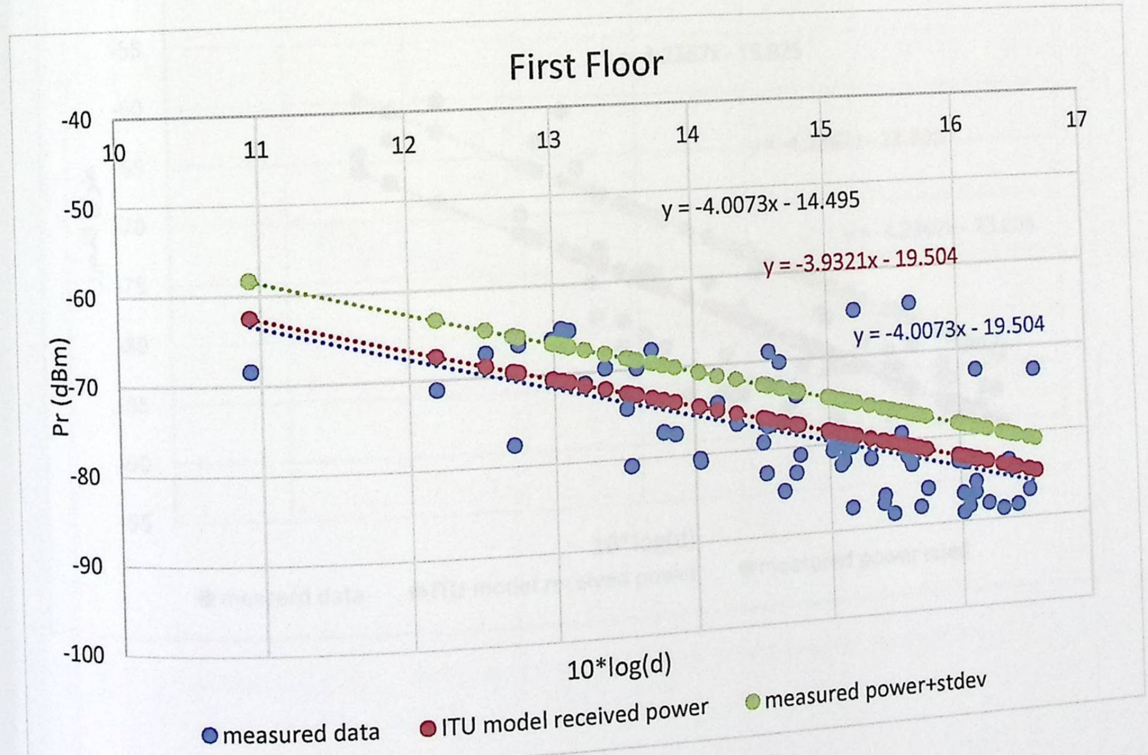
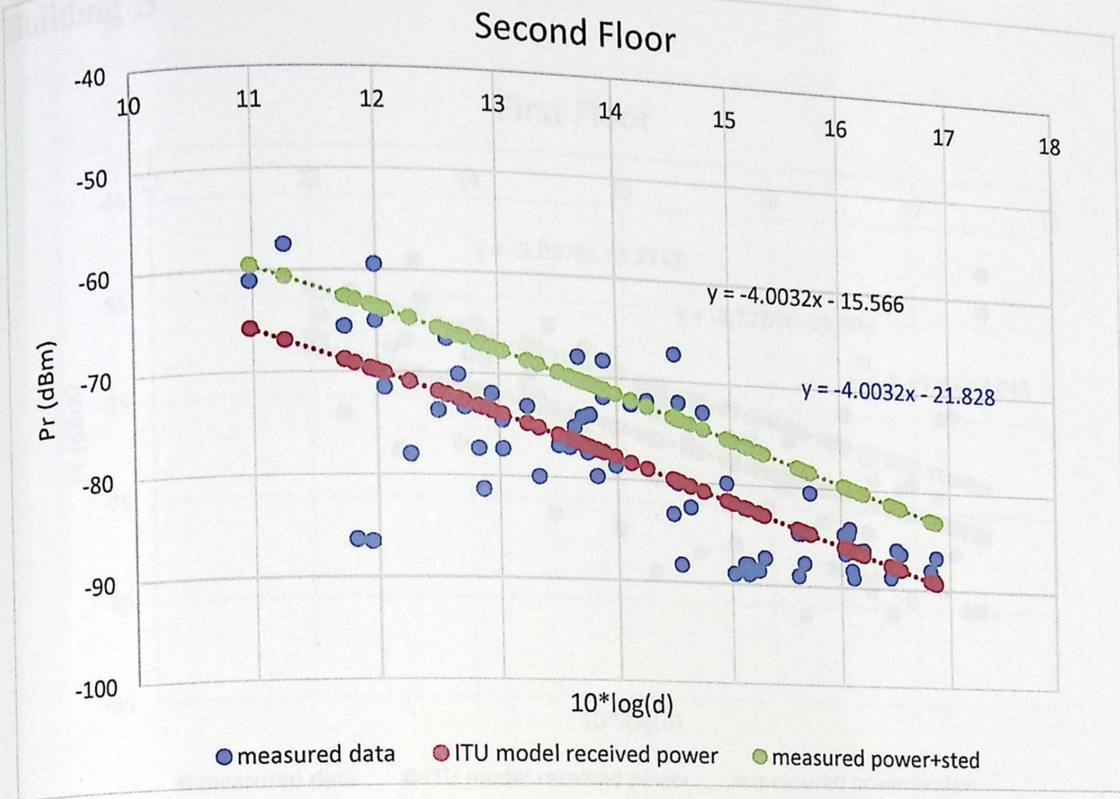
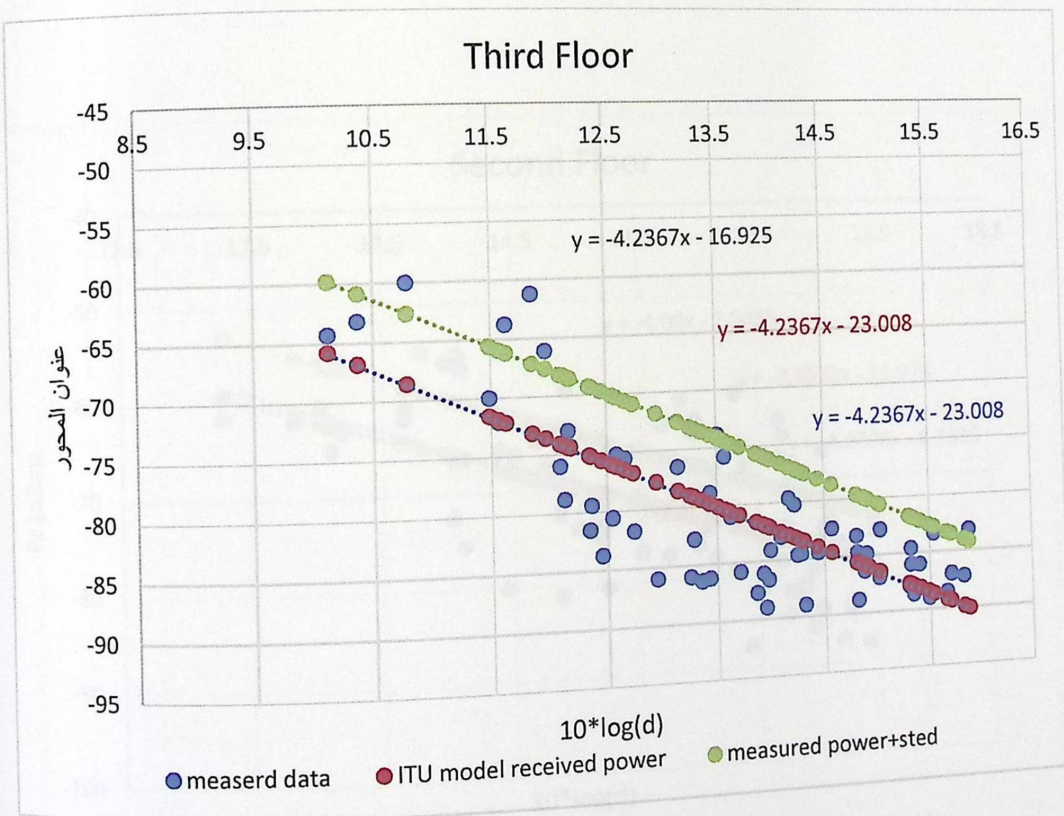
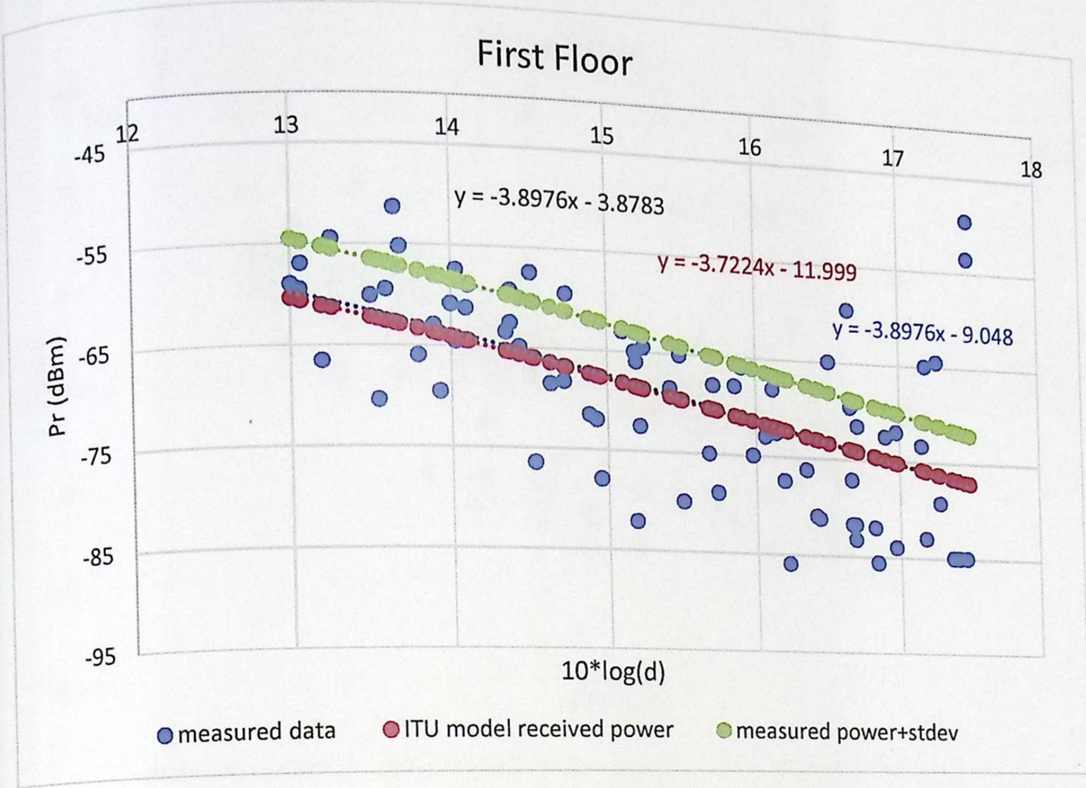
Building A



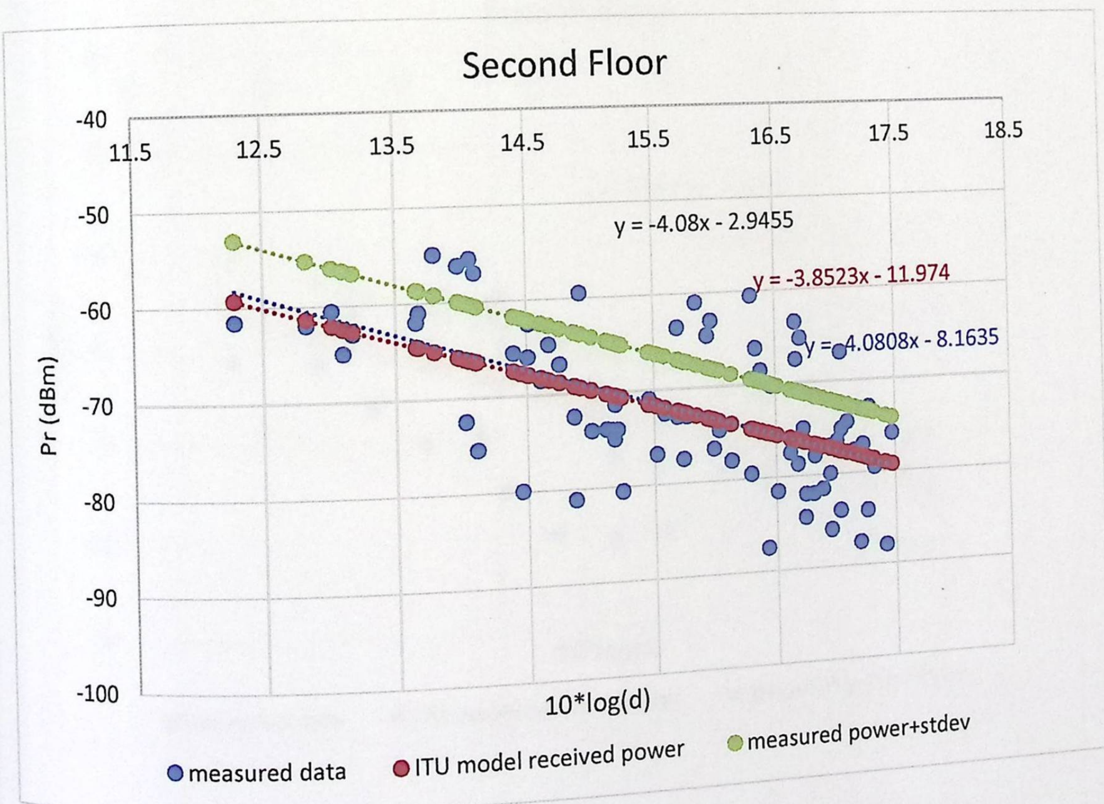

Second Floor
y = -4.0032x - 15.566
y = -4.0032x - 21.828
Pr (dBm)
10*log(d)
measured data
ITU model received power
measured power+sted


Third Floor
y = -4.2367x - 16.925
y = -4.2367x - 23.008
y = -4.2367x - 23.008
عنوان المحور
10*log(d)
measerd data
ITU model received power
measured power+sted

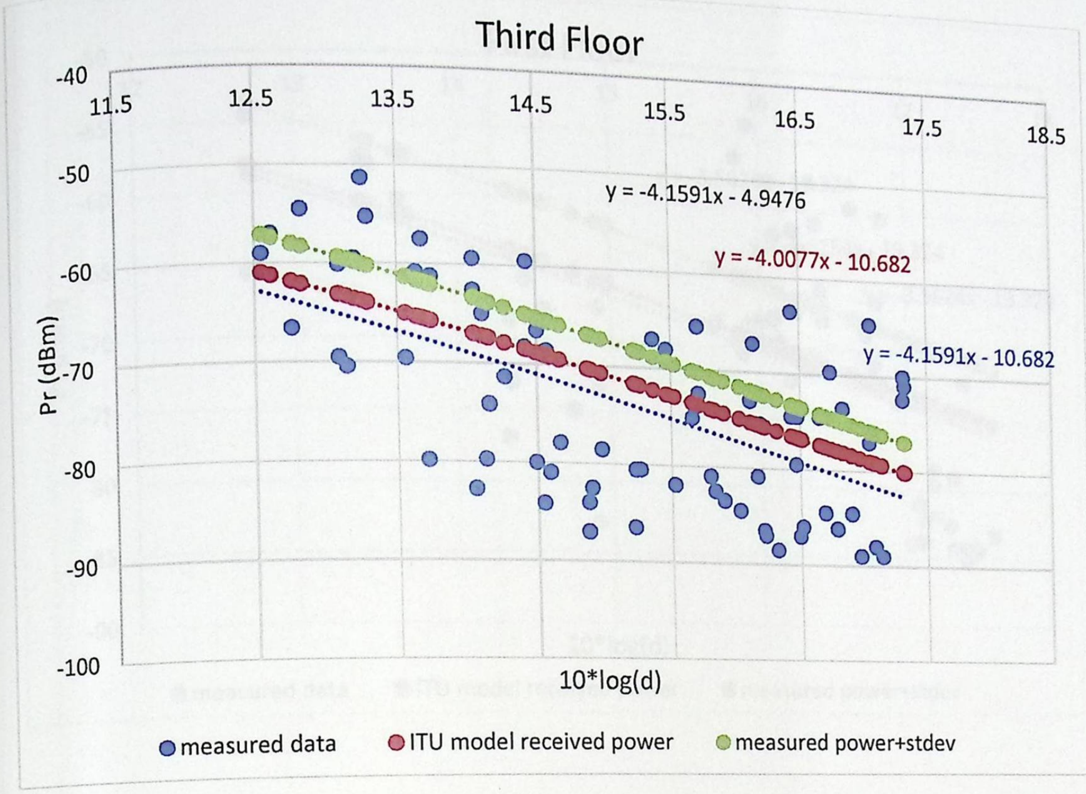
Building B

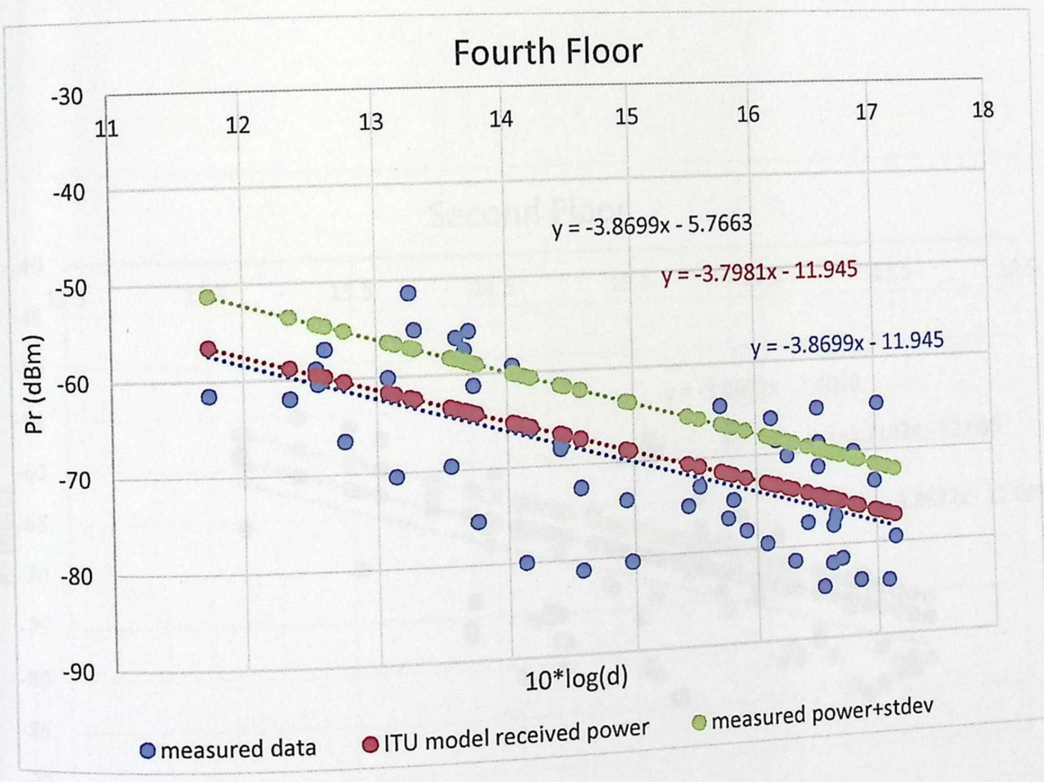


First Floor
y = -3.8976x - 3.8783
y = -3.7224x - 11.999
y = -3.8976x - 9.048
Pr (dBm)
10*log(d)
measured data
ITU model received power
measured power+stdev

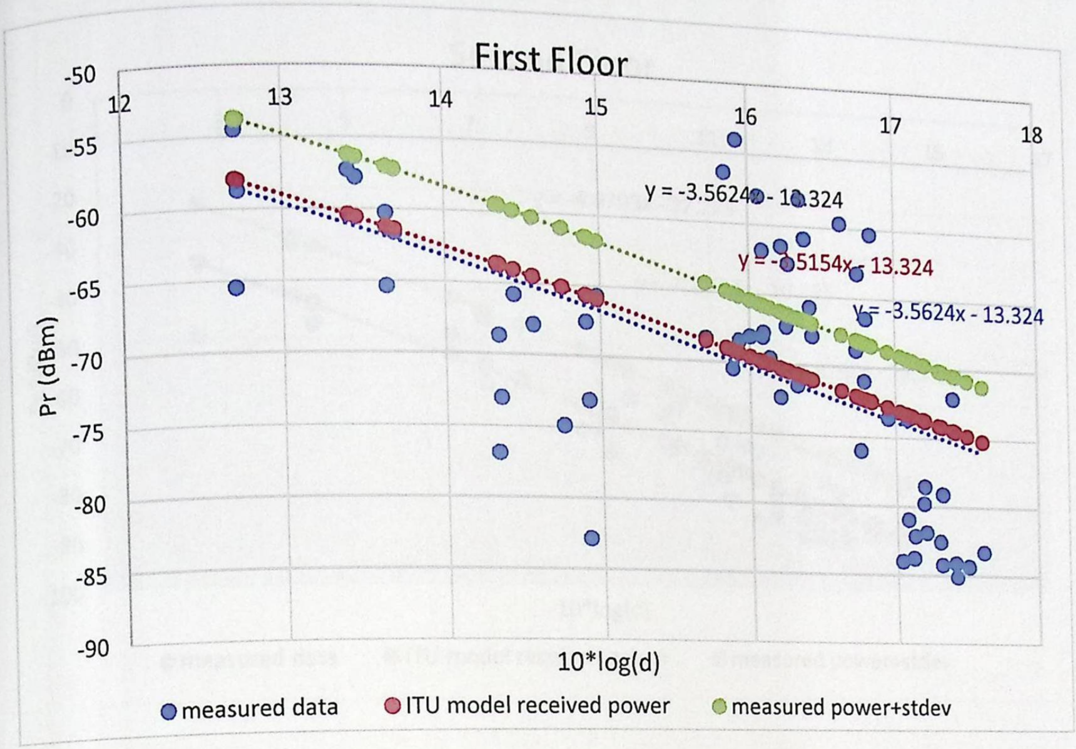


Second Floor
y = -4.08x - 2.9455
y = -3.8523x - 11.974
y = -4.0808x - 8.1635
Pr (dBm)
10*log(d)
measured data
ITU model received power
measured power+stdev

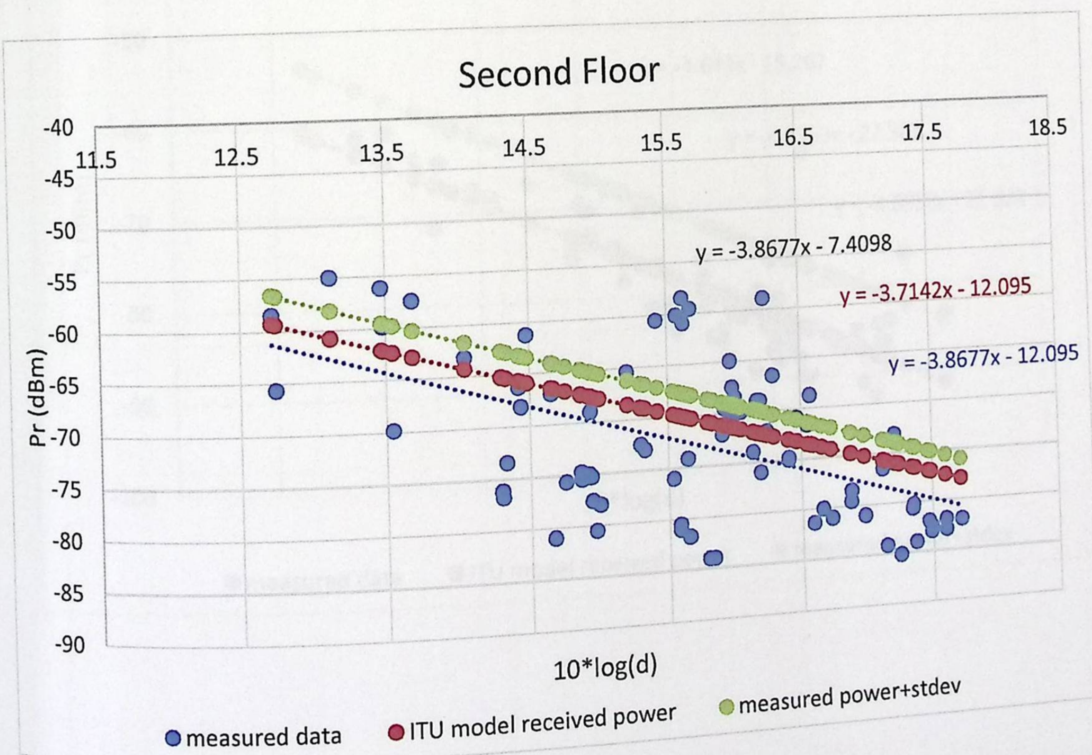

Third Floor
Pr (dBm)
10*log(d)
y = -4.1591x - 4.9476
y = -4.0077x - 10.682
y = -4.1591x - 10.682
measured data
ITU model received power
measured power+stdev


Fourth Floor
Pr (dBm)
10*log(d)
y = -3.8699x - 5.7663
y = -3.7981x - 11.945
y = -3.8699x - 11.945
measured data
ITU model received power
measured power+stdev

Building C:

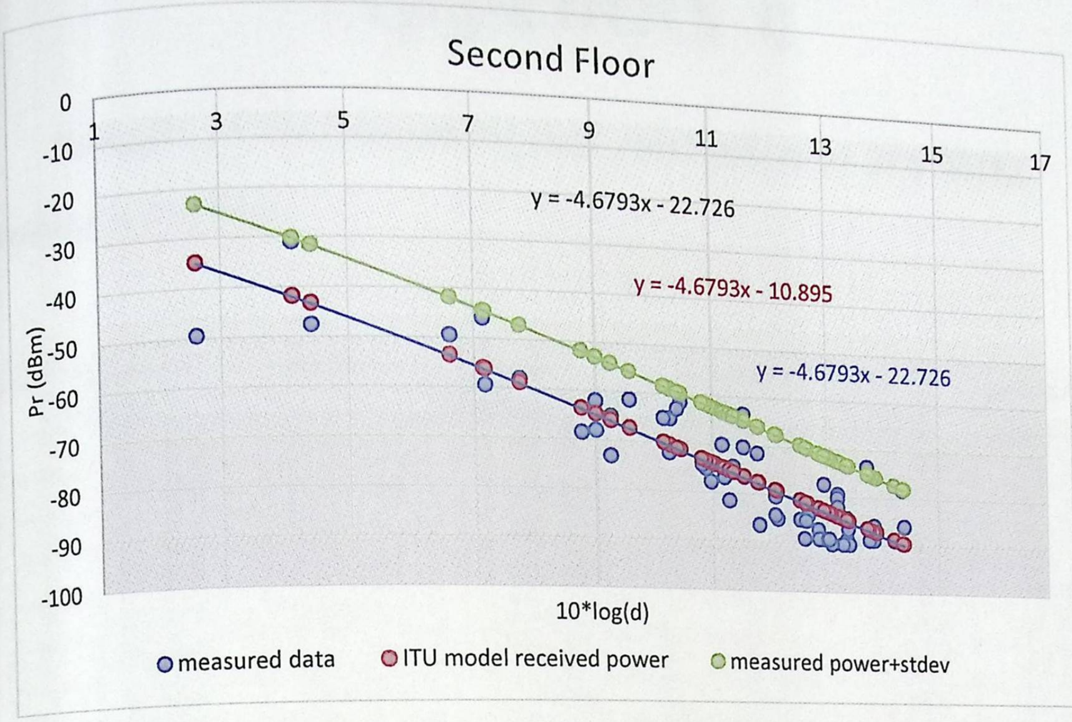


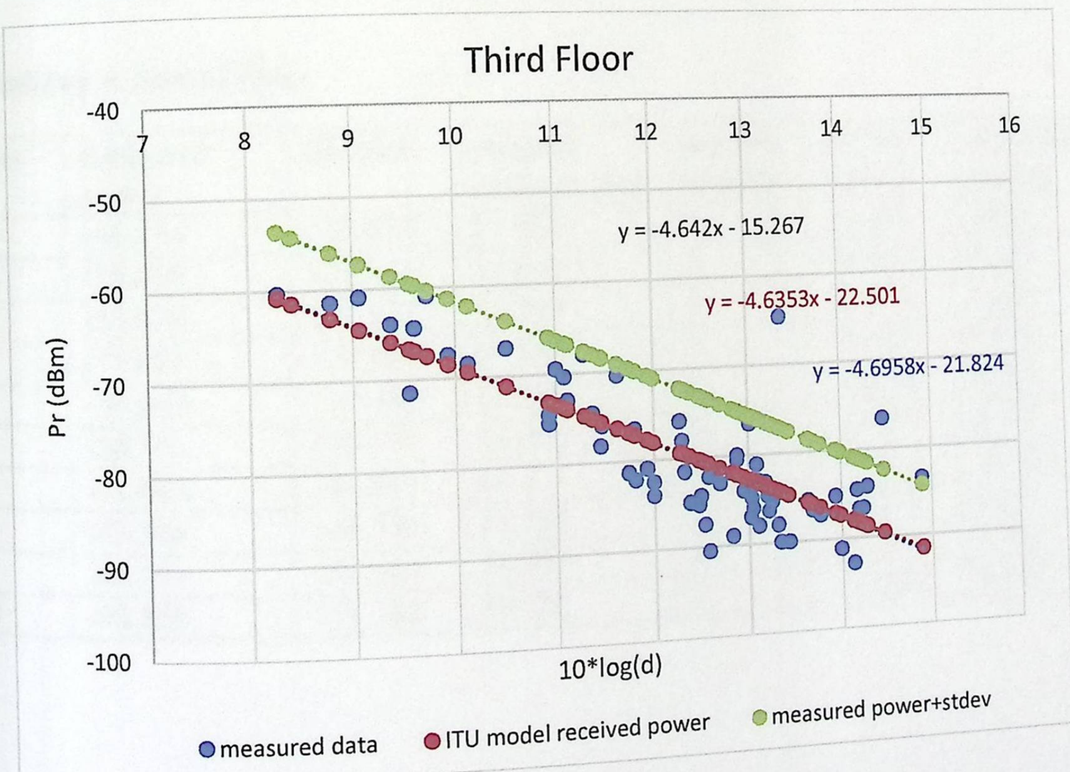
First Floor
y = -3.5624x - 13.324
y = -3.5154x - 13.324
y = -3.5624x - 13.324
Pr (dBm)
10*log(d)
measured data
ITU model received power
measured power+stdev



Second Floor
y = -3.8677x - 7.4098
y = -3.7142x - 12.095
y = -3.8677x - 12.095
Pr (dBm)
10*log(d)
measured data
ITU model received power
measured power+stdev

AL-Ahli Building





Appendix c

Sample of measurement and calculation at 900 MHZ

Building A first floor

point	measured power	distance	reduced distance (d0)	number of walls	pr (ITU model)	pr(SRAB model)
1	-33.325	121.332	36.332	0	-40.443	-31.282
2	-33.078	122.344	37.344	0	-40.557	-31.381
3	-37.173	129.731	44.731	1	-41.363	-36.734
4	-39.300	130.686	45.686	1	-41.463	-36.821
5	-42.919	133.612	48.612	2	-41.768	-41.929
6	-50.983	144.394	59.394	2	-42.833	-47.724
7	-46.669	144.090	59.090	3	-42.805	-47.699
8	-49.677	148.134	63.134	4	-43.185	-52.932
9	-44.797	150.719	65.719	5	-43.422	-58.221
10	-53.812	141.938	56.938	4	-42.598	-52.426

Building A second floor

point	measured power	distance	reduced distance (d0)	number of walls	pr (ITU model)	pr(SRAB model)
1	-31.130	118.858	33.858	0	-36.695	3.641
2	-29.430	116.642	31.642	0	-36.450	0.180
3	-30.878	111.762	26.762	1	-35.894	5.284
4	-31.654	110.680	25.680	1	-35.767	1.992
5	-39.097	137.980	52.980	2	-38.636	1.793
6	-38.161	140.476	55.476	4	-38.869	6.153
7	-42.463	146.411	61.411	3	-39.408	12.449
8	-43.304	144.750	59.750	3	-39.259	6.541
9	-48.521	143.983	58.983	4	-39.190	4.772
10	-48.855	145.182	60.182	5	-39.298	3.783

Building A third floor

point	measured power	Distance	reduced distance (d0)	number of walls	pr (ITU model)	pr(SRAB model)
1	-31.872	120.161	35.161	0	-35.984	-29.231
2	-33.729	121.460	36.460	2	-36.122	-38.861
3	-32.049	123.051	38.051	2	-36.289	-39.009
4	-34.047	123.532	38.532	2	-36.339	-39.054
5	-35.272	127.062	42.062	1	-36.701	-34.529
6	-37.670	127.509	42.509	3	-36.746	-44.293
7	-37.757	130.978	45.978	2	-37.090	-39.723
8	-35.147	135.749	50.749	1	-37.549	-35.285
9	-45.582	136.560	51.560	2	-37.626	-40.199
10	-43.438	138.950	53.950	2	-37.848	-40.397

Building C first floor

point	measured power	distance	reduced distance (d0)	number of walls	pr (ITU model)	pr(SRAB model)
1	-42.549	220.240	65.240	2	-36.520	-36.886
2	-43.073	219.503	64.503	2	-36.482	-36.853
3	-41.525	214.546	59.546	2	-36.219	-36.629
4	-33.851	215.329	60.329	0	-36.261	-27.158
5	-31.906	215.585	60.585	2	-36.275	-36.677
6	-37.948	215.864	60.864	1	-36.289	-31.843
7	-33.946	221.338	66.338	2	-36.577	-36.935
8	-38.284	223.801	68.801	1	-36.704	-32.196
9	-41.759	224.071	69.071	1	-36.718	-32.208
10	-50.568	229.240	74.240	3	-36.980	-42.155

Building C second floor

point	measured power	distance	reduced distance (d0)	number of walls	pr (ITU model)	pr(SRAB model)
1	-29.787	219.441	64.441	1	-33.903	-33.009
2	-30.332	219.912	64.912	0	-33.926	-28.370
3	-36.266	213.160	58.160	1	-33.583	-32.719
4	-30.475	212.775	57.775	0	-33.563	-28.041
5	-36.635	224.388	69.388	1	-34.148	-33.232
6	-36.641	223.677	68.677	1	-34.113	-33.200
7	-36.311	223.014	68.014	1	-34.081	-33.170
8	-37.326	227.641	72.641	1	-34.307	-33.375
9	-37.729	226.881	71.881	1	-34.270	-33.342
10	-38.640	226.374	71.374	1	-34.245	-33.320

Building B+ third floor

point	measured power	distance	reduced distance (d0)	number of walls	pr (ITU model)	pr(SRAB model)
1	-32.241	379.058	54.058	0	-42.047	-32.825
2	-30.447	381.895	56.895	0	-42.119	-32.886
3	-32.545	384.210	59.210	0	-42.178	-32.935
4	-36.661	381.357	56.357	1	-42.106	-37.534
5	-30.731	383.938	58.938	0	-42.171	-32.929
6	-38.962	383.483	58.483	1	-42.160	-37.580
7	-35.685	386.242	61.242	1	-42.229	-37.638
8	-33.439	388.743	63.743	0	-42.292	-33.030
9	-42.973	386.738	61.738	2	-42.242	-42.495
10	-44.564	389.920	64.920	2	-42.321	-42.562

Building B+ fourth floor

point	measured power	distance	reduced distance (d0)	number of walls	pr (ITU model)	pr(SRAB model)
1	-37.675	383.152	58.152	1	-41.573	-37.249
2	-38.530	380.913	55.913	1	-41.516	-37.202
3	-37.050	379.008	54.008	1	-41.468	-37.161
4	-37.437	381.565	56.565	1	-41.533	-37.216
5	-37.006	383.456	58.456	1	-41.580	-37.256
6	-39.096	385.681	60.681	2	-41.636	-42.149
7	-37.733	387.937	62.937	1	-41.692	-37.349
8	-38.671	385.726	60.726	1	-41.637	-37.303
9	-39.955	383.845	58.845	2	-41.590	-42.110
10	-34.825	372.359	47.359	0	-41.299	-32.358

Building B+ fifth floor

point	measured power	distance	reduced distance (d0)	number of walls	pr (ITU model)	pr(SRAB model)
1	-34.137	372.860	47.860	0	-40.613	-32.317
2	-36.495	370.539	45.539	1	-40.554	-36.927
3	-34.239	372.127	47.127	1	-40.595	-36.961
4	-34.681	373.776	48.776	1	-40.637	-36.997
5	-34.161	374.167	49.167	1	-40.646	-37.005
6	-34.679	376.008	51.008	1	-40.693	-37.045
7	-45.322	378.999	53.999	3	-40.768	-46.832
8	-45.710	380.763	55.763	3	-40.812	-46.870
9	-38.229	384.819	59.819	2	-40.912	-42.079
10	-39.113	386.995	61.995	2	-40.966	-42.124

Building B+ sixth floor

point	measured power	distance	reduced distance (d0)	number of walls	pr (ITU model)	pr(SRAB model)
1	-49.277	386.904	61.904	3	-40.020	-46.032
2	-49.698	388.193	63.193	3	-40.051	-46.059
3	-42.579	391.069	66.069	2	-40.120	-41.240
4	-49.906	383.820	58.820	3	-39.945	-45.969
5	-47.685	382.151	57.151	3	-39.905	-45.934
6	-45.663	379.272	54.272	3	-39.834	-45.875
7	-50.109	381.302	56.302	3	-39.884	-45.917
8	-47.664	383.774	58.774	3	-39.944	-45.968
9	-41.894	385.475	60.475	2	-39.985	-41.126
10	-50.436	386.764	61.764	3	-40.016	-46.029

Building B first floor

point	measured power	distance	reduced distance (d0)	number of walls	pr (ITU model)	pr(SRAB model)
1	-29.161	360.498	23.498	0	-41.613	-32.771
2	-29.654	362.206	25.206	0	-41.659	-32.809
3	-34.243	373.377	36.377	1	-41.953	-37.719
4	-32.975	369.506	32.506	1	-41.852	-37.633
5	-47.087	352.356	15.356	2	-41.391	-42.090
6	-48.435	353.889	16.889	2	-41.433	-42.126
7	-44.573	369.397	32.397	3	-41.849	-47.354
8	-47.417	371.065	34.065	3	-41.893	-47.391
9	-51.040	363.275	26.275	4	-41.687	-52.122
10	-55.499	365.176	28.176	4	-41.738	-52.165

Building B second floor

point	measured power	distance	reduced distance (d0)	number of walls	pr (ITU model)	pr(SRAB model)
1	-46.996	375.035	38.035	4	-39.469	-52.373
2	-48.462	376.638	39.638	3	-39.508	-47.503
3	-29.289	357.239	20.239	0	-39.018	-32.685
4	-30.566	356.070	19.070	0	-38.988	-32.659
5	-43.134	361.556	24.556	1	-39.130	-37.444
6	-39.952	359.178	22.178	1	-39.068	-37.390
7	-38.989	354.041	17.041	2	-38.935	-42.119
8	-38.476	359.569	22.569	2	-39.078	-42.246
9	-48.691	364.999	27.999	3	-39.217	-47.245
10	-47.300	368.310	31.310	3	-39.301	-47.319

Building B third floor

point	measured power	distance	reduced distance (d0)	number of walls	pr (ITU model)	pr(SRAB model)
1	-35.069	356.479	19.479	0	-38.019	-33.385
2	-35.057	351.160	14.160	0	-37.882	-33.260
3	-41.456	368.432	31.432	2	-38.319	-43.166
4	-42.917	371.061	34.061	2	-38.384	-43.225
5	-38.937	372.196	35.196	1	-38.412	-38.404
6	-38.018	370.852	33.852	1	-38.379	-38.374

7	-38.874	360.800	23.800	1	-38.129	-38.145
8	-43.673	360.060	23.060	2	-38.110	-42.975
9	-41.366	365.595	28.595	3	-38.249	-47.978
10	-38.397	362.726	25.726	1	-38.177	-38.189

Building B fourth floor

point	measured power	distance	reduced distance (d0)	number of walls	pr (ITU model)	pr(SRAB model)
1	-35.588	349.732	12.732	0	-37.415	-31.276
2	-31.132	352.928	15.928	0	-37.497	-31.349
3	-37.090	366.471	29.471	1	-37.837	-36.309
4	-35.830	364.491	27.491	1	-37.788	-36.266
5	-39.410	357.271	20.271	2	-37.608	-40.953
6	-40.592	354.414	17.414	2	-37.535	-40.889
7	-43.674	370.991	33.991	3	-37.948	-46.131
8	-45.064	368.860	31.860	3	-37.896	-46.085
9	-50.122	375.333	38.333	4	-38.053	-51.129
10	-50.079	376.843	39.843	4	-38.089	-51.161

Building B fifth floor

point	measured power	distance	reduced distance (d0)	number of walls	pr (ITU model)	pr(SRAB model)
1	-34.997	349.506	12.506	0	-38.550	-34.504
2	-35.323	353.493	16.493	0	-38.655	-34.601
3	-37.367	354.383	17.383	1	-38.678	-39.282
4	-32.015	353.470	16.470	1	-38.655	-39.260
5	-42.670	356.862	19.862	2	-38.743	-44.188
6	-41.211	361.814	24.814	2	-38.870	-44.306
7	-56.777	367.707	30.707	3	-39.019	-49.321
8	-56.788	369.599	32.599	3	-39.066	-49.365
9	-40.675	372.552	35.552	4	-39.140	-54.338
10	-44.605	376.597	39.597	4	-39.239	-54.430

Appendix D

Measurements and calculao ns of WLAN 2.4GHz

The following tables shows sample of measurements and calculations for each floor in buildings (B, C and A) at 2.4GHz:

B building   First Floor:

point	avg.power	distance	reduced distance (d0)	# of internal walls	pr(ITU model)	pr(SRAB model)
1	-59.539	51.182	46.182	0	-73.225	-60.787
2	-49.500	61.225	56.225	0	-76.122	-62.343
3	-69.580	51.285	46.285	1	-73.258	-69.434
4	-70.100	55.003	50.003	1	-74.389	-70.042
5	-73.350	56.952	51.952	2	-74.952	-77.160
6	-72.500	53.970	48.970	2	-74.083	-76.693
7	-81.245	49.003	44.003	3	-71.714	-80.160
8	-77.474	46.615	41.615	3	-72.522	-80.594
9	-83.259	51.602	46.602	4	-73.357	-84.317
10	-82.000	53.078	48.078	4	-73.813	-84.562

point	avg.power	distance	reduced distance (d0)	# of internal walls	pr(ITU model)	pr(SRAB model)
1	-63.000	44.497	39.497	0	-73.103	-59.571
2	-59.500	36.020	31.020	0	-69.567	-57.735
3	-66.000	40.108	35.108	1	-71.365	-67.299
4	-75.000	37.967	32.967	1	-70.447	-66.823
5	-72.467	35.645	30.645	2	-69.392	-73.090
6	-68.500	33.873	28.873	2	-68.538	-72.647
7	-81.143	35.682	30.682	3	-69.409	-78.966
8	-80.000	32.884	27.884	3	-68.043	-78.478
9	-86.000	54.542	49.542	4	-76.508	-84.798
10	-81.578	53.814	48.814	4	-76.283	-84.682

Second Floor:

Third Floor:

point	avg.power	distance	reduced distance (d0)	# of internal walls	pr (ITU model)	pr(SRAB model)
1	-64.586	57.703	50.703	0	-80.188	-62.828
2	-57.000	25.257	18.257	0	-65.808	-56.568
3	-61.259	30.663	23.663	1	-69.184	-65.749
4	-68.259	34.629	27.629	1	-71.301	-64.174
5	-74.959	43.849	36.849	2	-75.410	-75.889
6	-72.478	44.266	37.266	2	-75.574	-75.971
7	-80.500	40.608	33.608	3	-74.073	-79.961
8	-82.500	45.316	38.316	3	-75.982	-80.914
9	-88.000	58.045	51.045	4	-80.291	-86.339
10	-84.537	55.952	48.952	4	-79.652	-86.020

Fourth Floor:

point	avg.power	distance	reduced distance (d0)	# of internal walls	pr(ITU model)	pr(SRAB model)
1	-55.259	28.333	21.333	0	-64.763	-55.650
2	-64.565	44.211	37.211	0	-72.103	-59.515
3	-57.475	30.304	23.304	1	-65.872	-64.864
4	-59.359	32.379	25.379	1	-66.965	-65.440
5	-69.000	51.868	44.868	2	-74.737	-76.348
6	-75.000	41.953	34.953	2	-71.238	-74.505
7	-82.000	52.943	45.943	3	-75.076	-81.265
8	-81.578	53.814	46.814	3	-75.345	-81.407
9	-84.149	58.183	51.183	4	-76.632	-85.360
10	-84.000	55.458	48.458	4	-75.841	-84.943

C building First Floor:

point	avg.power	distance	reduced distance (d0)	# of internal walls	pr(ITU model)	pr(SRAB model)
1	-65.810	56.770	43.770	0	-71.268	-61.045

[illegible]	[illegible]	0	-71.177	-60.970
[illegible]	38.109	1	-69.960	-68.585
[illegible]	38.357	1	-69.738	-68.400
[illegible]	31.444	2	-67.531	-72.904
40.762	27.762	2	-66.210	-73.536
43.960	30.960	3	-67.363	-77.973
68.108	55.108	3	-74.048	-83.549
64.012	51.012	2	-73.101	-78.020
66.927	53.927	4	-73.781	-71.772

avg.power	distance	reduced distance (d0)	# of internal walls	pr(ITU model)	pr(SRAB model)
-80.135	49.062	36.062	0	-72.403	-61.948
-59.584	49.931	36.931	0	-72.686	-62.124
-69.500	52.098	39.098	1	-73.371	-70.473
-70.100	52.537	39.537	1	-73.507	-70.584
-73.424	40.111	27.111	2	-69.153	-74.394
-67.000	42.176	29.176	2	-69.963	-75.572
-74.137	49.669	36.669	3	-72.601	-82.116
-84.000	50.941	37.941	3	-73.009	-81.558
-73.160	65.616	52.616	1	-77.092	-73.522
-80.230	67.328	54.328	2	-77.508	-80.678

A building   First Floor

avg.power	distance	reduced distance (d0)	# of internal wals	pr(ITU model)	pr(SRAB model)
-50.6762	43.919	16.919	0	-74.19435195	-62.38464278
-66.118	46.8924	19.8924	1	-75.31302455	-73.37690737
-69.8274	49.8258	22.8258	1	-76.34919466	-73.57448843
-65.1923	47.4434	20.4434	1	-75.51251162	-71.43789151
-69.6364	48.6754	21.6754	2	-75.95029666	-79.66735416
-77.6667	45.658	18.658	2	-74.85747237	-78.97546565
-74.3421	49.4306	22.4306	3	-76.21320826	-85.81858302
-72.8593	72.5643	45.5643	3	-82.76902379	-85.11220564
-77.6053	51.3109	24.3109	4	-76.85074312	-90.8205892
-79.25	55.2153	28.2153	4	-78.10309744	-91.36338778

2	-60.917	56.435	43.435	0	-71.177	-60.970
3	-54.028	52.109	39.109	1	-69.960	-68.585
4	-56.400	51.357	38.357	1	-69.738	-68.400
5	-65.717	44.444	31.444	2	-67.531	-72.904
6	-65.816	40.762	27.762	2	-66.210	-73.536
7	-82.890	43.960	30.960	3	-67.363	-77.973
8	-85.143	68.108	55.108	3	-74.048	-83.549
9	-81.000	64.012	51.012	2	-73.101	-78.020
10	-79.105	66.927	53.927	4	-73.781	-71.772

Second Floor

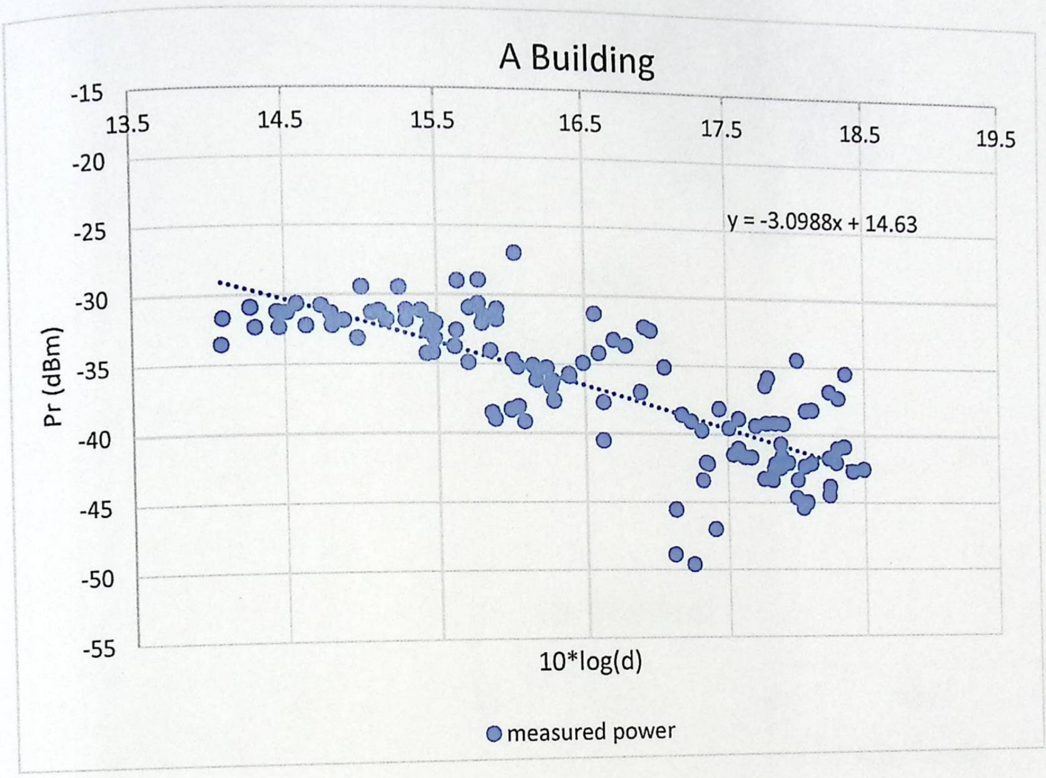
point	avg.power	distance	reduced distance (d0)	# of internal walls	pr(ITU model)	pr(SRAB model)
1	-60.135	49.062	36.062	0	-72.403	-61.948
2	-59.584	49.931	36.931	0	-72.686	-62.124
3	-69.500	52.098	39.098	1	-73.371	-70.473
4	-70.100	52.537	39.537	1	-73.507	-70.584
5	-73.424	40.111	27.111	2	-69.153	-74.394
6	-67.000	42.176	29.176	2	-69.963	-75.572
7	-74.137	49.669	36.669	3	-72.601	-82.116
8	-84.000	50.941	37.941	3	-73.009	-81.558
9	-73.160	65.616	52.616	1	-77.092	-73.522
10	-80.230	67.328	54.328	2	-77.508	-80.678

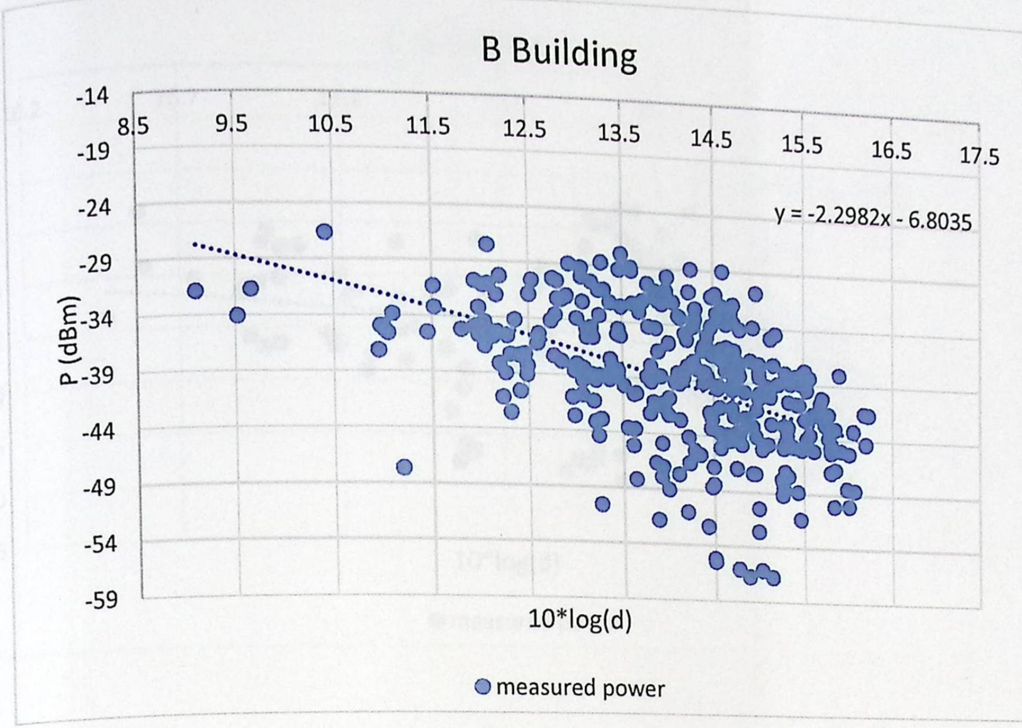
A building First Floor

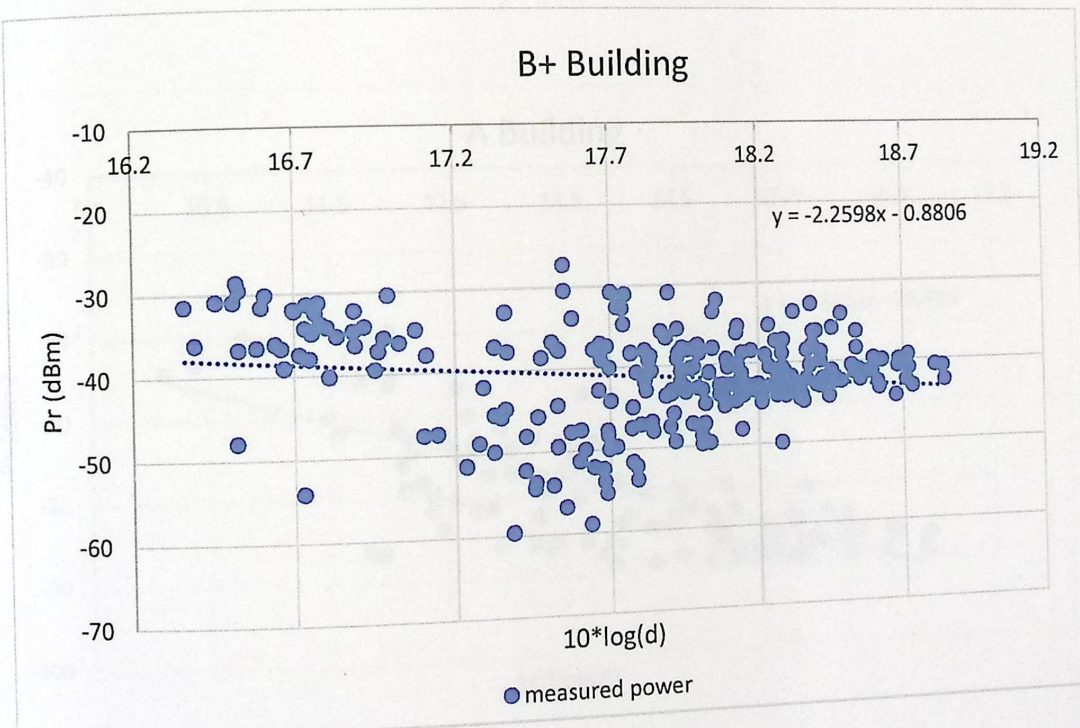
point	avg.power	distance	reduced distance (d0)	# of internal wals	pr(ITU model)	pr(SRAB model)
1	-50.6762	43.919	16.919	0	-74.19435195	-62.38464278
2	-66.118	46.8924	19.8924	1	-75.31302455	-73.37690737
3	-69.8274	49.8258	22.8258	1	-76.34919466	-73.57448843
4	-65.1923	47.4434	20.4434	1	-75.51251162	-71.43789151
5	-69.6364	48.6754	21.6754	2	-75.95029666	-79.66735416
6	-77.6667	45.658	18.658	2	-74.85747237	-78.97546565
7	-74.3421	49.4306	22.4306	3	-76.21320826	-85.81858302
8	-72.8593	72.5643	45.5643	3	-82.76902379	-85.11220564
9	-77.6053	51.3109	24.3109	4	-76.85074312	-90.8205892
10	-79.25	55.2153	28.2153	4	-78.10309744	-91.36338778

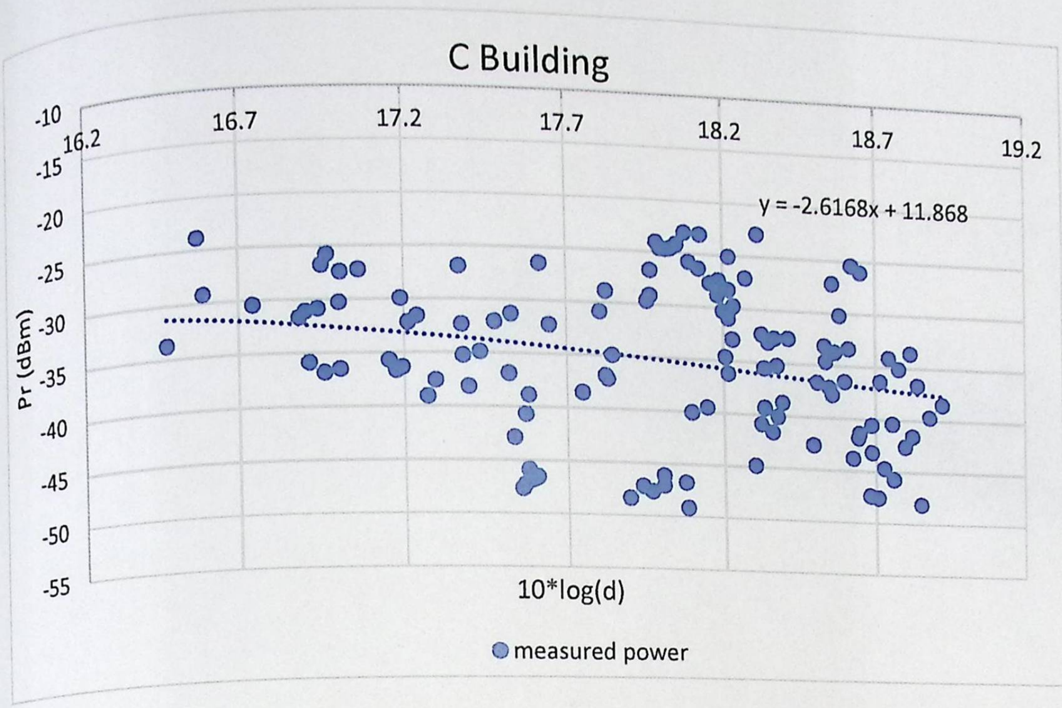
Appendix E

Overall scae r for each building at 900MHz

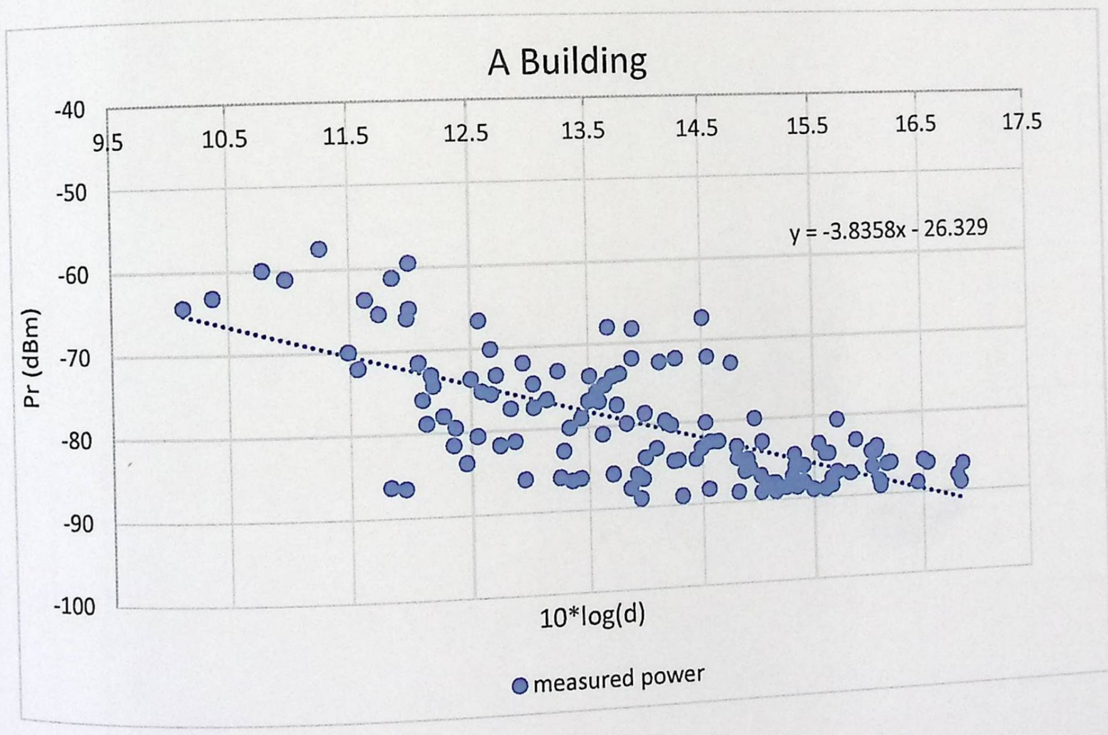


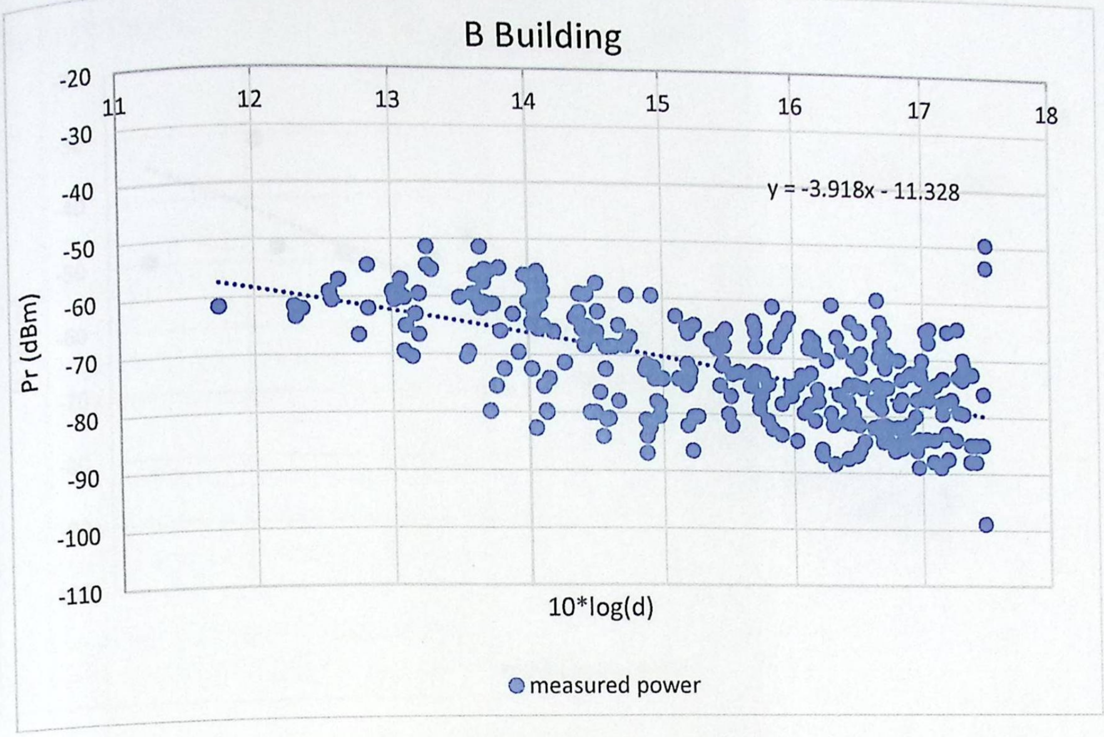

B Building
y = -2.2982x - 6.8035
P (dBm)
10*log(d)
measured power

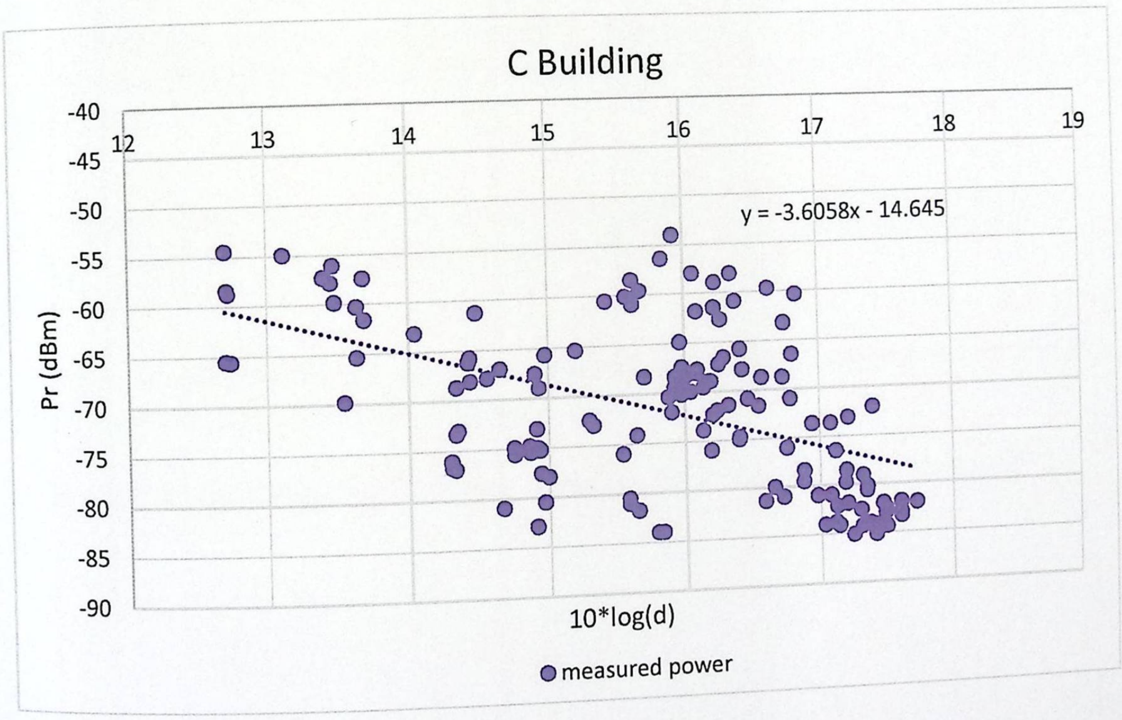

B+ Building
y = -2.2598x - 0.8806
Pr (dBm)
10*log(d)
measured power

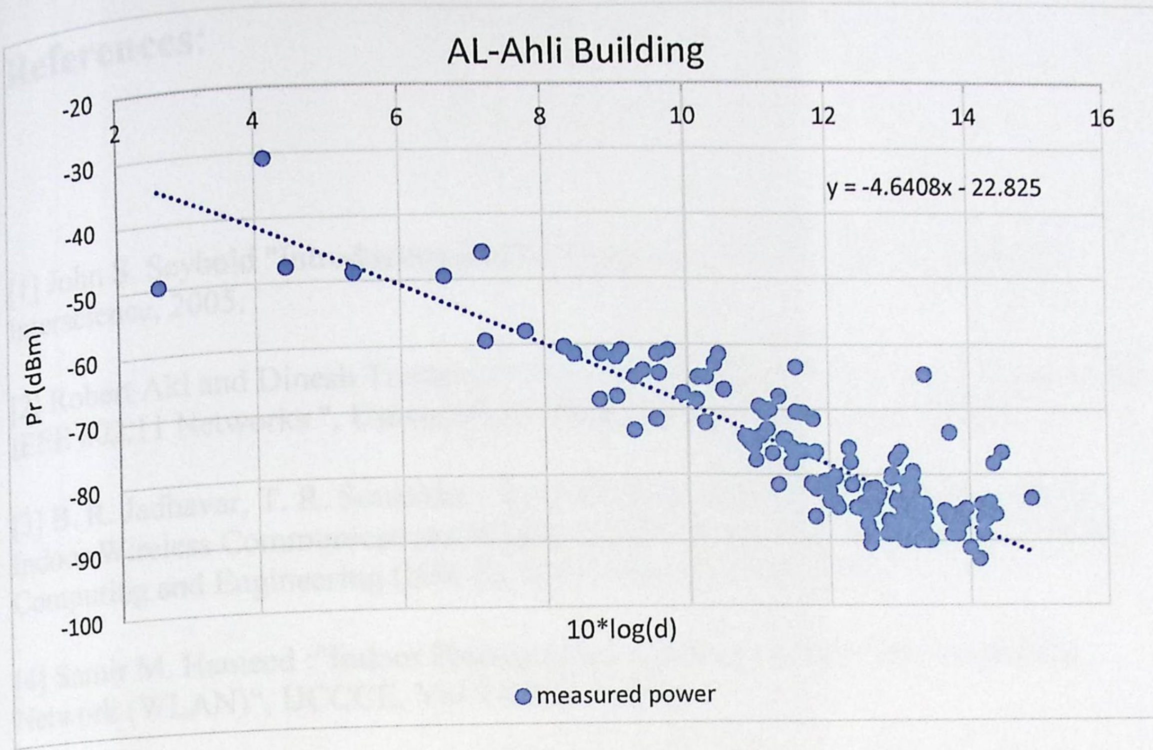


Overall scae r for each building at 2.4GHz




B Building
y = -3.918x - 11.328
Pr (dBm)
10*log(d)
measured power
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
11
12
13
14
15
16
17
18


C Building
y = -3.6058x - 14.645
Pr (dBm)
10*log(d)
measured power
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
12
13
14
15
16
17
18
19


AL-Ahli Building
y = -4.6408x - 22.825
Pr (dBm)
10*log(d)
measured power
-20
-30
-40
-50
-60
-70
-80
-90
-100
2
4
6
8
10
12
14
16

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