

Palestine Polytechnic University



College of Engineering & Technology

Electrical and Computer Systems Engineering Department

Graduation Project

In Building Penetration Loss in Commercial and Residential Building Structures in Palestine

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

Supervisor Signature

Testing Team Signature

Department Manager Signature

Abstract:

Mobile users may experience many problems when using their handsets inside buildings. This is due to lack of adequate in building coverage which would result into bad quality calls, drop calls, interference noise, to say the few. These are serious problems that would result into customer dissatisfaction and even customer churn for the operator. Customer churn due to lack of in building coverage constitutes 40%,[17] of the reasons for leaving an operator, in general, in a country such as the USA, where several giant operators compete with each other. The problem becomes even more serious when operators provide discounted call prices in the evening hours, after work hours, when callers would benefit from the offered discounts to call from their homes. This project will address the problem to try to come out with guidelines for the operators to adapt their in building penetration loss values in their developed link budgets. this project will generate a policy for predicting the signal strength in buildings depending on calculating the losses of signal power while it penetrates the outer and inner building walls, so we expect by the end of this project to come up with a prediction formula for indoor coverage.

Dedication

To Our Families

Especially To The Souls of Our Fathers,

May They Rest In Peace.

To Our Friends.

And To Our University

Acknowledgment

We would like to express our deep gratitude to Dr. Osama Ata who offered his time and efforts to successfully supervise this work.

We are deeply indebted to our Palestine Polytechnic University in Hebron, West Bank whose full cooperation made it possible for us to gain technical award to do this course, and special thanks to Eng. Abeer Imtair who helped us in our first steps during this project.

We also want to thank Eng. Asaad Amro from Dura Engineering office for answering our questions about the Building classification at the first steps for our trip.

Last but not least we thank planning manager, Dr. Khalid Hijeh and Eng. Arafat Tomeizeh from JAWWAL Company for their valuable his continuous consultation and support of this work.

We will be always indebted to our parents, brothers and sisters who have inspired us and for their cordial patience and continuous moral support through our studying period for this course.

To all who opened their hands to help us we say –Thank you.

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CHAPTER ONE

INTRODUCTION

- 1.1 OVERVIEW
- 1.2 MOTIVATION
- 1.3 LITERATURE REVIEW
- 1.4 METHODOLOGY OF STUDY
- 1.5 TIME PLANNING
- 1.6 COST ESTIMATION
- 1.7 REPORT CONTENT

1.1 OVERVIEW

In Palestine, like in all over the world, engineers who work in cellular companies have three major goals to achieve; these goals are: good coverage, high quality of service and capacity. The first two goals are tightly related to the nature of the transmitted signals, used antennas and medium of propagation. In this project, we are planning to find a model that describes the behavior of the signals from the moment they are transmitted until they reach the end-user in a manner that enables him to start and receive phone calls clearly.

The model we plan will be created using real measured data from the point of signal generation to the point of reception, and this can be helpful in finding the path loss for the signal indoor, outdoor and during penetration.

1.2 MOTIVATION

With the increasing number of subscribers to mobile communication networks and the introduction of new services, there is a growing interest in the question: “To what extent outside transmitters can provide coverage of indoor scenarios?”. With the introduction of high speed multimedia services, the demand of indoor coverage will become more important. Now in Palestine, there are no models for predicting the coverage inside the buildings; bearing in mind that current mobile operators use models that are not suitable for our type of buildings, so we made our model to guarantee 90% coverage inside buildings by predicting the penetration loss through external walls each according his class –which will be shown ahead-, outdoor path loss, indoor path loss, and internal wall penetration losses.

1.3 LITERATURE REVIEW

There are several previous studies that are close to what we are doing in our project, but in different places or in different circumstances.

We will take the NIST (National Institute of Standards and Technology) document titled “Electromagnetic Signal Attenuation in Construction Materials” October 1997; where they measured the penetration losses through several walls, each wall constructed of one material like stone, concrete, brick, etc...

In this report, the experiment was based on using a fixed transmitter and receiver which were designed to put the wall's material between them, in order to calculate the penetration loss for the signal through each material.

Another example of previous studies is a thesis entitled "NEW RESULTS FOR CHARACTERIZATION OF INDOOR CHANNELS IN TWO ISM BANDS (900-928 MHZ AND 2.4-2.5 GHZ)" By PREETHI SUNDARAM – March 2006.

This work is a collection of new measurement results for indoor channel characteristics in two unlicensed bands.

Their research is an extension of a previous research at the same university in which they take into consideration the movement of the people inside buildings; finally it has been observed that the propagation within buildings is strongly influenced by specific features such as the layout of the building, construction materials and the building type. [16]

1.4 Methodology of study:

First, we would like to describe our procedure in detail. The procedure we adopted was to take the following stages and this was the clearest way to proceed.

1.4.1 Stage One:

Calculating the Outdoor path loss per distance, this is the first loss that the signal faces when propagating through space. This stage will be accomplished by the following steps:

- It is necessary to choose a good area for test. At the same time, we have to locate the cell which covers that area.
- Afterwards, we divide the total area into subareas or levels spaced 20 meters apart.
- The received level measurement will be taken using TEMS handset for each level separately.
- Take a log file reading for two minutes within each zone. The handset will take several readings in this zone that leads us to know the average and standard deviation of received level.
- This helps us get the losses by subtracting the average received level signal power at two successive levels. (see the following figure)

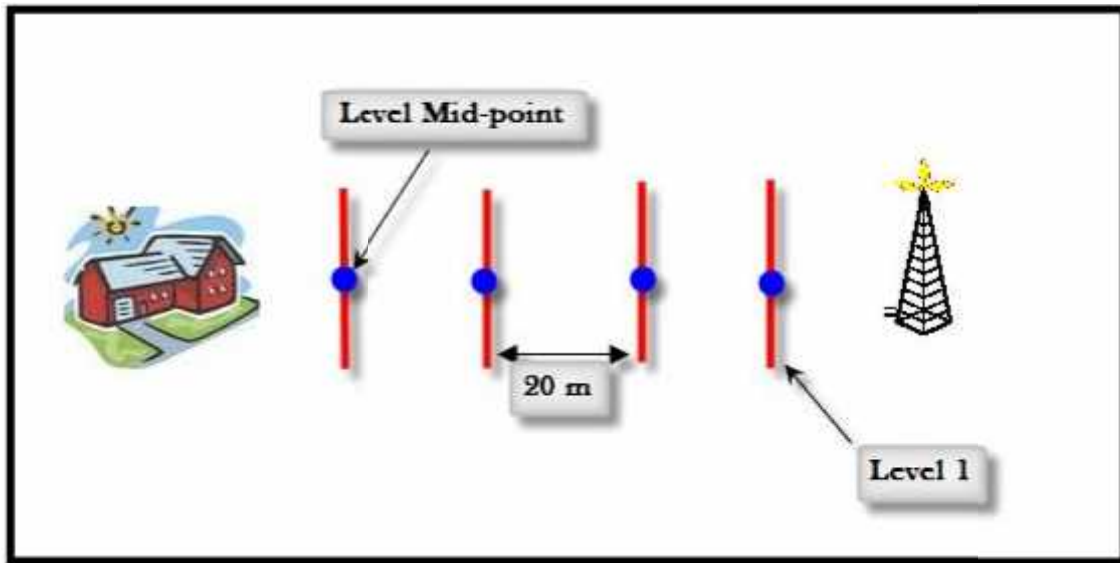


Figure 1.1: outdoor scenario.

- Finally, by taking the total average for all those averages, we have outdoor path loss per meter.

1.4.2 Stage Two:

In this stage, we will calculate the penetration loss in the walls.

- This procedure will be applied on twelve walls (classes) so we choose several buildings where we can find all the classes.
- Then, we will choose a building and identify its class.
- We lock the TEMS handset on the covering cell that we are interested in. Thus, our measurements are related to one cell.
- Then we tend to calculate the penetration loss through the wall. The proper idea is to choose many points (samples) outside the wall and measure the signal strength in each point separately, and by taking the average for all points, we get the average signal power outside this wall.
- The same steps are done for the inner side of the wall to come up with average power inside the wall.

- Then, we calculate the penetration loss for this class by taking the difference between signal strength for each side.
- We will use the TEMS handset to measure the average signal strength in each point. TEMS can record log file with many values with record time up to 15 seconds for each point.
- Then we take the average of the log file recorded at each point which represents a sample, afterwards we calculate the average of all points at the side (inner or outer) of the wall.
- Finally, we take the difference between the average inside and outside the wall, so we can get the penetration losses through that certain wall.
- This procedure will be repeated for all fourteen classes. (see the following figure)

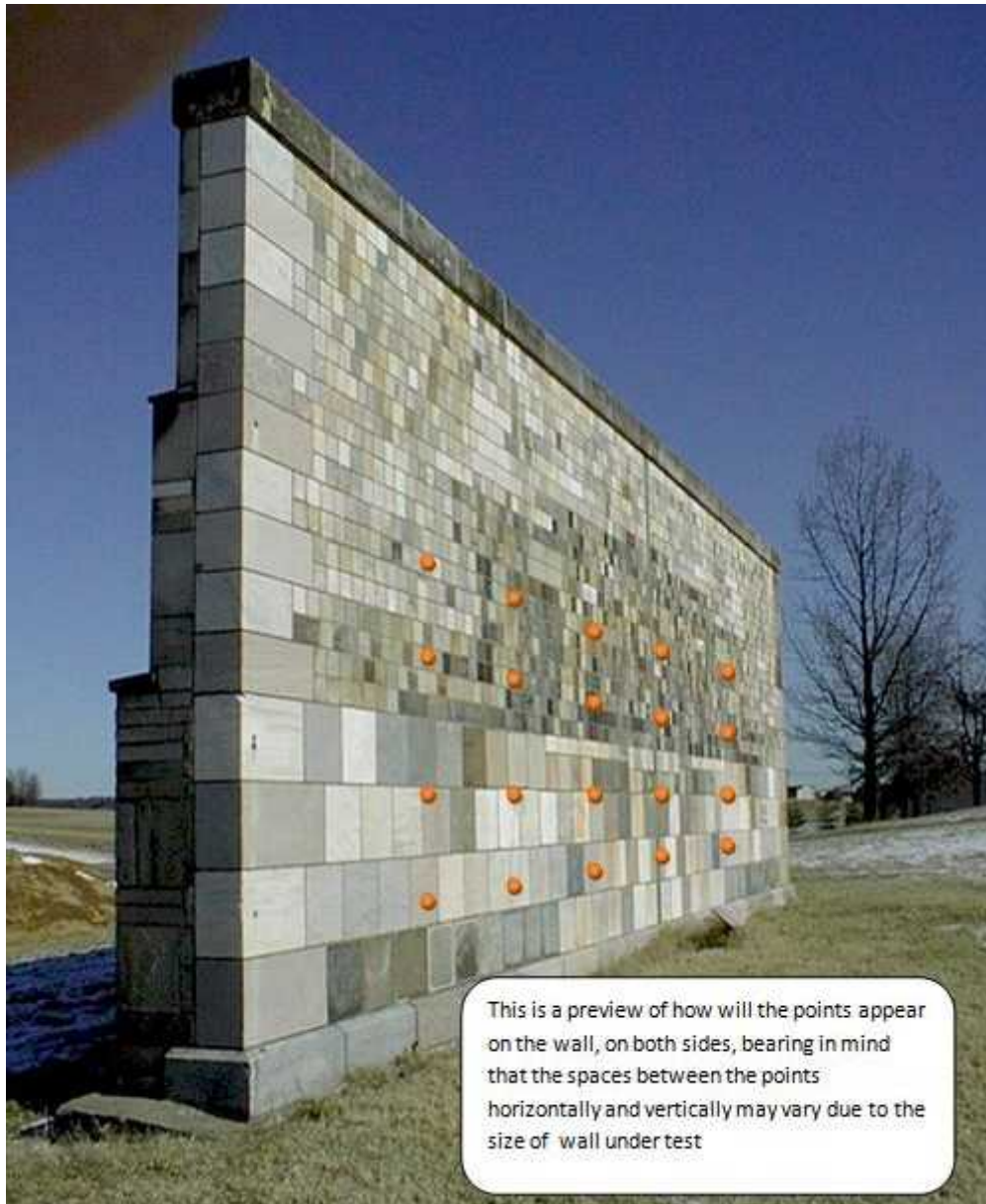


Figure 1.2: example wall for measurements.

1.4.3 Stage three:

In this stage, we tend to calculate the indoor path-loss per distance .This happens to be inside the building after penetrating the walls:

- We will divide the area into tracks, and at each track we took 4 points.
- We will assign one track each 3m.
- The first track at zero distance far from the wall.

- In each track, the hand set will record the average signal strength at each point alone.
- Finally, we get the average power at these points, then comes the analytical stage of the work.

We suppose that this result is applicable for any covered building. So, we can get the indoor losses for any building by knowing the indoor distance.

1.5 Time Planning

Table 1.1 distributes the tasks of project to IDs so that each one has its own time line, in accordance. Table 1.2 shows clearly the tasks and time plane managed over 16 weeks.

Tasks ID	Description
T1.1	Data Collection
T1.2	Requirement Analysis
T1.3	Tools Training
T1.4	First Draft for Measurements
T1.5	Documentation Writing of the Introduction
T2. 1	Choose Buildings for Test
T2.2	Apply Measurements
T2.3	Analyze Measurement Data
T2.4	Complete Documentation

Table 1.1: Tasks description.

Task/ week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
T1.1																
T1.2																

1.7 Report Content

Chapter one: Introduce our project in general: our problem of outdoor to coverage, view of previous study which is close to our project. The first steps of our procedure.

Chapter two: Signal propagation behavior in free space and how signal power is affected by propagation mechanisms, outdoor & indoor propagation.

Chapter three: View of the most popular models, and how they calculated the path loss due to several parameters, and presenting our model.

Chapter four: Explanation of our measurement procedure.

Chapter Five: Measurement results, and comments.

Chapter Six: Analyzing the results, with practical example on our model.

Chapter seven: Conclusions and Recommendations for Future work.

Chapter Two

Signal Propagation Mechanisms

- 2.1 Introduction
- 2.2 Propagation Mechanisms
- 2.3 Outdoor Propagation
- 2.4 Outdoor-to-Indoor Propagation
- 2.5 Indoor Propagation

2.1 Introduction:

When a Wireless signal is transmitted, there is no exact path to determine its propagation direction. In free space, a radio signal propagates as light does so these signals follow straight lines besides gravitational effect. If such a straight line exists between sender and receiver it's called line of sight. The received power P_r is proportional to $1/d^2$, where d : the distance between transmitter and receiver (inverse square law).

2.2 Propagation Mechanisms:

2.2.1 Diffraction:

The following figure illustrates diffraction, which occurs when the transmission path between the transmitter and the receiver is obstructed by a surface that has a sharp edge. Once the wave strikes the surface edge, diffraction occurs (i.e. the wave bends). The waves produced by the obstructing surface are present throughout space and even behind the obstacle giving rise to the bending of waves around the obstacle; even when a line of sight (LOS) path does not exist between the transmitter and the receiver. At high frequencies, diffraction depends on the geometry of the object as well as on the amplitude. Phase and polarization of the incident wave at the point of diffraction; the following figure shows what is known as “knife-edge” diffraction. [2]

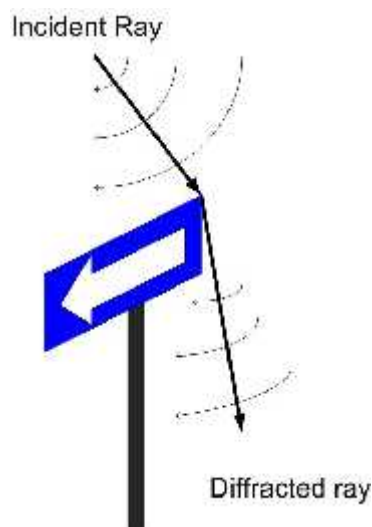


Figure 2.1: Diffraction

2.2.2 Shadowing:

The following figure illustrates shadowing, which is the result of an electromagnetic wave being diffracted by an obstruction. The angle of incidence will determine the angle of diffraction and how the wave propagates behind the object. The area immediately behind the object is said to be in the shadow. [2]

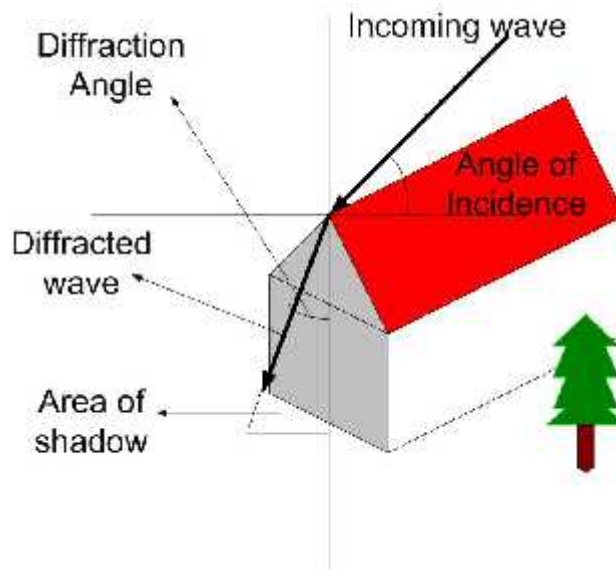


Figure 2.2: shadowing over a large obstacles (like big buildings) [15]

2.2.3 Reflection:

Figure 2.3 illustrates reflection, which occurs when a propagating electromagnetic wave strikes an object that is very large (e.g. the surface of the earth, buildings or walls) compared with the wavelength of the propagating wave. When reflection occurs, the wave may be partially reflected; the coefficients of reflection and refraction are functions of the material properties of the medium, and generally depend on the angle of incidence, the frequency of the propagation wave, and the wave polarization, incident and reflected angles are equal $\theta_i = \theta_r$. Refracted wave follows Snell's law $n_1 \sin \theta_1 = n_2 \sin \theta_2$. [2]

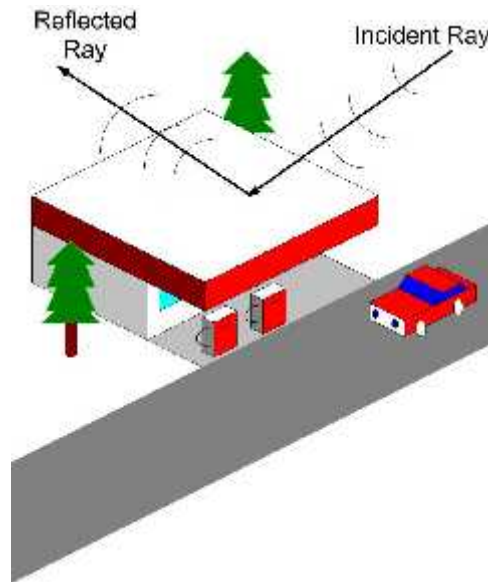


Figure 2.3: reflection

2.2.4 Scattering:

Figure 2.5 illustrates scattering, which occurs when a propagating electromagnetic wave strikes an object that is very small (e.g. foliage, street signs and lampposts) compared with the wave length of the propagating wave. Scattered waves are produced by rough surfaces, small objects or by other irregular obstructions. The nature of this phenomenon is similar to reflection, except that the radio waves are scattered in many directions. Of all the previously mentioned phenomena, predictions of scattering effects are the most complex. [2]

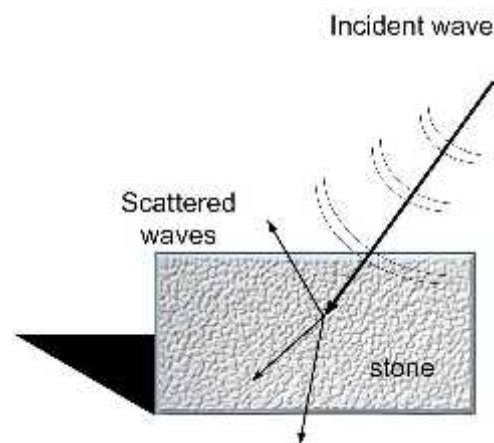


Figure 2.4: scattering over rough surfaces.

2.3 Outdoor Propagation

The following areas represent the propagation environments.

- **Open area**
Open space, no tall trees or buildings in path.
- **Suburban area**
Village, highway scattered with trees and houses, some obstacles near the mobile but not congested.
- **Urban area**
Built up city or large town with large buildings and houses.

These types shown in the figure below: [4]

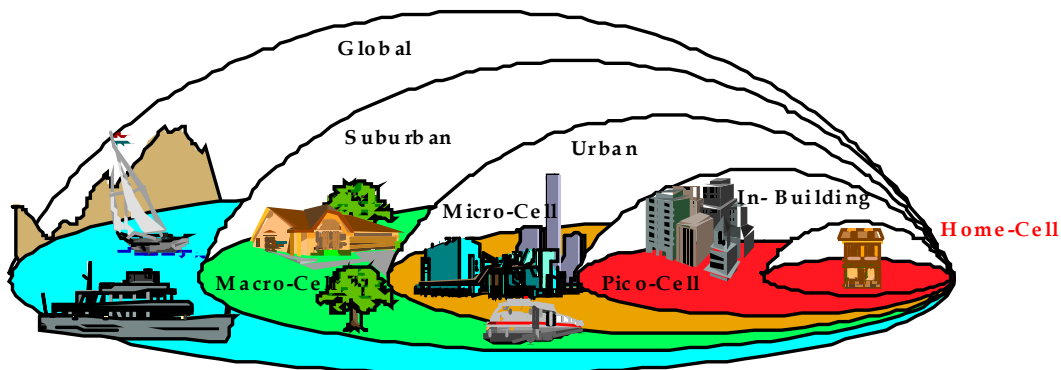


Figure 2.5: Types of terrain. [4]

The following table describes the various cell types:

Cell Type	Typical Cell Radius	Location	Typical Position of BS Antenna
Large Macro-Cell	1 km to 30 km	Outdoor	Mounted above medium roof-top level, all surrounding buildings are below base station antenna height.
Small Macro-Cell	0.5 km to 3 km	Outdoor	Mounted above medium roof-top level, some surrounding buildings are above base station antenna

			height.
Micro-Cell	Up to 1 km	Outdoor	Mounted below medium roof-top level.
Pico-Cell	Up to 500 m	Indoor; Outdoor	Mounted below roof-top level.

Table 2.1 Cell types. [16]

The macro cellular areas were the basis of first generation cellular radio systems. These systems generally place base stations at high points just as in broadcasting systems. A microcellular environment is significantly different. It has a smaller range of coverage, with lower antenna height and lower transmission power. The microcellular base antenna heights are lower than those of macro cells, and since they are often deployed in urban areas, the effect of buildings and natural obstacles are more pronounced than in macro cells in suburban or rural settings.

2.3.1 Multi path fading:

Signal fading is split into two types: large-scale fading and small-scale fading; it appears obviously in the presence of forests, buildings, hills, etc. lying between the transmitter and receiver. The statistics of large scale fading offer a means to compute an estimate of the path loss as a function of distance and other relevant factors. On the other hand, small scale fading is attributing of RF propagation resulting from the presence of reflecting and scattering objects that cause multiple versions of the propagated signals to reach the receiver, each distorted in angle of arrival, amplitude and phase.[19]

2.3.1.1 Small scale fading:

Small scale fading is divided into four fading types (frequency-selective, flat, fast and slow fading) by comparing the symbol duration with the coherence time, and the bandwidth of the baseband signal (i.e. fast or slow fading) compared with the coherence bandwidth of the channel (i.e. frequency selective or flat fading). [19]

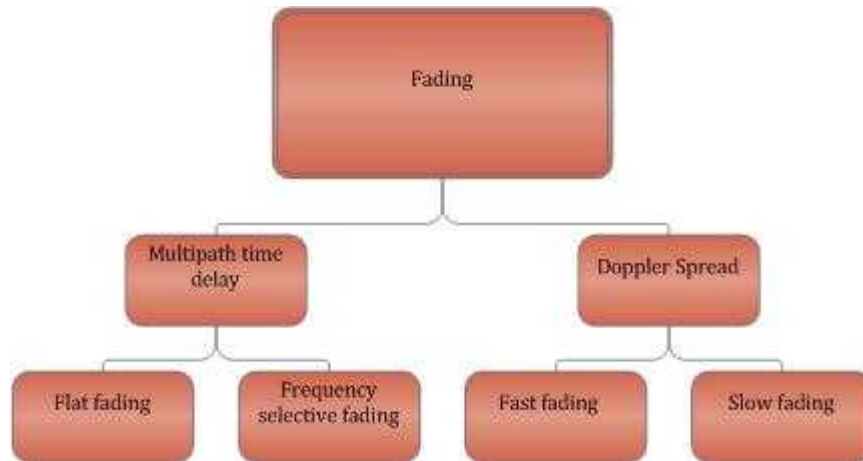


Figure 2.6 Type of fading.

- **Flat fading :**

Occurs when symbol period of the transmitted signal is much larger than the Delay Spread of the channel (bandwidth of the applied signal is narrow), and when the signal bandwidth is less than the bandwidth of the channel .[19]

- **Frequency Selective Fading:**

Occurs when channel multipath delay spread is greater than the symbol period, or when the bandwidth of the signal $s(t)$ is wider than the channel impulse response.[19]

- **Fast and slow fading:**

They are categorised based on how quickly the transmitted signal changes, in comparison with the rate of change of the channels on electrical parameter. Fast fading channel is one in which the channels impulse response changes at a rate much faster than the transmitted baseband signal, while a slow fading channel is one where in the channels impulse response changes at a much lower rate than the transmitted signal.[19]

Fast and slow fading are classified by situations where the transmitter and/or receiver moves or is movable. As a result, the speed of the mobile unit or the speed of the objects utilising the channel, through which the transmitted signal

propagates, determines if a signal will be experiencing fast fading or slow fading. The faster the rate of change of the location of the mobile unit, the more likely the channel will be undergoing fast fading, and vice versa.[19]

2.3.1.2 Large scale fading: path loss, shadowing

The variation in received signal power over distance is due to path loss and shadowing, path loss is caused by dissipation of the power radiated by the transmitter as well as effects of the propagation channel. Path loss models generally assume that path loss is the same at a given transmit-receive distance. Shadowing is caused by obstacles between the transmitter and receiver that attenuate signal power through absorption, reflection, scattering and diffraction. When the attenuation is very strong, the signal is blocked.

Variation due to path loss occurs over very large distances (100-1000 meters), whereas variation due to shadowing occurs over distances proportional to the length of the obstructing object (10-100 meters in outdoor environments and less in indoor environments). Since variations due to path loss and shadowing occur over relatively large distances, this variation is sometimes referred to as large-scale propagation effects. [2]

Figure 2.7 illustrates the ratio of the received-to-transmitted power in dB versus log-distance for the combined effects of path loss, shadowing and multipath.

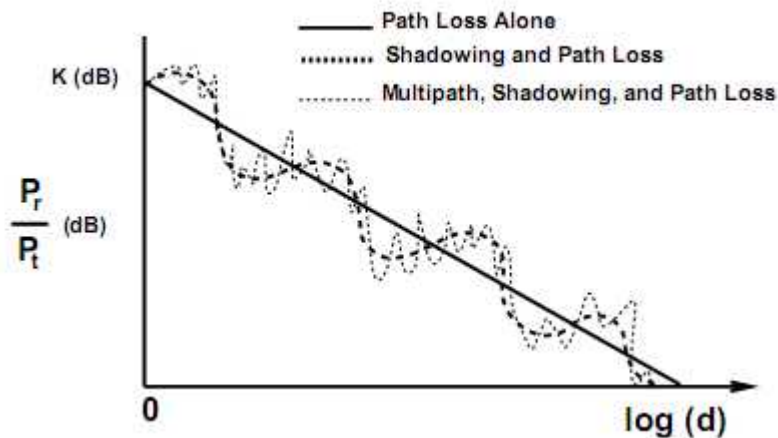


Figure2.7: Path Loss, Shadowing and Multipath versus Distance [2]

Constructive and destructive interference:

Signals are received in a terrestrial environment, i.e. where reflections are present and signals arrive at the receiver from the transmitter via a variety of paths. The overall signal received is the sum of all the signals appearing at the antenna. Sometimes signals arrived to the receiver from multipath will be in phase with the main signal and will add to it, increasing its strength (constructive addition). At other times those signals will interfere with each other. This will result in the overall signal strength being reduced (destructive addition). As illustrated in the figure below.

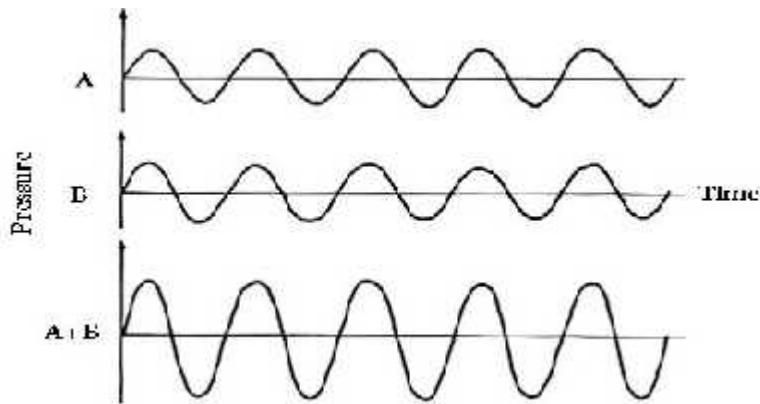


Figure 2.8: Since A and B have the same frequency, amplitude and phase values, their addition results in constructive interference: the combined signal has amplitude equal to the sum of the initial amplitudes. [10]

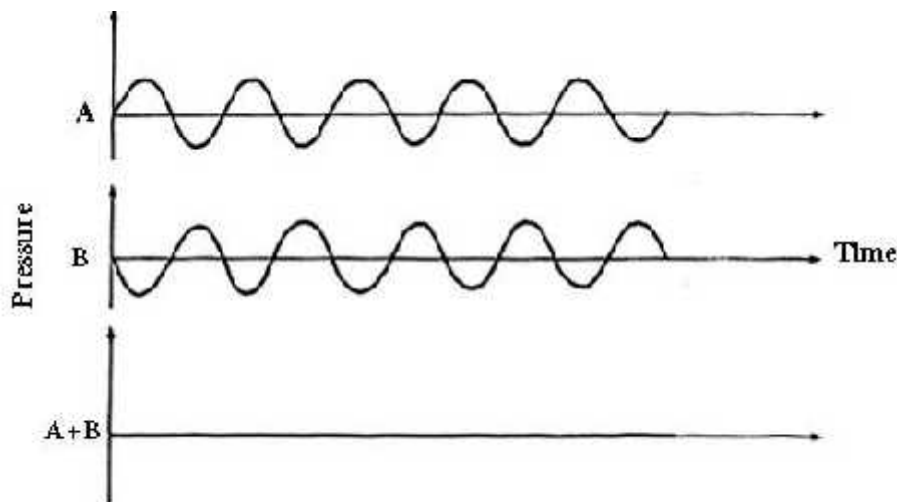


Figure 2.9 Since A and B have the same frequency and amplitude values but opposite phases, their addition results in destructive interference: the combined signal has amplitude 0, which is again the sum of the two amplitudes. The only difference is that, since the signs are out of phase, at every moment in time; their amplitudes have opposite signs (one positive, one negative).

2.4: Outdoor -to -Indoor Propagation (building penetration loss):

The penetration loss of a building is determined as the ratio of the average electric-field strength outside a building E_{out} on the ground floor and the average electric-field strength inside that building E_{in}

$$\text{Penetration loss [dB]} = E_{out} [\text{dB}_\mu\text{V/m}] - E_{in} [\text{dB}_\mu\text{V/m}] \dots \dots \dots \text{Eq. (2.1)}$$

Or in another way, we define aggregate penetration loss (APL) into a home as the ratio between the averaged outdoor and indoor local area powers for a single house with the same transmitter location expresses this relationship:

Aggregate penetration loss

$$\text{Loss dB} = 10 \log_{10} \frac{\frac{\sum_{i=1}^N p_i^{(outside)}}{N}}{\frac{\sum_{j=1}^M p_j^{(inside)}}{M}} \dots \dots \dots \text{Eq. (2.2) [1]}$$

The summation in the numerator is over the N interior local area power measurements, each denoted as P_i , while the summation in the denominator is over the M exterior local area power measurements, each denoted as P_j . All powers are in absolute power scale (not dB values).

In mobile communication systems, it is important to clarify the outdoor to indoor propagation loss (building penetration loss) characteristics to improve the quality of communication within buildings. In this project, we will propose a penetration loss prediction formula in the coming chapters that is derived based on measurement results. We will measure and analyze the building penetration loss at 900 MHz frequency.

In mobile communication system, the coverage area must fully extend inside the buildings. It is well-known that the wave penetration loss through a building is a function of several parameters that include the building construction material, distribution and size of the windows, existence of frames, internal wall reinforcement, foliage, nature of

surroundings and the position of transmitter and receiver, but most of these parameters are difficult to be taken into consideration in one formula, specially as students it is hard for us to control all these parameters within our capabilities. Propagation losses are also a strong function of frequency for most materials as well.

2.4.1 Building penetration and indoor analysis consist of two parts:

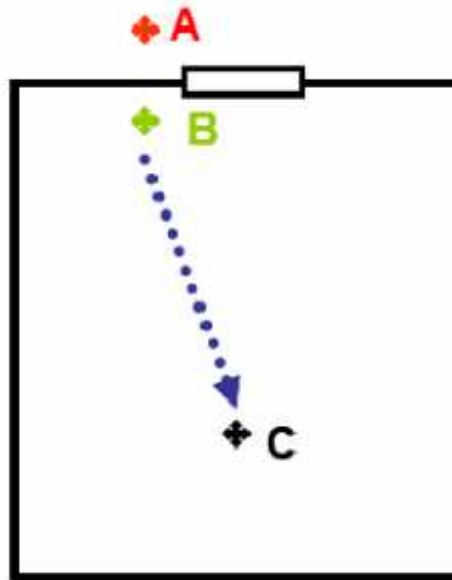


Figure 2.10: signal penetrates buildings and propagates inside a building. [8]

- Building Penetration Loss (BPL).
Loss at the first wall (between point A and point B).
- Indoor penetration.
Penetration margin inside the building (between points B and C).

It is impossible to find a building that does not have multipath reflections, diffraction around sharp edges, or scattering from wall, window, ceiling, or floor surfaces. As known, a perfect conductor reflects 100% of RF energy while a perfect insulator reflects none. In practice, most materials act like dielectrics that partially reflect (with a 180 degree phase shift) and partially refracts (transmits through the material and then bends), signals incident upon them. Metallic walls are the best reflectors in the buildings, but in practice even insulating materials cause significant reflections.

For mobile operators, it is essential to predict accurately the wave propagation mechanisms for system establishment and deployment. In Most cases, by making measurements before installing the system, the channel and its characteristics are predicted to some certainty. Thus, accurate prognosis about coverage-area, “power-drops,” inter-cell-interferences, etc. can be made. For path loss, this channel knowledge allows us to specify transmitter power, antenna parameters, and all of the link budget parameters.

2.5 Indoor Propagation

Objects that surround transmitters and receivers can significantly affect the propagation characteristics of a radio channel. Thus, it is important to understand the characteristics of the major physical objects in an indoor environment, since they will affect the propagation in a building, and hence affect the performance of any system deployed in such an environment. The indoor radio channel differs from the traditional mobile radio channel in two aspects – distances covered are generally much smaller, and the variability of the indoor environment can be much greater for a much smaller range of transmitter-receiver separation distances.

Similar to outdoor propagation, indoor propagation is also affected by scattering, diffraction and reflection. Some issues to be considered in indoor propagation are the presence of windows as a reflective component, the mounting locations of the antennas, the number of floors in a building, or even the effect of having doors open instead of closed. All these could vary the signal levels greatly. Buildings have a wide variety of partitions and obstructions. There are typically two types of partitions in a building- hard and soft partitions. Hard partitions are immobile structures formed as a part of the building. Soft partitions can be moved and do not span from the floor to the ceiling

These partitions cause signal attenuations, or losses. The partition losses on a given floor can occur from a variety of structures including walls, windows and doors. These partition losses are a function of the partition’s electrical and physical parameters. Researchers at the National Institute of Standards and Technology (NIST) have carried out signal propagation measurements through a variety of construction materials such as brick, concrete, glass, plywood, masonry block and lumber. The material properties and

dimensions are detailed from NIST. These measurements have helped determine the building material characteristics needed for the design of engineering systems which make use of signal. [5]

Propagation through these materials, for each material, varying thickness specimens was fabricated in order to measure attenuation as a function of penetration distance and frequency.

The propagation losses between the floors of a building are determined by the internal dimensions and materials of the building, as well as the type of construction used to create the floors and external surroundings. In order to measure the distance through an obstruction (e.g. a concrete wall) two separate antennas have to be used (mobile handset as a receiver and mobile base station as a transmitter). [3]

Chapter Three

Propagation Models

3.1 Introduction

3.2 Why Model Propagation?

3.3 Empirical Path Loss Models

3.4 Simplified Path Loss Model

3.5 Free Space Propagation Models

3.6 In Building Penetration Losses model (IBPL). (Our model)

3.1 Introduction

In the development of new wireless communications system, a versatile and accurate radio channel for indoor communications is needed. In particular, the investigation of radio transmission into buildings is very important.

Analysis of the electromagnetic wave environment is a prerequisite for efficient wireless communications; such investigation can be successfully done using simulation models to complement the measurements of signal power in a test site.

These models can be broadly categorized into three types: empirical, deterministic and stochastic. First of all, empirical models are those based on observations and measurements alone. They are mainly used to predict the path loss. The second type is the deterministic models which make use of the laws governing electromagnetic wave propagation to determine the received signal power at a particular location. Also, deterministic models often require a complete 3-D map of the propagation environment. An example of a deterministic model is one that uses a ray technique model. The last type of the models is the stochastic models. In other words, modeling the environment as a series of random variables. These models are the least accurate but never the less require the least information about the environment and use much less processing power to generate predictions.

3.2 Why Model Propagation?

The goal of propagation modeling is often used to determine the probability of satisfactory performance of a communication system or other system that is dependent upon electromagnetic wave propagation. It is a major factor in communication network planning. If the modeling is too conservative, excessive costs may be incurred, whereas too liberal of modeling can result in unsatisfactory performance. Thus, the fidelity of the modeling must fit the intended application.

For communication planning, the modeling of the propagation channel is for the purpose of predicting the received signal strength at the end of the link. In addition, to signal strength, there are other channel impairments that can degrade link performance.

These impairments include delay spread (smearing in time) due to multipath and rapid signal fading within a symbol (distortion of the signal spectrum).

These effects must be considered by the equipment designer, but they are not generally considered as part of communication link planning. Instead, it is assumed that the hardware has been adequately designed for the channel. In some cases, this may not hold true and a communication link with sufficient receive signal strength may not perform well. [7]

3.3 Empirical Path Loss Models

These models are mainly based on empirical measurements over a given distance for a given frequency range and a particular geographical area or building.

The most commonly used path loss models are:

3.3.1 Okumura Model:

Okumura developed an empirical model that is derived from extensive radio propagation studies in Tokyo. It is represented by means of curves which are applicable to urban areas.

The empirical path loss formula of Okumura at distance d parameterized by the carrier frequency f_c is given by:

$$P_{L(d)} \text{ dB} = L(f_c, d) + A_{mu}(f_c, d) - G(h_t) - G(h_r) - G_{AREA} \text{ (dB)} \dots \text{Eq.(3.1) [2]}$$

Where $L(f_c, d)$ is free space path loss at distance d and carrier frequency f_c , $A_{mu}(f_c, d)$ is the median attenuation in addition to free space path loss across all environments, $G(h_t)$ is the base station antenna height gain factor, (h_r) is the mobile antenna height gain factor, G_{AREA} is the gain due to the type of environment.

The values of $A_{mu}(f_c, d)$ and G_{AREA} are obtained from Okumura's empirical plots. Okumura derived empirical formulas for $G(h_t)$ and $G(h_r)$ as:

$$G(h_t) = 20 \log_{10}(h_t/200), \quad 30\text{m} < h_t < 1000\text{m} \dots \text{Eq.(3.2). [2]}$$

$$G(h_r) = 10 \log_{10}(h_r/3), \quad h_r > 3\text{m} \dots \text{Eq.(3.3). [2]}$$

$$G(h_r) = 20 \log_{10}(h_r/3), \quad 3\text{m} < h_r < 10\text{m} \dots \text{Eq.(3.4). [2]}$$

3.3.2 HATA Model:

The HATA model is an empirical formulation of the graphical path loss data provided by Okumura. HATA presented the urban area propagation loss as a standard formula and supplied correction equations for other types of areas.

$$L_{pu} = 69.55 + 26.16 \log_{10} f - 13.82 \log_{10} h(t) - ah(r) + [44.9 - 6.55 \log_{10} h(t)] \log_{10} d \quad (dB) \dots\dots\dots \text{Eq.(3.5). [4]}$$

Where:

L_{pu} = Propagation loss in urban area (dB).

f = The carrier frequency (150 MHz ~ 1500 MHz).

$h(t)$ = Base station antenna height (20 – 200 m).

$h(r)$ = Mobile station antenna height (1m - 10 m).

d = Distance (1- 20 Km).

- For small to medium city:

$$ah(r) = 1.1 \log_{10} f - 0.7 h(r) - 1.56 \log_{10} f - 0.8 \quad (dB) \dots\dots\dots \text{Eq.(3.6). [4]}$$

- For large city:

$$ah(r) = 3.2 \log_{10} 11.75h(r) - 4.97 \quad (dB) \dots\dots\dots \text{Eq. (3.7). [4]}$$

Where $ah(r)$ is a correction factor.

- Suburban area, the standard HATA formula in equation (3.5) is modified as:

$$L_{ps} = L_{pu} - 2 \log_{10} \frac{f}{28} - 5.4 \quad (dB) \dots\dots\dots \text{Eq. (3.8). [4]}$$

Where L_{ps} = path loss (dB) in suburban area.

Open Area: equation (3.5) is modified to:

$$L_{po} = L_{pu} - 4.78 [\log_{10} f]^2 + 18.33 \log_{10} f - 40.94 \quad (dB) \dots\dots\dots \text{Eq. (3.9). [4]}$$

Where L_{po} = path loss (dB) in open area. Based on urban macro cell for GSM 900:

$$f = 900 \text{ MHz}, h(t) = 30 \text{ m}, h(r) = 1.5 \text{ m}.$$

Equation (3.6) and (3.7) are negligible here.

The path loss for urban, suburban and open areas using equations 3.5, 3.8 and 3.9 are plotted as a function of cell radius as shown in figure (3.1).

Figure (3.2) is a plot of urban area path loss as a function of cell radius, at $f = 900$ MHz, $h(r) = 1.5$ and $h(t)$ varied from 30 m to 100 m.

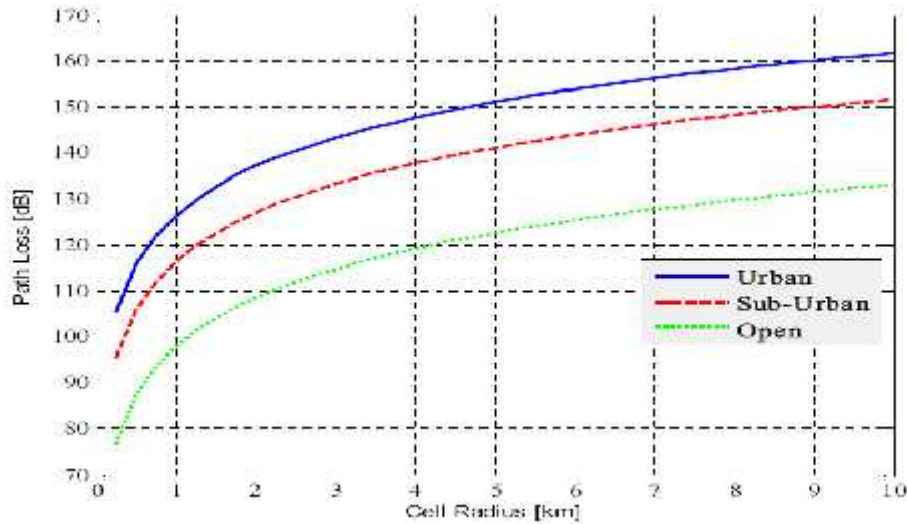


Figure 3.1: Path Loss as a Function of Cell Radius for Urban, Sub-Urban & Open Area, at $f=900$ MHz, $h(t)=30$ m.

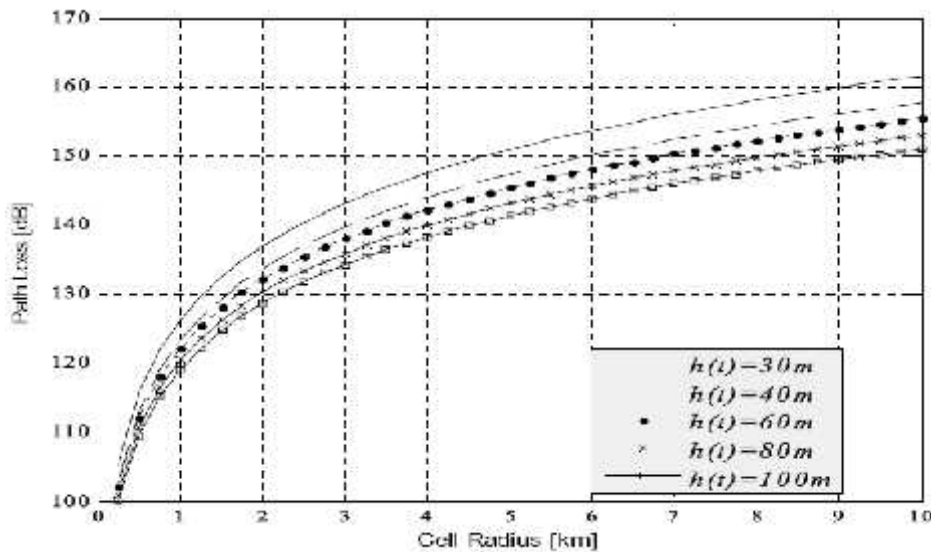


Figure 3.2: Path Loss versus Cell Radius for Urban Area at $f = 900$ MHz, $h(r) = 1.5$ m.[4]

3.3.3 Cost 231-HATA Model:

This model is developed; which is an extended version of HATA model for frequencies of 1500 MHz to 2000 MHz.

This model is applicable for GSM 1800-urban area.

$$P_{L,urban} \text{ dB} = 46.3 + 33.9 \log_{10}(f_c) - 13.82 \log_{10}(h_t) - a(h_r) + 44.9 - 6.55 \log_{10} h_t \log_{10} d + C_M \dots \text{Eq. (3.10)}$$

Where:

f_c :is the frequency in MHz

h_t :is the base station height in meters

h_r :is the mobile station height in meters

$a(h_r)$: is the mobile antenna height correction factor

d : is the link distance in km

C_M : 3 dB for metropolitan centers

C_M : 0 dB for medium city and suburban centers with moderate tree density.

The COST 231 model is restricted to applications where the base station antenna is above the adjacent roof tops. HATA and COST 231 are central to most commercial RF planning tools for mobile telephony.

3.4 Simplified Path Loss Model

In order to calculate and measure the path loss accurately, we must use complex models, or empirical models which depend on measurements. Sometimes, for general tradeoff analysis of various system designs, it is best to use a simple model that captures the essence of signal propagation without resorting to complicated path loss models which may only be specific to the real channel anyway. Thus, the following simplified model for path loss as a function of distance is commonly used for system design:

$$P_r = P_t K \frac{d_0^\gamma}{d} \dots \text{Eq. (3.11)}$$

The dB attenuation is thus:

$$P_r \text{ dBm} = P_t \text{ dBm} + K \text{ dB} - 10\gamma \log_{10} \frac{d}{d_0} \dots \text{Eq. (3.12)}$$

Where:

K: is a unit less constant which depends on the antenna characteristics and the average channel attenuation.

d_0 : is a reference distance for the antenna far-field.

n : is the path loss exponent, which equals 2 for free space line of sight but can vary between (2-5 or 6) for different morphology.

When the simplified model is used to approximate empirical measurements, the value of $K < 1$ is sometimes set to the free space path gain at distance d_0 assuming Omni-directional antennas:

$$K(dB) = 20 \log_{10} \frac{\lambda}{4\pi d_0} \dots \dots \dots \text{Eq. (3.13)}$$

This assumption is supported by empirical data for free-space path loss at a transmission distance of 100 m.

3.5 Free Space Propagation Model:

The free propagation model is used to predict receiver signal strength when the transmitter and receiver have a clear, unobstructed line of sight path between them. The free propagation predicts that the received power decays as a function of transmitter receiver distance raised to some exponent. The power is received by the receiving antenna (P_r) when placed at distance D (meters) from the transmitting antenna which transmits a given power level (P_t) can be calculated by the Friss free space transmission equation as:

$$P_r d = \frac{P_t G_t G_r \lambda^2}{4\pi^2 d^2 L} \text{Watt} \dots \dots \dots \text{Eq. (3.14). [16]}$$

Where G_r and G_t are the gains of the receiving and transmitting antenna, respectively, L is the system loss factor not associated with propagation ($L \geq 1$, e.g. for RF cable losses) and is the wave length in meters.

Large scale propagation models typically use a “close-in” distance as a reference distance and this is termed d_0 . The value of $P_r(d_0)$ is measured by taking the average received power at this distance from the transmitter. The received power in free space at a distance greater than d_0 is then given by:

$$P_r d = P_r d_0 \left(\frac{d_0}{d} \right)^2 (dB) \dots \dots \dots \text{Eq. (3.15). [16]}$$

In the following table we make a Comparison of some types of Propagation Models for Built-Up Areas:

Model	Application	Frequency (MHz)	Advantages	Disadvantages
Okumura	Equation with correction factors from plots	200-1920	Widely used as a reference	Limited data, Tokyo 1960, tedious to apply
HATA	Equation	150-1500	Widely used, straight forward to apply	Based on limited data, does not cover PCS band
COST 231	Equation	1500-2000	Same as HATA but also covers PSC frequencies	

Table 3.1: a comparison between some models

3.6 In Building Penetration Losses (IBPL). (Our model)

In this project we performed an outdoor-to-indoor propagation measurements in many buildings in Palestine, the results obtained from this experiment was considered in our model in order to predict the signal strength exactly. There is many models that predict the signal in free space, but the strongest point in our work is considering the penetration losses in walls according to its type (class).

These classes which to be explained in chapter 4 , are fourteen classes, appear clearly in our formula.

The basic formula for calculating the path loss is :

$$PL \text{ dBm} = P_{Tx} \text{ dBm} - P_{Rx,measured} [\text{dBm}] \dots \dots \dots \text{Eq. (3.15).}$$

Path loss represents the attenuation on signal traveling from transmitter to receiver, we assumed that the location of the receiver is inside the building ,in order to

calculate the losses due to building walls, so the attenuation between the Tx and Rx, is path loss because of distance in free space, losses in external building walls, losses in internal walls, and the total path loss, expressed in the following equation :

$$P_L = P_{OL} + P_{EW} + P_{IL} + \dots \dots \dots \text{Eq. (3.16).}$$

P_{OL} : outdoor path loss .

P_{EW} : penetration loss in the external wall .

P_{II} : losses due to indoor distance between the reference point d_0 and the receiver.

$$= \sum_{i=1}^L K_i L_{wi} \dots \dots \dots \text{Eq. (3.17).}$$

L_{wi} : attenuation due to inner walls.

i : the wall type.

K : the number of walls .

σ_{Total} : the combined standard deviation for outdoor, indoor, and walls penetration respectively.

$$\sigma_{Total} = \sigma_1 + \sigma_2 + \sigma_3 + \sigma_4 \dots \dots \dots \text{Eq. (3.18).}$$

where :

σ_1 : the standard deviation outdoor .

σ_2 : the standard deviation due to external wall.

σ_3 : the standard deviation due to the indoor path loss.

σ_4 : the standard deviation due to internal walls.

Statistical notation:

The mean (μ), and the standard deviation (σ) are useful terms which come up in modeling of a given set of data. The mean or the expectation represent the center of any data set, the standard deviation simply measure how far the values in the data set are away from the center (the mean), which may have appositive or negative values, its considered as the error, in the formula .

Measured signal power at any point always varies within a small range of values according to the everlasting changes of the environment, It is the nature of Radio Signal, so we add the term () to our formula as a correction factor.

3.6.1 Modeling of Outdoor stage:

We took along path for outdoor measurement in order to be accurate as possible, to make our model more realistic as possible, also its known in the empirical analysis that to achieve this goal you must increase your samples, as will be shown in chapter 4.

The outdoor scatter plot describes the relation between the two variables, logarithmic distance and power ,from this curve we tend to get a simple formula in which it can be generalized in other samples , it's clear that the association in the scatter plot between power and distance is not linear , and the obtained curve is closer to the logarithmic relationship.

The general formula of free space path loss is as follows:

$$\text{Path loss} = C + 10n \log(d) \dots\dots\dots \text{Eq. (3.19).}$$

Where:

C: is constant.

n: is the path loss exponent ,which refers to how fast the signal strength for a given environment deteriorates with increasing distance . n & c differ according to the environment .

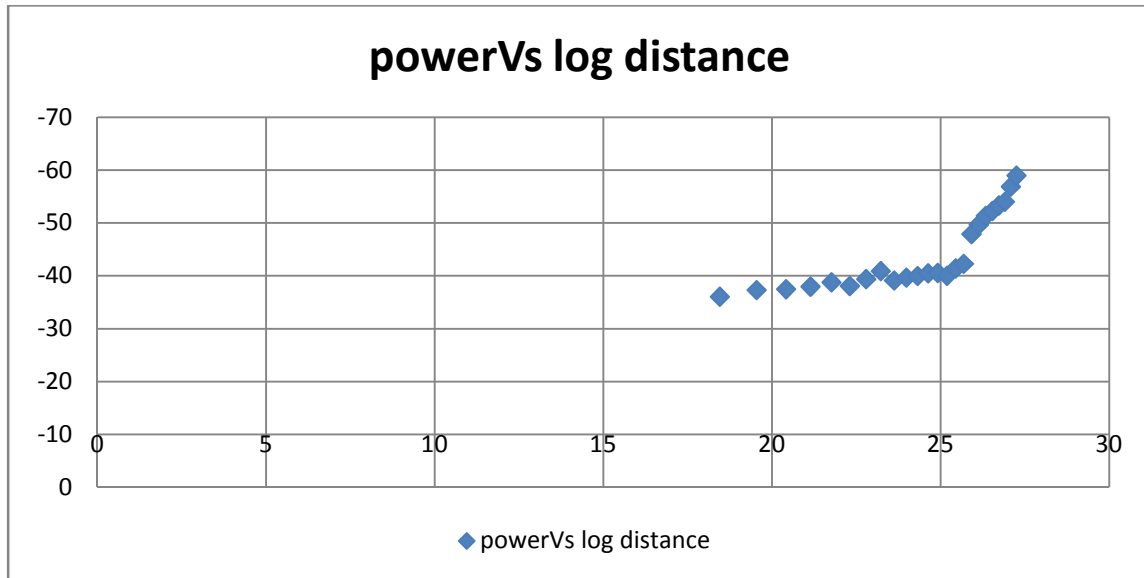


Figure 3.3: Scatter plot of the outdoor path loss

in the previous figure we took the log of the x axis multiplied by 10 , because the y axis represents the power in dBm which equal to 10 multiplied by logarithm of the power value in mW.

$$x_{in\ dBm} = 10 * \log x_{in\ mW} \dots\dots\dots \text{Eq.(3.20).}$$

Afterwards Linear regression was done to the last curve to evaluate the values of n & c ,this is done using SPSS software,

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta	B	Std. Error
1	(Constant)	11.084	8.470		1.309	.204
	Distance	-2.274	.349	-.812	-6.523	.000

Dependent Variable: power

Table 3.2: spss regression result for outdoor

$$P_{OL} = 11.08 - 10 * 2.273 \log (d) \dots\dots\dots \text{Eq. (3.21).}$$

Where:

P_{OL} : Outdoor path loss.

$C = 11.08$.

$n = 2.273$, the slope of the curve called the path loss exponent.

3.6.2 Modeling of the indoor path loss:

When talking about indoor path loss, its similar to the procedure of outdoor path loss , but in indoor , the received signal affected by reflections and multipath more than in outdoor environment , because the internal walls are close to each other ,and the internal area is small compared with outdoor area ,also the presence of furniture affects the propagation of signals.

So the indoor path loss have a different value of n than the used in outdoor path loss. The second graduation group who worked on “ **indoor modeling for building c**” project supervised by PhD. Osama Ata, they made a procedure to compute the indoor path loss, their sample was in building c of the PPU in the second floor , a GIS lab with 9 m x 7 m dimensions , the distance is about 24 m between the microcell and the external wall of the building, which guarantees a good coverage to do the experiment. They divided the internal area to four tracks with 3 m separation, each track of four points.[21]

The following figure illustrates the relationship between power in dbm and log distance, measured on building C by the second group.

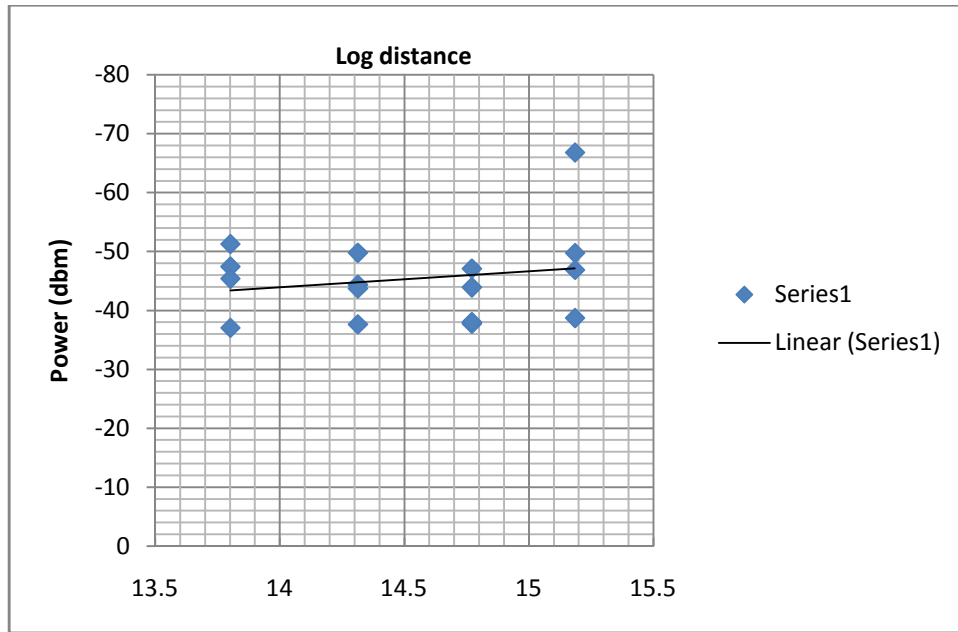


Figure 3.4: The relation between the power and the log distance

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta	B	Std. Error
1	(Constant)	-6.001	58.591		-.102	.928
	distance	-2.709	4.033	-.429	-.672	.571

Dependent Variable: power

Table 3.3: spss result for indoor values

where C the constant equal to -6.001 ,and n is the slope which equal to 2.7

So the final equation will be :

$$Indoor\ path\ loss = 6.008 - 2.7088 * 10 \log d \dots\dots\dots Eq. (3.22).$$

3.6.3 External walls part of the model:

Here we made our measurements on each class in order to predict the signal strength when it penetrates walls.

We measured signal strength in each class at the inner and the outer side , thus by take the difference we have the penetration loss with which represent the error , for penetration taken from the inner wall measurement , each class has different value of depends on its constructing material.

3.7 Conclusion

To sum up, these previous models are not all propagation models known, but they are the most used. Also, they are almost enough to predict the signal power according to several parameters like distance, the height of the T_X and RX antenna and frequency. In fact, there are other parameters that are not considered in our models because it makes it more complex to modulate, so we tend to use simplified models.

On the other hand, these models like HATA and empirical are applied in known cities such as Tokyo; and we applied our calculation in Palestine area, because it may not be accurate enough to adapt these models; our building arrangement is different and our building materials are different too.

Chapter Four

Survey and Measurement Procedures

- 4.1 Introduction
- 4.2 Equipments
- 4.3 Stage one (outdoor measurement)
- 4.4 Stage two (classes measurement)

4.1 Introduction

We would like to introduce this chapter with brief explanation of the equipment that we used in our study, JAWWAL telecommunications Company and our university gave us the chance to use these equipments through our research. We use these tools to get instantaneous records for measured samples at 900 MHz band which is basically used by JAWWAL. We applied our measurements by using these tools on sample buildings. Also, we are trying to make it a general model for buildings in Palestine. As mentioned in chapter One, our measurement procedure is divided into three stages, outdoor path losses, indoor path losses, and penetration losses.

4.2 Equipments

Ericsson`s TEMS investigation 4.0.8. 4.2.1

Ericsson TEMS is a portable device for RF scanning and active call measurement, The hardware components of the system include one Ericsson TEMS handset and a laptop with two serial ports. The scanning function of this TEMS is used to collect data for the predicted signals. The Ericsson TEMS also provides the function to record the active call data, which includes network measurement reports (NMRs). This active call function is used to collect NMRs for testing the performance of the RSS location engine. [9]

Now bear in mind that we used the TEMS handset on idle mode, to assure that the received signal at the handset is not loaded, TEMS handset takes about 5 measurements per second, this high number of measurements gives the TEMS the ability to give a clear view of the nature of signal at a certain point, to achieve a reliable readings TEMS have the ability to lock its record with a certain cell.



Figure 4.1: TEMS software in mobile and laptop. [9]

4.2.2 EMF meter (Electromagnetic Field Meter).



Figure 4.2: EMF meter.

The EMF meter is an instrument for measuring electromagnetic fields, this device we used, measured the received power in (mW), one drawback in this device is its low sensitivity for electromagnetic waves, this device measures all the electromagnetic waves within a range of frequencies despite the transmitter of this signal, so there is no such thing as locking on a cell as in the TEMS handset.

To make use of this device in our project it should be used with a transmitter (spectrum analyzer), which we couldn't find. But we used instead of in a function generator to generate a signal with the wanted frequency, combined with a yagi antenna to transmit the signal in the wanted direction.

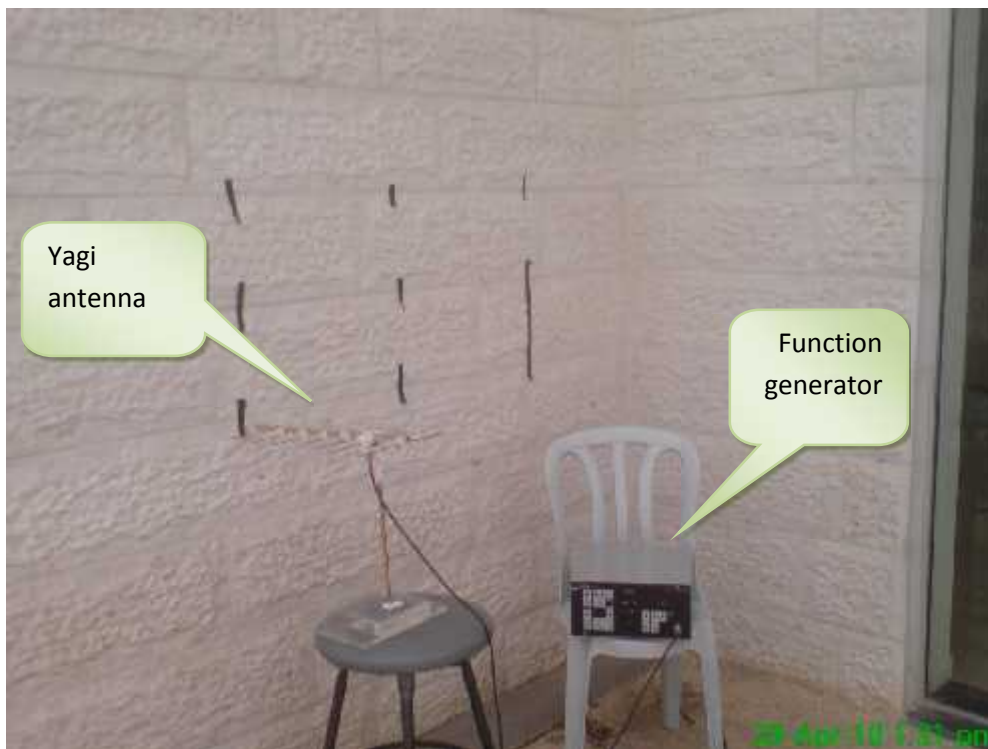


Figure 4.3: Yagi antenna with the function generator as a transmitter.

4.3 Stage one (outdoor path loss):

We took into consideration that we need to find a very wide area to measure with a fair LOS of the serving cell, and we did, it was a wide street with about 700 m long, located in Hebron, Al-Hawooz, near Al-Tahreer gas station, the base station is located over a four story building, the antenna is sectored into three sectors, one of them is directed towards the street we measured the signal at, as shown in the following satellite view.



Figure 4.4: a satellite view of the outdoor path taken.

We divided the street into zones each zone is about 10m X 20m, after we locked the TEMS handset to the sector looking at the street (cell 64-B) we started a log file for two minutes while the observer takes tracks within that zone. We had 24 zone along 500m, the first zone started after 70m from the base station in order to guarantee a good covering signal from the wanted cell, most of the zones have LOS, but after about 400m there is smooth bend in the street which caused a partial LOS for the final zones, the following picture illustrates the way how the zones were placed.

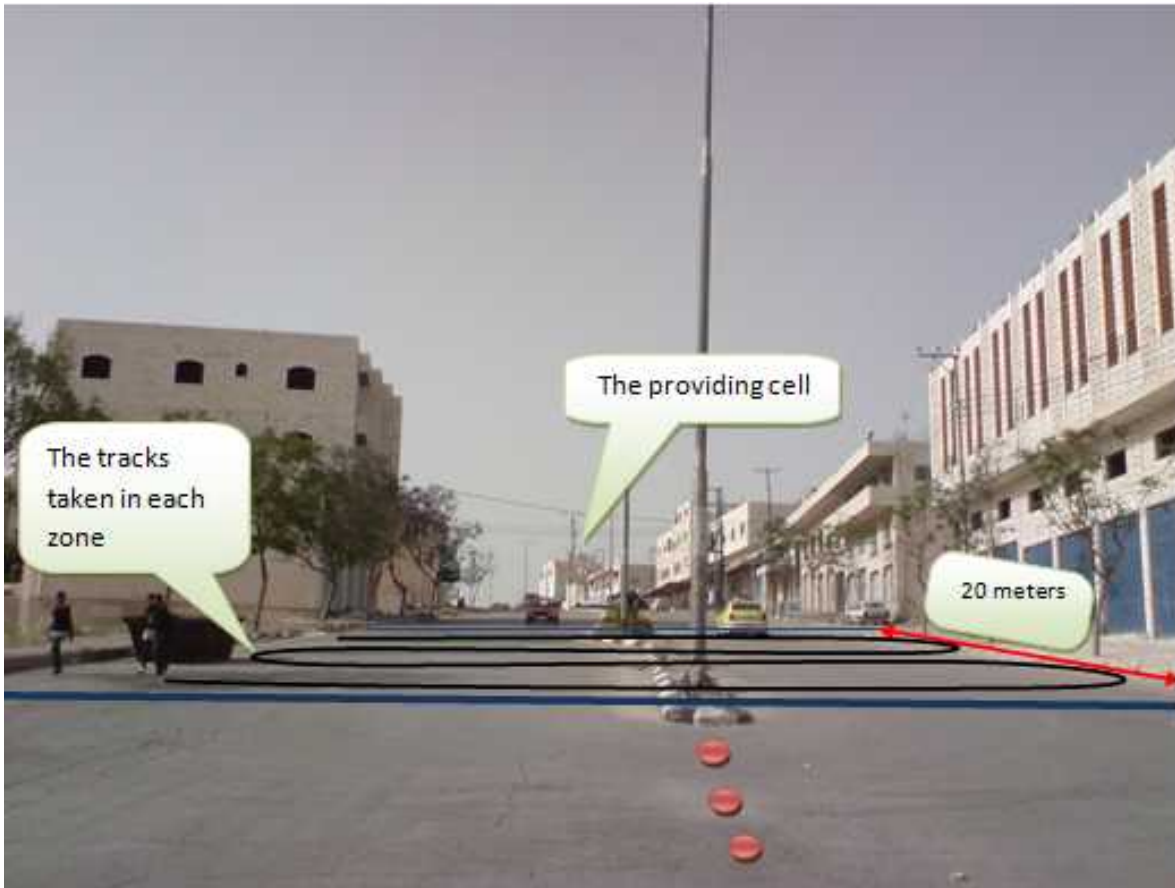


Figure 4.5: illustration of the mechanism of taking log files.

4.4 Stage two:

The sample buildings we intend to apply stage 3 of our measurement on are located in Hebron. They represent 90% of the buildings in Palestine [12]. We will classify these buildings into several categories according to the section materials in each class for outer walls and inner walls.

Our measurement procedure was applied on each wall .It was done by recording the RSS (received signal strength) outside each wall, and the same thing is done inside the same wall (as mentioned in chapter one). That's how we calculated the penetration losses in each building class.

4.4.1 Building Classifications

Depending on what we are supposed to do in this research, we have to know the main kind of buildings in the area .We can't finish our study without knowing the walls construction materials which we applied on our experiments. We planned to visit the TRADE UNION OF ENGINEERS because it's only our basic resource to provide us with enough information about what we need.

According to international previous studies, many experts found that there are define rules for the walls constructions materials .For example, the commercial buildings consists of materials that are considered as a standard. As a result, all the commercial building will follow that standard. Moreover, there is a specific standard for the residential, public buildings and old buildings.

One of our processes in our study is to apply the measurements according to these standards so we adapted the final results for all standards. For instance, every standard has its penetration loss. After we finished this step, the members of the TRADE UNION OF ENGINEERS told us that there are no definite standards for each type (commercial, residential and building internal walls). Those results forced us that we have to work individually to find all the probabilities of constructions walls materials which are used in Palestine buildings. These probabilities represent 90% of the Palestinian buildings [12].

As we have researched that there are 12 classes of external walls in building structure, in addition to two common internal walls. Each class has its own constructional materials. Here we will show more details about each class [12]:

4.4.1.1 Class One:



Figure 4.6: Cross-sections in outer wall for class 1. [12]

This class is composed of 1 cm of outer plasterer, 20 cm of Bricks, and another 1 cm of inner plasterer.

Location and serving cell

The following figure illustrates the location of the measured building compared to the cell providing it, which is located in Dura ,Sanjer, near Abu-Obaida Mosque. The serving cell is 52-A with partial LOS (line of sight) and 0.62 Km away from the building, the building is located in a residential area with close homes to it.



Figure 4.7: a satellite view of class 1 compared to the providing cell.

Interior and outer description of the building.

The area of this building is around 300 m^2 , it is not heavily furniture except of plastic chairs and tables as showed in the following figure, the building have 7 metal-shielded aluminum windows with one layer of glass, with dimensions of $2 \times 1.2 \text{ m}^2$.



Figure 4.8: an internal view of the building where class 1 was measured.

We intended to make our measurements at late night to assure that the serving cell has least traffic.

Measurement procedure.

We divided the wall into 42 samples, on each inner and outer sides of the wall. The horizontal distance is about 64 cm between every two samples, and the vertical distance between every two samples is about 20 cm, the following picture will make it clearer.



Figure 4.9: The distribution of points at the inner side of the wall in class 1.



Figure 4.10: the distribution of outer points at class 1.

As we said before, we have 42 points. At each sample we located the TEMS handset for half a minute (about 300 readings), bearing in mind that during the record the TEMS handset shouldn't be shaken or moved in any way, then we took the average value of each log file, that value represents the exact value at each sample, afterwards we took the average value of the signal at the sample points for the inner side of the wall, same work was done for the outer side of the wall.

4.4.1.2 Class two:



Figure 4.11: cross section of the outer wall for class 2.[12]

This class is composed of 30 cm meter stone, and 37cm concrete and 3 cm paint.

Location and serving cell:

The following satellite view shows the location of this certain class, related to the providing cell (14-C) with full line of sight, this old building is located in Halhul, Hebron,

Al-Nabiyounis ST. surrounded by other homes, and due to its location on the main street there is a lot of car traffic passing in front of it.



Figure 4.12: a satellite view of class 2 compared to the providing cell.

Interior and outer description of the building.

This wall is located in the western part of the old building with direct line of sight with the providing cell with a large window, the following figure shows the geometry of the wall, note that it is an abandoned old house so there is no furniture inside.



Figure 4.13: the distribution of points at the inner side of wall in class 2.

Measurement procedure:

We divided the wall into 15 points, separated 55 cm horizontally and 35 cm vertically, and with regards to the measurement, it's the same as described in class 1.

Now the distribution of points at the outer side of the wall in class 2.



Figure 4.14: the distribution of measurement points at the outer side of class 2.

4.4.1.3 Class three:

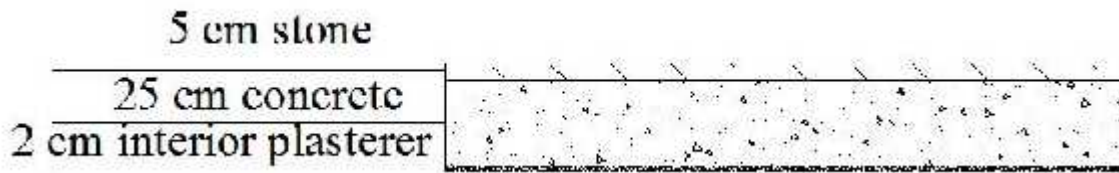


Figure 4.15: cross section of outer wall in class 3.[12]

This class is composed of 5 cm stone (mlatah), 25 cm concrete, and 2 cm inner plasterer.

Location and serving cell:

The following figure shows the location of this certain class, related to the serving cell (112-B) with full LOS, building is located in Hebron, Wad al Haryeh, Palestine Polytechnic University (PPU), Building C, the building is located in an industrial area near Neiroukh factory.

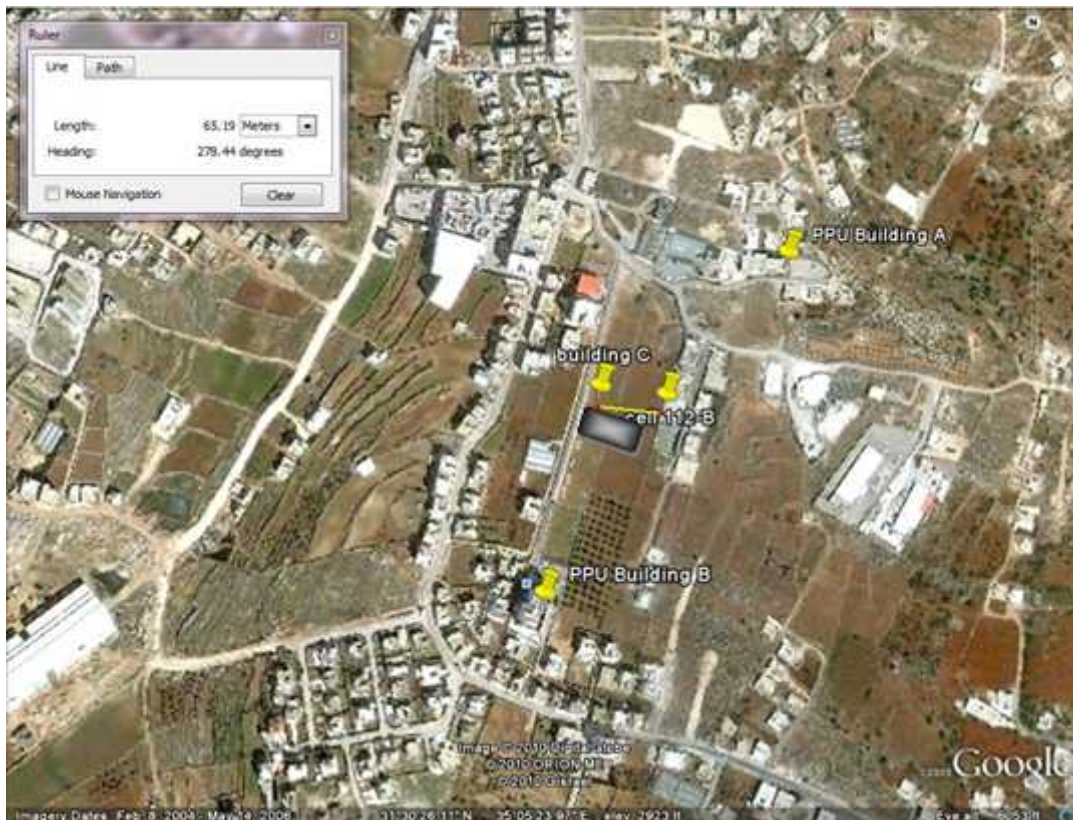


Figure 4.16: a satellite view of class 3 compared to the providing cell.

Interior and outer description of the building.

This wall is located in the entrance of the building it has no windows, behind the wall there is a corridor with 3 m width, no furniture there, a door with 3x2m dimensions beside the wall, the following figure describe it in detail.



Figure 4.17: a general view of the wall under test.

Measurement procedure .

We divided the wall into nine samples with 50 cm horizontal spacing between every neighboring samples, and a 25cm vertical spacing, with regards to the mechanism of measurement, it is the same as described in class 1.

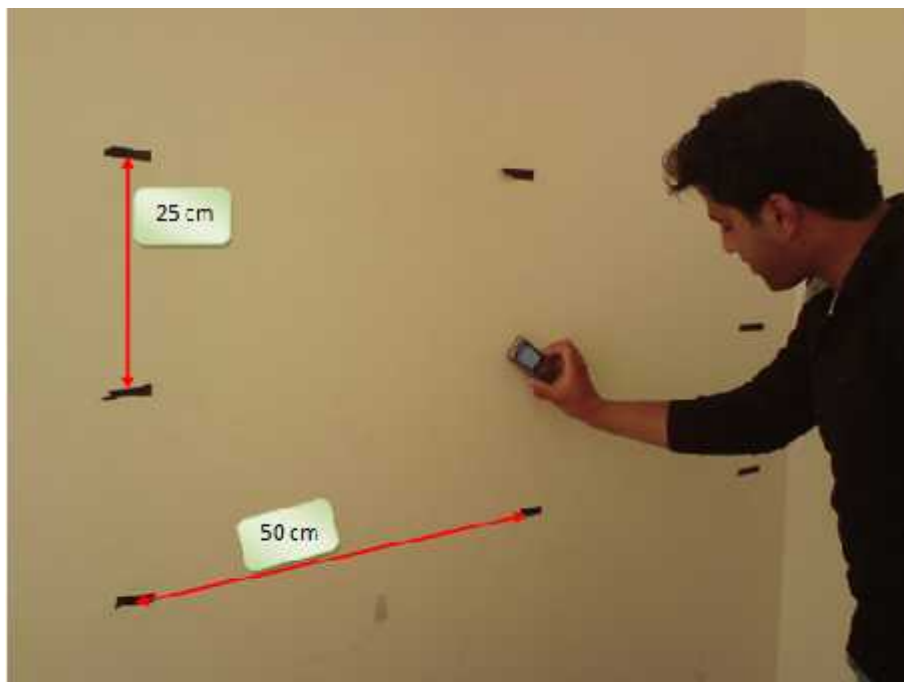


Figure 4.18: the distribution of points at the inner side of the wall of class 3.

Now the distribution of points at the outer side of class 3.



Figure 4.19: the distribution of points at the outer side of the wall in class 3.

4.4.1.4 Class Four:

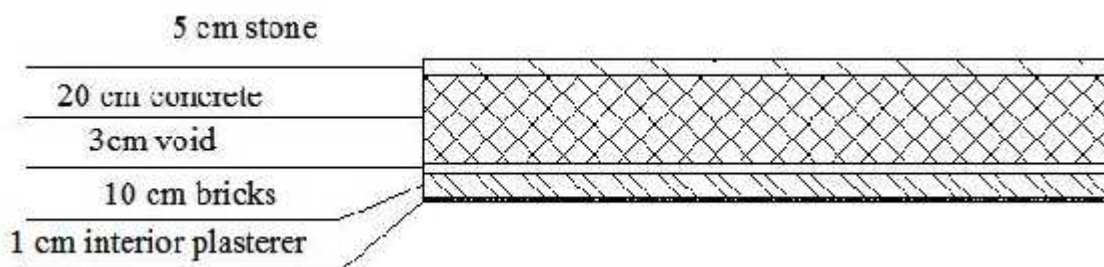


Figure 4.20: Cross-sections in outer wall for class 4. [12]

This class is composed of 5 cm, 20 cm reinforced concrete, 3 cm polystyrene insulation, 10cm brick, and 1 cm of interior plasterer.

Location and serving cell:

The following figure shows the location of this class related to the serving cell (32-A), with no LOS, this building is the same building in class 8 where it is located in Dura, near Dura Cultural Center, not so many buildings surround that building which will affect the propagation of the signal.



Figure 4.21: a satellite view of class 4 in comparison to the providing cell.

Interior and outer description of the building.

This wall is located in the southern side of the building, at the entrance of the stairs, notice that there is an 2.1m X 1.5m iron door beside the wall under test, since the building is still under construction there is no furniture inside but the stairs themselves.

Measurement procedure.

This wall was divided into 16 points with 31 cm horizontal spacing and a 25 cm vertical spacing as shown in the following figure, and with regards to the measurement mechanism it's the same as described in class 1.



Figure 4.22: the distribution of points at the inner side of the wall in class 4.

Now the distribution of points at the outer side of the wall in class 4, is as shown in the following figure.

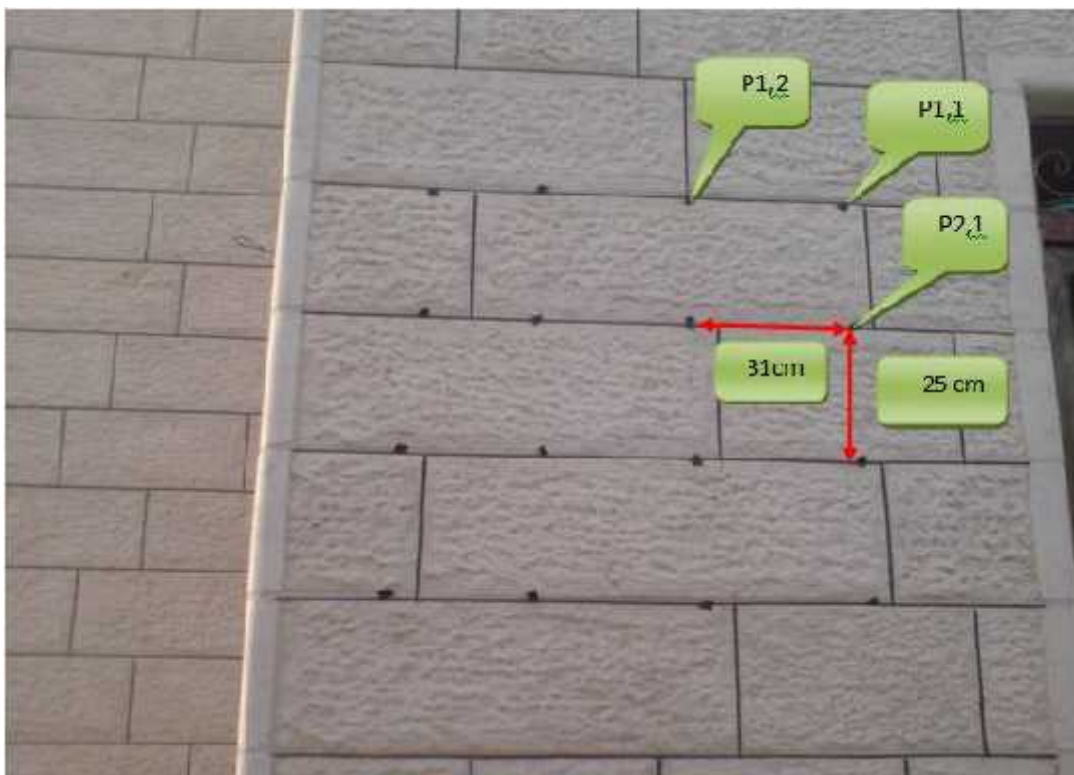


Figure 4.23: the distribution of points at the outer side of the wall under test in class 4.

4.4.1.5 Class five:

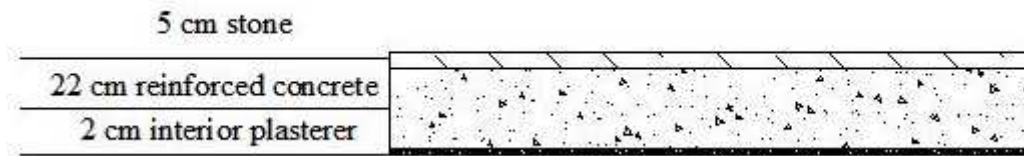


Figure 4.24: cross-section of the outer wall of class 5.[12]

This class is composed of 5 cm stone, 22 cm reinforced concrete, and 2 cm plasterer and paint.

Location and serving cell:

This class is located in Sanjer, Dura, Hebron in the south if the west bank, the serving cell is 52-A with full LOS (Line Of Sight), the distance between the serving cell and the sampled wall as measured on Google earth is (550 meters), the following satellite view may make it more obvious.

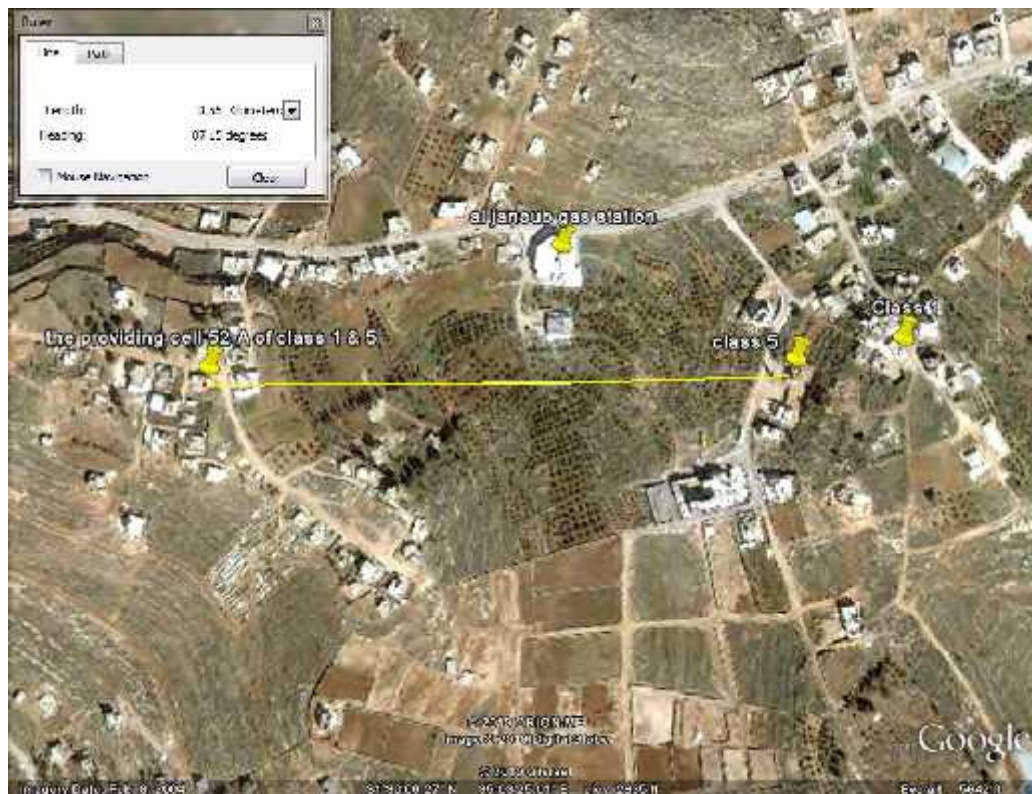


Figure 4.25: a satellite view of class 5 in comparison to the providing cell.

Interior and outer description of the building:

This wall is a side of a garage in a residential building with no windows in the direction of the providing cell or neither in any other side, the area of the garage is 4X3 meters, the following figure illustrates these properties.



Figure 4.26: inner view of class 5.

As we did in other classes we intended to do our measurements in a low traffic time at the cell (Friday morning) .

Measurement procedure

The wall was divided into (6 X 8) 48 points, at each point we took a sample inside and another outside the wall, the horizontal distance between every two adjacent points is (100 cm) and the vertical distance is (25 cm), the following picture shows the distribution of the points on the wall.



Figure 4.27: the distribution of points at the inner side of the wall of class 5.

As done for other samples, the measurement procedure is repeated as described in class 1.

Now the distribution of points at the outer side of the wall is as shown in the following figure.



Figure 4.28: the distribution of points at the outer side of the wall of class 5.

4.4.1.6 Class Six:



Figure 4.29: cross section of outer wall of class 12.[12]

This class is composed of 5 cm mlatash stone, 10 cm concrete, 10 cm bricks, and 1 cm interior plaster.

Location and serving cell:

This building is located in Dura, at the same residential building where we measured class 5, which means same geographical area, and same providing cell (52-A), the following satellite view will illustrate the location of this class.



Figure 4.30: a satellite view of class 6 compared to the providing cell.

Interior and outer description of the building:

This wall is a guest room in a residential building, which means that it's pretty furnished, as shown in the following figure, the wall under test has a 1.2 m x 1 m window, with metal shielding, the dimensions of the room is 4m X 4m where it has two door leading to that room.



Figure 4.31: interior view of room under test for class 6.

We measured this class at a low traffic hour to assure receiving a clear signal, with no much data loaded on it.

Measurement procedure.

The wall was divided into 28 points (7 x 4), the horizontal spacing is 57 cm while the vertical spacing between points is 25 cm, the following picture shows the distribution of points on the wall at the outer side of the wall.

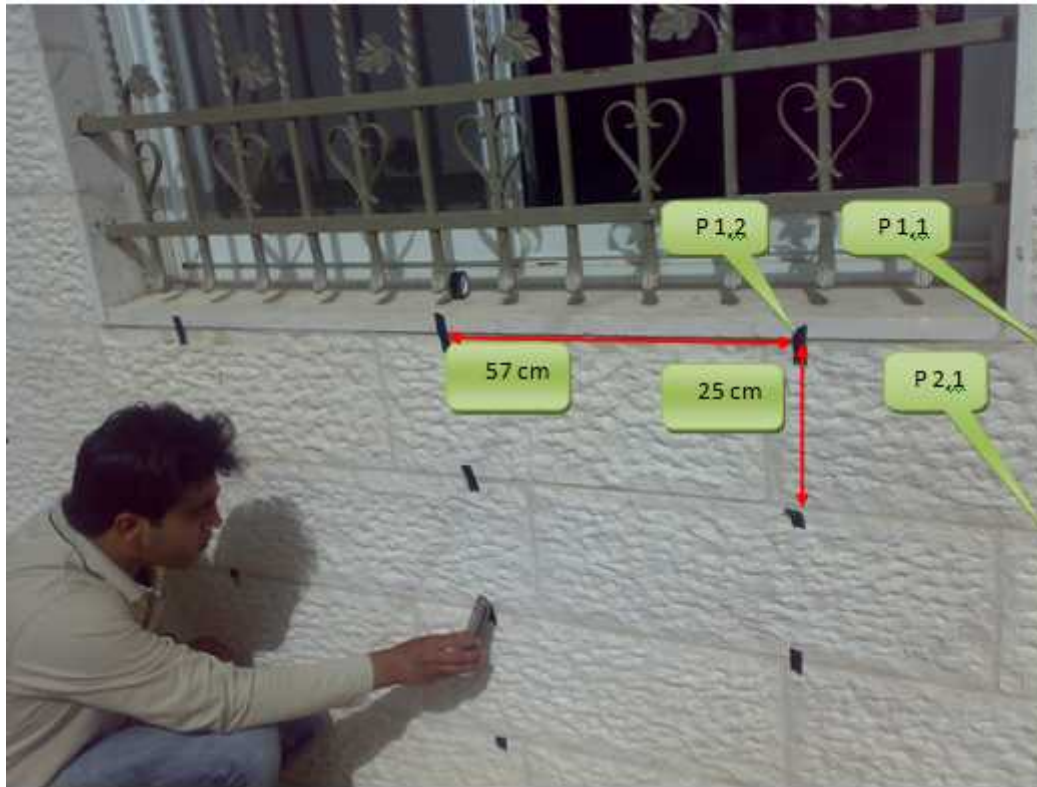


Figure 4.32: the distribution of point at the outer side of the wall of class 6.

Now for the inner side of the wall the distribution of the point is as in the following picture.



Figure 4.33: the distribution of points at the inner side of the wall.

4.4.1.7 Class Seven:

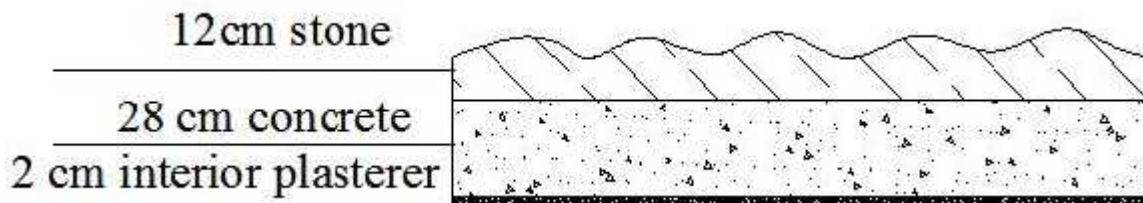


Figure 4.34: cross-section in outer wall for class 7.

This class is composed of 12 cm stone (Tobzeh), 28 cm concrete, and 2 cm plasterer which gives a total width of the wall 42 cm.

Location and serving cell.

This class is located close to class 1 and covered by the same cell (52-A), with LOS to the providing cell, the distance between the providing cell and the building under test is (630 meters) as measured using Google Earth.



Figure 4.35: a satellite view of class 7 in relation to the providing cell.

Interior and outer description of the building.

The wall under test is a part of an old residential building, with 1.2m X 1m iron window with metal shielding, and iron abjure, the wall under test is a part of a guest room which means that the room is furniture, and has a carpet on the floor, and the dimension of the room is 4m X 4m.

Measurement procedure

The wall was divided into 24 points (4 X 6), the horizontal spacing between points is 54 cm, while the vertical spacing is 30 cm, the following figure shows the distribution of points on the inner side of the wall.

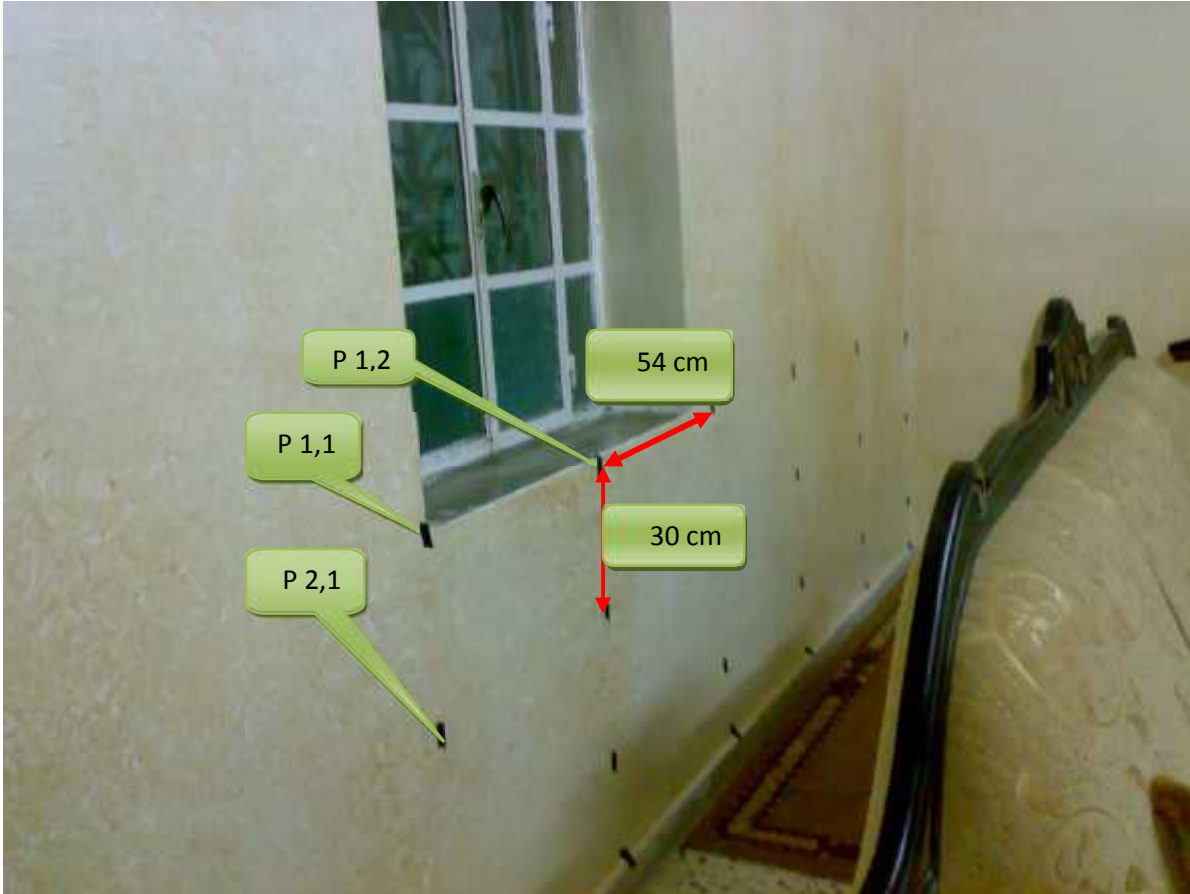


Figure 4.36: the distribution of points on the inner side of the wall.

Now the following figure shows the distribution of point at the outer side of the wall.

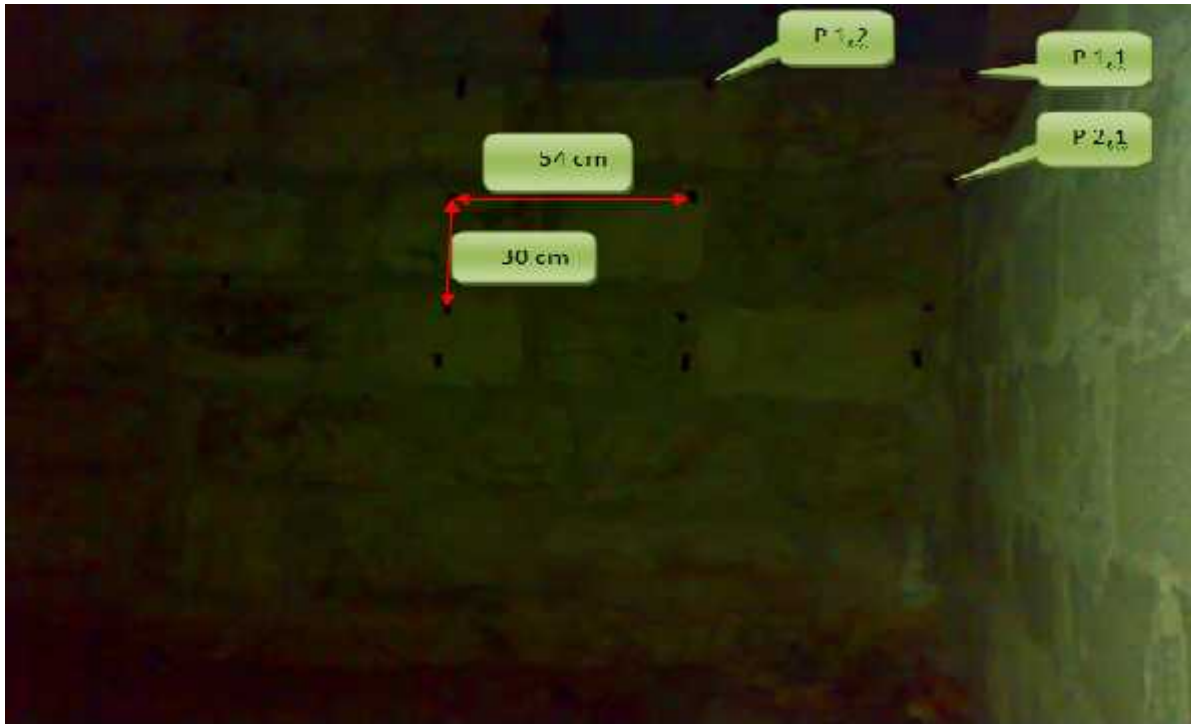


Figure 4.37: the distribution of points at the outer side of the wall.

4.4.1.8 Class Eight:

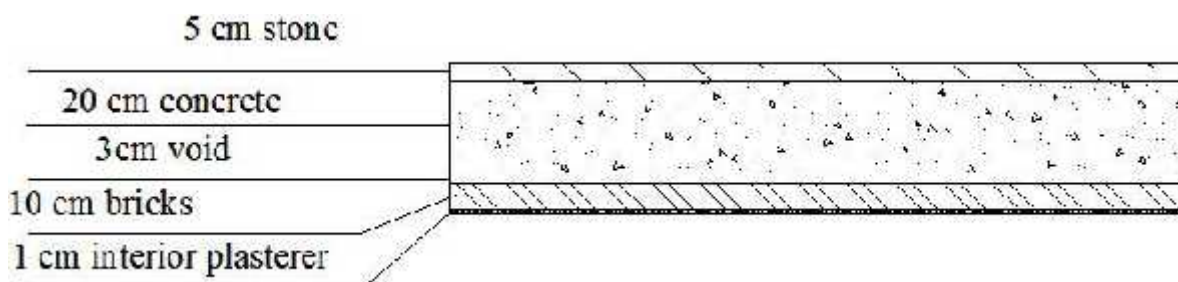


Figure 4.38: Cross-sections in outer wall for class 8. [12]

This class is composed of 5 cm mlatash stone ,20 cm concrete, 3 cm air space, 7 cm Bricks, and 1 cm interior plasterer.

Location and serving cell

The following figure shows the exact location of this class, related to the serving cell (10-B) with no LOS, the building is located in Dura, Abu-Hlal area, the building is not surrounded with many buildings, as shown.

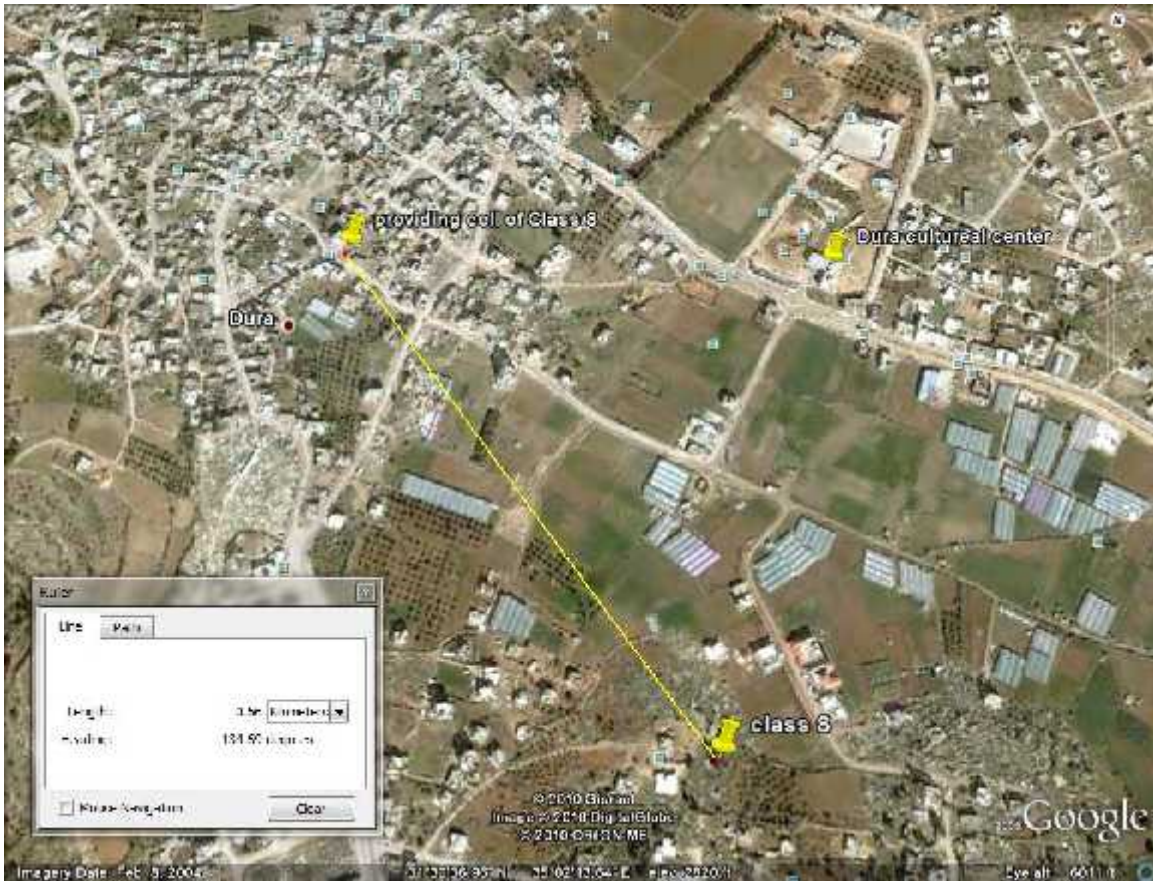


Figure 4.39: a satellite view of class 8 in relation with the providing cell.

Interior and outer description of the building:

The wall under test is located in a residential building under construction, with a 1.3m x 1.5m window in the middle and two standard doors leading to the room where the dimensions of the room are 3 x 3.5 meters, the following figure illustrates the measured room and wall.



Figure 4.40: interior description of the tested room for class 8.

Measurement procedure.

We divided the wall into 20 sample points on each inner and outer side of the wall, the spacing between every two horizontal neighboring points is 100 cm, and the vertical spacing is 25 cm, as shown in the following picture, which shows the distribution of points at the outer side of the wall under test.



Figure 4.41: the distribution of point at the outer side of class 8.

For the inner side of the wall, the distribution of points is as shown in the following figure.

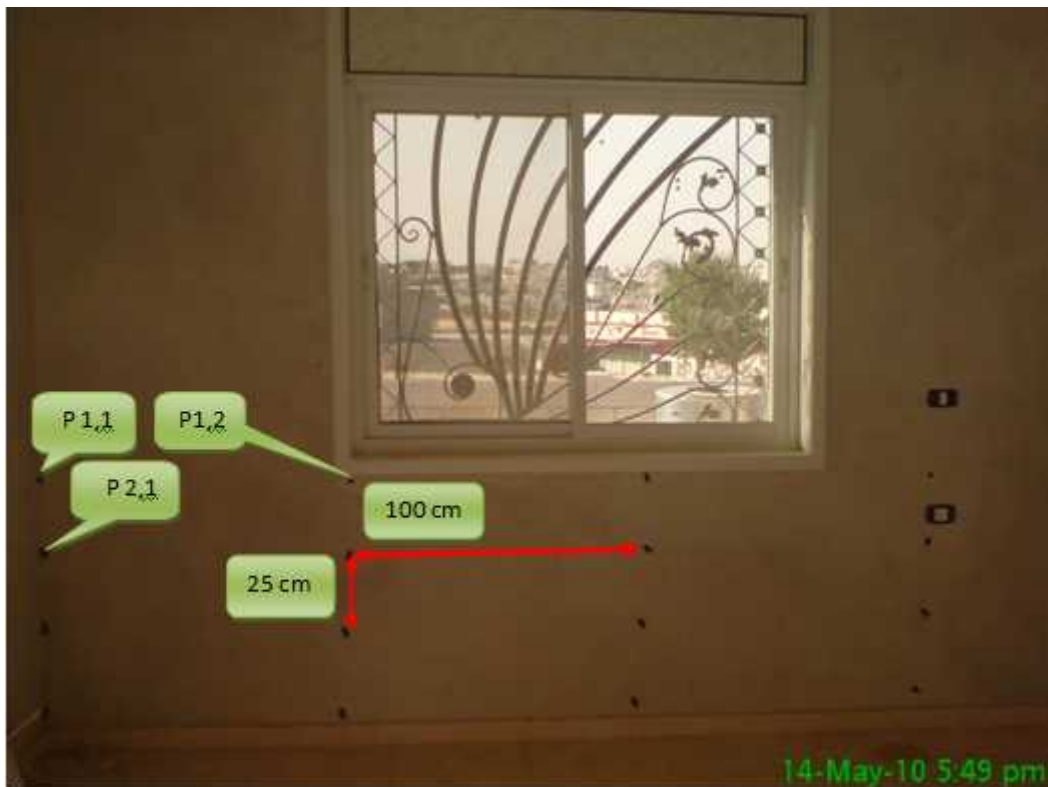


Figure 4.42: the distribution of points at the inner side of the wall for class 8.

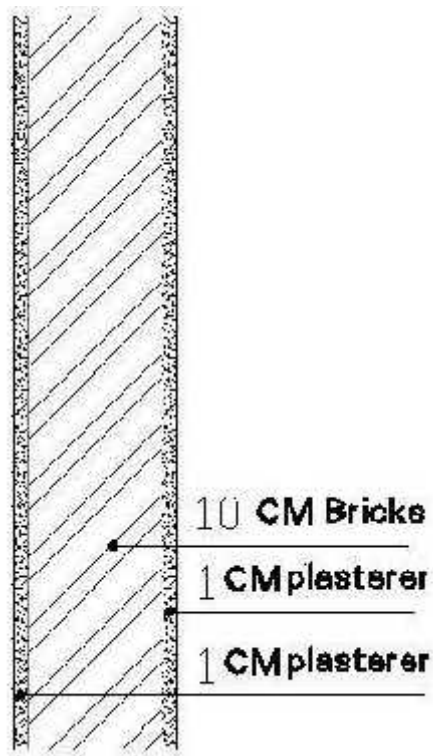
4.4.1.9 Class Nine:

Figure 4.43: Cross-sections in outer wall for class 9. [12]

This class is composed of 10 cm of bricks, and two cm of inner and outer plasterer.

Location and serving cell:

This class was tested on a wall in the same building where we tested class three, and since this class is used inside buildings there is no LOS, taking into consideration that the providing cell is the same as in class three (112-B), and the high use of mobile services because this class is located in an educational institution, the following figure is a satellite view of the location of this class with respect to the providing cell.



Figure 4.44: a satellite view of the buildings under test compared to the providing cell.

Interior and outer design of the building.

The wall under test is located in the second floor of building C, where it's a lecture room, not so heavily furnished, but of some chairs, and tables, also there is a door leading to that room in addition to three double layer glass windows, the following picture may make it easier to understand the geometry of this class.



Figure 4.45: the geometry of the interior of class 9.

Measurement procedure.

we divided this wall into 16 (4 X 4) points with 50 cm horizontal spacing and 25 cm vertical spacing, taking into consideration that we took a 60 cm spacing between the points and the door, and with regards to the mechanism of measurement, it's the same as described in class 1, the following figure illustrates the distribution of points at the inner side of this wall.



Figure 4.46: the interior distribution of the points at class 9.

Now the following figure shows the distribution of points at the outer side of this wall.

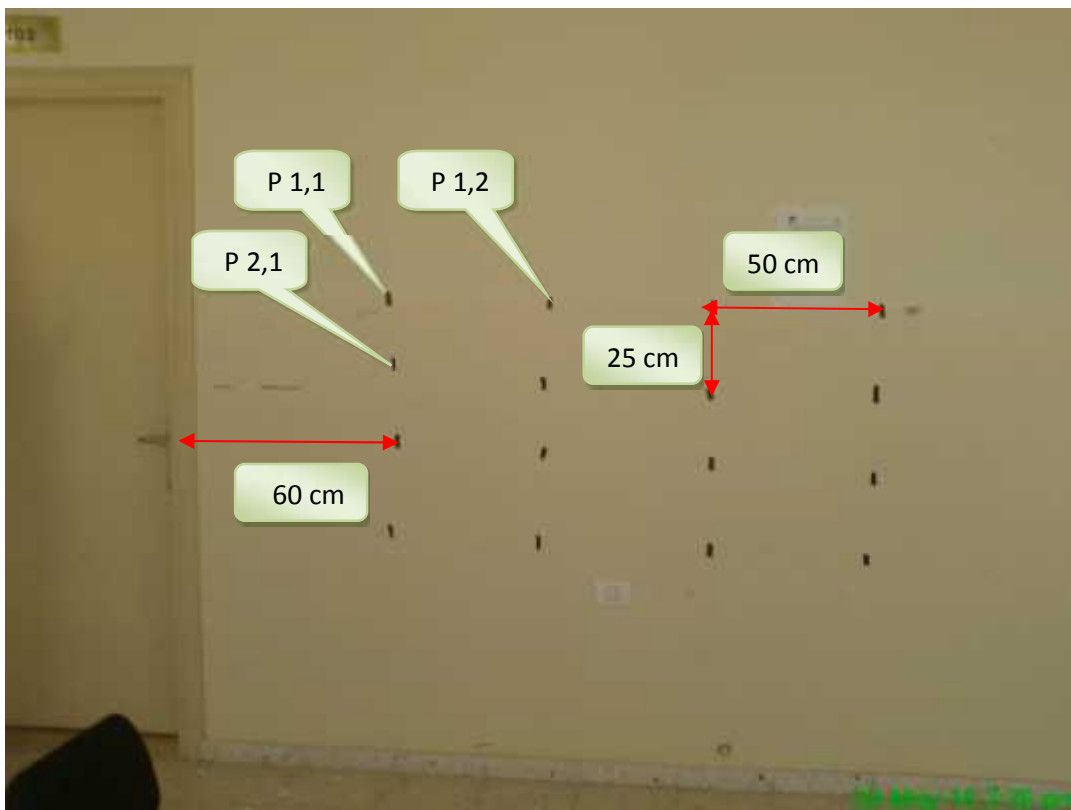


Figure 4.47: the distribution of points at the outer side of the wall of class 9.

4.4.1.10 Class 10 .

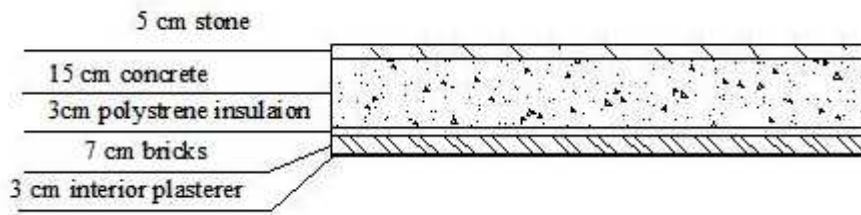


Figure 4.48: cross-section in outer wall of class 10.[12]

This wall is constructed of 5 cm stone, 15 cm concrete, 3 cm polystyrene isolation, 7 cm bricks, and 3 cm plasterer and paint.

Location and serving cell:

The following figure shows the location of this class related to the serving cell (62-A) with full LOS on the wall. The building where this wall is located in Al-Fawwar, Hebron, in a residential area, and the distance between the serving cell and the wall as measured using Google Earth is 1.17 Km.



Figure 4.49: a satellite view of class 10 compared to the providing cell.

Interior and outer description.

This class is located in a bedroom where its furniture with two beds and a table and some accessories, there is two doors in the room one leading to the room and the other is leading to a balcony, there is also two aluminum windows with abjure.

Measurements procedure

The following figure show the distribution of the points on the interior part of the wanted wall, where the total number of points is 24 points (4 X 6), where the horizontal spacing between points is 40 cm and the vertical spacing is 25 cm, with regards to the measurement procedure it is as described in class 1.

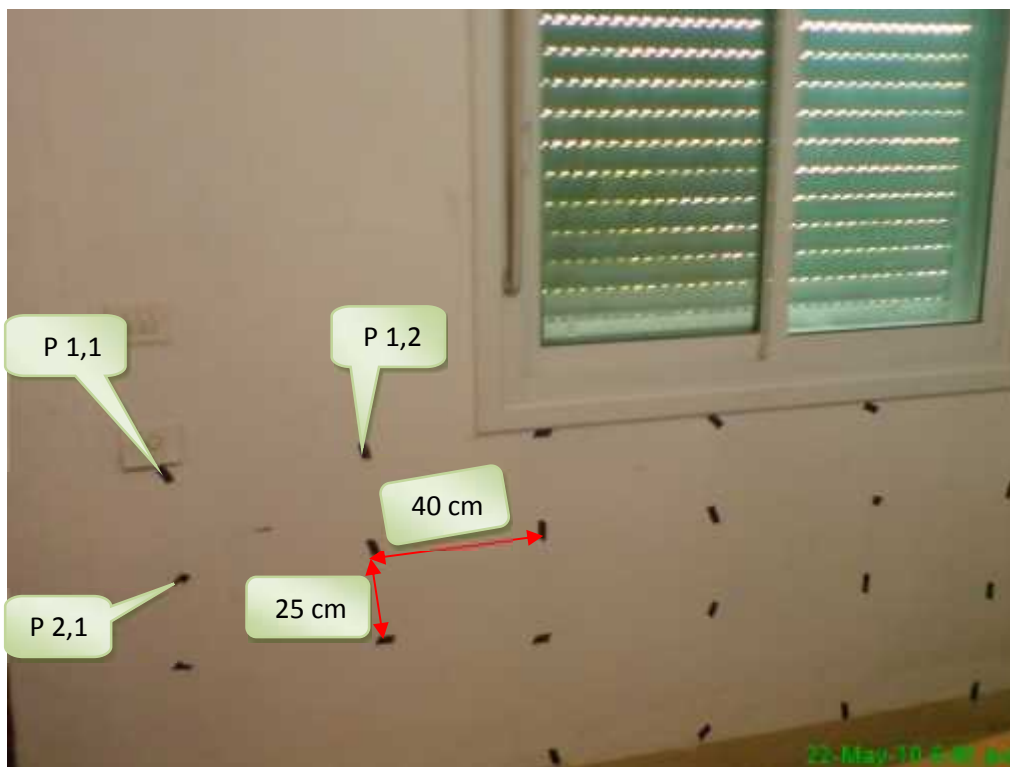


Figure 4.50: the distribution of points at the inner side of the wall of class 10.

Now the distribution of points at the outer side of the wall is as follows.



Figure 4.51: the distribution of points at the outer side of the wall in class 10.

4.4.1.11 Class 11.

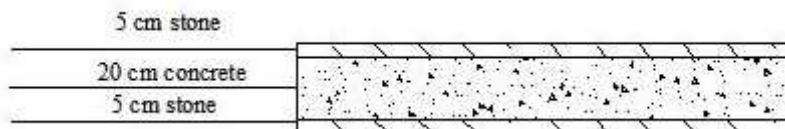


Figure 4.52: cross-section in outer wall for class 11. [12].

This class is composed of 5 cm stone, 20 cm concrete, and another 5 cm stone, which gives a total of 30 cm.

Location and serving cell

This class is located in Hebron, Dura, on the main street. The providing cell (32-A) is located far away from the building about 1.86 Km, as shown in the following satellite view.

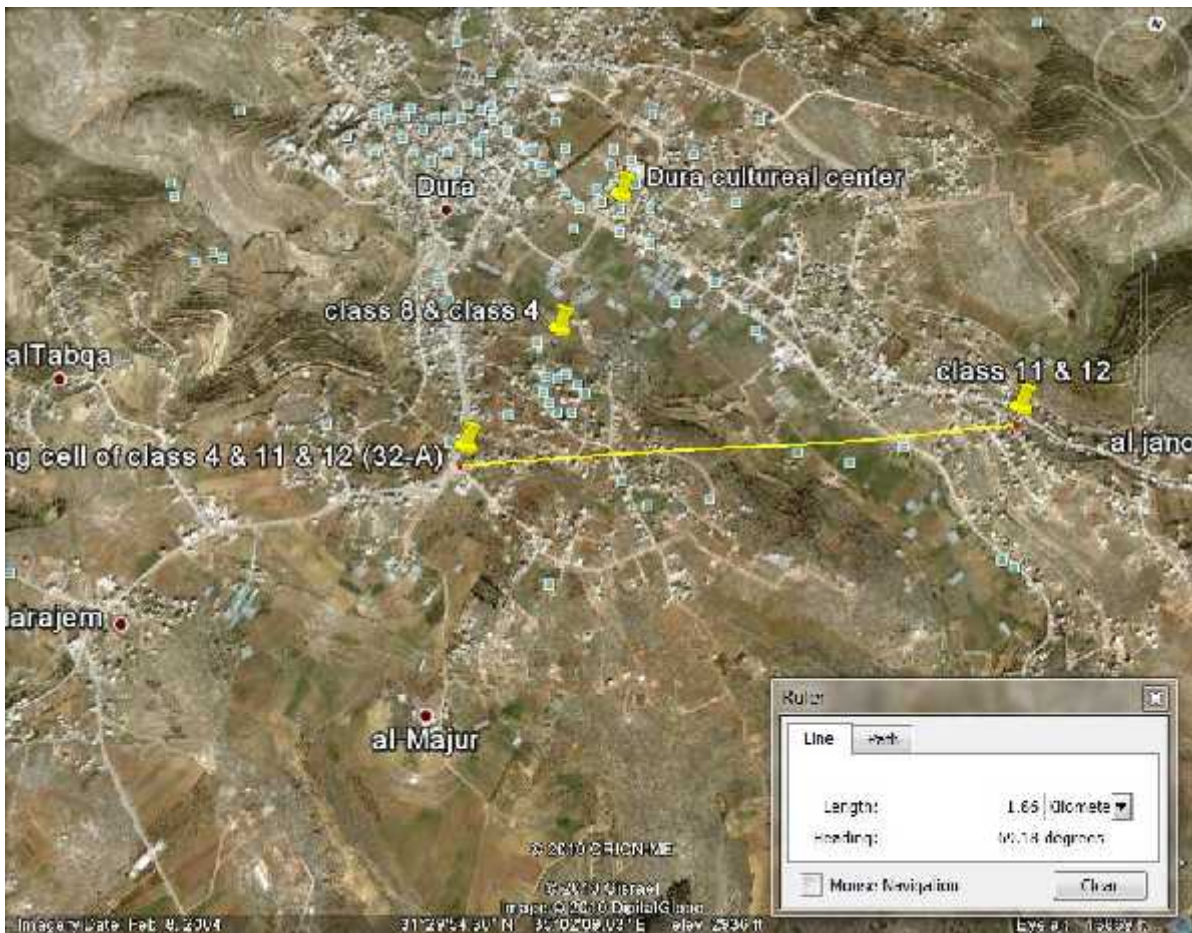


Figure 4.53: a satellite view of class 11 in comparison to the providing cell.

Interior and outer description of the building.

This building is located in a residential area, while this exact wall is an veranda with (2.5m X 1.5m) aluminum window, note here that most verandas use stone at the inner and outer side of the wall, which affects the penetration values of the signal as we will see ahead, the following figure will illustrates some of the wall specifications mentioned.

Measurement procedure

We divided the wall into 20 points (4 X5), with 50 cm horizontal spacing, and 25 cm vertical spacing, with regards to the measurement procedure it's the same as described in class 1.

The following figure shows the distribution of the points on the outer side of the wall under test.



Figure 4.54: the distribution of points at the outer side of the wall in class 11.

Now the distribution of points at the inner side of the wall is as follows.



Figure 4.55: the inner distribution of points for class 11.

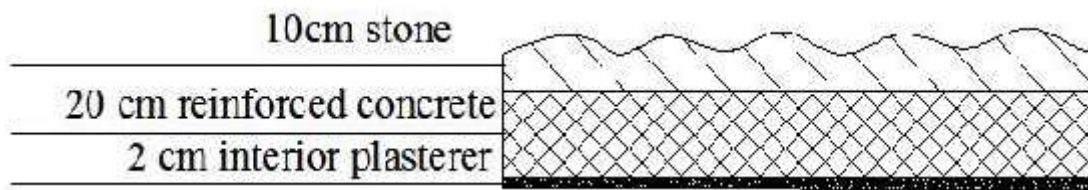
4.4.1.12 Class 12 :

Figure 4.56: a cross-section in the outer wall of class 12. [12].

This class is composed of 10 cm of stone (Tobzeh), 20 cm reinforced concrete, and 2 cm plasterer and paint, which gives a total width of 32 cm.

Location and serving cell.

The location of this class is at the same building we measured class 11, so it's the same properties and same providing cell.

Interior and outer description of the building.

As said before this class is located in the same building where class 11 is located, in fact it's the next room, the difference is that there is no other stone layer, noting that the outer stone is Tobzeh, the following figure makes it clearer.



Figure 4.57: interior description of the room where class 12 was measured.

Measurements procedure.

The wall was divided into 16 points (4 X 4), the horizontal spacing between points is 50 cm, the vertical spacing is 30 cm, with regards to the measurement mechanism it is as described in class 1.

Now the following figure shows the distribution of points at the outer side of the wall.



Figure 4.58: the distribution of measurement points at the inner side of class 12.

The following figure shows the distribution of points at the inner side of the wall under test.

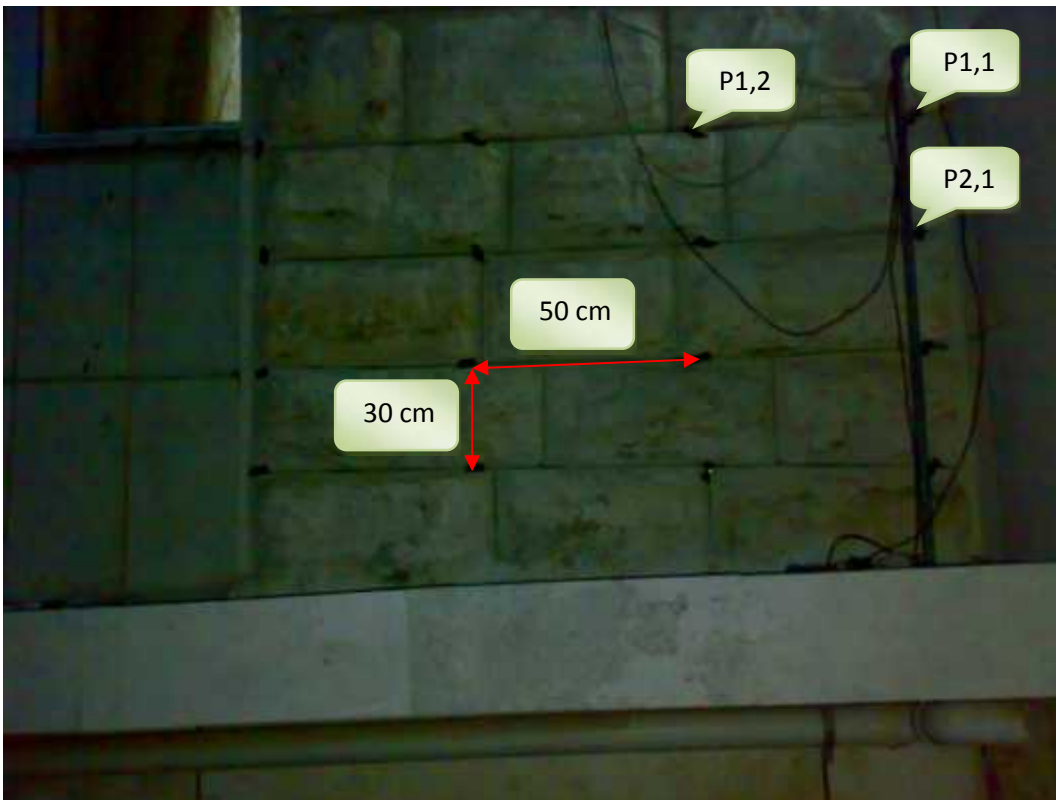


Figure 4.59: the distribution of point at the outer side of the wall of class 12.

4.4.1.13 Class 13 :

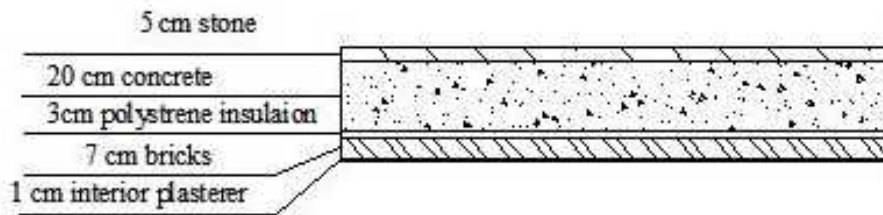


Figure 4.60: Cross-sections in outer wall for class 13.[12]

This class is composed of 5 cm stone, 20 cm concrete, 3 cm polystyrene insulation, 7cm bricks, and 2 cm plasterer and paint, which gives a total of 37 cm.

Location and serving cell.

This Class is located in Honainah, Dura, Hebron, in the south of the westbank. The following satellite view shows the location of this class compared to the providing cell (183-A), bearing in mind that there is no LOS, and the distance between the serving cell and the building under test is 930 meters as measured using Google Earth.



Figure 4.61: a satellite view of Class 13 and the providing cell 183-A.

Interior and outer description of the building:

The wall under test is a part of a living room, so it would be furnished with some couches and a T.V and some additional accessories, it also has two (2m X 1.5m) aluminum windows.

Measurement procedure.

This wall was divided into 15 points (3 X 5) at the inner side and the outer side, with horizontal spacing of 45 cm and vertical spacing of 25 cm, the following picture shows the distribution of points at the inner side of the wall.

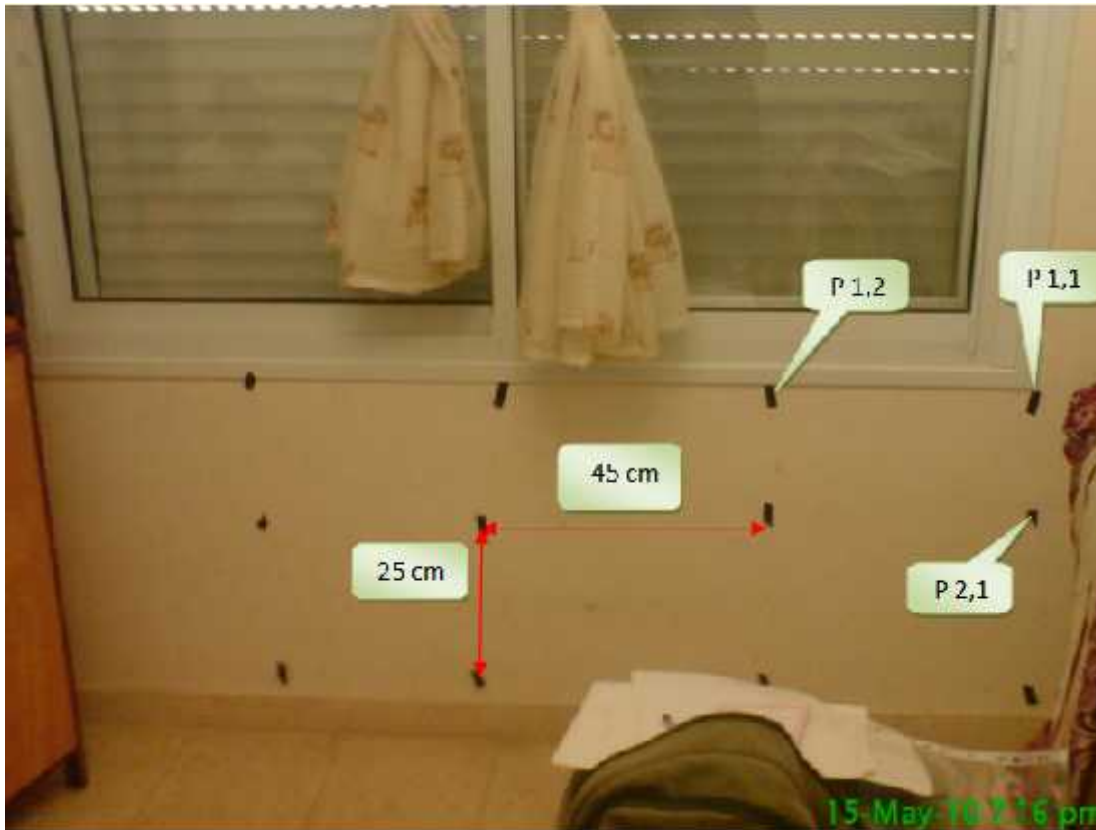


Figure 4.62: the inner distribution of points for class 13.

The following figure shows the distribution of points at the outer side of the wall.

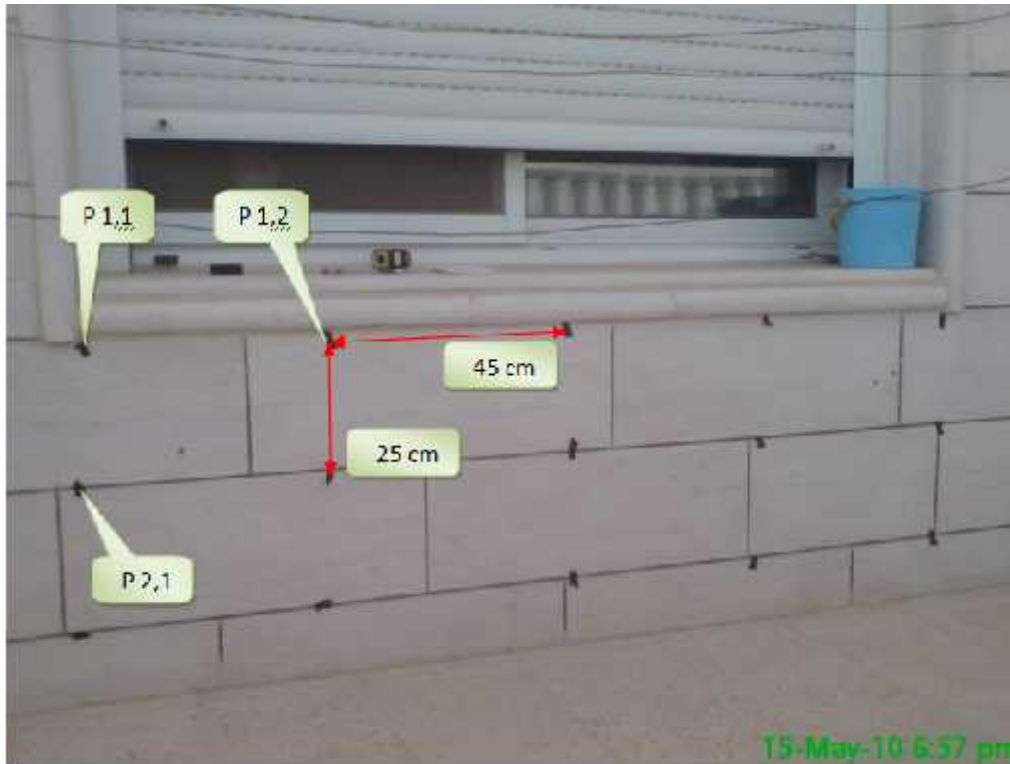


Figure 4.63: the distribution of points at the outer side of the wall of class 13.

4.4.1.14 Class 14.



Figure 4.64: a cross section in the class wall.[12].

This class is composed of 2 cm gypsum, 6 cm of air, and another 2 cm of gypsum.

Location and serving cell.

The location of this class is the same building for class 3, and since this wall is an internal wall there is no LOS with the providing cell, see figure 4.16 to give a clearer view of the location of this class compared to the providing cell.

Measurement procedure.

This class was divided into 15 points (3 x 5) with 50 cm vertical separation between point and 100 cm horizontal spacing, and with regards to the measurement procedure it's the same as described in class 1.

The following figure shows the distribution of points at the inner part of this wall.

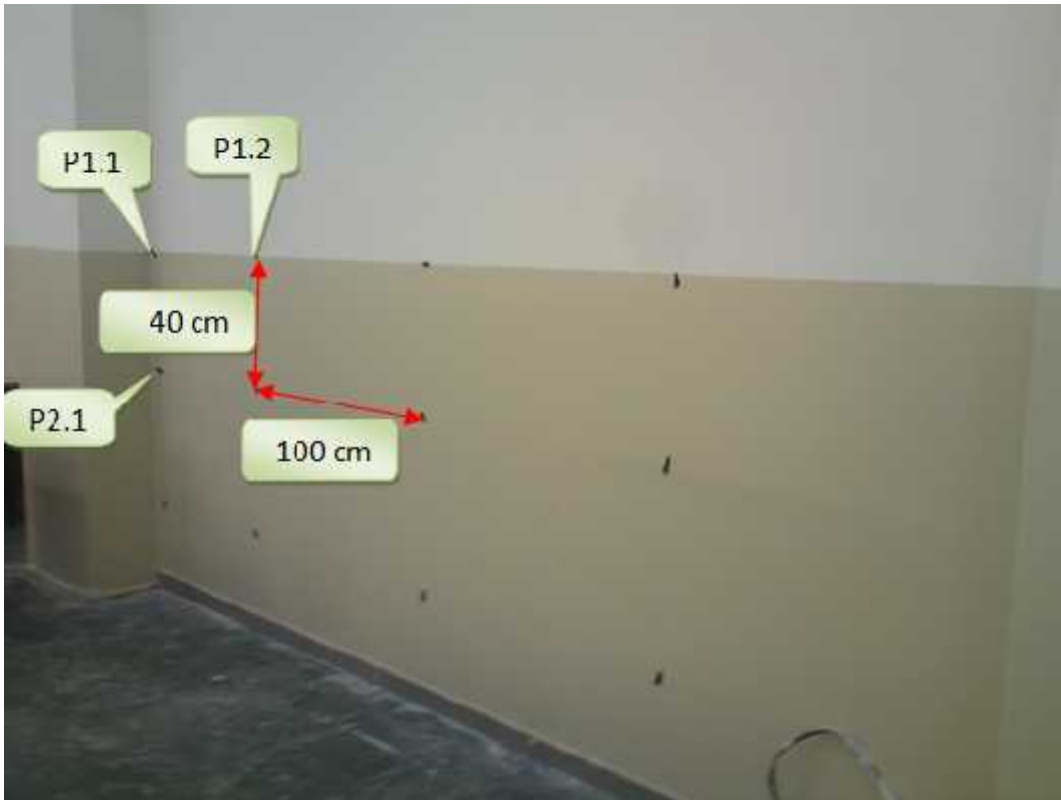


Figure 4.65: the inner side of class 14.

The following figure shows the distribution of points at the outer side of class 14.



Figure 4.66: the outer side of class 14.

Chapter five

Measurements Results

5.1 Introduction

5.2 Outdoor results

5.3 Classes measurements

5.4 Indoor results

5.1 Introduction

This chapter represent our measurement results taken from the three stages ,these measurements was taken using TEMS handset , every single measurement represent the average of a recorded log file , this log file was converted to an excel sheet contains the signal power measured (about 5 measures per second) at the point with its time.

To calculate the penetration losses we took the average value of all points at the inner side and the outer side of each wall, which is shown later in this chapter.

The standard deviation was calculated in three stages separately, at the outdoor stage the standard deviation was taken from the whole outdoor values, same was done for the indoor stage, now with regards to the standard deviation for the penetration loss in the classes, it depends on each class, since it was taken for the inner side of each class.

5.2 Outdoor results:

The following table shows the average measured power in dbm`s at each track in the outdoor measurements, where every values represents an average of about 500 readings, the mechanism to taking each track within every zone , is shown in figure 4.5 , where the width of each zone is 20 meters, so the distance between every two average track is assumed to be 20 meters.

Track #	Distance (10log d)	average power (dbm)	Track #	Distance (10log d)	average power (dbm)
Track 1	18.45098	-36.034091	Track 13	24.91362	-40.5304647
Track 2	19.54243	-37.290113	Track 14	25.18514	-40.9964727
Track 3	20.41393	-37.453405	Track 15	25.44068	-41.3902896
Track 4	21.13943	-37.939863	Track 16	25.68202	-42.2592593
Track 5	21.76091	-37.757189	Track 17	25.91065	-47.8697605
Track 6	22.30449	-38.06199	Track 18	26.12784	-46.6655949
Track 7	22.78754	-39.369231	Track 19	26.33468	-47.3007752
Track 8	23.22219	-38.87449	Track 20	26.53213	-52.2424242
Track 9	23.61728	-39.096075	Track 21	26.72098	-50.2801083
Track 10	23.9794	-39.654839	Track 22	26.90196	-50.1746725
Track 11	24.31364	-37.946755	Track 23	27.0757	-54.846442
Track 12	24.62398	-40.448331	Track 24	27.24276	-54.9329806

Table 5.1: the average value of each log file taken at each track in dBm.

These results are taken to consider a general case for outdoor path losses, since outdoor free space path loss is similar in most cases, because the environment is a like for

most Palestinian areas, these outdoor readings will be used as a part of our model for calculating the in building penetration losses for any wanted class of the 14 classes.

Standard deviation = 7.020248

5.3 Classes measurements

The results of the Classes, are as follows, taking into consideration that the distribution of points in the tables is the same as distributed on each wall:

5.3.1 Class One:

the following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.9.

Point	1	2	3	4	5	6
1	-57.5417	-55.7778	-60.0167	-63.5882	-59.7955	-62.5391
2	-56.299	-53.4173	-51.5758	-55.3732	-51.4318	-61.5369
3	-58.994	-57.3103	-58.0373	-60.0156	-54	-59.8492
4	-55.1716	-62.2657	-51	-62.684	-58.6831	-60.6439
5	-57.3931	-60	-60.1508	-58.2183	-59.3116	-57
6	-56.8855	-54	-59.9874	-62.684	-58.4351	-55.6423
7	-57.0236	-55.932	-56.4225	-58.1527	-60.3889	

Table 5.2: the log file average values at the inner points in dbm.

the following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.10.

Point	1	2	3	4	5	6
1	-44.7193	-41	-46.757	-45.0364	-44.9174	-49.1349
2	-45.9712	-43.0268	-42.0763	-43.8218	-40.246	-48.7607
3	-43.7069	-46.7706	-39.68	-44.0926	-42.25	-42.4352
4	-40.4425	-46.769	-40.5378	-45.3	-39.1776	-44.252
5	-43.0429	-45.8624	-43.3068	-44.2162	-46.1826	-39.8785
6	-42.211	-42.6667	-48.8092	-45.06	-46.0091	-46.6842
7	-44.1897	-44.8761	-48.3471	-46.1019	-44.1739	

Table 5.3: the average values of the log file readings at the outer points in dbm.

The following table shows the average power of all points at each side of the wall (inner alone and outer alone) obtained from the previous two table, in addition to 10th percentile value taken for each side, which if achieved it will guarantee 90% coverage, also u can get from the following table the 50th percentile, which may guarantee 50% coverage that is not that satisfying for users, and may cause customer churn from the operator, finally the last row in the table shows the standard deviation for the outer and inner side of the wall, taking into consideration that we adapted the standard deviation of the inner side because it represents the standard deviation of the penetrating signal through the wall.

	outside (dBm)	inside (dBm)	Delta (dB)
Average power	-44.2073	-57.9311	13.72379
10 th percentile	-46.7706	-62.2657	15.4951
50 th percentile	-44.2162	-58.1527	13.9365
Standard deviation ()	2.595704	3.144131	3.144131

Table 5.4: class one values.

5.3.2 Class two:

the following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.13.

Point	1	2	3	4	5
1	-79.2276	-85.4803	-89.8667	-81.0818	-84.6495
2	-83.0354	-81.2381	-81.1075	-79.9904	-81.5122
3	-81.6455	-81.3906	-87.3089	-87.9787	-83

Table 5.5 the average power values taken at the inner side of the wall in dBm

the following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.14.

Point	1	2	3	4	5
1	-39	-40.3049	-42.0299	-38.0917	-38.6602
2	-39.2593	-39.5856	-39	-38.8542	-37.6503
3	-39	-41.0556	-38.5167	-38.4014	-38

Table 5.6: the average power values taken at the outer side of the wall in dbm.

The following table shows the average power of all points at each side of the wall (inner alone and outer alone) obtained from the previous two table, in addition to 10th percentile value taken for each side, which if achieved it will guarantee 90% coverage, also u can get from the following table the 50th percentile, which may guarantee 50% coverage that is not that satisfying for users, and may cause customer churn from the operator, finally the last row in the table shows the standard deviation for the outer and inner side of the wall, taking into consideration that we adapted the standard deviation of the inner side, not the outer, because it represents the standard deviation of the penetrating signal through the wall.

	outside (dBm)	inside(dBm)	Delta (dB)
Average power	-39.1607	-83.2342	44.07356
10th percentile	-40.7553	-87.7108	46.95546
50th percentile	-39	-81.6455	42.6455
Standard deviation ()	1.180402	3.149254	3.149254

Table 5.7: class two values.

5.3.3 Class Three:

the following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the

logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.18.

Point	1	2	3
1	-55.1341	-59.4651	-53.4654
2	-62.8068	-63.2279	-61.3134
3	-58.1907	-55.4533	-60.7697

Table 5.8: the average power values in dbm at the inner side of the wall in class 3.

the following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.19.

Point	1	2	3
1	-36.4048	-36.1134	-38.8247
2	-41.125	-36.6429	-39.9313
3	-39.8235	-42.3252	-36.8487

Table 5.9: the average measured power values at the outer side of the wall in dbm`s.

The following table shows the average power of all points at each side of the wall (inner alone and outer alone) obtained from the previous two table, in addition to 10th percentile value taken for each side, which if achieved it will guarantee 90% coverage, also u can get from the following table the 50th percentile, which may guarantee 50% coverage that is not that satisfying for users, and may cause customer churn from the operator, finally the last row in the table shows the standard deviation for the outer and inner side of the wall, taking into consideration that we adapted the standard deviation of the inner side, not the outer, because it represents the standard deviation of the penetrating signal through the wall.

	outside (dBm)	inside(dBm)	Delta (dB)
Average power	-38.6711	-58.8696	20.19854
10th percentile	-41.365	-62.891	21.52598
50th percentile	-38.8247	-59.4651	20.6404

Standard deviation ()	2.27559	3.530666	3.530666
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Table 5.10: class three values

5.3.4 Class four:

the following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.22.

P	1	2	3	4
1	-101.5816	-100.2912	-101.7179	-99.3293
2	-100.4886	-101.0632	-101.2807	-99.9714
3	-102.9231	-101.8	-101.1415	-100.0308
4	-107	-102.2479	-102.5493	-101.0847

Table 5.11: indoor average measured power values at the inner side of class 4 in dbm.

the following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.23.

P	1	2	3	4
1	-64.8974	-67.1481	-66.0741	-66.8276
2	-64.0549	-65	-65.6991	-67.4277
3	-64.4857	-65.7475	-66.2604	-66.96
4	-64.1538	-67.5122	-70.0313	-66.1783

Table 5.12: the average power values taken at the outer side of the wall in class 4 in dBm`s.

The following table shows the average power of all points at each side of the wall (inner alone and outer alone) obtained from the previous two table, in addition to 10th percentile value taken for each side, which if achieved it will guarantee 90% coverage, also u can get from the following table the 50th percentile, which may guarantee 50%

coverage that is not that satisfying for users, and may cause customer churn from the operator, finally the last row in the table shows the standard deviation for the outer and inner side of the wall, taking into consideration that we adapted the standard deviation of the inner side, not the outer, because it represents the standard deviation of the penetrating signal through the wall.

	outside (dBm)	inside (dBm)	Total (dB)
Average power	-66.1536	-101.5313	35.37769
10th percentile	-67.47	-102.7362	35.26625
50th percentile	-66.1262	-101.2111	35.0849
Standard deviation ()	1.529348	1.756799	1.756799

Table 5.13: class four values

5.3.5 Class five:

the following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.28.

P	1	2	3	4	5	6
1	-39.7032	-38.1618	-39	-39.9203	-40.3688	-38.8582
2	-36.624	-38.5333	-36.4806	-37.3583	-37.0811	-37
3	-36.0297	-37.8049	-37.9474	-39.1645	-36.832	-38.3443
4	-36.5145	-39.1232	-38.7606	-43	-38.7647	-37.0506
5	-36.2434	-37.0476	-36.9638	-36.9558	-40.268	-37
6	-38.7265	-36.6594	-36.4573	-36.4097	-37.198	-37.9328
7	-41.9662	39.927	-36.3758	-38.6014	-36.5486	-39.4497
8	-37.5275	-37.5043	-39	-41.2696	-41.2617	-41.8933

Table 5.14: measurement results obtained at the outer side of the wall in dBm.

the following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.27.

P	1	2	3	4	5	6
1	-61.2797	-63.7898	-68.7059	-60.1615	-61.9331	-63.7434
2	-60.7573	-58.2558	-61.4465	-64.7273	-57.845	-60.3497
3	-58.1404	-62.9824	-61	-59.4396	-60.7551	-60
4	-60.486	-56.0573	-61.9412	-61.7353	-64.0088	-59.1905
5	-61.969	-62.3008	-59.4	-60.6476	-60.8762	-62.1802
6	-61	-67.5438	-58.0926	-58.7374	-59.719	-59.2793
7	-60.3645	-59.3407	-65.1016	-60.8487	-59.9681	-63
8	-66.041	-60.7596	-63.2963	-67.5942	-67.595	-65.0718

Table 5.15: the measurement results obtained at the inner side of wall in dBm.

The following table shows the average power of all points at each side of the wall (inner alone and outer alone) obtained from the previous two table, in addition to 10th percentile value taken for each side, which if achieved it will guarantee 90% coverage, also u can get from the following table the 50th percentile, which may guarantee 50% coverage that is not that satisfying for users, and may cause customer churn from the operator, finally the last row in the table shows the standard deviation for the outer and inner side of the wall, taking into consideration that we adapted the standard deviation of the inner side, not the outer, because it represents the standard deviation of the penetrating signal through the wall.

	outside (dBm)	inside (dBm)	Delta (dB)
Average power	-38.2836	-61.6554	23.37178
10th percentile	-40.6367	-65.3834	24.74675
50th percentile	-37.9401	-60.9381	22.998
Standard deviation ()	1.719281	2.801668	2.801668

Table 5.16: class five values

5.3.6 Class Six:

the following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the

logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.31.

P	1	2	3	4	5	6	7
1	-59.7273	-56.0588	-61.8932	-61.9439	-58.3737	-64.4488	-60.0333
2	-62.1048	-61.1805	-69.1418	-62.0286	-63.181	-60.4609	-67.7263
3	-67.4732	-59.4679	-61.7059	-71.4058	-59.8319	-65.9919	-60.8667
4	-64.3214	-68.2763	-62.2222	-76.3933	-65.9118	-66.3269	-64.9898

Table 5.17: the measurement results obtained at the inner side of class 6 wall in dBm.

the following table shows the average of each log file taken at every point , where every value shown in the table represent an average of about 60 power value taken in the log file attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.32.

P	1	2	3	4	5	6	7
1	-36.9254	-38.2338	-42	-43.1818	-41.3806	-40	-39.5875
2	-39.0442	-39.0104	-39	-42	-39.9444	-43.2977	-40.1743
3	-40.5432	-45.6185	-39.4828	-42.7	-42.384	-44.9174	-43.4904
4	-45.1188	-44.8067	-44.0084	-41.1087	-39.903	-45.1266	-44.3229

Table 5.18: average power values at the outer side of the wall in dBm`s.

The following table shows the average power of all points at each side of the wall (inner alone and outer alone) obtained from the previous two table, in addition to 10th percentile value taken for each side, which if achieved it will guarantee 90% coverage, also u can get from the following table the 50th percentile, which may guarantee 50% coverage that is not that satisfying for users, and may cause customer churn from the operator, finally the last row in the table shows the standard deviation for the outer and inner side of the wall, taking into consideration that we adapted the standard deviation of the inner side, not the outer, because it represents the standard deviation of the penetrating signal through the wall.

	outside (dBm)	Inside(dBm)	Delta (dB)
Average power	-41.6897	-63.696	22.0063
10th percentile	-44.9778	-68.536	23.55813
50th percentile	-41.6903	-62.1635	20.4732
Standard deviation ()	2.431894	4.358896	4.358896

Table 5.19: class six values

5.3.7 Class Seven:

the following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.37.

Point	1	2	3	4	5	6
1	-39	-39.2857	-37.9677	-38.0607	-39.6568	-40.6549
2	-39	-39.7515	-37	-38.5042	-38.7158	-41.623
3	-39	-37.6037	-40	-39.8285	-40.213	-39.5909
4	-38.1282	-37.5498	-38.6667	-39.8827	-38.4771	-41.6804

Table 5.20: the average power measurement at the marked points on the outer side of the wall in dbm.

The following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.36.

Point	1	2	3	4	5	6
1	-64.1024	-66.7083	-65.6232	-71.4603	-68.0536	-66
2	-66.4211	-66	-63.6453	-74.1414	-67.1	-64.7285
3	-66.3911	-65.7267	-62.375	-78.1095	-68.3791	-67.8684

4	-66.0156	-70.6037	-62	-65.9455	-65.8623	-68.277
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Table 5.21: the average power values measured at the interior points in dbm.

The following table shows the average power of all points at each side of the wall (inner alone and outer alone) obtained from the previous two table, in addition to 10th percentile value taken for each side, which if achieved it will guarantee 90% coverage, also u can get from the following table the 50th percentile, which may guarantee 50% coverage that is not that satisfying for users, and may cause customer churn from the operator, finally the last row in the table shows the standard deviation for the outer and inner side of the wall, taking into consideration that we adapted the standard deviation of the inner side, not the outer, because it represents the standard deviation of the penetrating signal through the wall

	outside (dBm)	inside (dBm)	Total(dB)
Average power	-39.1601	-67.1474	27.98736
10 th percentile	-40.5223	-71.2033	30.68099
50 th percentile	-39	-66.2034	27.20335

Standard deviation ()	1.198264	3.569621	3.569621
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Table 5.22: class seven values

5.3.8 Class Eight:

The following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.42.

P	1	2	3	4	5
1	-83.7051	-86.1709	-80.3689	-80.0706	-79
2	-91.3592	-85.2273	-80.974	-79	-77.6264
3	-86.451	-87.0439	-78.439	-78.3276	-80.5152
4	-88.4031	-85.1731	-80.2043	-81	-79

Table 5.23: the average data at the inner wall in dbm.

The following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.41.

P	1	2	3	4	5
1	-54.9024	-51.4624	-54	-46	-47.0458
2	-55	-53.3465	-52.1628	-46.2248	-47
3	-53.9468	-46.4	-54.1795	-48.798	-48
4	-48.3453	-49.4409	-55	-48	-48.0364

Table 5.24: the average data at the outer wall in dbm.

The following table shows the average power of all points at each side of the wall (inner alone and outer alone) obtained from the previous two table, in addition to 10th percentile value taken for each side, which if achieved it will guarantee 90% coverage, also u can get from the following table the 50th percentile, which may guarantee 50% coverage that is not that satisfying for users, and may cause customer churn from the operator, finally the last row in the table shows the standard deviation for the outer and inner side of the wall, taking into consideration that we adapted the standard deviation of the inner side, not the outer, because it represents the standard deviation of the penetrating signal through the wall.

	outside (dBm)	inside (dBm)	Total(dB)
Average power	-50.3646	-82.4029801	32.0384
10th percentile	-54.9122	-87.17982	32.26766
50th percentile	-49.1195	-80.7446	31.62515
Standard deviation ()	3.369574	3.957319754	3.957319754

Table 5.25: class eight values

5.3.9 Class Nine:

The following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.46.

Point	1	2	3	4
1	-58.1017	-59.3315	-62.1569	-56.7368
2	-58.3838	-57.121	-55.9398	-65.0161
3	-59.0743	-53.7596	-59.3068	-58.3385
4	-56.8435	-54.2167	-59.05	-56.0625

Table 4.26: the average power values in dbm taken at the inner points of class 9.

The following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.47.

Point	1	2	3	4
1	-47.9204	-48.5138	-45.5347	-47.459
2	-49.1111	-49.7672	-51.2069	-46.2963
3	-46.5	-49.2105	-47.6064	-49.0256
4	-48.1712	-45.803	-46.0284	-48.7364

Table 5.27: the average power measured in dbm at the outer points of class 9.

The following table shows the average power of all points at each side of the wall (inner alone and outer alone) obtained from the previous two table, in addition to 10th percentile value taken for each side, which if achieved it will guarantee 90% coverage, also u can get from the following table the 50th percentile, which may guarantee 50% coverage that is not that satisfying for users, and may cause customer churn from the operator, finally the last row in the table shows the standard deviation for the outer and inner side of the wall, taking into consideration that we adapted the standard deviation of the inner side, not the outer, because it represents the standard deviation of the penetrating signal through the wall.

	outside (dBm)	inside (dBm)	Total(dB)
Average power	-47.9307	-58.09	10.15929
10th percentile	-49.4889	-60.7442	11.25535
50th percentile	-48.0458	-58.2201	10.1743
Standard deviation ()	1.598246	2.785485	2.785485

Table 5.28 class nine values

5.3.10 Class Ten:

The following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.50.

Point	1	2	3	4	5	6
1	-69.7417	-75.3394	-67.2317	-68.5118	-63.7961	-66.5474
2	-67.64	-66.6667	-57.1852	-69.1682	-64.8241	-65.125
3	-67.5455	-68.6977	-61.4483	-67.2973	-63.907	-65.6847
4	-70.2699	-71.4259	-66.939	-70.7398	-62.1339	-67.0368

Table5.29 : the measured values at the inner side of the wall in dbm.

The following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.51.

Point	1	2	3	4	5	6
1	-47.8621	-47.8947	-43.7234	-44.2727	-46.1011	-45.3444
2	-49.033	-49.2635	-50.2778	-49.4972	-46.7917	-46.4107
3	-47.0819	-48.0873	-46.2895	-43	-46.5952	-47.9832
4	-44.4646	-43.2407	-47.6842	-43.2703	-46.6496	-45.3889

Table5.30 : the measured values at the outer side of the wall in dbm.

The following table shows the average power of all points at each side of the wall (inner alone and outer alone) obtained from the previous two table, in addition to 10th percentile value taken for each side, which if achieved it will guarantee 90% coverage, also u can get from the following table the 50th percentile, which may guarantee 50% coverage that is not that satisfying for users, and may cause customer churn from the operator, finally the last row in the table shows the standard deviation for the outer and inner side of the wall, taking into consideration that we adapted the standard deviation of the inner side, not the outer, because it represents the standard deviation of the penetrating signal through the wall.

	outside (dBm)	inside(dBm)	Total(dB)
Average power	-46.5087	-66.871	20.36231

10th percentile	-49.1944	-70.5988	21.40448
50th percentile	-46.6224	-67.1343	20.51185
Standard deviation ()	2.091205	3.686705	3.686705

Table 5.31 class 10 values.

5.3.11 Class Eleven:

The following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.55.

Point	1	2	3	4	5
1	-70.3041	-69.1022	-73.2513	-74.1552	-67.3563
2	-75.9593	-70.7391	-74.4071	-75.4	-66.88
3	-73.8421	-68.8797	-73.9623	-76	-64.2869
4	-69.4135	-69.4277	-74.6383	-69.1824	-64.5111

Table5.32 : the measured power values at the inner side of the wall in class 11 in dBm.

The following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.54.

Point	1	2	3	4	5
1	-44.2314	-47.2784	-49.1875	-45.0617	-46.9457
2	-46.5139	-46.7317	-50.9762	-45	-46.863
3	-47	-47.3964	-49.0789	-45.7872	-44.9355
4	-46.4882	-48.0909	-49.8976	-45.7652	-45.3814

Table 5.33 : the measured power values at the outer side of the wall in class 11 in dBm.

The following table shows the average power of all points at each side of the wall (inner alone and outer alone) obtained from the previous two table, in addition to 10th percentile value taken for each side, which if achieved it will guarantee 90% coverage, also u can get from the following table the 50th percentile, which may guarantee 50% coverage that is not that satisfying for users, and may cause customer churn from the

operator, finally the last row in the table shows the standard deviation for the outer and inner side of the wall, taking into consideration that we adapted the standard deviation of the inner side, not the outer, because it represents the standard deviation of the penetrating signal through the wall.

	outside (dBm)	inside(dBm)	Total(dB)
Average power	-46.9305	-71.0849	24.15439
10 th percentile	-49.2585	-75.4559	26.19742
50 th percentile	-46.7974	-70.5216	23.72425
Standard deviation ()	1.784925	3.698487	3.698487

Table 5.34: class 11 values

5.3.12 Class Twelve:

The following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.58.

Point	1	2	3	4
1	-84.365	-80.3902	-70.7736	-74.75
2	-85.8636	-82.9333	-77.7526	-73.4045
3	-85.65	-83	-77.992	-73.9608
4	-79.9828	-82.1495	-82.192	-72

Table 5.35: the average power values taken at the inner points of class 12.

The following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the

logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.59.

Point	1	2	3	4
1	-45.5379	-44.2872	-45.0297	-48.7909
2	-45.522	-44.3293	-45.2755	-51.0759
3	-47.1436	-45.8125	-46.2	-49.504
4	-45.7407	-44.4578	-46.2593	-50.1233

Table 5.36: the average power values taken at the outer points of class 12.

The following table shows the average power of all points at each side of the wall (inner alone and outer alone) obtained from the previous two table, in addition to 10th percentile value taken for each side, which if achieved it will guarantee 90% coverage, also u can get from the following table the 50th percentile, which may guarantee 50% coverage that is not that satisfying for users, and may cause customer churn from the operator, finally the last row in the table shows the standard deviation for the outer and inner side of the wall, taking into consideration that we adapted the standard deviation of the inner side, not the outer, because it represents the standard deviation of the penetrating signal through the wall.

	outside(dBm)	inside(dBm)	Total (dB)
Average power	-46.5681	-79.1975	32.62939
10th percentile	-49.8137	-85.0075	35.19385
50th percentile	-45.7766	-80.1865	34.4099
Standard deviation ()	2.147849	4.952977	4.952977

Table 5.37: class 12 values

5.3.13 Class Thirteen:

The following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.62.

Point	1	2	3	4	5
1	-80.02	-78.6757	-80.8438	-79.2162	-84.32
2	-84.061	-78.1695	-88.9872	-78.6931	-84.3832
3	-78.7	-79.2254	-78.2796	-80	-83

Table 5.38: the average power values taken at the inner points of class 13.

The following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.63.

Point	1	2	3	4	5
1	-54.4206	-52.0966	-53.4314	-52.3191	-53.4186
2	-51.9167	-53.2391	-55.9675	-54.4444	-51.371
3	-53.3762	-51.7795	-56.033	-53.7143	-52.0556

Table 5.39: the average power measured at the outer points of class 13.

The following table shows the average power of all points at each side of the wall (inner alone and outer alone) obtained from the previous two table, in addition to 10th percentile value taken for each side, which if achieved it will guarantee 90% coverage, also u can get from the following table the 50th percentile, which may guarantee 50% coverage that is not that satisfying for users, and may cause customer churn from the operator, finally the last row in the table shows the standard deviation for the outer and inner side of the wall, taking into consideration that we adapted the standard deviation of the inner side, not the outer, because it represents the standard deviation of the penetrating signal through the wall.

	Outside(dBm)	inside(dBm)	Total(dB)
Average power	-53.3056	-81.105	27.79941
10th percentile	-55.3583	-84.3579	28.99966

50th percentile	-53.3762	-80	26.6238
Standard deviation ()	1.445871	3.15335	3.15335

Table 5.40: class 13 values.

5.3.14 Class Fourteen

The following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.65.

Point	1	2	3	4	5
1	-79.0533	-80.374	-74.453	-80.3182	-85.0169
2	-76.8649	-80	-79.1149	-85	-87.6698
3	-80.0984	-81.5692	-80	-75.5641	-84.125

Table 5.41: the measured average power values at the inner side of the wall in dBm`s.

The following table shows the average of each logfile taken at every point , where every value shown in the table represent an average of about 60 power value taken in the logfile attached in appendix D, the distribution of points shown in the following table is represented on the wall in figure 4.66.

point	1	2	3	4	5
1	-71.7798	-76.6625	-72.6281	-74.7385	-81.5591
2	-71.8764	-77.7778	-76.3451	-79.1486	-81.9888
3	-76.725	-78.6078	-74.6383	-72.3158	-81.0667

Table 5.42: the measured average power values at the outer side of the wall in dBm`s.

The following table shows the average power of all points at each side of the wall (inner alone and outer alone) obtained from the previous two table, in addition to 10th percentile value taken for each side, which if achieved it will guarantee 90% coverage, also u can get from the following table the 50th percentile, which may guarantee 50% coverage that is not that satisfying for users, and may cause customer churn from the operator, finally the last row in the table shows the standard deviation for the outer and inner side of the wall, taking into consideration that we adapted the standard deviation of the inner side, not the outer, because it represents the standard deviation of the penetrating signal through the wall.

	outside (dBm)	inside (dBm)	Total (dB)
Average power	-76.5239	-80.6148	4.090893
10th percentile	-81.0667	-85.0101	3.94344
50th percentile	-80.0984	-76.6625	3.4359
Standard deviation ()	3.63524	3.510039	3.510039

Table 5.43: class 14 values.

5.4 Indoor results:

Signal strength in dBm	Distance m	10*log(distance)	Total
-47.4235	24	13.80211	7.460721
-45.3676	24	13.80211	
-51.25	24	13.80211	
-37.0196	24	13.80211	
-49.7755	27	14.31364	
-44.3267	27	14.31364	
-37.6154	27	14.31364	
-43.6923	27	14.31364	
-47.0824	30	14.77121	
-37.7222	30	14.77121	
-38	30	14.77121	
-43.8987	30	14.77121	
-66.8	33	15.18514	
-49.7183	33	15.18514	
-46.8519	33	15.18514	
-38.6806	33	15.18514	

Table 5.44: Indoor measurement values

The last table shows the measured values in each track , there is 4 points in each line separation between lines is 3 m .

And the next table take the average power in each track which consist of four points:

Average power	10 log (distance)
-45.2652	13.80211
-43.8525	14.31364
-41.6758	14.77121
-50.5127	15.18514

Table 5.45: Indoor measurement with average power

Standard deviation = 7.460721

Chapter six:

Discussion and Analysis

6.1 Introduction.

6.2 Discussion and analysis.

6.3 In building penetration loss scenario.

6.1 Introduction.

In this chapter we carry our results forward to the analytical stage, so we take the measurement results and clarify the behavior of the signal according to the changes of the signal strength values, when it travels through the free space environment or when it penetrate the walls.

We measured the penetration loss in the classes, in these fourteen samples improving their network average to achieve 90% , but in fact this coverage is affected by other circumstances, like windows, doors which may improve the coverage, this explains some unexpected result appears in our results.

6.2 Discussion and analysis

From figure 3.1, the outdoor curve, we noticed the signal power is decaying at the fist 300m in a fixed step, after that distance the signal power decayed in a fast step, it's a logical behavior because it follows a logarithmic scale.

In class one it appears that the 10th percentile value is more than the 50% value by 2 dB, this value must be considered to achieve 90% coverage for this class.

The penetration loss appears high in class two ,because here we have an old building which have 70cm thickness, this class is not widely spread in Palestine, it`s not being build anymore ,but still can`t be neglected, its existence appears in the old cities like Hebron ,Nablus [20]

The 10th percentile in class three is close to the 50th percentile, this because in this class (building c) we have a wide glass side view, the glass has low- attenuation path to the radio waves. [18]

Class four has a high penetration loss compared with class eight, both have the same thickness but class four has reinforced concrete, and has void insulation so the metal and void affects the signal attenuation.

Class five has a small thickness but it cause high attenuation because of the reinforcement also there is no windows inside the measured sample to improved the average.

The penetration loss in class six higher than the losses in class three, the second layer in class three is concrete, but in this class we have brick instead of concrete, the brick is isolated, it contains an air gaps, also there is a window in the room which improve the coverage.

Class seven represent another sample of old buildings but its thickness less than class two , 42cm of stone and concrete , also it has a high value of attenuation , this class is spread more than class two, so we must take it`s coverage into consideration.

Class eight has high attenuation but the 10th percentile in this class is close to the 50th percentile, we achieve a good coverage here, because there is two windows and one door, they improve the coverage.

Class nine represent the most familiar internal walls, it consists of brick and the two layers of plasterer , the brick is internally insulated ,it`s used in the commercial and residential buildings .

Class ten penetration loss value is not high with respect to the other classes with the same constructing material, because its concrete layer is thinner than other classes, about 15cm, also the brick layer is 7cm, this class`s 10th percentile is slightly higher than the 50th percentile, taking into consideration that there is two windows and one door exist in this class.

The difference in class eleven that it has two layers of stone, which increase the penetration loss, the 10th here exceeds the 50th percentile by 3 dB, this number must be considered when setting the link margin to have a good coverage.

In class twelve we have Tobzeh stone, it has irregular shape which increases the effect of diffraction, so the signal outside this wall varies widely .High penetration also appears because of the thickness of this stone.

Class thirteen similar to class eight but with 7cm brick and has polystyrene isolation instead of void, these parameters decreases the penetration losses.

Generally when talking about insulation, it plays an important part of radio wave penetration loss, because recently it's used frequently in building's external walls, and in our results it increase the penetration loss.

Penetration losses is heavy in reinforced classes, even if the width of the wall is less than other classes with no reinforcement, that is caused by the presence of iron bars, which cause high attenuation in the signal.

Theoretically The 10th percentile value for a data set means that 90% of these data above the 10th value ,so it leads us to the wanted value for achieving 90% coverage .

6.3 In building penetration loss scenario:

It means that we tend to predict the signal strength inside the building, taking into consideration the external walls, in addition to the internal walls in our calculation, because it attenuates the signals penetrating to the inner rooms through the inner walls.

We have an example for a sample building covered by a neighboring cell shown in figure 6.1.

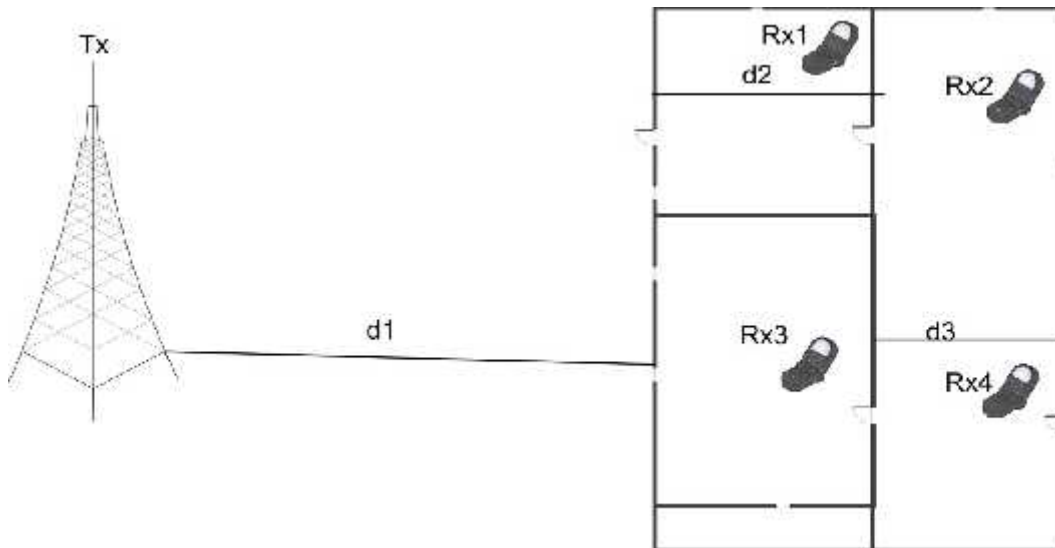


Figure 6.1 In building penetration loss calculation.

Let us say the external wall represents class eight materials and the internal walls represent class 9, then if the signal strength coming from the outside reaching the external wall equal to -40 dBm , class eight attenuate the signal by 32 dB, so the resulting signal after the wall equal to -72 dBm.

Suppose that the indoor free space loss equals 5 dB at Rx 1 additional losses happens to the signal due to the indoor free space loss , so the signal reaching Rx 1 will be -77 dBm.

The receiver in the location of Rx 2 will suffer from the attenuation in the second wall, knowing that the internal wall is a class 9 wall, which attenuate the signal by 10 dB, so , according to Eq (3.16) and Eq (3.17) the total received signal in the location of Rx 2, assuming that the inner space distance for both rooms is the same, is equal to :

$$\text{received signal at Rx 2} = \text{transmitted signal} - P_{OL} - P_{EW} - P_{II} - \tau$$

$$\tau = 2 * 10 = 20$$

$$\text{received signal} = -40 \text{ dBm} - 32 - 2 * (5) - 2 * (10) = -102 \text{ dBm}$$

The same procedure can be applied in any building which has one of the provided classes to get the received power value , the difference will be in the walls constructing materials , number of internal walls, and internal free space.

Mobile operator just estimate a certain value for most of the walls according to its thickness without focusing how many layers is there in each wall ,or is there an isolation or not, also they don't take into consideration the presence of internal walls which, as we can see, attenuates the signal with a value that cannot be neglected , so finally they will got inaccurate values .

Chapter Seven

Conclusion and Recommendation for future work

7.1 Conclusion

7.2 Recommendation for future work

7.1 Conclusion:

We proposed a new model for in-building penetration loss. The model incorporates penetration loss of 14 different external wall classes that represent over 90% of Palestinian building structures. It also includes penetration loss and number of inner walls attenuating the propagating signal as well as the indoor propagation loss. For each of those losses, the standard deviation from the mean is taken into account and the overall deviation is summed up in the model.

The model relies on penetration wall measurements based on 50th percentile but also on the 10th percentile logged data measured by the TEMS tool. This way we presented and compared indoor penetration loss for 50% and 90% in-building coverage percentages. The link margin that serves in-building structures is thus left to the cellular operator to decide what in building coverage quality of service they would target. Of course various in-building coverage percentages could be calculated from our data.

Eleven out of fourteen classes show that the penetration loss of only the external walls range between 20 dB and 45 dB. For each value the 10th percentile penetration loss is clearly larger than the 50th percentile value. This warrants that the default value of 10 dB or 20 dB often set by operators would not be suitable for in-building coverage and hence in-building solutions would be in demand if the customer is a top priority for the cellular operator. If this range becomes representative for a wider sample per class, then solutions may vary between including more base stations or repeaters to improve in-building coverage.

Taking into consideration that available simulation tools used by mobile operators give only estimation for values of the external walls, in our model we predict the values for each class of external and internal wall for mean and 90% coverage percentages which should serve as an added value to operators.

We further calculated the indoor path loss exponent “n” in the indoor free space, without the effect of internal walls intercepting the signal, the internal walls penetration values was taken alone, if we took a grid points over the whole indoor space (including the walls), we can't generalize it because buildings differ in their number and type of their internal walls, so it would only be specialized in that certain building.

So if we take a building used class 2 for external wall for example the 10th percentile is 47 db, a 20 db or even 30 db link margin assumed by an operator, is not enough to guarantee a 90% coverage in the building, so they need to increase their link margin by an enough power to guarantee a satisfying 90% coverage, since customer satisfaction is the goal of every cellular operator, so we have reservations on mobile operators on their link margin since it should take into consideration the types of buildings in their covered areas.

Its noticed recently that the new buildings tend to have an additional layers, like void and polystyrene isolation, and reinforcement, those layers represented in classes with heavy penetration loss like class four, class eight, and class six, so by spreading of these buildings, the in-building coverage will decay, and more base stations is to be installed to solve this problem.

Again, we took one sample for each class to predict our model, since we are limited in our resources, but for an operator to adapt this model it need to take a lot more samples on each class to make it more reliable and applicable, so our model serves as a guideline for the operators to consider by gathering more samples, bearing in mind that it's going to be conservative, to grant a better quality of service than calculated.

7.2 Recommendation for future work:

We recommend to those interested to in our project to consider the number of floors in the measured building, so a new parameter must be added to the model; the height gain parameter. This is usually added when a GSM frequency is setup on the floor level, just outside the building. The height gain may also be incorporated if the difference in height between the base station antenna and the building floor is considered to warrant the inclusion of a gain factor resulting from such a difference.

Other frequencies of operation are recommended, so the model can be developed to consider the 700MHz, 1800 / 1900 MHz or other frequency bands of interest.

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