



PPU College of
Engineering and Technology
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**Electrical and Computer Engineering
Department**

Communication and Electronics Engineering Program

Bachelor Thesis

Graduation Project

**Penetration Loss Comparative Study for Building
Structure Outer Walls at 2.4 GHz and 900 MHz
Frequency Band**

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إهداء

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.. وتميزوا

... ينابيع

.. معهم وبرفقتهم الحياة الجميلة والحزينة

طريق والخير ..

كيف نجدهم نضيعهم الاهل

ضاقت السطور من ذكرهم فوسعتهم قلوبنا.....

الى من ضحوا بحريتهم من اجل حرية غيرهم..... الاسرى والمعتقلين

الى من هم اكرم منا مكانة..... شهداء فلسطين

كل هذا الكم من السنين فلسطين الحبيبة

كل الزملاء والزميلات في يتك فلسطين

الى كل من ساهم في انجاح هذا العمل

فريق المشروع

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Chapter 1

Introduction

1.1 Overview

The Project focuses on the penetration loss of residential buildings outer walls at 2.4 GHz and 900 MHz, how such losses vary due to different structural classes and how they compare in different frequency bands. We will build a model for the penetration loss at both frequency bands that will cover thirteen classes of outer walls which represent more than 90% of commonly used structures in Palestine. A great outcome, expected from this project, is the degree of correlation between 900 MHz and 2.4 GHz which are relevant to GSM and WiMax frequency bands.

Stemmed from the fact that having fast mobile connection is a goal every country tries to achieve, there has been much tangible development in mobile technologies during the previous decade. Starting from GSM technology which now dominates the market in different countries (including Palestine) and provides a speed of few Kilo bits per second, followed by that many Carriers around the World began deploying 3G technology which Provides better speeds at some Mega bits per second, some countries, like the United States recently embraced 4G/LTE technology, which offers speeds of tens Megabits per second.

In recent years many Carriers globally began building WiMax Networks. Some of the WiMax networks operate at 2.5 GHz which is close to the unlicensed 2.4 GHz band. Here in Palestine, there are two Carriers; JAWWAL and Wataniya Mobile. Both use GSM Technology while awaiting the acquisition of necessary bands that could operate WiMax networks.

Building a WiMax Network needs intensive planning. Many variables and scenarios are taken into consideration. Penetration Loss of the transmitted signal is one of those variables. Once completed, this project will be an important reference for measuring penetration loss of common outer walls in Palestine, and will provide a guideline to cellular operators.

We intend to select thirteen different classes of outer walls as candidates for measurements at both GSM and WiMax bands.

. Motivation

There has been an increase in demand of mobile communication which has resulted in the development of micro-cellular and pico-cellular mobile system operating outside and inside building structure. The deployment of Wimax cells is likely to be next step in the effort of mobile service providers to provide higher capacity networks and better performance satisfactory to customers' needs. No wonder in future there will be increase in demand for speed and distance. Knowledge of mean signal strength is one of the essential factors for the design of a mobile radio system. To have a satisfactory operation of mobile system in an outdoor/indoor environment there is a desire to predict penetration loss within buildings so that optimum location of base stations can be chosen which maximizes converge and capacity. Such predictions are becoming very useful to mobile operators these days.

1.3 Methodology

The procedure we will follow consists of the following four stages

1.3.1 Stage One

We will measure the outdoor path loss due to the distance away from the 2.4 GHz (PPU Transmitter), as well as, the 900 MHz transmitter (Jewel Microcell.)

Figure (1.1) shows how measurements are to be taken on a sample wall, each side the wall will be divided into sample points, the black points are shown in the graph. Keep in mind that spaces between points may vary due to the size of the wall under test, at every black point the spectrum analyzer will be used to record at least 150 readings (stored in a log file). Afterwards the average of these 150 reading will be found.

The same method will be applied inner and outer of the wall. Average power of all points at each side of the wall and the 10th percentile, 50th percentile the Standard Deviation will be found.

As mentioned in the methodology above, in order to determine the Penetration loss we will calculate the average signal strength on both sides of the wall, then simply the Penetration loss will be the difference between the readings on both sides. To count for margins at low powers, the 10th Percentile will also be calculated. This will help determine whether the penetration loss will change at low power values or not. It will determine a slightly higher penetration loss margin to count for 90% coverage instead of 50% coverage, inside the building structure.

. . Stage Two

We will use a handheld Spectrum Analyzer to measure the loss of the signal that penetrates different outer walls structures; Specifications of Equipments we will use in our research are available in Appendix 1.

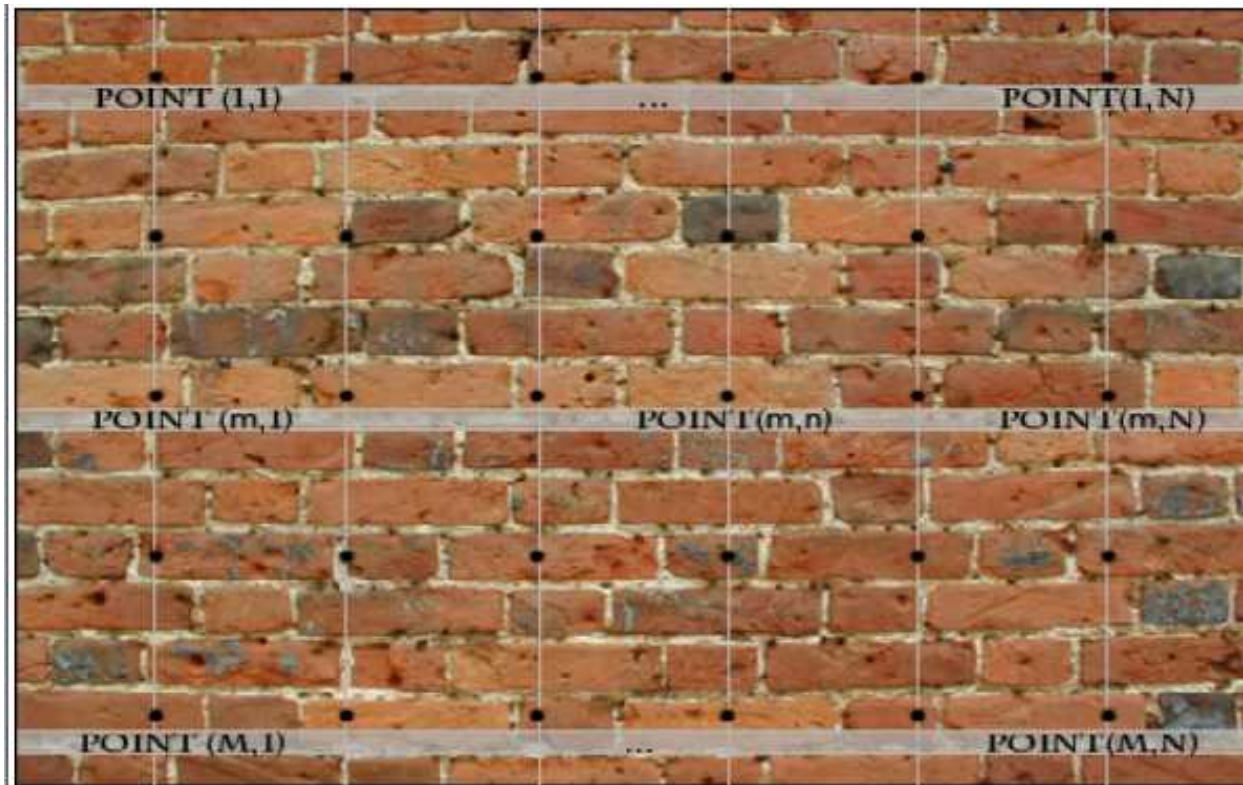


Figure 1.1: Sample wall, where outdoor measurements will be carried on. The Sample points are marked as black dots.

. . **Stage Three**

Results gained will be used to build a model and to find out the equation that governs such loss at both 900 MHz and 2.4 GHz; we will draw a best fit line from scattered measurements.

. . **Stage Four**

We will analyze and compare the models, at 900 MHz and at 2.4 GHz to derive a correlation, see how a 2.4 GHz can be predicted from available 900 MHz data.

1.4 Equipments

- 2.4 GHz Transmitter (available from a research grant awarded to Dr. Osama Ata)
- Spectrum Analyzer (available from a research grant awarded to Dr. Osama Ata)
- Laptop.
- INSIDER (software used with laptop NIC cards.)
- Vistumbler[©] (software used with laptop NIC cards for recording measurements at 2.4 GHz).
- MCS Spectrum Analyzer (software used with spectrum analyzer.)

. . Cost

\$0 Budget all devices and equipment, used in this project, are currently available as described above. We are looking forward to finish this project at zero cost.

. Timeline

Spring semester Time Table (In weeks)																
Task/Week	1 st	2 nd	3 rd	4 th	5 th	6 th	7 th	8 th	9 th	10 th	11 th	12 th	13 th	14 th	15 th	16 th
Researching references and collecting information	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
Classes' sites surveying	■	■	■													
Hardware and Software learning			■	■	■											
AutoCAD chart preparing of the buildings			■	■	■	■	■									
Measurements																
Conclusion and documentation writing Delivery to the supervisor for review												■	■			
Submission to the department														■		

Fall semester Time Table (In weeks)																
Task/Week	17 th	18 th	19 th	20 th	21 st	22 nd	23 rd	24 th	25 th	26 th	27 th	28 th	29 th	30 th	31 st	32 nd
Researching references and collecting information																
Classes' sites surveying																
Hardware and Software learning	■	■	■													
AutoCAD chart preparing of the buildings																
Measurements	■	■	■	■	■	■	■	■	■	■	■	■				
Conclusion and documentation writing										■	■	■				
Delivery to the supervisor for review												■	■			
Submission to the department														■		

Figure 1.2: Time plan

Chapter 2

Literature Review

A great number of authors have studied the problem of building penetration loss, and modeled it as the distance-dependence of the path loss when the mobile is outside a building - free-space loss, plus a building loss factor. The building loss factor is included in the model to account for the increase in attenuation of the received signal observed when the mobile is moved from outside a building to inside ^[1]. The model assumes that the building loss is independent of the distance between base and mobile, although no verification of this assumption has been reported.

Building loss can be utilized in the engineering of a radio system in much the same way as other propagation losses. For example, the measure of the penetration loss is important for the reuse of a frequency in a cellular type of system. One aspect of building loss -its amplitude distribution- has an important effect on the range of reliable coverage into buildings.

Two definitions of building penetration loss can be found. For a given distance to the transmitter, the difference between the median field intensity in the streets and the field intensity at a location on the main floor of a building is defined, by L. P. Rice ^[2], as the building loss for that location. The second definition of building loss is due to Durante. M. Durante ^[3]. He compares the signal strength inside and outside the building at the same height at various floor levels. Rice also uses a different term, called local building losses, which is defined as the difference between the median field in the streets adjacent to an individual building and the field intensity at a location on the main floor of the building. The difference between both terms is that building loss is a concept useful for the estimation of service range, while local building loss is useful in evaluating the coverage of an individual building. Most of the authors, who have studied the building losses from Rice's statements, use the second term as building loss in their experiments.

The main objective of this project is to characterize the behavior of radio waves transmitted through buildings in order to develop a simple attenuation model. This model will be used to predict the attenuation suffered by radio signals transmitted through buildings 900 MHz and 2.4

GHz One first approach to this objective is to try to characterize the mechanism of penetration

Into buildings. In order to achieve the goal, a literature research about the topic mentioned before is done. Results from all the papers described below:

In an article titled "*Building Entry Loss and Delay Spread Measurements on a Simulated HAP-to-Indoor Link at S-Band*"^[4]. Penetration loss measurements were conducted in different building types including an airport, an office building, a shopping mall, a residential house, and skyscraper. The article states that Building entry loss largely depends on the building type, construction, and electrical parameters of material used. Measurements were made in different locations on different structures, one of which was a residential house, a house in open area with no other houses in close vicinity with 45 cm thick external walls made of light concrete. Roof is made of wooden framing covered with concrete roof tiles. The internal walls are made of 10 cm and 25 cm thick light concrete. There were in total six different measurement positions of the receiver within the house all deep in the building. It was found that building entry loss measurements in eight different locations correspond well to the building material and type of the building, that is, the lighter construction, the lower loss. Results are shown in the figure below.

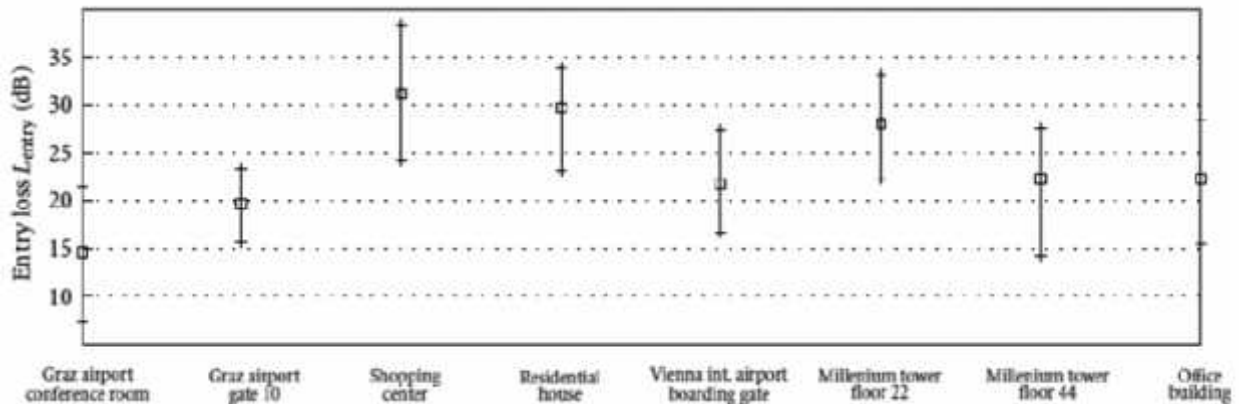


Figure 2.1: Building entry loss; the rectangle represents the mean loss, the line shows the minimum-maximum interval

Other Previous studies on building Penetration loss include a study titled "*Propagation losses Through Common Building Materials 2.4 GHz vs. 5 GHz*"^[5] prepared by two researchers in the University of Southern California. The two researchers performed an experiment to investigate RF propagation through different common building materials over arrange of frequencies (very thin material of mm thickness). Results they obtained showed that propagation losses through most building and home-construction materials are almost the same for both frequency regimes. Though cement blocks and red bricks displayed somewhat more loss at 5 GHz than at 2.4 GHz. Actually the bricks showed a linear increase (in dB) in absorption over frequency, with a relatively constant degree of reflection.

Other published papers include a recent paper titled “*Building Penetration Measurements for*

2.4 GHz Broadcasting CDMA System” [6]. The goal was to find building penetration path loss and indoor radio propagation characteristic at 2.4 GHz as it constitutes a prerequisite to the design of a low power microcellular point to multipoint broadcasting spread spectrum systems. The measurement campaign was held within the campus of National Technical University of Athens including buildings of maximum 3 floors height. Each floor consists of working offices of 34 m² – 70 m². Consecutive order, flanked on both sides of two main corridors. The offices were separated by soft partitions, and furnishing includes wooden desks, bookshelves, computer terminals and peripherals. The innermost side of the offices consists of concrete wall. Measurement Methodology they used is the same Methodology we are going to use in our experiment, they divided walls into sample points of some distance apart from each others, the receiver was set to record 1000 samples per second resulting in a total number of 15.000 samples per measurement point. For each office or corridor, using each separate file, the median signal level (dBm) and the standard deviation (dB) was derived. Using relevant office and corridor data the median signal, standard deviation and penetration loss for each floor was calculated, The results obtained from remote areas in the building where there was no line of sight path between any of the sides of the office or corridor with the transmitter indicate that signal experiences great attenuation, and penetration loss increased by 3dB as we move from one office to another consecutive office.

Other papers include a recent study “*Propagation into and within buildings at 900, 1800 and*

2300 MHz” [7]. Measurements of the received signal strength were undertaken within buildings in the University of Liverpool precinct. The buildings were Blocks A and B of the Department of Electrical Engineering & Electronics and the Departments of Computer Science and Life Sciences, These buildings being at 180, 240, 300 and 350 m, respectively from the transmitter. No line-of-sight existed between Electrical Engineering Block B and the transmitter. Partial line-of-sight existed, however to the three other buildings. No specific details of the buildings wall structure were mentioned, majority of the buildings were of reinforced concrete, the main objective was to find out a relationship between the penetration loss and height!

Results showed that the average measured penetration loss at ground floor level was found to be 14.2, 13.4 and 12.8 dB respectively at 900, 1800 and 2300 MHz The rate of change of penetration loss with height was -1.4 dB per floor. The rate of change of mean signal level for signals travelling within buildings was, on average, 8.5 dB per floor. The path loss attenuation factor, n , that best modeled the within-building measurement was found to be 5.3, 5.5 and 6.0 respectively for 900, 1800 and 2300 MHz The correlation Coefficients have been determined around 0.7.

Other Papers on Penetration loss include a paper titled “*CHARACTERIZATION OF IN-DOOR PENETRATION LOSS AT ISM BAND*” [8]. The paper presents information about the penetration loss for some dielectric materials, which are widely, used in indoor environments such concrete, wood, glass by using vector network analyzer. Measurements were performed

At 160 MHz bandwidth centered in 2.4GHz. Methodology of measurement is based on a vector network analyzer (VNA) that is capable of calculating S- parameters of a quadruple connected between its two ports from 300 KHz up to 6 GHz. The transmitting and receiving antennas, both standard pyramidal horns were connected to port 1 and port 2 of the test set respectively using a flexible microwave coaxial cable. Measurements were taken on the second floor of T-telecommunication Metrology Center of MII in Beijing. Five different types of materials were measured. a 2m x1.2mx 12” glass, a 2.2m x 1m x 8mm chip wood, a 2m x 1.2m x 38” thick wood partition, a 4.5m x 2.8m x 250” concrete wall whose surface was covered by plasterboard, and run x 1.4m x 40” door. Results and The penetration loss values for the materials at 2.4 GHz are given in Table (2).

Materials	No. of samples	Penetration loss (dB)	
		(VP)	(HP)
Class	5	1.622	2.543
Chip wood	5	1.133	1.641
Thick wood	6	1.609	2.195
Door	6	2.261	2.739
Concert wall	10	21.601	20.45

Figure 2.2 : Results and The penetration loss values for the materials at 2.4 GHz in ^[8]

From the above table, Penetration loss depends on material considered and its thickness, it’s been found that when the thickness of the material is not too large compared to wavelength; multiple reflections inside the materials are accrued.

Other papers include one titled “ *In-building Penetration Loss Modeling and Measurement in Suburban, Urban and Dense Urban Morphologies* ” ^[9] by Dr. Osama Ata of Sprint. The paper aimed to evaluate the design criteria assumptions for PCS/MMDS (1.9 / 2.5 GHz band) wireless networks and how they relate to in-building coverage. Not all construction-wall type buildings were covered in this paper. Instead, measurements applied to a concrete-wall commercial/office floor plan with external wall consists of: 0.5 inch of drywall, 3.5 inch of metal enforced stud and insulation, 1 inch of insulation and 8 inch of concrete blocks. And an internal wall consists of: 0.5 inch of drywall, 3.5 inch of metal enforced stud, and another 0.5 in of drywall. Results showed Total penetration loss of 15 dB through the external wall. 15 dB through 3 inner walls (5 dB x 3). 4 dB for shelves or cubes above the handset level. This brings the total to 34 dB of total penetration loss. For brick wall construction type offices (without a basement), total penetration loss has been found to be 30 dB.

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Chapter 3

Propagation models

3.1 Brief introduction to propagation model

Propagation models are empirical mathematical formulations to characterize how radio waves behave as a function of frequency, surrounding environment and distance. Several propagation models exist for different link scenarios and these are helpful to service providers for designing and deploying their networks in the best possible way.

3.2 Current industry standard

Currently separate propagation models exist for indoor and outdoor environments. Majority of the wireless systems are made up of outdoor macro cellular networks. But in recent times the use of wireless devices in indoor environments has greatly increased which has resulted in major changes in design considerations for outdoor as well as indoor wireless networks. The indoor models do not take into account the effects of an already deployed outdoor system while making calculations and vice-versa.

. Existing Propagation Models & Path loss

Path Loss depends on many factors such as frequency, antenna height, receive terminal

Location relative to obstacles and reflectors, and link distance. It is the largest and most variable quantity in the link budget. Usually a statistical path loss model or prediction program is used to estimate the median propagation loss in dB. There are many different path loss models available now based on different condition such as line of sight (LOS) or non-LOS. The National Institute of Standards and Technology (NIST) have done an excellent job in documenting and comparing several realistic empirical propagation loss models^[10]. Based on the NIST study examines the following loss models:

- Free Space Propagation Model (FSPL)
- Plane Earth Propagation Model
- Kumara Model
- Empirical Hata Model
- COST 231-Hata model MCS Spectrum Analyzer (software used with spectrum analyzer).

- Walsh-Ikegami Propagation Model

3.3.1 Free space Propagation Model (FSPL)

Generally radio transmission systems consist of transmitter, antennas and receiver. In radio transmission the most important questions are: how far apart can the transmitter and receiver be in distance while maintaining acceptable performance, and what can be changed to increase this separation distance? The simple answer is: Use the Free Space Path Loss model in determining transmitter and receiver separation, and change the transmitter power to increase separation distance [11].

FSPL is a fundamental factor for numerous radio frequency calculations and it is used in various locations for predicting power of radio signals which probably anticipated in a radio frequency system. FSPL is basically the sort of failure in signal strengths which happens when an electromagnetic wave communicate over a line of sight path in free space. It assumes a transmit antenna and a receive antenna to be located in an otherwise empty environment. Neither absorbing obstacles nor reflecting surfaces are considered. In particular, the influence of the earth surface is assumed to be entirely absent, FSPL represents the communication range as a circle around the transmitter. If a receiver is within the circle, it receives all packets. Otherwise, it loses all packets [12].

For propagation distances much larger than the antenna size, the far field of the electromagnetic wave dominates all other components. That is, we are allowed to model the radiating antenna as a point source with negligible physical dimensions. In such case, the energy radiated by an Omni directional antenna is spread over the surface of a sphere. This allows us to analyze the effect of distance on the received signal power.

The equation for free space path loss is pretty easy to employ .In this case path loss is proportional to the square of distance among the receiver and transmitter whereas, the signal level is proportional too for the square of frequency in use [13]. It is describe more briefly in Equation (3.1).

$$FSPL = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi df}{c}\right)^2 \quad (3.1)$$

Where: FSPL is the free space path loss.

d is the distance in meters for the receiver from the transmitter.

f Is the frequency in Hertz.

λ Is the wavelength in meters.

c Is the speed of light in meters per second.

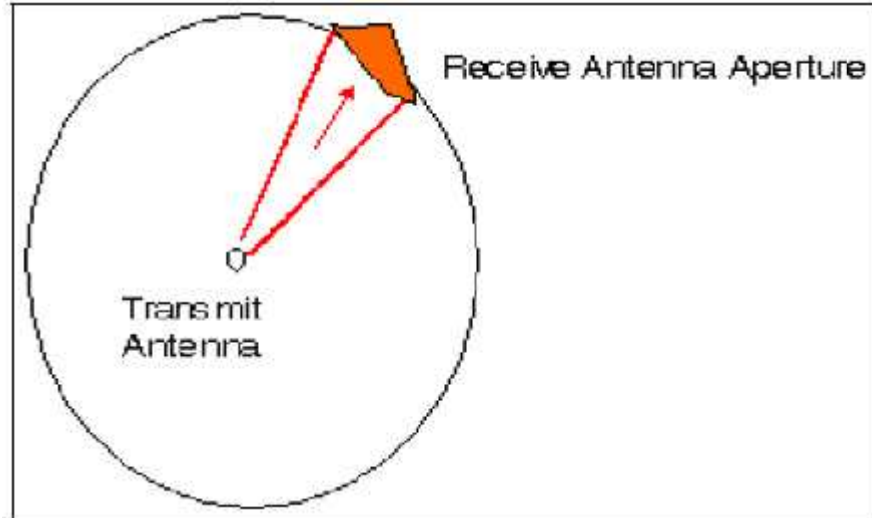


Figure 3.1: Transmit antenna modeled as a point source. Transmit power is spread over the surface area of a hypothetical sphere. The receiver antenna has an aperture A , illustrated in orange.

Decibel Version of FSPL Equation

The majority radio frequency evaluations and dimensions are achieved in decibels (dB). It Provides a simple and steady method to balance the signal levels formed at different position:

$$FSPL (dB) = 20\log_{10}(d) + 20\log_{10}(f) + 32.44 \quad (3.2)$$

Where:

d Is the distance in km from receiver to the transmitter.

f Is the signal frequency in MHz

The surface area of a sphere of radius d is $4\pi d^2$. The power density W at distance d from a Transmitter with power P_t and antenna gain G_t is :

$$W = \frac{P_t G_t}{4\pi d^2} \quad (3.3)$$

The available power P_r at a receive antenna with gain G_r is:

$$P_r = \frac{G_r P_t}{4\pi d^2} \cdot A = \frac{\lambda^2}{(4\pi d)^2} \cdot P_t G_t G_r \quad (3.4)$$

Where A is the elective area or `aperture' of the antenna, with $G_r = 4\pi A / \lambda^2$. The wave-length λ is c / f_c ; with c the velocity of light and f_c the carrier frequency. The product gets put Is called the electively radiated power (ERP) of the transmitter. The above Equation called Fries equation, the relationship between the received power and the distance is shown in Figure (3.2).

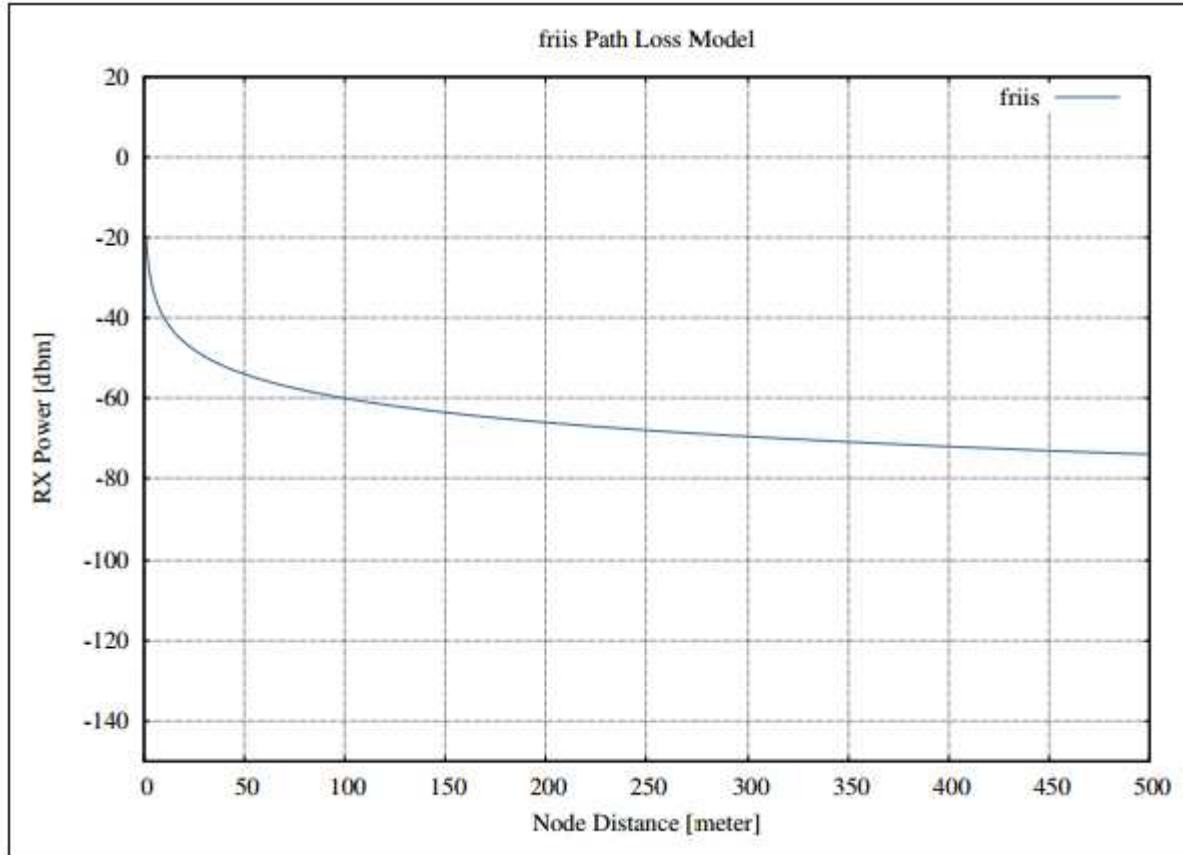


Figure 3.2: Received power versus distance between a mobile terminal and a base station

3.3.2 Plane Earth Propagation Model

The free space propagation model does not consider the effects of propagation over ground. When a radio wave propagates over ground, some of the power will be reflected due to the presence of ground and then received by the receiver. Determining the effect of the reflected power, the free space propagation model is modified and referred to as the ‘Plain-Earth’ propagation model. This model better represents the true characteristics of radio wave propagation over ground. The plane earth model computes the received signal to be the sum of a direct signal and that reflected from a flat, smooth earth. The relevant input parameters include the antenna heights, the length of the path, the operating frequency and the reflection coefficient of the earth. This coefficient will vary according to the terrain type (e.g. water, desert, wet ground etc). Path Loss Equation for the plane Earth Model is illustrated in Equation (3.5).

3.3.3 Okumara Model

Okumura's model is one of the most frequently used macroscopic propagation models. It was Developed during the mid 1960's as the result of large-scale studies conducted in and around Tokyo. The model was designed for use in the frequency range 200 up to 1920 MHz and mostly In an Urban Propagation environment ^[15].

Okumura's model assumes that the path loss between the TX and RX in the terrestrial Propagation environment can be expressed as:

$$L_{50} = L_{fs} + A_{mu} + H_{tu} + H_{xu} \quad (3.5)$$

Where:

- $L(50)$ - Median path loss between the TX and RX expressed in dB
- L_{fs} - Path loss of the free space in dB
- A_{mu} - Basic median attenuation" additional losses due to propagation in Urban environment in dB
- H_{tu} - TX height gain correction factor in dB
- H_{xu} - RX height gain correction factor in dB

Basic Median Attenuation (A_{mu}):

This term models additional propagation losses due to the signal propagation in a Terrestrial environment. The curves for determining the basic median attenuation are provided in Figure (3.3). On the horizontal axis of the graph in Figure (3.3), we find operating frequency expressed in MHz On the vertical axis we find the additional path loss attenuation expressed in dB. The parameter of the family of the curves is the distance between the transmitter and receiver. The curves in Figure (3.3) were derived for TX height reference of 200m and Rx height of 3m. If the actual heights of the TX and Rx differ from those referenced, the appropriate correction needs to be added. For example, at 850MHz frequency and the transmitter-receiver distance of 5km, the attenuation is close to 26dB. This value is read from the leftmost scale in Figure (3.3) at the point where constant vertical line at 850MHz intersects with the parametric 5km distance curve. The projection of this intersection on the basic median attenuation scale gives the resulting Attenuation of approximately 26dB.

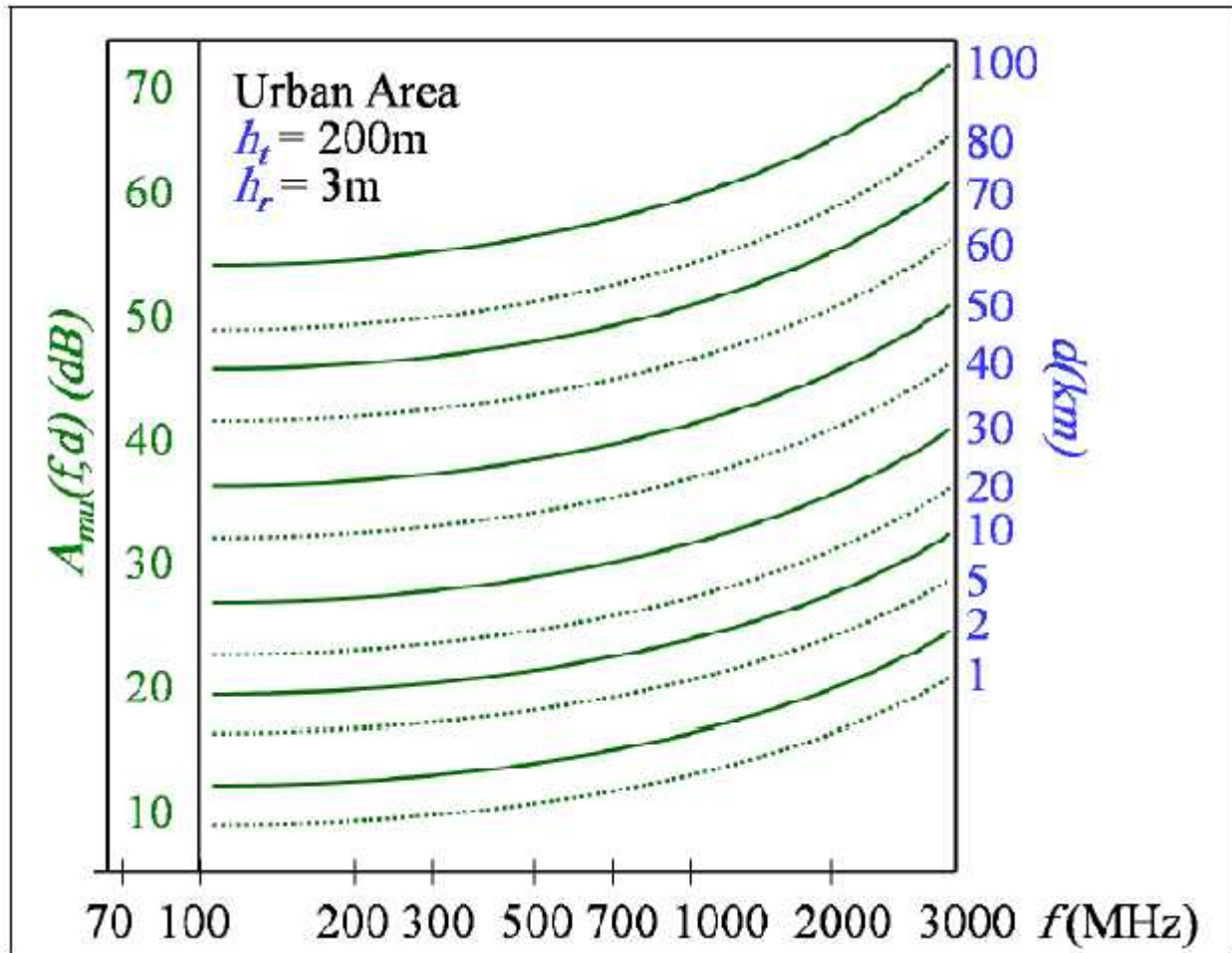


Figure 3.3: Basic median attenuation as a function of frequency and path distance

3.3.4 Empirical Hata Model

Hata model is the most popular model that extensively used in Europe and North America. The model is based on measurements in urban and suburban areas at Japan in 1968. Validity range of the model is frequency range between 150 MHz and 1500 MHz, Tx height h_t between 30 and 200 m, Rx height h_r between 1 and 10 m and Tx-Rx distance r between 1 and 10 km. Hata's Equations are classified into three models

- Rural: open space, no tall trees or building in path.
- Suburban area: Village Highway scattered with trees and house with some obstacles near the mobile but not very congested.
- Urban area: Built up city or large town with large building and houses.

Definition of parameters: h_m : mobile station antenna height above local terrain height [m].

d_m : distance between the mobile and the building.

ho: typically height of a building above local terrain height [m]

hte: base station antenna height above local terrain height [m]

r: great circle distance between base station and mobile [m]

$R = r \times 10^{-3}$ great circle distance between base station and mobile [km]

f: carrier frequency [Hz]

$F_c = f \times 10^{-6}$ carrier frequency [MHz]

λ : free space wavelength [m]

Path loss for Hata-model is defined as below:

- Urban area path loss (dB):

$$L_{dB} = 69.55 + 26.16 \log_{10} f_c - 13.82 \log_{10} h_{te} + (44.9 - 6.55 \log_{10} h_{te} \log_{10} R) - E \quad (3.7)$$

- Suburban areas path loss:

$$L_{dB} = 69.55 + 26.16 \log_{10} f_c - 13.82 \log_{10} h_{te} + (44.9 - 6.55 \log_{10} h_{te} \log_{10} R - 2[\log_{10}(\frac{f_c}{28})^2 + 5.4]) \quad (3.8)$$

- Rural path loss:

$$L_{dB} = 69.55 + 26.16 \log_{10} f_c - 13.82 \log_{10} h_{te} + (44.9 - 6.55 \log_{10} h_{te} \log_{10} R - 4.78 \log_{10}(f_c)^2 + 18.33 \log_{10} f_c + 40.94) \quad (3.9)$$

3.3.5 COST 231-Hata model

The COST-231-Hata model is an extension of the Okumura-Hata model to 2 GHz. It is Also an empirical model, and is suitable for microcells and small macrocells. This model is suitable when f_c is within 1.5GHz-2GHz, h_t is within 30-200m, h_r is within 1-10m, and d is within 1-20 km. here All walls intersecting the direct ray between transmitter and receiver are considered and for each wall individual material properties are taken into account. ^[16]

The COST-231 model is given by:

$$L_{urban} = 46.3 + 33.9 \log_{10} f_c - 13.82 \log_{10} h_r + 44.9 - 6.55 \log_{10} h_r \log_{10} d - C + CM \quad (3.10)$$

Where C is the correction factor for mobile antenna height in urban areas, CM is 0dB for

Medium-sized cities and suburbs, and 3dB for metropolitan areas. Although both the Okumura-Hata and COST-231-Hata models are specified to have a BS antenna height above 30 m, they can be used when h_t is less than 30m, as long as the Surrounding buildings are well below this height. They are not suitable for microcells like urban canyons. Also note here that this model and the previous two models were developed in Japan and suburban areas in Japan may be equal to dense urban areas elsewhere.

3.3.6 Walfisch-Ikegami Propagation Model

This empirical model is a combination of the models from J. Walfisch and F. Ikegami. It was further developed by the COST 231 project. It is now called Empirical COST-Walfisch-Ikegami Model. The model considers only the buildings in the vertical plane between the transmitter and the receiver. The accuracy of this empirical model is quite high because in urban environments especially the propagation over the rooftops (multiple diffractions) is the most dominant part.

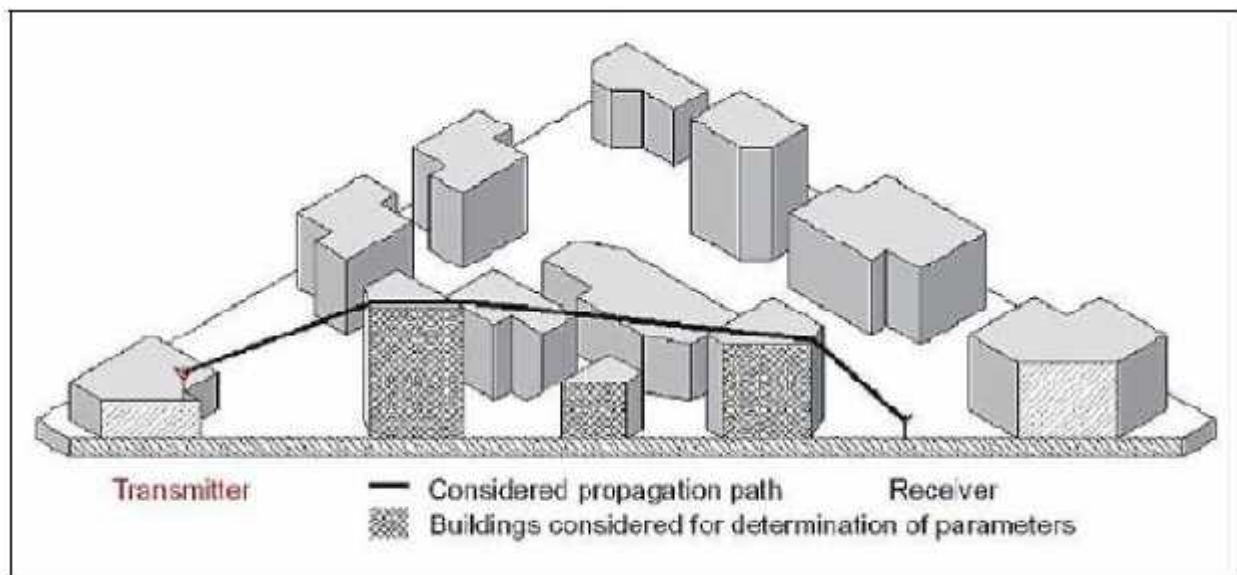


Figure 3.4: Propagation scenario with the COST 231 Walfisch-Ikegami Model.

The general parameters of the model are:

- Frequency f (800. . . 2000 MHz)
- Height of the transmitter h_{TX} (4. . . 50 m)
- Height of the receiver h_{RX} (1. . . 3 m)
- Distance d between transmitter and receiver (20. . . 5000 m)

Parameters depending on the buildings:

- Mean value of building heights h_{ROOF}
- Mean value of widths of streets w
- Mean value of building separation b

The classical COST Walfisch-Ikegami model determines the mean street width, mean building height, mean building separation for the whole building database (i.e. the whole cell area).

3.3.7 ITU Model for Indoor Attenuation

The ITU Indoor Propagation Model, also known as ITU Model for Indoor Attenuation, is a radio propagation model that estimates the path loss inside a room or a closed area inside a building delimited by walls of any form. Suitable for appliances designed for indoor use, this model approximates the total path loss an indoor link may experience.

This model is applicable to only the indoor environments. Typically, such appliances use the lower microwave bands around 2.4 GHz. However, the model applies to a much wider range. ^[16]

The ITU indoor path loss model is formally expressed as:

$$L = 20 \log f + N \log d + P_f n - 28 \quad (3.11)$$

Where:

- L = the total path loss. Unit: decibel (dB).
- f = Frequency of transmission. Unit: megahertz (MHz).
- d = Distance. Unit: meter (m).
- N = the distance power loss coefficient.
- n = Number of doors between the transmitter and receiver.
- $P_f(n)$ = the floor loss penetration factor.

Chapter 4

Structure of classes, location and surveying

After consulting a group of civil Engineering offices in Palestine we learned that the outer walls structures in Palestine fall under 15 different categories (classes). Here are the details of each class with the exact location of the serving cell.

1. Class one:

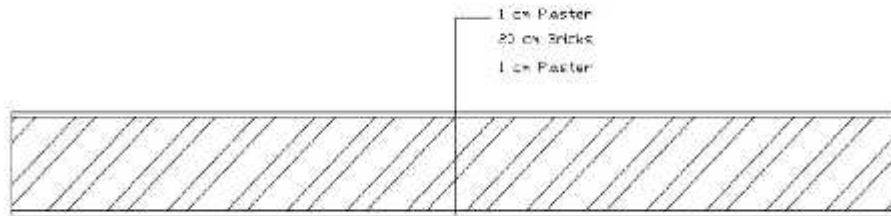


Figure 4.1: Cross sections in outer walls for class one

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



Figure 4.2: Outer wall in Class one

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 Los (line of sight) and 587.84 m away from the building, the building is located in a residential area.

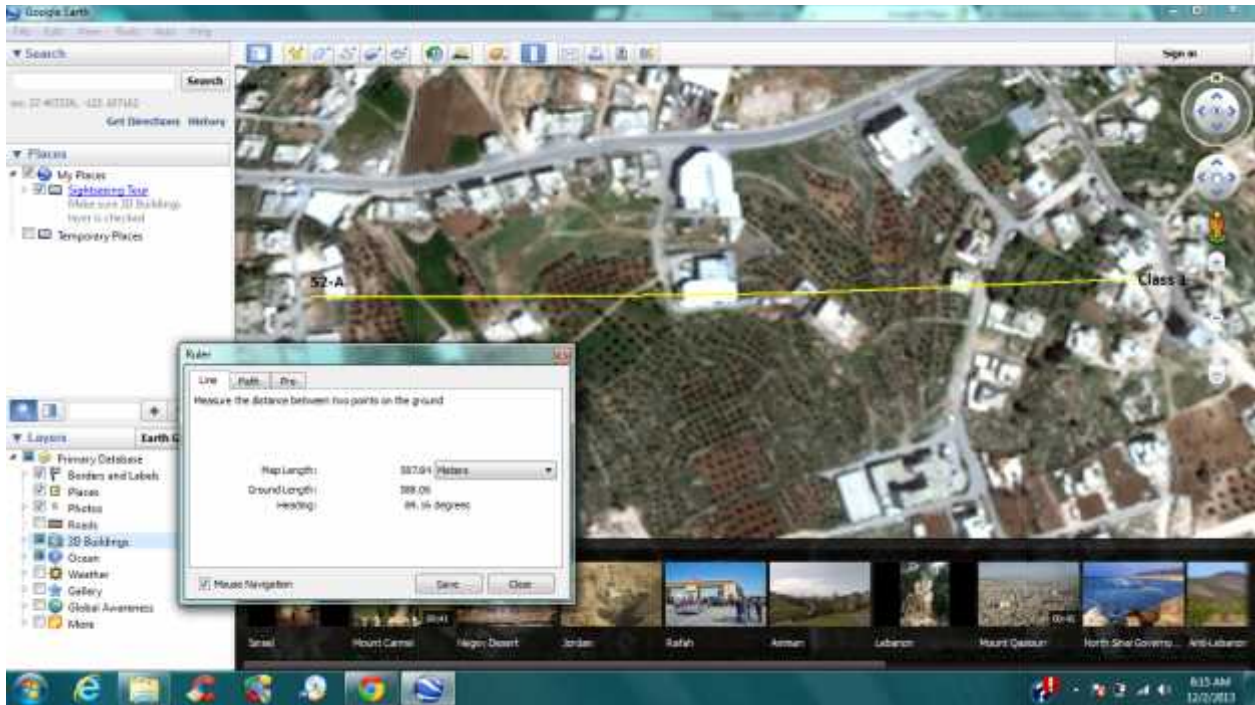


Figure 4.3: Location of class 1 with respect to the serving cell

2. Class Two:

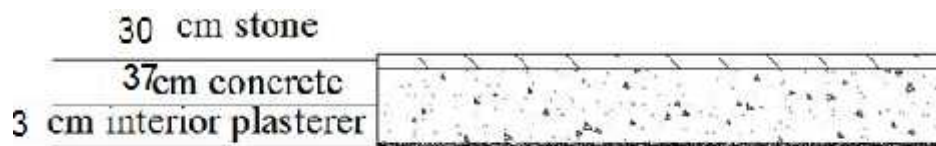


Figure 4.4: Cross sections in outer walls for class 2

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



Figure 4.5: Outer wall in Class two

Location and Serving Cell

The following satellite view shows the location of this certain class, related to the providing cell **HV2336A** with full line of sight, this old building is located in Halhul , Hebron. Al-Nabiyounis ST. Surrounded by other homes.

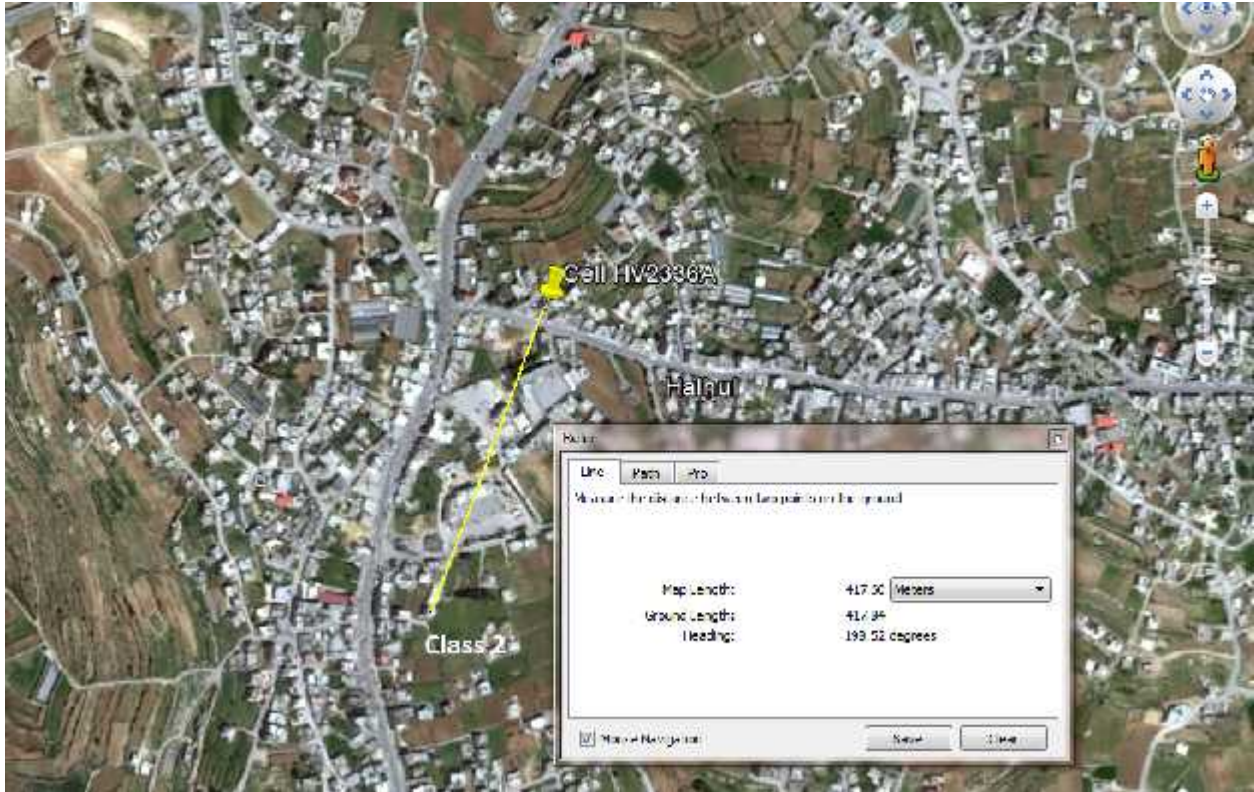


Figure 4.6: Location of class 2 with respect to providing cell HV2336A

3. Class Three:

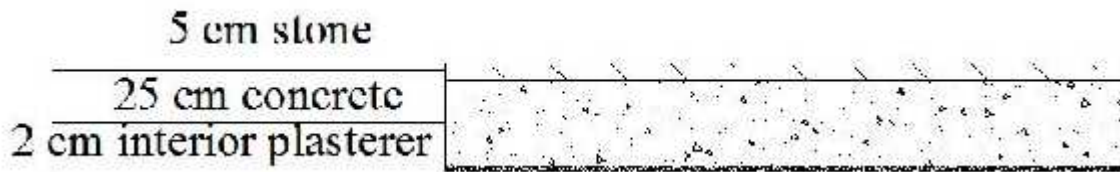


Figure 4.7: Cross sections in outer walls for class 3

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



Figure 4.8: Outer wall in Class three

Location and Serving Cell

The following figure shows the location of this certain class, related to the serving cell **HBR225B** with full LOS, building is located in Hebron, Wad Haryeh , Palestine Polytechnic University (PPU) ,building C , the building is located in an industrial area near Neiroukh factory

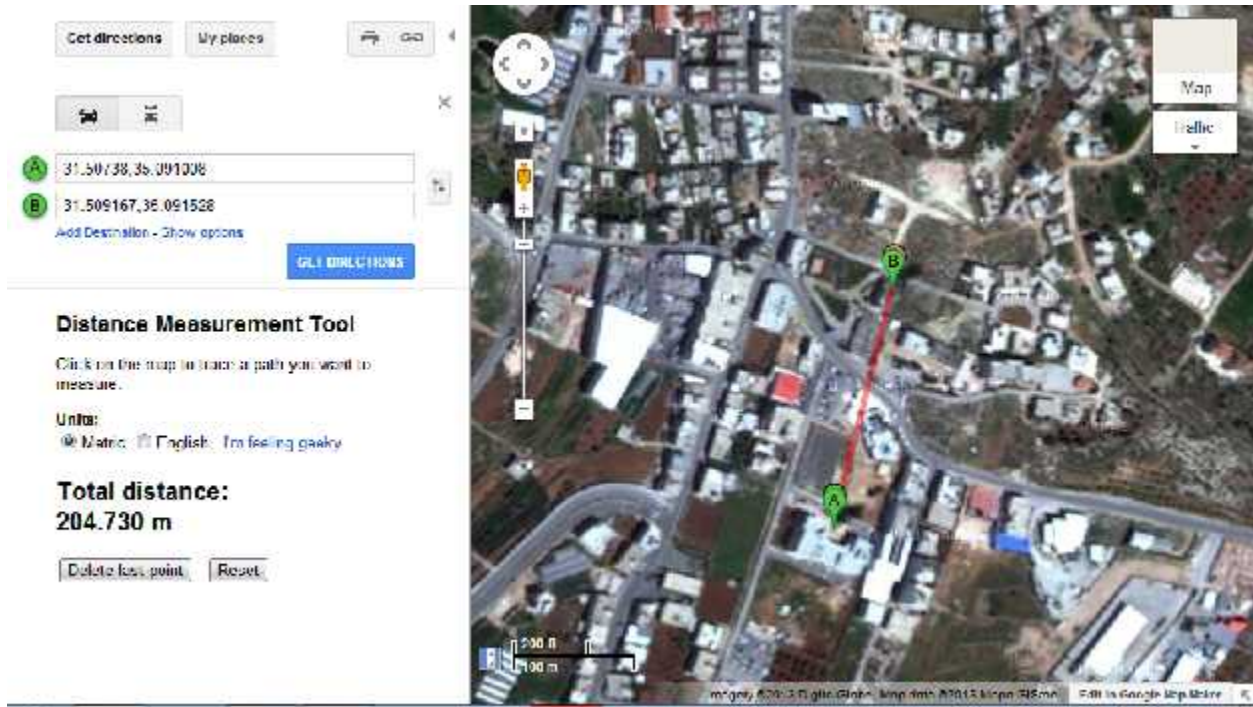


Figure 4.9: Location of class 3 with respect to providing cell, where point A is the class, Point B is the providing cell

4. Class Four:

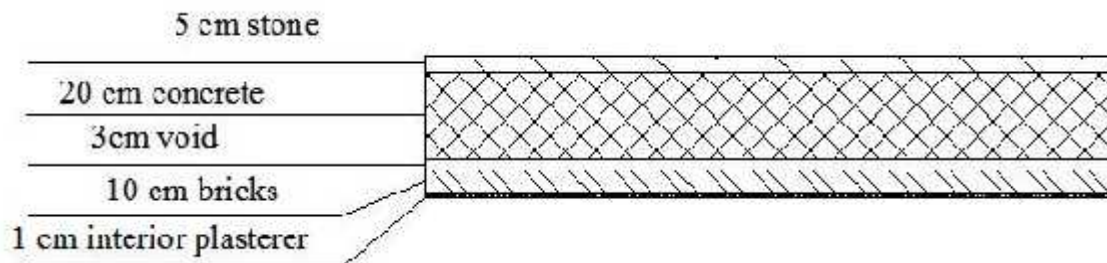


Figure 4.10: Cross sections in outer walls for class 4

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

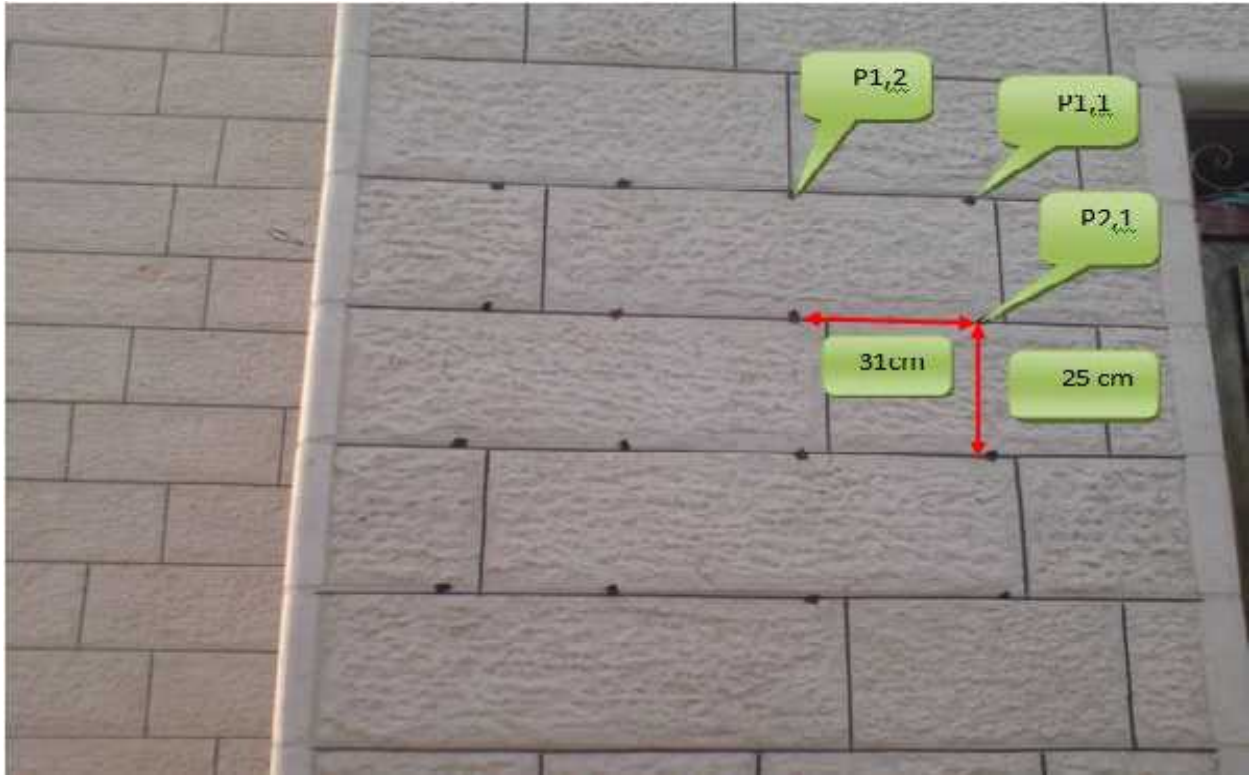


Figure 4.11: Outer wall in Class four

Location and Serving Cell

The following figure shows the location of this class related to the serving cell **HV2039B**, with no LOS, It's is located in Dura, near Dura cultural Center, With few building around.

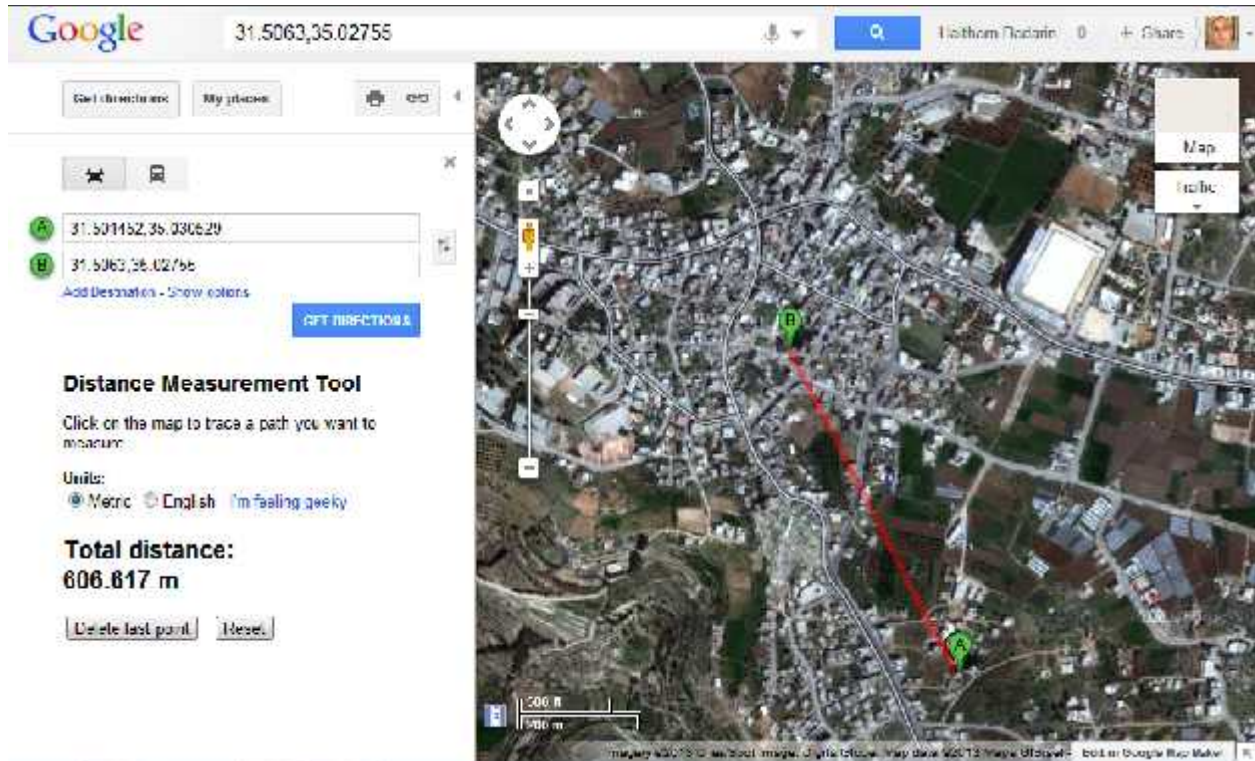


Figure 4.12: Location of class 4 with respect to providing cell HV2039B, point A is the class and Point B is the providing cell

5. Class Five:

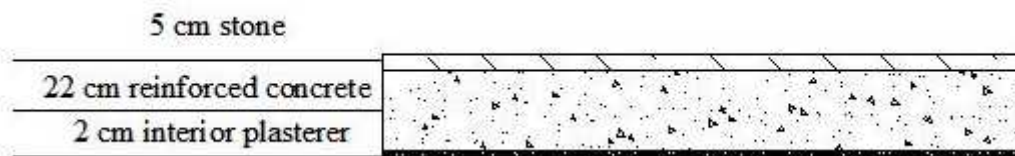


Figure 4.13: Cross sections in outer walls for class 5

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



Figure 4.14: Outer wall in Class five

Location and Serving Cell

This class is located in Sanjar, Dura, and Hebron. 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 maps and is approximately 481m ,The following satellite shows the class and the cell.

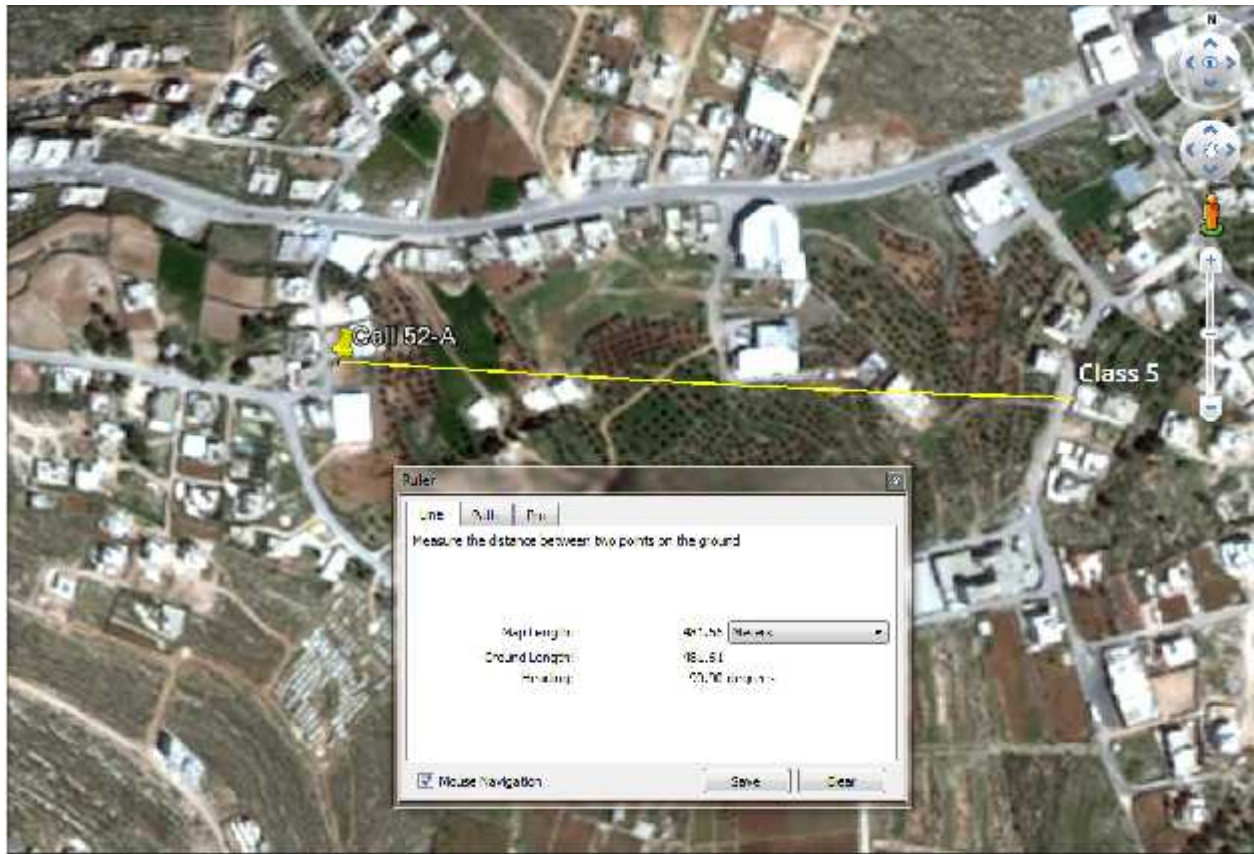


Figure 4.15: Location of class 5 with respect to providing cell

6. Class Six:

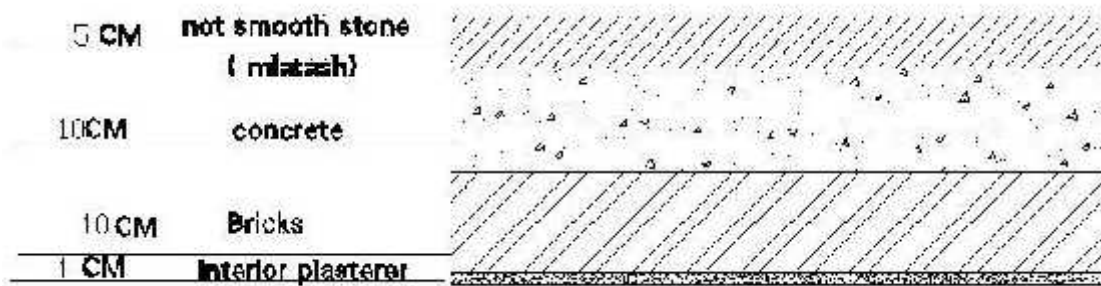


Figure 4.16: Cross sections in outer walls for class 6

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

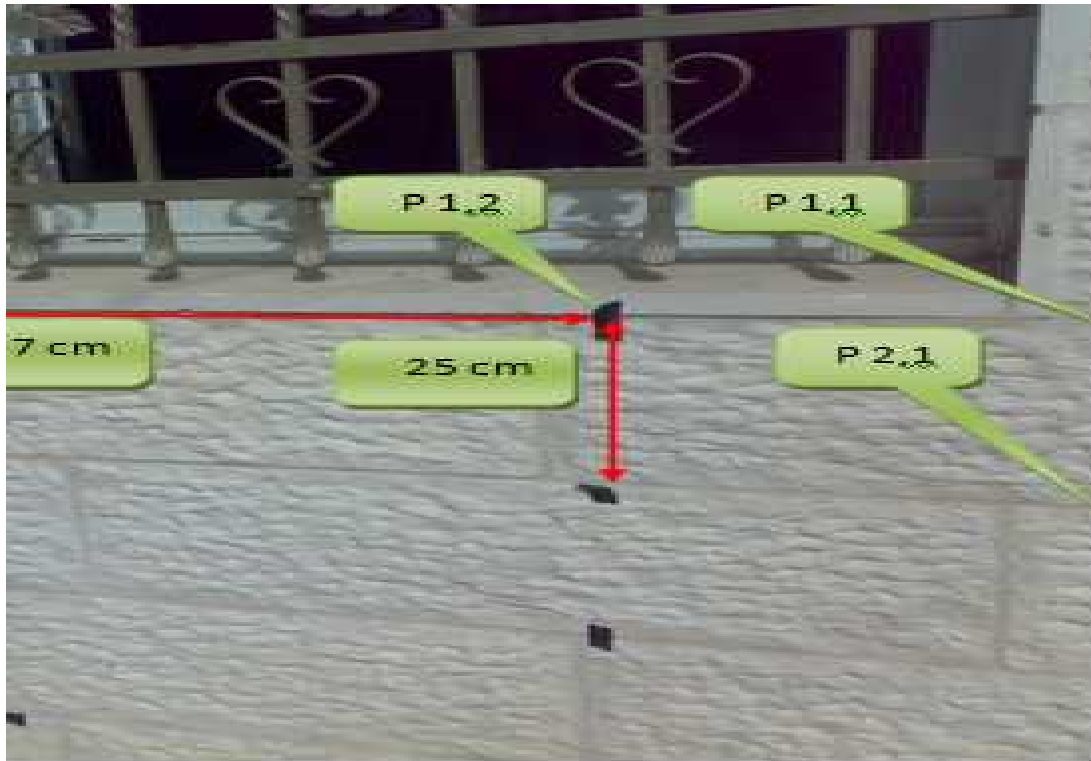


Figure 4.17: Outer wall in Class six

Location and Serving Cell

This building is located in Dura, at the same residential building where we measured class 5, i.e. same geographic area, and same providing cell **52-A** the following satellite view will illustrate the location of this class.

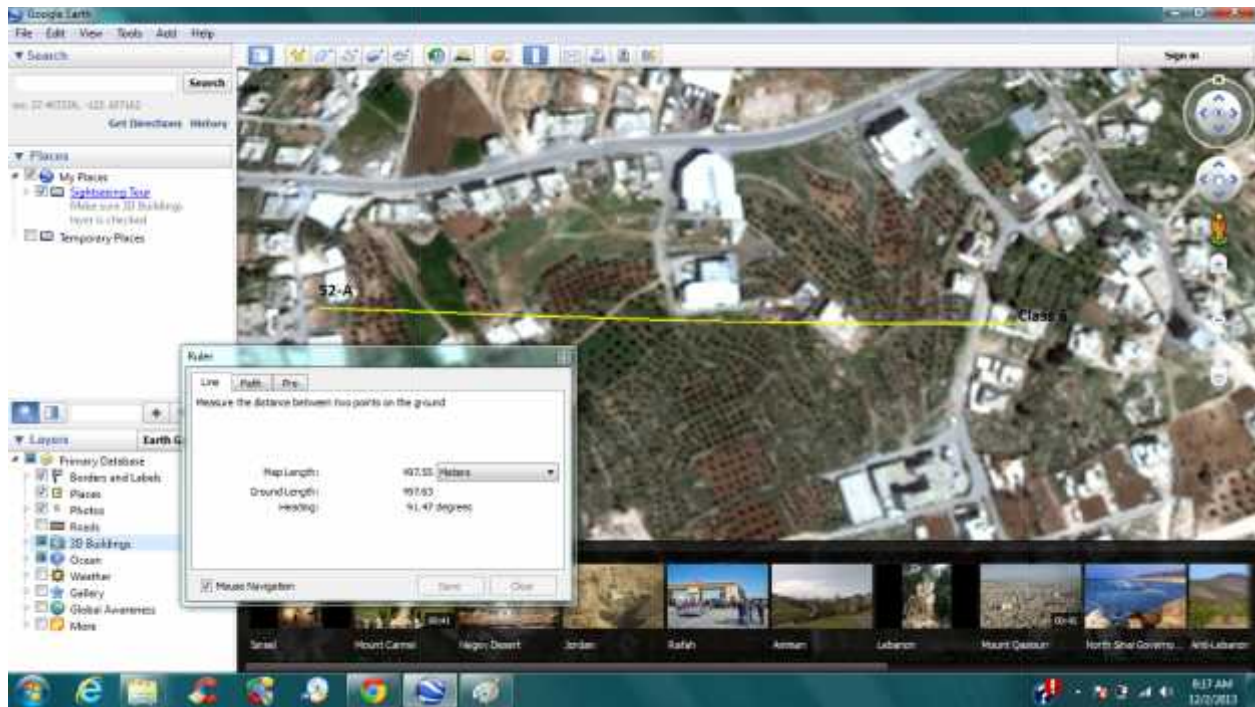


Figure 4.18: Location of class 6 with respect to providing cell

7. Class Seven:

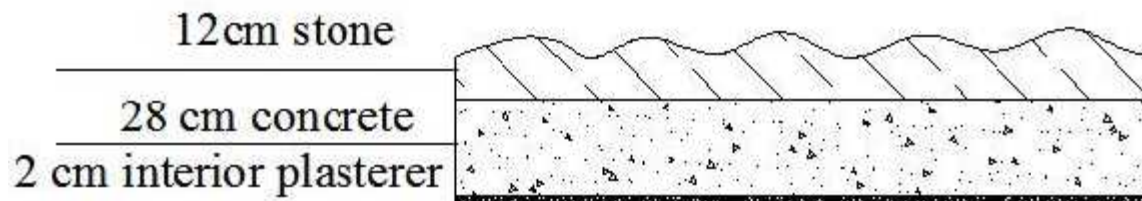


Figure 4.19: Cross sections in outer walls for class 7

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



Figure 4.20: Outer wall in Class seven

Location and Serving Cell

This class is located close to class 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 almost 582.23 m as measured using Google earth.

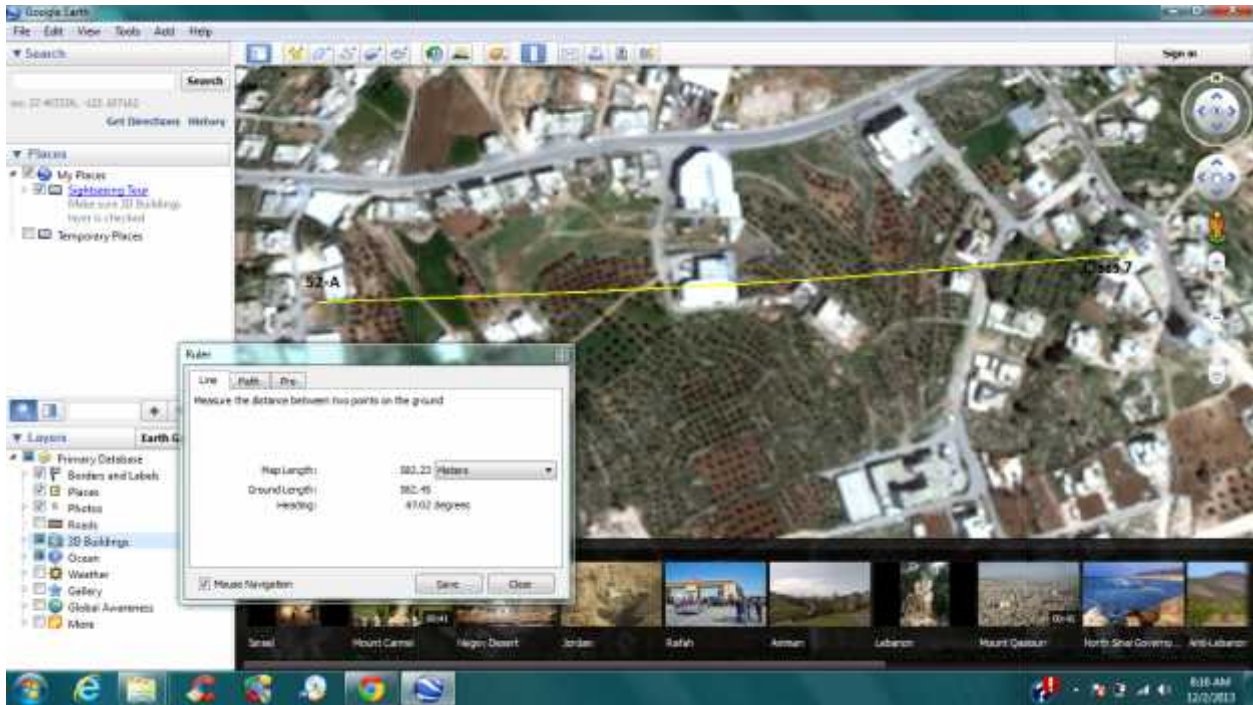


Figure 4.21: Location of class 7 with respect to providing cell

8. Class Eight:

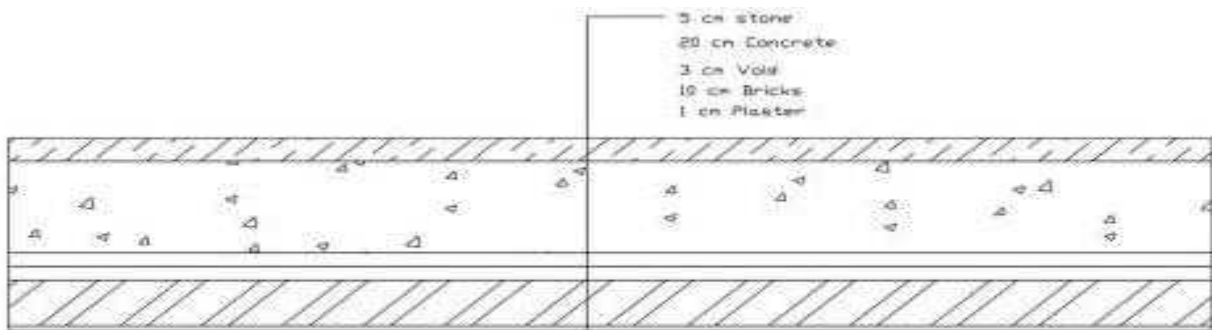


Figure 4.22: Cross sections in outer walls for class 8

This class is composed of 5 cm mlatash stone , 20 cm concrete , 3 cm air space ,10 cm Bricks and 1 cm interior plasterer .



Figure 4.23: Outer wall in Class eight

Location and Serving Cell

The following figure shows the exact location of this class, related to the serving cell **HV2039B** with no LOS; the building is located in Dura, Abu-Hlal area, with few buildings around.

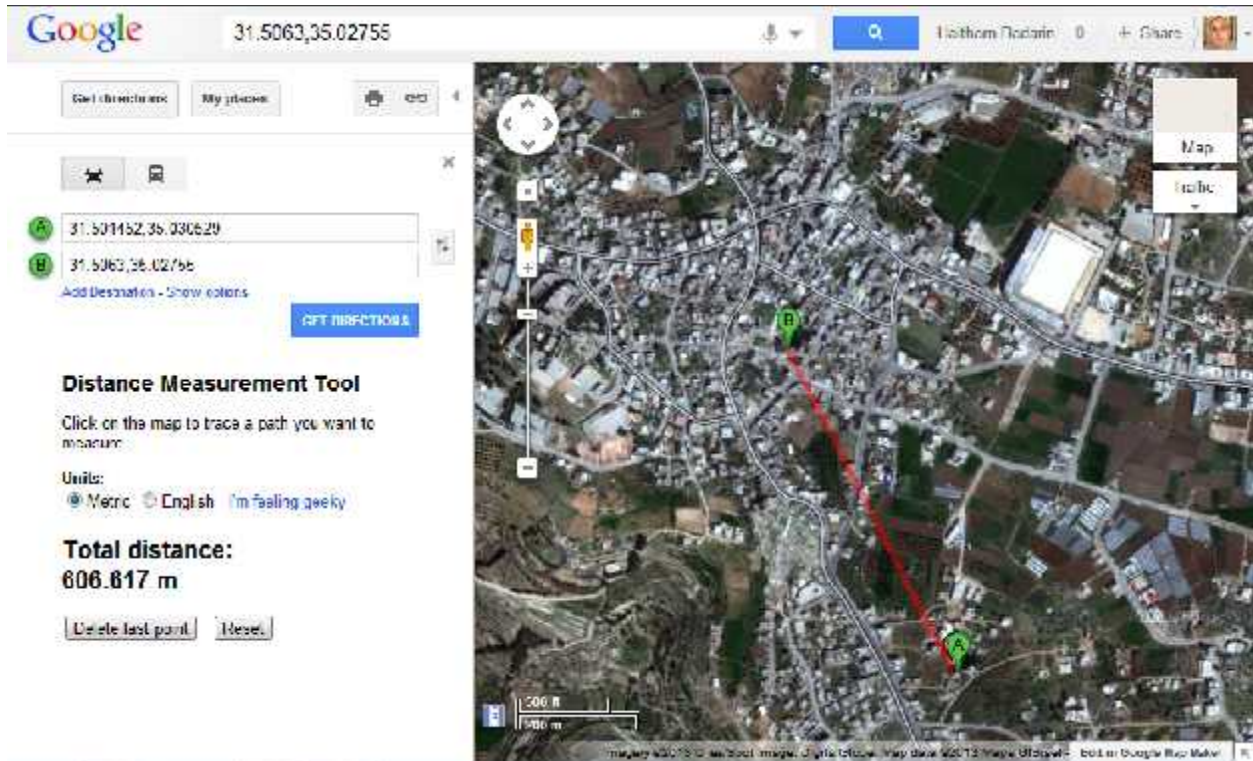
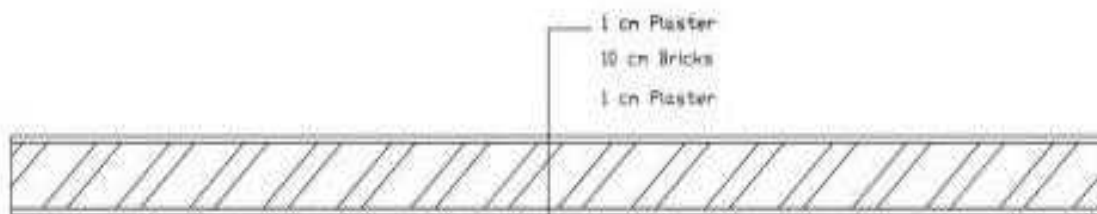


Figure 4.24: Location of class 8 with respect to providing cell, Point A is the class; Point B is the providing cell

9. Class Nine:



.Figure 4.25: cross sections for class 9

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



Figure 4.26: Wall in Class nine

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 building there is no LOS, taking into consideration that the providing cell is the same as in class three **HBR225C**, the following figure is a satellite view of the location of this class with respect to providing cell.

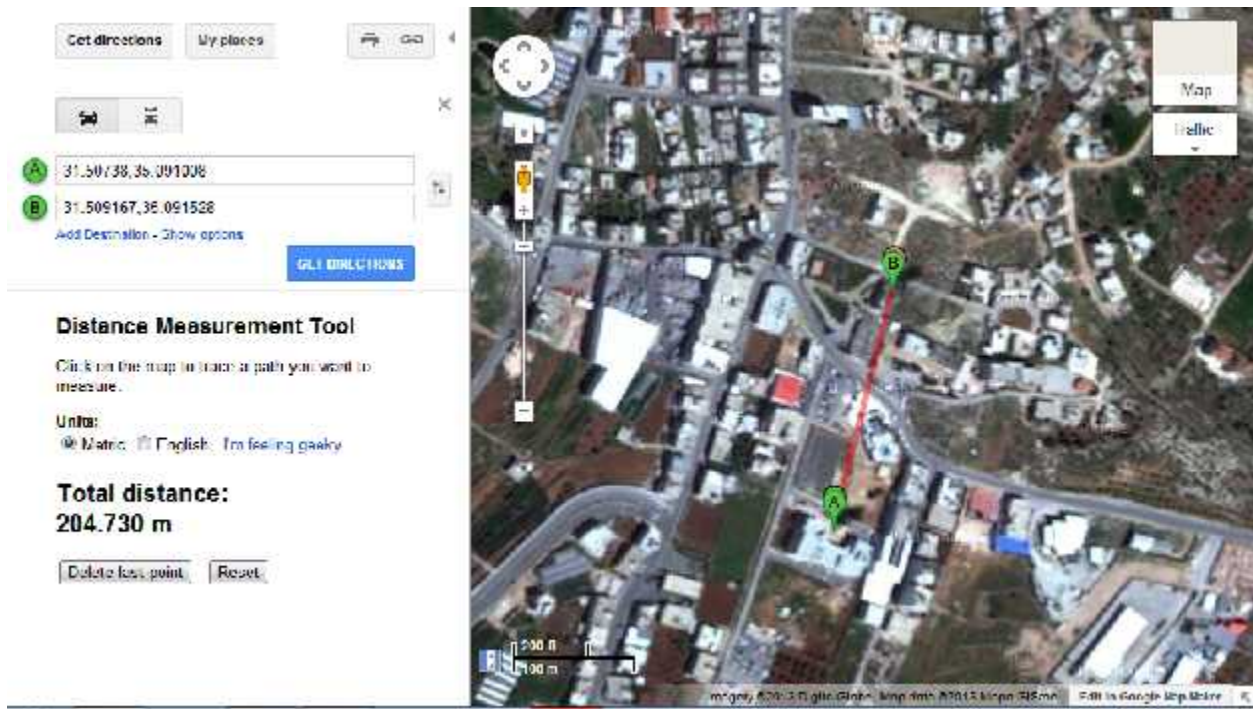


Figure 4.27: Location of class nine with respect to providing cell, where point A is the class and point B is the providing cell

10. Class Ten:

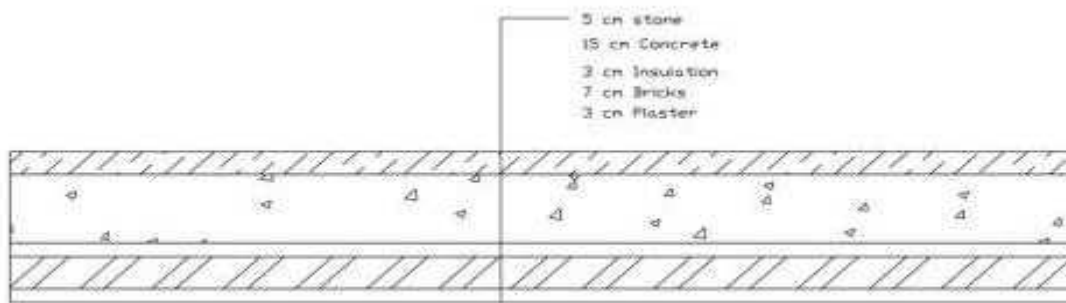


Figure 4.28: cross sections in outer walls for class 10

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



Figure 4.29: Outer wall in Class ten

Location and Serving Cell

The following figure shows the location of this class related to the serving cell **HV2037C** with full LOS on the wall .the building located in Al-Fawwar , Hebron , in a residential area ,and the distance between the serving cell and the wall as measured using Google maps is 1.19 Km .



Figure 4.30: Location of class 10 with respect to providing cell, point B is the class and point A is the providing cell

11. Class Eleven:



Figure 4.31: Cross sections in outer walls for class 11

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



Figure 4.32: Outer wall in Class eleven

Location and Serving Cell

The following satellite view show the exact location of the class and it's providing cell **HV2410B**, this class is located in Hebron, Samu'a , near Muta secondary school , in a residential area , the class is almost 115 m away from the serving cell

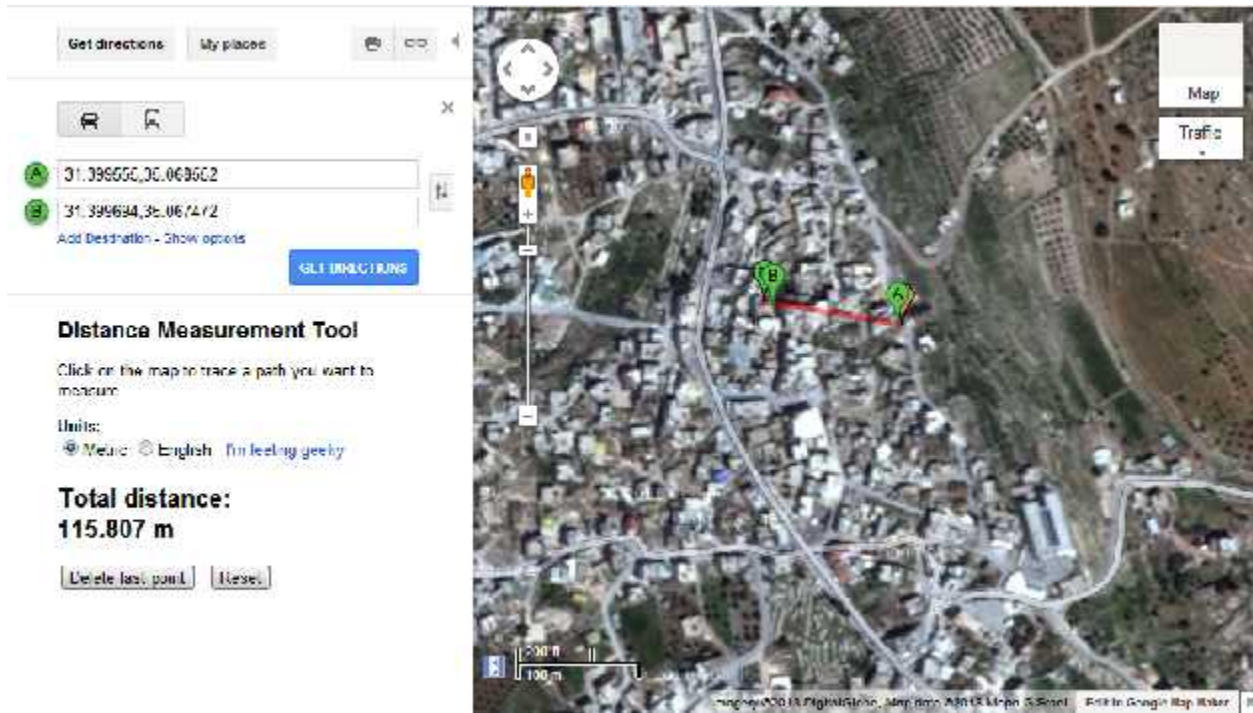


Figure 4.33: Location of class 11 with respect to providing cell, point A is the class and point B is the providing cell

12. Class Twelve:

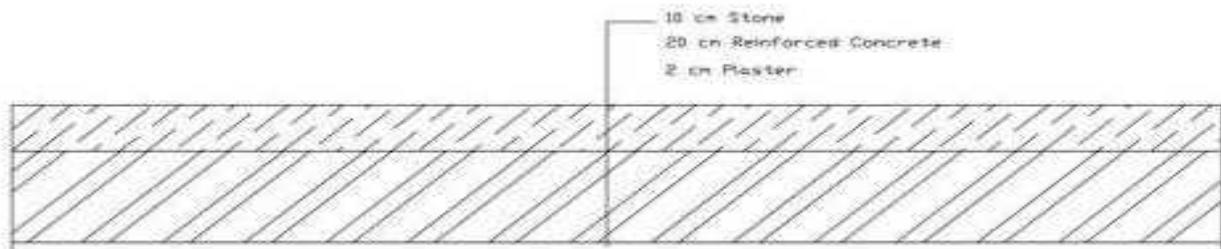


Figure 4.34: Cross section in outer walls for class 12

This Class is composed of 10 cm stone (Tobzeh), 20 cm reinforced concrete, and another 2 cm of plasterer and paint.



Figure 4.35: Outer wall in Class twelve

Location and Serving Cell

The following satellite view show the location of class 12 with respect to providing cell **HV2410C** , it's located in Hebron, Samu' near Ja'far Bin AbiTalib elementary school , distance between the class and the providing cell is 155 m measured on Google maps

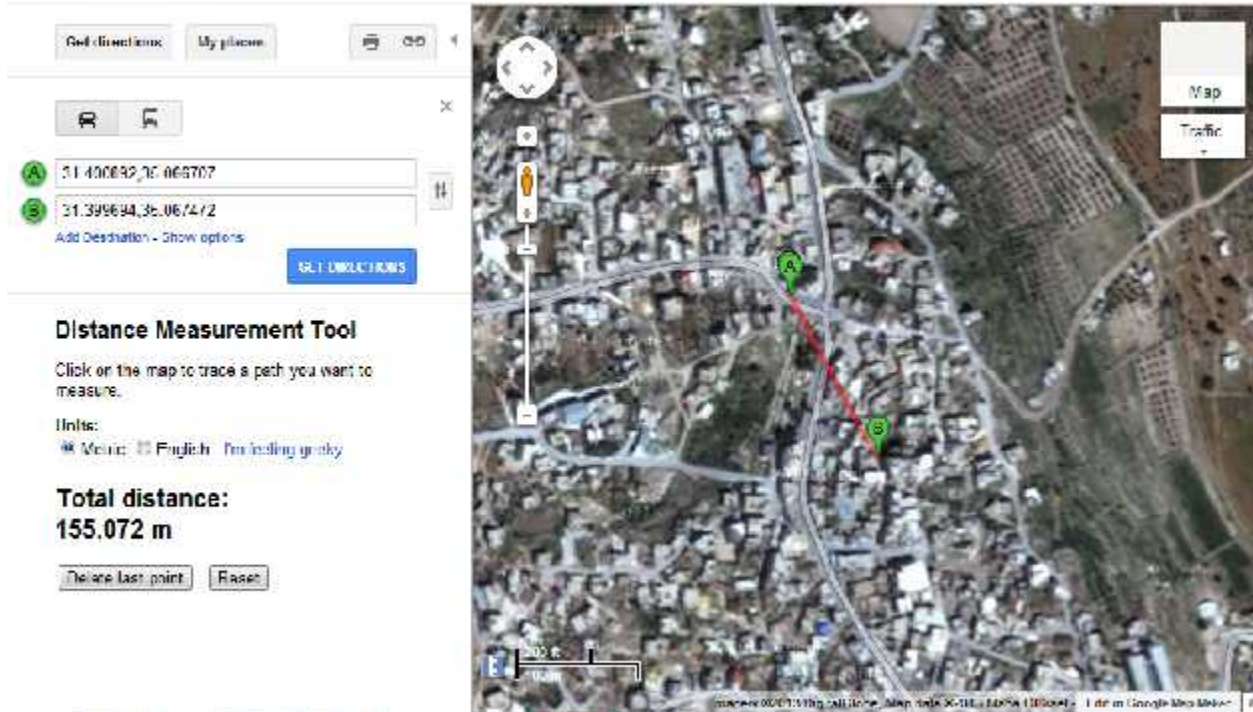


Figure 4.36: Location of class 12 with respect to providing cell, where Point A is the class and point B is the providing cell

13. Class Thirteen:

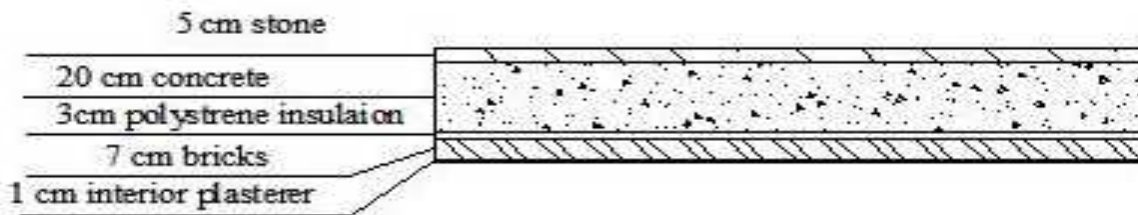


Figure 4.37: Cross sections in outer walls for class 13

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

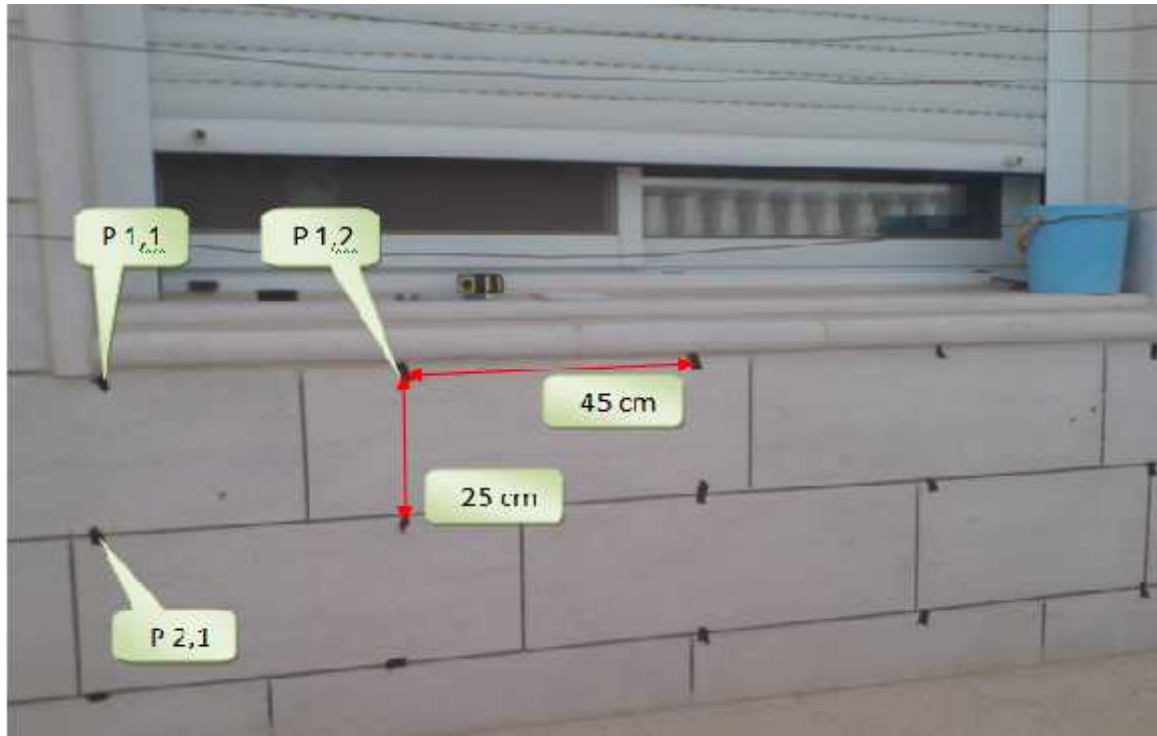


Figure 4.38: Outer wall in Class thirteen

Location and Serving Cell

The following satellite view show the exact location of the class and it's providing cell **HV2039B** , its located in Honaina, Dura , Palestine , the distance between the class and the serving cell is 180.581 as measured on Google maps.

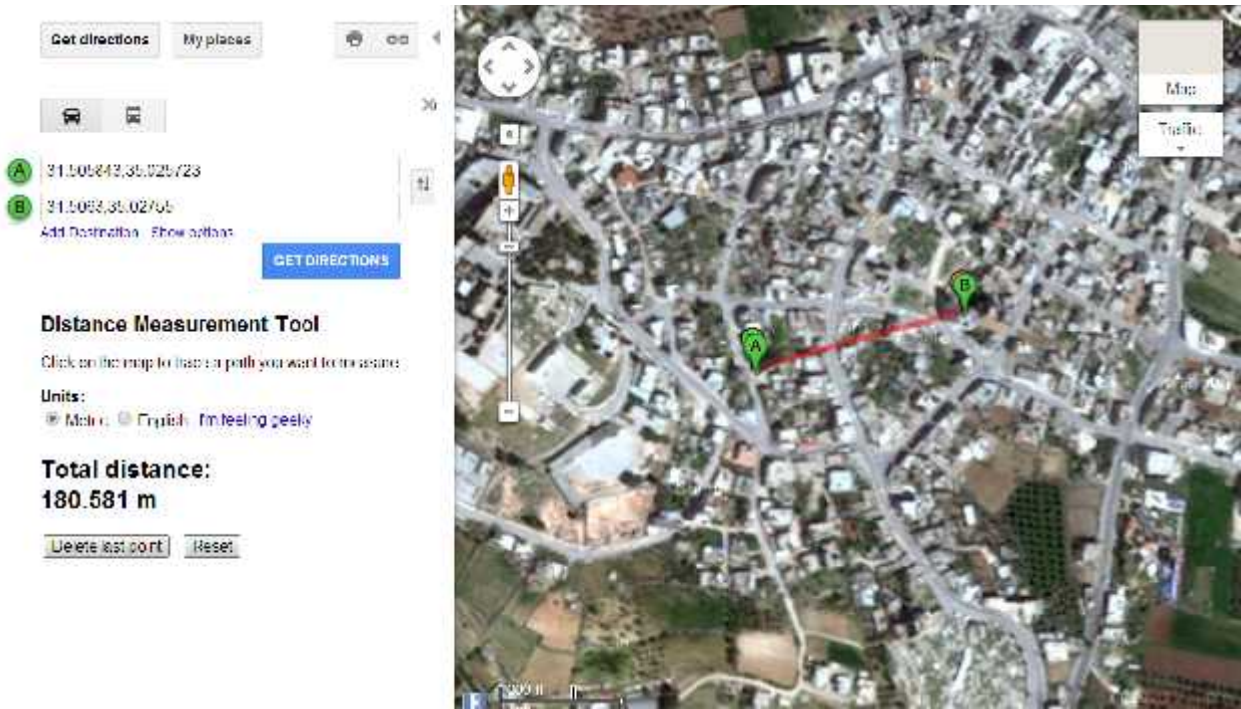


Figure 4.39: Location of class 13 with respect to providing cell, Point B is the class and Point A is the providing cell

14. Class Fourteen:

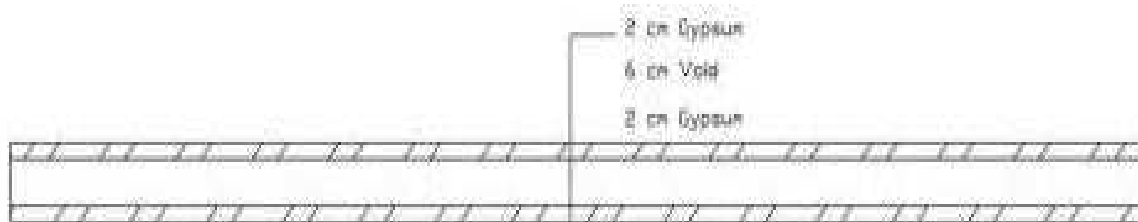


Figure 4.40: Cross sections for class 14

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



Figure 4.41: Wall in Class fourteen

Location and Serving Cell

This class is located in the same building for class 3, it's an internal wall where a LOS doesn't exist, the following satellite view shows the exact location of the class and it's providing cell **HBR225C**

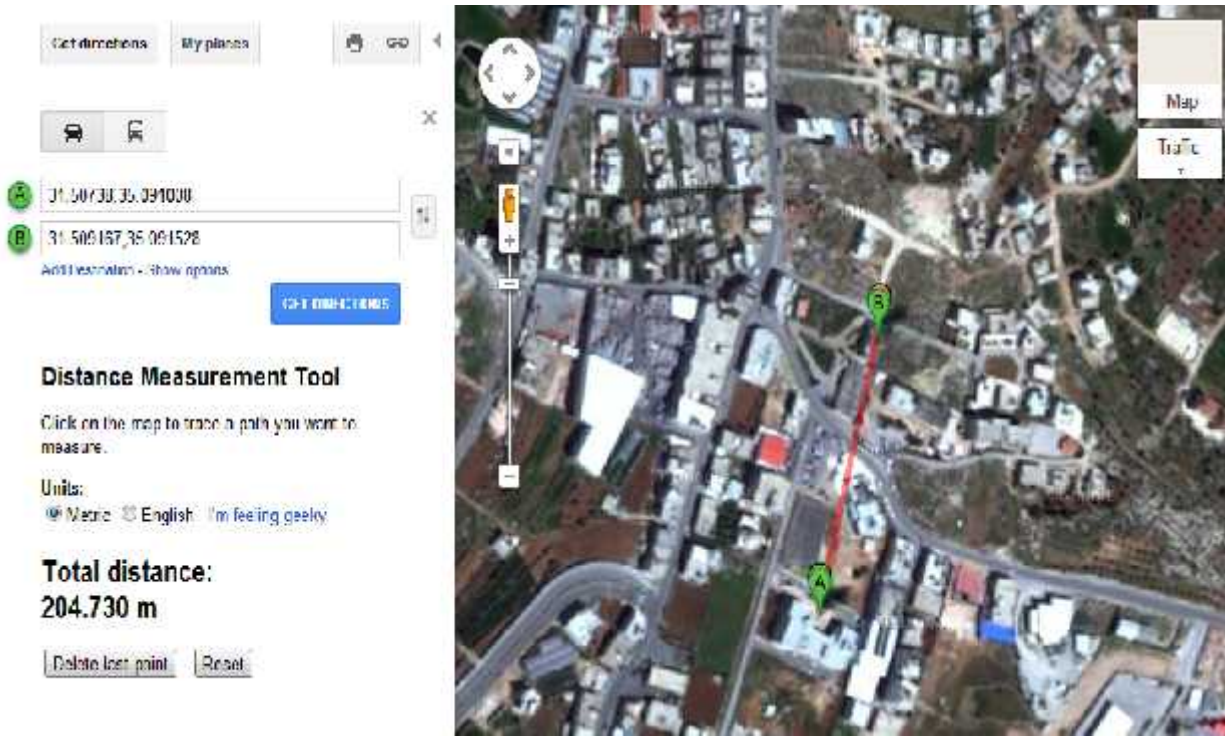


Figure 4.42: Location of class 14 with respect to the providing cell, where point A is the class and point B is the providing cell.

15. Class Fifteen:

This class is composed of 5 cm stone, 20cm concrete, 3 cm plaster, the structure is similar to that of class 5 but here the tale patterns are quite different and, this class is commonly known as the 12-cm Stone.

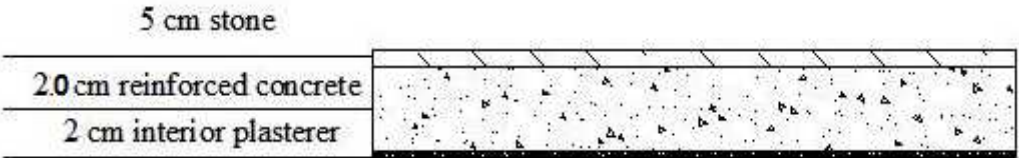


Figure 4.43: Cross sections for class 15



Figure 4.44: Outer wall in Class fifteen

Location and Serving Cell

This class is located in Samu'a , Southern Hebron , it's surrounded by many houses , the location of this class and it's providing cell is shows in the following satellite view

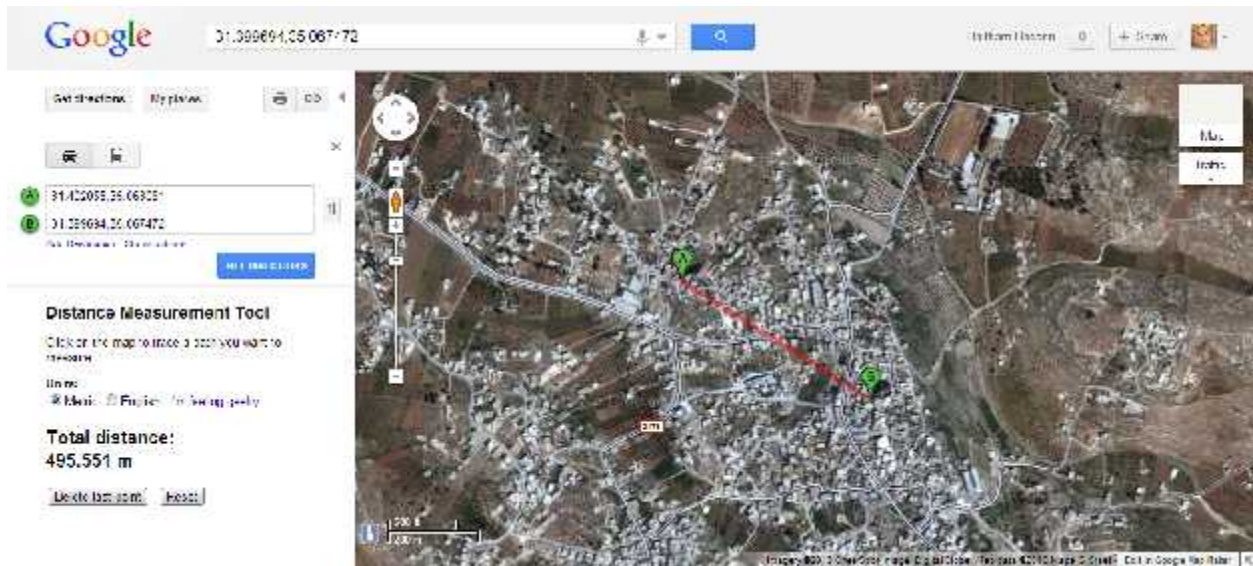


Figure 4.45: Location of class 15 with respect to its providing cell, point A is the class and Point B is the providing cell

Chapter 5

Measurement Procedure

5.1 Measurement Procedure at 900MHz

- Ñ Charge the spectrum analyzer three hours prior to work.
- Ñ At each measurement location make sure you wait for two or three minutes before you start recording ; this would help stabilize the reading on the spectrum analyzer .This is important for preventing any sudden change in the reading which may be due to swinging of the receiving antenna in many directions .
- Ñ To get best results you need to adjust the antenna attached to the spectrum analyzer so you get maximum value. This because base station electric fields are 45 degrees cross polarized .The receiving antenna must be adjusted at the same angle as shown in the Picture below.



Figure 5.1: The receiving antenna at 900 MHz is adjusted at - 45 degrees

Ñ When starting to record keep an eye on the reading available in the “ Results “ section to make sure everything is ok .This will help you in anticipating any problem in the earliest possible time . See the following screenshot.

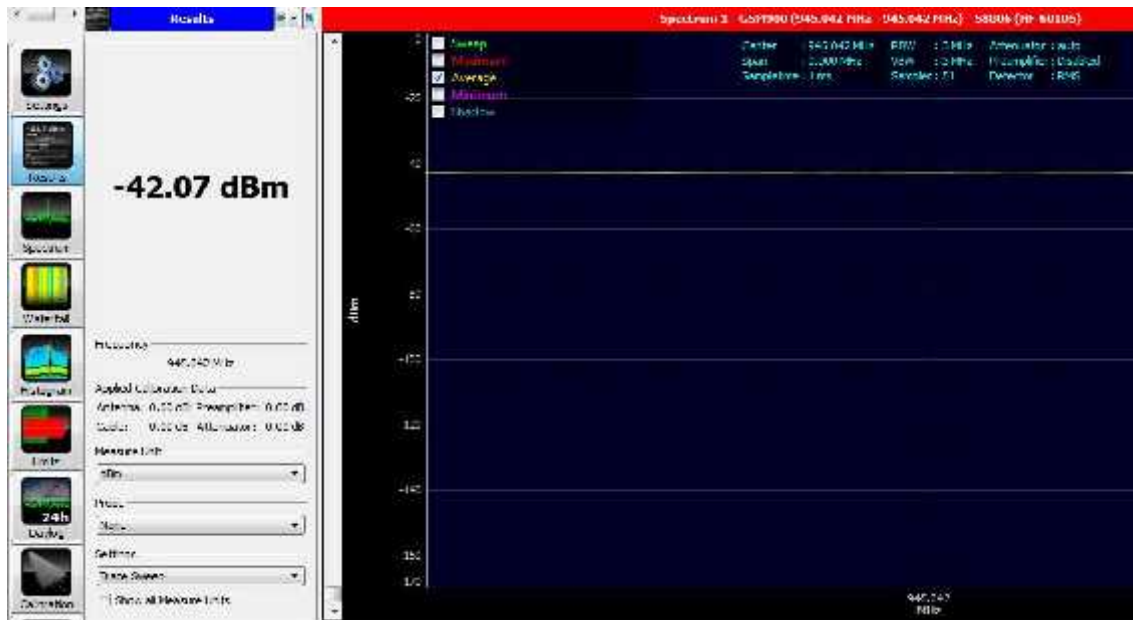


Figure 5.2: Instant display of the received power value in the “result” section of the software

Ñ On the wall which contains the measurement points label every point with a name; P (1, 1) for example, and make sure you choose the same name when prompted by the software to start making measurements.

Ñ You need to adjust the frequency on the software to match the carrier frequency. Make sure you select the span of 200 KHz (that’s actually the bandwidth of GSM channel in the 900 MHz freq. band). GSM-900 uses 890 - 915 MHz to send information from the Mobile Station to the Base Transceiver Station (uplink) and 935 - 960 MHz for the other direction (downlink), thus providing 124 RF channels (channel numbers 1 to 124) spaced at 200 kHz. The following figure gives more details about the GSM channel:

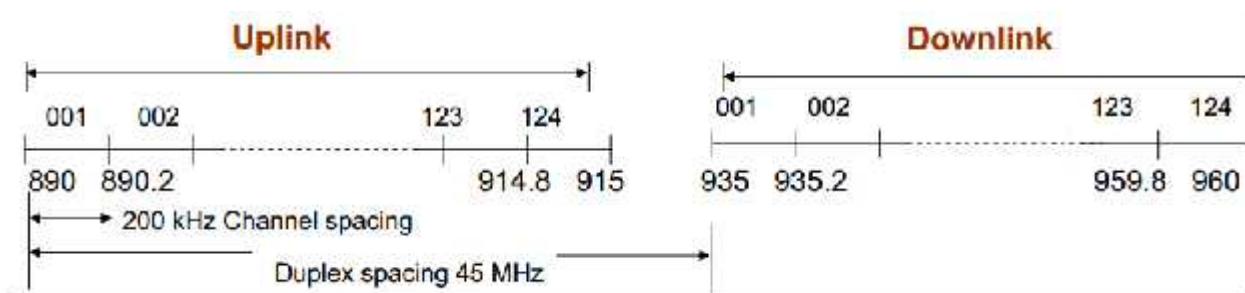


Figure 5.3: Channels distribution in the GSM900

5.1 Measurement Procedure at 2.4 GHz

We adopted the following steps for making measurements at 2.4GHz; as mentioned earlier, measurements at 2.4 GHz were recorded by using Vistumbler© Software; a free wifi analysis tool.

- I.** To access the setting page use the IP address 192.168.1.20 , a prompt window will ask for a username and a Password. Both are provided in the antenna guide, you can change them later.
- II.** Under the “ Link setup “ menu adjust the settings for the 2.4 transmitting antennas by choosing a name for your AP, and a transmitting Channel that will minimize interference. To view other APs in the region use The Vistumbler© itself, it will list active APs once you run it.
- III.** After you choose settings place the 2.4 GHz antenna on an adequate distance away from the outer wall of the class. Make sure the antenna isn't surrounded by many objects, also make sure you and your partners stay away from the antenna since the transmitted power can cause dizziness and may have direct effect on your eyes.
- IV.** At each point change the orientation of the laptop so you get maximum received power; you need to wait every time you change the position of your laptop with reference to the antenna until the reading on the program becomes stable.
- V.** The Program by default records readings for all active APs , Use “ filter “ feature to make sure that the resulting logfile will contain readings for your 2.4 GHz transmitting antenna only .This can save time and help later with calculations and analysis . the following is a screenshot of the software that shows the available wifi networks in the location of class 15 ,UBNT is our wifi network's SSID ; neighboring SSIDs were stricken through for privacy concerns

#	Action	Mac Address	SSID	Signal	High Signal	RSSI	High RSSI	Channel	Authentication
1	Active	16:CC:2B:8A:26:01	[REDACTED]	50%	54%	-75 dBm	-67 dBm	1	WPA-Personal
2	Active	74:FC:75:A7:D1:67	UNINT	100%	125%	-45 dBm	-60 dBm	6	WPA2-Personal
3	Active	45:85:C1:93:78:98	[REDACTED]	50%	55%	-75 dBm	-67 dBm	13	Open
4	Active	A5:F3:C1:CA:85:9C	[REDACTED]	20%	22%	-85 dBm	-70 dBm	6	Open
5	Used	80:85:24:54:45:CC	[REDACTED]	0%	0%	-120 dBm	-70 dBm	1	Open

Figure 5.4: List of available wifi networks in the location of class 15 scanned by Vistumbler

- VI.** Adjust your stop watch and start making measurements, Click “stop “when you are done.
- VII.** Repeat the last three steps at each point

Chapter 6

Results

This chapter presents the results of penetration loss at 900 MHz and 2.4 GHz of residential houses classified as Class 1, 2, ..., Class 15. It also provides results for indoor measurements of Class five which has been chosen as candidate class due to the presence of several internal walls that follows the outer wall. The structures of each class below including class 5 are available in Ch.4.

6.1 Penetration loss

For each class below there are two sections : One section for results at 900 MHz and the other section for results at 2.4 GHz, Now for each section there are three tables : The 1st table represents the resulted received power for each point of the inner points in the class , the 2nd table shows the resulted received power for each point of the outer points in the class while the 3rd table provides the final results for the Penetration loss and standard deviation , it also provides the 10th percentile value taken for each side, which if achieved will guarantee 90% coverage .The table contains also the 50th percentile which may guarantee 50% coverage.

Points of measurements are denoted as P (i,j) where $i=1,2,3,..$ And $J=1,2,3,..$ Distance between each Point and the neighboring points varies according to the wavelength; for the 900 MHz the distance was $d_1 = 30$ cm while the distance between the points at 2.4 GHz was from 12-15 cm.

Class 1:

Results at 900 MHz:

Table 6.1: Received power (indBm) at each point of the inner points in class 1 at 900 MHz

Point	1	2	3	4
1	-43.7931	-47.1996	-42.1159	-47.0546
2	-39.2039	-49.3787	-42.9988	-43.1827
3		-50.7701	-48.3741	

Table 6.2: Received power (indBm) at each point of the outer points in class 1 at 900 MHz

Point	1	2	3	4
1	-31.2386	-36.3533	-40.0609	-30.2784
2	-33.616	-30.2491	-29.8416	-35.0011
3		-38.2507		-29.9434

Table 6.3: Class One Values at 900 MHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-33.4833	-45.4072	11.9329
10 th percentile	-34.2779	-46.6406	12.3627
50 th Percentile	-32.4273	-45.4239	12.9966
Standard deviation (σ)	3.772912	3.680739	3.772912

Results at 2.4 GHz:

Table 6.4: Received power (indBm) at each point of the inner points in class 1 at 2.4 GHz

Point	1	2	3	4	5
1	-46.2899	-46.1167	-45.968	-46.4279	-46.6357
2	-47.8657	-47.6838	-47.619	-51.8786	-44.9091

Table 6.5: Received power (indBm) at each point of the outer points in class 1 at 2.4 GHz

Point	1	2	3	4	5
1	-28.6145	-32.7606	-22.2967	-25.6988	-24.1077
2	-22.3211	-20.4414	-21.3067	-20.7217	-20.0222

Table 6.6: Class One Values at 2.4 GHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-23.8291	-47.1394	23.3103
10th percentile	-21.153	-46.542	25.3885
50th Percentile	-22.3089	-46.5318	24.2229
Standard deviation ()	4.121134	1.897016	4.121134

Class 2:**Results at 900 MHz:****Table 6.7:** Received power (indBm) at each point of the inner points in class 2 at 900 MHz

Point	1	2	3	4
1	-64.2366	-58.7785	-61.0809	-63.4661
2	-62.2719	-64.3645	-67.3456	-62.6987

Table 6.8: Received power (indBm) at each point of the outer points in class 2 at 900 MHz

Point	1	2	3	4	5
1	-30.1127	-32.7983	-32.0391	-29.2247	-33.4506
2	-28.4196	-31.5427	-31.7823	-28.6254	-35.1346

Table 6.9: Class Two Values at 900 MHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-31.313	-63.0304	31.7174
10 th percentile	-31.8798	-64.0741	32.1943
50 th Percentile	-31.6625	-63.0824	31.4199
Standard deviation ()	2.200441	2.524444	2.524444

Results at 2.4 GHz:**Table 6.10:** Received power (indBm) at each point of the inner points in class 2 at 2.4 GHz

Point	1	2	3	4	5
1	-65.7048	-69.651	-66.6103	-65.4253	-66.9429
2	-64.7056	-70.1494	-67.8498	-66.0779	-65.456

Table 6.11: Received power (indBm) at each point of the outer points in class 2 at 2.4 GHz

Point	1	2	3	4
1	-18.3089	-18.5088	-18.3287	-18.2239
2	-19.6638	-19	-19.2845	-18.4231

Table 6.12: Class Two Values at 2.4 GHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-18.7177	-66.8573	48.1396
10 th percentile	-19.143	-69.91	50.7679
50 th Percentile	-18.4659	-66.3441	47.8782
Standard deviation (σ)	0.533019	1.834125	1.834125

Class 3:

Results at 900 MHz:

Table 6.13: Received power (indBm) at each point of the inner points in class 3 at 900 MHz

Point	1	2	3	4	5
1	-46.524	-45.2451	-45.125	-44.125	-47.125
2	-49.125	-45.1256	-43.124	-44.125	-47.1256

Table 6.14: Received power (indBm) at each point of the outer points in class 3 at 900 MHz

Point	1	2	3	4	5	6
1	-24.3366	-19.2095	-22.5198	-23.1707	-19.125	-24.3366
2	-20.351	-23.245	-19.452	-24.456	-22.14	-20.351

Table 6.15: Class Three Values at 900 MHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-21.8006	-45.3148	23.5142
10 th percentile	-24.3485	-49.3255	24.977
50 th Percentile	-22.3299	-45.1854	22.8555
Standard deviation (σ)	2.096784	1.792942	2.096784

Results at 2.4 GHz:

Table 6.16: Received power (in dBm) at each point of the inner points in class 3 at 2.4 GHz

Point	1	2	3	4	5
1	-49.1382	-54.8103	-47.7377	-50.2911	-53.9922
2	-50.8784	-47.7669	-54.5397	-51.659	-49.4989

Table 6.17: Received power (in dBm) at each point of the outerpoints in class 3 at 2.4 GHz

Point	1	2	3	4	5
1	-21.6346	-22.027	-21.8077	-16.9487	-16.7156
2	-17.847	-16.765	-17.301	-18.43	-17.3884

Table 6.18:Class Three Values at 2.4 GHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-18.6865	-51.0312	32.3447
10th percentile	-21.952	-55.488	33.5351
50th Percentile	-17.6177	-50.5848	32.9671
Standard deviation ()	2.225209	2.66163	2.66163

Class 4:

Results at 900 MHz:

Table 6.19:Received power (in dBm)at each point of the inner points in class 4 at 900 MHz

Point	1	2	3	4	5
1	-61.4099	-66.0828	-62.4771	-66.6638	-58.0867
2	-61.3225	-63.2086	-57.8609	-64.4126	-60.4687

Table 6.20:Received power (in dBm) at each point of the outer points in class 4 at 900 MHz

Point	1	2	3	4	5
1	-43.8162	-39.3501	-39.9919	-41.6794	-39.4399
2	-41.9398	-39.6873	-39.7776	-40.1361	-39.4587

Table 6.21:Class four Values at 900 MHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-40.5277	-62.1994	21.6717
10th percentile	-41.1222	-63.3108	22.1886
50th Percentile	-39.8848	-61.9435	22.0605
Standard deviation ()	1.474094	3.002422	3.002422

Results at 2.4 GHz:**Table 6.22:**Received power (in dBm)at each point of the inner points in class 4 at 2.4 GHz

Point	1	2	3	4
1	-57.0805	-59.5133	-57.0388	-53.712
2	-52.2312	-56.0536	-56.4815	-57.3721

Table 6.23:Received power (in dBm)at each point of the outer points in class 4 at 2.4 GHz

Point	1	2	3	4
1	-23.7722	-21	-19.6383	-19.7586
2	-24.7931	-22.2941	-24.0625	-23.1438

Table 6.24:Class four Values at 2.4 GHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-22.3078	-56.1854	33.8776
10th percentile	-24.541	-58.845	34.3033
50th Percentile	-22.719	-56.7601	34.0411
Standard deviation ()	1.979685	2.263718	2.263718

Class 5:**Results at 900 MHz:****Table 6.25:** Received power (in dBm)at each point of the inner points in class 5 at 900 MHz

Point	1	2	3	4	5
1	-42.5403	-39.2476	-41.3732	-41.7517	-44.4511
2	-40.9759	-44.6862	-44.7084	-44.6186	-44.5087
3	-42.9417	-47.396	-42.6285	-38.9401	-37.4514

Table 6.26: Received power (in dBm)at each point of the outerpoints in class 5 at 900 MHz

Point	1	2	3	4	5
1	-22.1484	-27.5551	-25.2791	-23.4576	-22.1484
2	-22.3967	-23.7075	-24.3392		-22.3967
3	-26.6049	-23.8795	-28.9299	-24.4044	-26.6049

Table 6.27: Class Five Values at 900 MHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-24.7911	-42.548	17.7569
10th percentile	-25.5793	-45.6253	20.046
50th Percentile	-24.3392	-42.6285	18.2893
Standard deviation ()	2.124891	2.659601	2.659601

Results at 2.4 GHz:**Table 6.28:** Received power (in dBm) at each point of the inner points in class 5 at 2.4 GHz

Point	1	2	3	4	5
1	-50.1458	-46.3146	-46.2781	-48.7098	-51.4088
2	-50.0748	-48.4451	-48.251	-47.6011	-47.3509

Table 6.29: Received power (in dBm)at each point of the outerpoints in class 5 at 2.4 GHz

Point	1	2	3	4	5
1	-24.1765	-23.0534	-24.8707	-20.7805	-19.7363
2	-19.2935	-19.1944	-18.3034	-18.3881	-18.3881

Table 6.30: Class Five Values at 2.4 GHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-20.6185	-48.458	27.8395
10th percentile	-24.125	-51.981	27.8569
50th Percentile	-19.5149	-48.348	28.8331
Standard deviation ()	2.507024	1.685971	2.507024

Class 6:

Results at 900 MHz:

Table 6.31:Received power (in dBm)at each point of the innerpoints in class 6 at 900 MHz

Point	1	2	3	4
1	-43.0459	-43.3966	-40.4105	-42.6108
2	-42.2254	-40.7671	-40.2797	-46.4088

Table 6.32: Received power (in dBm) at each point of the outer points in class 6 at 900 MHz

Point	1	2	3	4
1	-25.6391	-25.393	-25.7301	-25.7133
2	-25.4978	-26.0947	-24.7591	-25.4161

Table 6.33: Class Six Values at 900 MHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-25.5304	-42.3931	16.8627
10th percentile	-25.3924	-42.8387	17.4463
50th Percentile	-25.5685	-42.4181	16.8496
Standard deviation ()	0.383861	2.023987	2.023987

Results at 2.4 GHz:

Table 6.34: Received power (in dBm) at each point of the inner points in class 6 at 2.4 GHz

Point	1	2	3	4
1	-45.9754	-42.643	-41.3579	-47.5526
2	-47.1823	-45.7454	-45.2167	-45.9161

Table 6.35: Received power (in dBm) at each point of the outer points in class 6 at 2.4 GHz

Point	1	2	3	4
1	-19.6889	-21.9267	-22.0361	-21.9003
2	-19.1809	-20.8667	-22.8419	-18.5319

Table 6.36: Class Six Values at 2.4 GHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-20.8717	-45.1972	24.3255
10th percentile	-22.318	-47.654	25.3367
50th Percentile	-21.3835	-45.8307	24.4472
Standard deviation ()	1.564843	2.146246	2.146246

Class 7:**Results at 900 MHz:****Table 6.37:** Received power (in dBm) at each point of the inner points in class 7 at 900 MHz

Point	1	2	3
1	-58.242	-59.0854	-62.853
2	-60.4214	-59.1258	-59.1379
3	-59.3317	-58.0724	-58.1945

Table 6.38: Received power (in dBm) at each point of the outerpoints in class 7 at 900 MHz

Point	1	2	3
1	-30.6112	-33.6448	-32.0515
2	-33.8668	-32.7913	-31.2167
3	-33.4607	-32.4231	-32.6923
4	-33.4378	-31.7013	

Table 6.39: Class seven Values at 900 MHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-32.5361	-59.5914	27.0553
10th percentile	-33.6448	-61.5904	27.9456
50th Percentile	-32.6923	-59.1318	26.4395
Standard deviation ()	1.055836	1.549455	1.549455

Results at 2.4 GHz:**Table 6.40:** Received power (in dBm) at each point of the inner points in class 7 at 2.4 GHz

Point	1	2	3	4
1	-57.1702	-56.4066	-54.3495	-57.6727
2	-53.9821	-59.3093	-55.0263	-56.4444

Table 6.41: Received power (in dBm) at each point of the outerpoints in class 7 at 2.4 GHz

Point	1	2	3	4
1	-18.6489	-18.4902	-18.0714	-16.4286
2	-18.9873	-18.0273	-15.8841	-17.8958

Table 6.42: Class seven Values at 2.4 GHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-17.8042	-56.2952	38.491
10th percentile	-18.648	-58.3	39.6523
50th Percentile	-18.0494	-56.4255	41.3761
Standard deviation ()	1.088428	1.793981	1.793981

Class 8:

Results at 900 MHz:

Table 6.43: Received power (in dBm) at each point of the innerpoints in class 8 at 900 MHz

Point	1	2	3
1	-42.1083	-43.0193	-39.6781
2	-45.5503	-39.5633	-39.4008
3	-42.818	-43.2078	

Table 6.44: Received power (in dBm) at each point of the outerpoints in class 8 at 900 MHz

Point	1	2	3
1	-60.0784	-60.5618	-60.795
2	-58.711	-59.5354	-61.4263
3	-55.9994	-60.8435	-61.0796

Table 6.45: Class eightvalues at 900 MHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-41.9182	-59.8923	17.9741
10th percentile	-42.5041	-60.886	18.3819
50th Percentile	-42.4632	-60.5618	18.0986
Standard deviation()	2.197876	1.682355	2.197876

Results at 2.4 GHz

Table 6.46: Received power (in dBm) at each point of the inner points in class 8 at 2.4 GHz

Point	1	2	3	4
1	-42.1548	-41.2548	-39.5847	-46.2544
2	-47.1258	-44.2514	-47.2541	-44.2541

Table 6.47: Received power (in dBm) at each point of the outer points in class 8 at 2.4 GHz

Point	1	2	3	4
1	-22.3564	-20.345	-19.6383	-22.7586
2	-22.3451	-22.2941	-24.0625	-22.1147

Table 6.48: Class eight values at 2.4GHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-21.9893	-44.0168	22.0275
10th percentile	-23.154	-48.125	24.9712
50th Percentile	-22.3196	-44.2528	21.9332
Standard deviation ()	1.388265	2.828513	2.828513

Class 9:

Results at 900 MHz:

Table 6.49: Received power (in dBm) at each point of the innerpoints in class 9 at 900 MHz

Point	1	2
1	-22.4687	-28.4686
2	-27.381	-24.6634
3	-21.2128	-26.5539

Table 6.50: Received power (in dBm) at each point of the outerpoints in class 9 at 900 MHz

Point	1	2
1	-17.9165	-22.1446
2	-17.7637	-21.9245
3	-17.7336	-16.5925

Table 6.51: Class nine Values at 900 MHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-19.0126	-25.1247	6.1121
10th percentile	-19.5145	-25.9336	6.4191
50th Percentile	-17.8401	-25.6086	7.7685
Standard deviation ()	2.389245	2.859573	2.859573

Results at 2.4 GHz**Table 6.52:** Received power (in dBm) at each point of the innerpoints in class 9 at 2.4 GHz

Point	1	2	3	4	5
1	-42.2308	-42.32	-44.674	-42.765	-43.9424
2		-45.0473	-47.8154	-43.1636	-45.3535

Table 6.53: Received power (in dBm) at each point of the outerpoints in class 9 at 2.4 GHz

Point	1	2	3	4	5
1	-32.543	-32.5235	-33.9808	-27	-35.1232
2		-32.645	-31.27	-30.103	-33.659

Table 6.54: Class nine Values at 2.4 GHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-32.0942	-44.1458	12.0516
10th percentile	-33.014	-47.125	14.1105
50th Percentile	-32.543	-43.9424	11.3994
Standard deviation ()	2.410052	1.800336	2.410052

Class 10:**Results at 900 MHz:****Table 6.55:** Received power (in dBm) at each point of the innerpoints in class 10 at 900 MHz

Point	1	2	3	4
1	-74.6323	-72.9695	-73.9297	-73.4264
2	-71.9127	-73.1379	-74.8518	-74.3927

Table 6.56: Received power (in dBm) at each point of the outerpoints in class 10 at 900 MHz

Point	1	2	3	4
1	-56.757	-54.2029	-53.517	-54.1739
2	-54.0061	-53.305	-53.653	-55.2667

Table 6.57: Class ten Values at 900 MHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-54.3602	-73.6566	19.2964
10th percentile	-54.7524	-74.6782	19.9258
50th Percentile	-54.09	-73.678	19.5881
Standard deviation ()	1.13865	0.987938	1.13865

Results at 2.4 GHz**Table 6.58:** Received power (in dBm) at each point of the inner points in class 10 at 2.4 GHz

Point	1	2	3	4
1	-52.2989	-52.2164	-54.5823	-53.8684
2	-54.3366	-53.3295	-56.5515	-56.7905

Table 6.59: Received power (in dBm)at each point of the outer points in class 10 at 2.4 GHz

Point	1	2	3	4
1	-26.0394	-28.38	-26.9124	-25.1587
2	-27.4459	-24.5385	-26.8916	-25.0778

Table 6.60: Class ten values at 2.4 GHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-26.3055	-54.2468	27.94123
10th percentile	-27.7261	-56.6232	28.89707
50th Percentile	-26.4655	-54.1025	27.637
Standard deviation ()	1.327264	1.723955	1.723955

Class11:

Results at 900 MHz:

Table 6.61: Received power (in dBm) at each point of the inner points in class 11 at 900 MHz

Point	1	2	3
1	-48.2159	-44.944	-46.4482
2	-44.3014	-42.7768	-44.9987
3	-45.4616	-44.8605	-46.4634

Table 6.62: Received power (in dBm) at each point of outer points in class 11 at 900 MHz

Point	1	2	3
1	-28.5053	-30.8272	-30.9864
2	-31.4181	-33.0529	-31.8518
3	-33.0016	-33.8901	-33.1342

Table 6.63: Class eleven values at 900 MHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-31.852	-45.3856	13.5336
10th percentile	-33.2854	-46.8139	13.5285
50th Percentile	-31.8518	-44.9987	13.1469
Standard deviation ()	1.648847	1.537408	1.648847

Results at 2.4 GHz

Table 6.64: Received power (in dBm)at each point of the inner points in class 11 at 2.4 GHz

Point	1	2	3	4
1	-42.1329	-43.0507	-42.4583	-40.8051
2	-41.7963	-42.6364	-42.1881	-42.516

Table 6.65: Received power (in dBm)at each point of the outer points in class 11 at 2.4 GHz

Point	1	2	3	4
1	-20.9157	-22.3716	-20.8151	-22.5531
2	-21.905	-21.3592	-20.0413	-21.523

Table 6.66: Class eleven values at 2.4 GHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-21.4355	-42.198	20.76445
10th percentile	-23.512	-44.951	21.4389
50th Percentile	-21.4411	-42.3232	20.8821
Standard deviation ()	0.841617	0.67551	0.841617

Class 12:

Results at 900 MHz:

Table 6.67: Received power (in dBm)at each point of the inner points in class 12 at 900 MHz

Point	1	2	3	4
1	-61.8174	-64.3485	-65.2589	-61.0972
2	-65.3705	-64.0443	-66.1196	-63.7931

Table 6.68: Received power (in dBm)at each point of the outer points in class 12 at 900 MHz

Point	1	2	3	4
1	-48.2561	-45.7951	-45.4522	-45.0819
2	-44.6912	-43.8131	-45.625	-44.1783

Table 6.69: Class Twelve values at 900 MHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-45.3616	-63.9812	18.6196
10th percentile	-46.5334	-65.5952	19.0618
50th Percentile	-45.267	-64.1964	18.9294
Standard deviation ()	1.361149	1.744769	1.744769

Results at 2.4 GHz

Table 6.70: Received power (in dBm) at each point of the innerpoints in class 12 at 2.4 GHz

Point	1	2	3	4
1	-51.377	-48.8824	-49.4054	-51.2374
2	-52.8143	-51.6176	-52.0702	-55.7643

Table 6.71: Received power (in dBm) at each point of the outerpoints in class 12 at 2.4 GHz

Point	1	2	3	4
1	-22.3333	-22.2269	-22.3077	-21.6071
2	-21.4821	-23.4379	-22.7928	-23.2731

Table 6.72: Class Twelve values at 2.4 GHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-22.4326	-51.6461	29.2135
10th percentile	-23.321	-54.147	30.8256
50th Percentile	-22.3205	-51.4973	29.1768
Standard deviation ()	0.70704	2.118072	2.118072

Class 13:

Results at 900 MHz:

Table 6.73: Received power (in dBm)at each point of the inner points in class 13 at 900 MHz

Point	1	2	3	4
1	-55.0286	-56.0448	-62.2656	-59.2499
2	-58.6199	-57.1625	-57.1139	-58.2289

Table 6.74: Received power (in dBm)at each point of the outer points in class 13 at 900 MHz

Point	1	2	3	4
1	-43.7016	-43.4785	-44.7029	-43.8078
2	-44.3873	-43.025	-44.605	-42.4307

Table 6.75: Class thirteen values at 900 MHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-43.7673	-65.5757	21.8084
10th percentile	-44.6344	-67.4026	22.7682
50th Percentile	-43.7547	-65.0741	21.3194
Standard deviation ()	0.791786	1.413508	1.413508

Results at 2.4 GHz

Table 6.76: Received power (in dBm) at each point of the inner points in class 13 at 2.4 GHz

Point	1	2	3	4	5
1	-48.318	-51.3333	-54.2364	-45.7143	-48.2066
2	-45.4419	-48.4231	-47.0337	-46.9394	-48.5106

Table 6.77: Received power (in dBm) at each point of the outer points in class 13 at 2.4 GHz

Point	1	2	3	4
1	-19.8202	-18.0488	-20.9038	-21.6575
2	-17.6154	-21.1226	-28.7164	-20.4214

Table 6.78: Class thirteen values at 2.4GHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-21.0383	-48.4157	27.3774
10th percentile	-23.7752	-51.6236	27.8484
50th Percentile	-20.6626	-48.2623	27.5997
Standard deviation ()	3.42011	2.639145	3.42011

Class14:

Results at 900 MHz:

Table 6.79: Received power (in dBm) at each point of the inner points in class 14 at 900 MHz

Point	1	2	3
1	-44.577	-47.4782	-46.1315
2	-48.1849	-41.5083	-46.3213
3	-44.599	-46.9185	-43.4976

Table 6.80: Received power (in dBm) at each point of the outer points in class 14 at 900 MHz

Point	1	2	3
1	-49.242	-47.2356	-48.1012
2	-55.3933	-50.2161	-43.1856
3	-43.7243	-51.7389	-56.9009

Table 6.81:Class fourteen values at 900 MHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-45.4685	-49.5265	4.058
10th percentile	-47.6195	-55.6948	8.0753
50th Percentile	-46.1315	-49.242	3.1105
Standard deviation ()	2.115583	4.682467	4.682467

Results at 2.4 GHz**Table 6.82:**Received power (in dBm) at each point of the inner points in class 14 at 2.4 GHz

Point	1	2	3	4	5
1	-60.8306	-63.4884	-63.9565	-64.2102	-64.4683
2	-65.6076	-64.1986	-65.8352	-66.2089	

Table 6.83:Received power (in dBm) at each point of the outer points in class 14 at 2.4 GHz

Point	1	2	3	4	5
1	-57.8678	-54.8092	-57.4558	-55.0956	-57.0662
2		-57.4265	-55.5217	-56.8676	-58.2161

Table 6.84:Class fourteen values at 2.4 GHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-56.7029	-64.3116	7.6087
10th percentile	-58.514	-66.61	8.096
50th Percentile	-57.0662	-64.2102	7.144
Standard deviation ()	1.248033	1.603501	1.603501

Class 15:**Results at 900 MHz:****Table 6.85:** Received power (in dBm) at each point of the inner points in class 15 at 900 MHz

Point	1	2	3	4
1	-82.356	-80.6295	-82.7402	-83.1622
2	-79.3219	-82.1032	-82.544	-81.1595

Table 6.86:Received power (in dBm) at each point of the outer points in class 15 at 900 MHz

Point	1	2	3	4
1	-61.7114	-62.1505	-63.4928	-61.1972
2	-61.8478	-61.0204	-59.7792	-62.4394

Table 6.87: Class Fifteen values at 900 MHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-61.7049	-81.7521	20.0472
10th percentile	-62.7554	-82.8668	20.1114
50th Percentile	-61.7796	-82.2296	20.45
Standard deviation ()	1.094767	1.287136	1.287136

Results at 2.4 GHz**Table 6.88:**Received power (in dBm) at each point of the inner points in class 15 at 2.4 GHz

Point	1	2	3	4
1	-61.0357	-61.7622	-60.0352	-62.8046
2	-64.0812	-61.2255	-61.1782	-61.4027

Table 6.89:Received power (in dBm) at each point of the outer points in class 15 at 2.4 GHz

Point	1	2	3	4
1	-30.7241	-30.0032	-28.8696	-29.6619
2	-27.6316	-33.195	-29.7486	-32.3831

Table 6.90: Class Fifteen values at 2.4 GHz

	Outside (dBm)	Inside (dBm)	Total (dB)
Average Power	-30.2771	-61.6907	31.4136
10th percentile	-31.125	-64.125	33.0009
50th Percentile	-29.8759	-61.3141	31.4382
Standard deviation ()	1.807197	1.235889	1.807197

6.2 Indoor Results

As we early mentioned in the beginning of this chapter, Class 5 has been chosen for making Indoor Propagation analysis, the building where the class is located consists of a garage that's $6*4 \text{ m}^2$, the outer wall of the garage is the outer wall of class 5 which consists of 5cm stone, 22cm concrete and 2cm interior plaster. Adjacent to the garage there's an office that's $8*5 \text{ m}^2$, followed by a bathroom which occupies an area of $2*5 \text{ m}^2$. In this premises we have two internal walls: the 1st internal wall separates the garage from the office and consists of 10cm concrete. The 2nd internal wall consists of 10 cm bricks and it separates the office from the bathroom. 21 indoor Points were chosen across the building, denoted as P1, P2, to P21. The following AutoCAD figure provides the plan of the building where indoor measurements were taken.

Autocad

The following two tables represent the received Power at each point of the 21 indoor points for both frequencies 900 MHz and 2.4 GHz. The analysis of these results and the final conclusion are both available in the next chapter; Chapter7.

Table 6.91: Received power at indoor points at 900 MHz

Point	Received Power(in dBm)	Distance from the cell (in meters)
1	-48.169621	481.23
2	-36.315598	480.59
3	-39.732469	479.95
4	-36.038263	479.31
5	-41.382138	482.25
6	-48.941871	481.6
7	-48.322558	480.96
8	-44.103734	480.33
9	-45.47318	483.77
10	-48.526474	482.81
11	-45.852466	481.85
12	-56.964838	484.08
13	-53.987191	483.13
14	-56.030654	486.77
15	-51.64297	485.37
16	-47.252338	489.08
17	-54.709195	487.51
18	-57.907986	492.22
19	-62.432716	490.66
20	-68.222042	492.38
21	-68.556418	490.81

Table 6.92: Received power at indoor points at 2.4 GHz

Point	Received Power(in dBm)	Distance from the cell (in meters)
1	-56.448	17.7
2	-54.239	17.4
3	-53.096	17.3
4	-54.906	17.33
5	-55.871	18.86
6	-55.558	18.61
7	-60.032	18.5
8	-58.095	18.52
9	-53.199	20.6
10	-50.824	20.33
11	-57.743	20.32
12	-71.869	20.97
13	-68.436	20.71
14	-71.259	24.08
15	-68.352	23.89
16	-74.19	26.78
17	-66.803	26.57
18	-72.189	30.44
19	-75.719	30.26
20	-82.263	30.62
21	-83.2206	30.45

Chapter 7

Analysis and discussion

7.1 Introduction

In this chapter results are carried forward to the analytical stage, the chapter will clarify the behavior of the signal according to the values represented in Ch6. Comparison and degree of correlation between the two frequency bands are also represented.

7.2 Penetration loss

From the results it's clear that the penetration loss of the outer walls is much higher at 2.4GHz frequency band compared to the 900 GSM. The difference ranges from 3.5 dB in class fourteen to a 16.5 dB in class two. The following figure compares between both frequencies 900 MHz and 2.4 GHz:

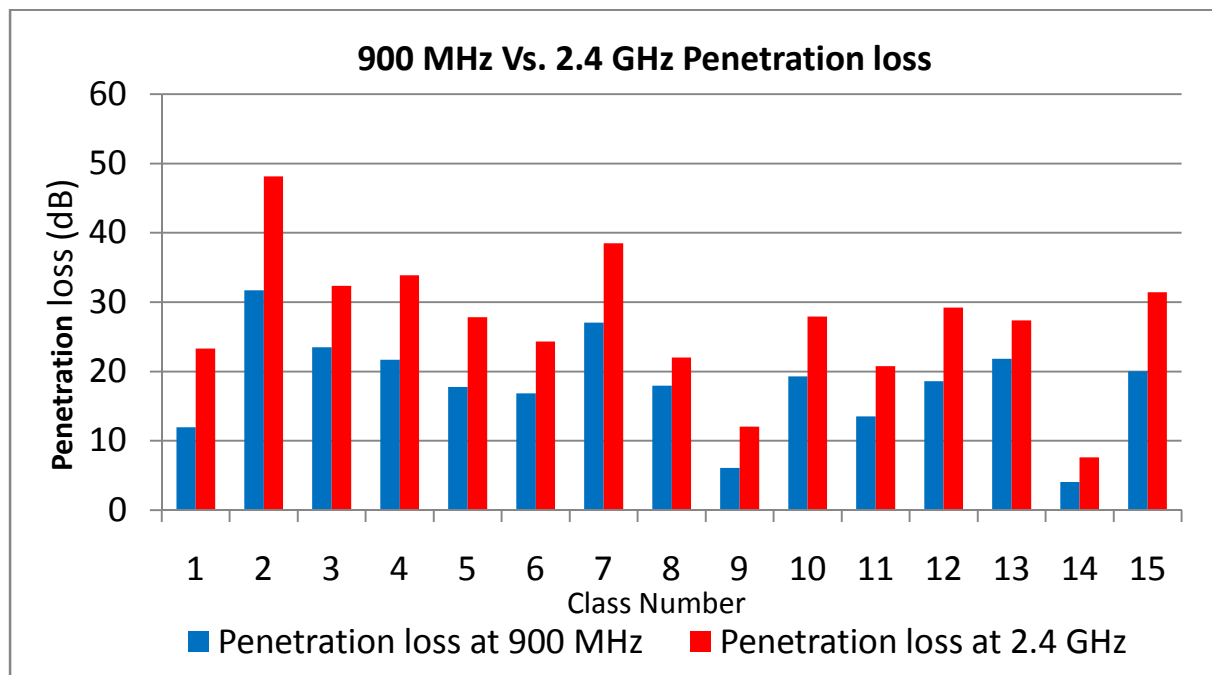


Figure 7.1: 900 MHz and 2.4 GHz Penetration loss comparison

From the Figure we have the following results:

Class 7 consists of 12cm stone followed by 28 cm concrete that produced 27 dB penetration loss at 900 MHz and 38 dB Penetration loss at 2.4 GHz, class 2 which has similar structure but larger thickness that consists of 30cm stone and 37cm concrete created 32 dB of penetration loss at 900 MHz and 48 dB penetration loss at 2.4 GHz.

Class 5 has similar structure to class 12, they have 20 cm of reinforced concrete, class 12 however has 5 cm more stone thickness than class 5 which's given it a further penetration loss of 1db at 900 MHz and 1.2 dB at 2.4 GHz

Class 4 and class 8 are in same location, they share similar structures but for class 4 the penetration loss is higher than that of class 8 at both frequencies, the excess loss in class 4 is due to the outer wall pattern (Tobzah) which results in more reflections of the incident signal.

The same is applied to class 10 which has similar structures to class 4 and 8 have intermediate penetration loss value between class 4 and class 8.

We pointed out earlier in this project that two of the fifteen walls covered in this project are internal walls; Class 9 and class 14 and both of them located in Building C at Palestinian Polytechnic University. Class 14 has 4dB penetration loss at 900 MHz and 7 dB loss at 2.4 GHz. While class 3 which consists of a 10 cm block scored 6dB penetration loss at 900 MHz and 12 dB Penetration losses at 2.4 GHz.

The following two figures compare between the average Penetration loss and the 10th percentile loss at 900 MHz and 2.4 GHz

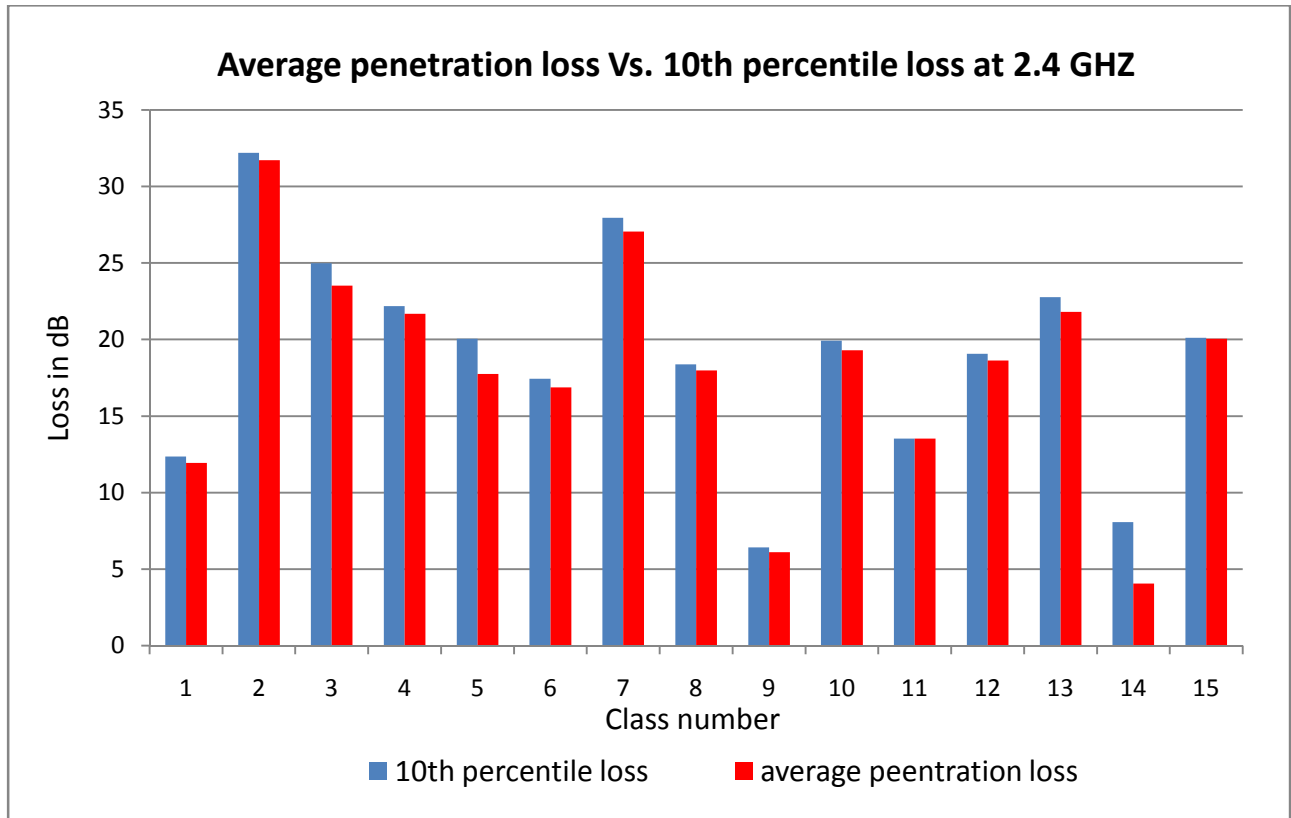


Figure 7.2: Average penetration loss vs. 10th percentile at 900 MHz

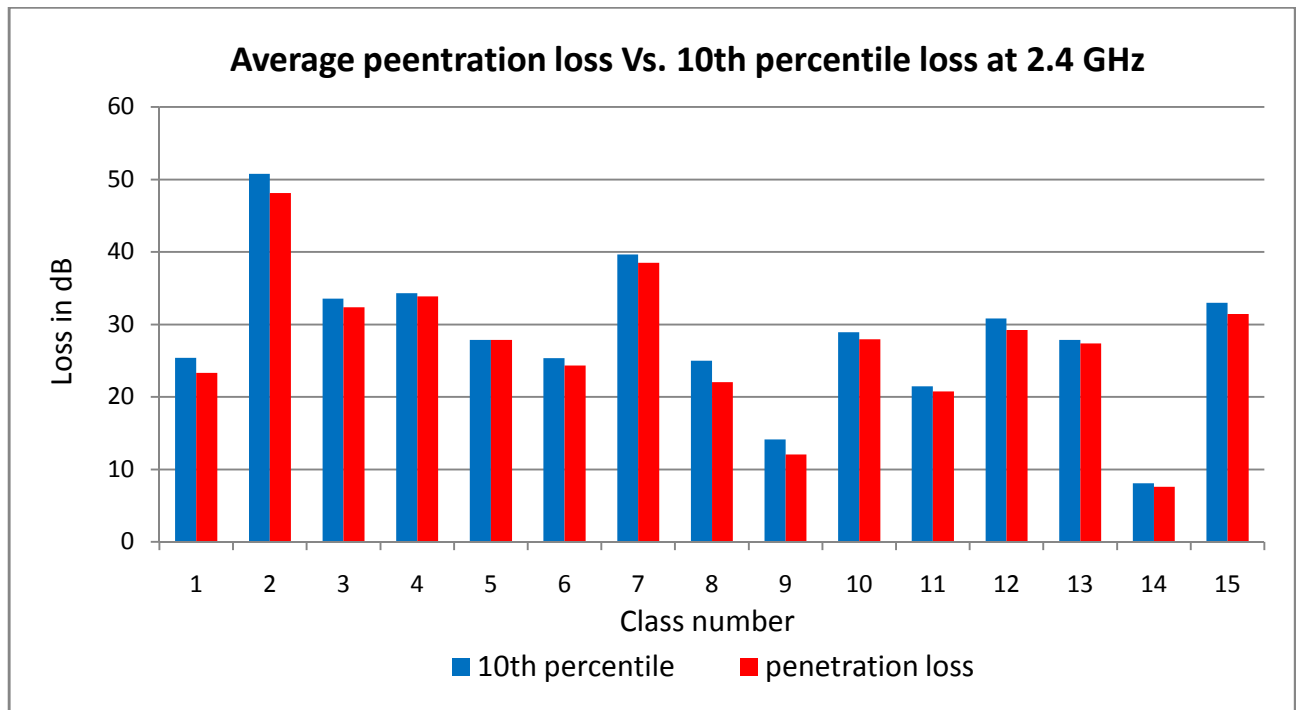


Figure 7.3: Average penetration loss vs. 10th percentile at 2.4 GHz

From the two figures we noticed that for the majority of the classes the 10th percentile was greater than the average penetration loss at both frequencies. The difference between the 10th percentile and the average penetration loss if considered in the link budget will for sure guarantee 50-90 % coverage.

7.3 In building penetration loss scenario

We tend here to predict the signal strength inside the building, taking into consideration the external walls and the internal walls as well. As mentioned in Ch6. class five has been chosen to study indoor propagation, to demonstrate the basic difference in wave propagation of 900 MHz and 2.4 GHz waves, a quick look at path loss is provided. As waves propagate out from the transmitter, some attenuation of the signal takes place due to properties of the medium (air in most cases). Path loss describes this attenuation as a function of the wavelength of the operating frequency and the distance between the transmitter and receiver, keep in mind that Path loss analysis does not account for effects such as differing TX power outputs and RX sensitivities.

We will depend on the ITU attenuation formula in our analysis; this formula relates the Path loss to the range and frequency.

$$L = 20 \log f + 10n \log d + P_f n - 28 \quad (7.1)$$

Where:

L = the total path loss. Unit: decibel (dB).

Remember: $L = P_t \text{ (dBm)} - P_r \text{ (dBm)}$.

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

d = Distance. Unit: metre (m).

n = Number of floors between the transmitter and receiver.

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

$P_f(n)$ wasn't considered in the measurements and analysis, the location where the measurements were carried out consists of a basement only, So $P_f(n) = 0$. Thus:

$$L = 20 \log f + 10n \log d - 28 \quad (7.2)$$

The Transmitted Power, the frequency of operation for both frequency regimes are shown in the following table:

Table 7.1: Power and frequency used for both 900 MHz and 2.4 GHz Indoor measurements

	900 MHz Band	2.4 GHz Band
Frequency of operation	957.6 MHz	2447 MHz (Ch8)
Transmitted Power	43 dBm	30 dBm

To calculate the modeled path loss exponent (n) the error function analysis must be used as follow:

- Calculate the Path loss exponent (**L**) at each Point of the 21 Points by using the following formula :

$$L \text{ dB} = P_t \text{ dBm} - P_r \text{ dBm} \quad (7.3)$$

Where:

P_t is the transmitted Power in dBm (43 dBm at 900 MHz and 30 dBm at 2.4 GHz).

P_r is the received Power at each point of the 21 points.

- Find $Z=(20\log f)$, $Z= 59.62368$ dB at 900 MHz and 67.772679 dB at 2.4 GHz
- Find $Y=10*\log (d)$ at each Point of the 21 Points.

The path loss exponent then equals: $n = \sum \frac{X*Y}{Y^2}$

Where $X=L-Z+28$.

The following table shows the implementation of these calculations at 900MHz:

Table 7.2: Calculating path loss exponent (n) by using Error function analysis at 900MHz

Point	d*	Pt (dBm)	Pr (dbm)	Y	L	F=957.6	X	Y^2	X*Y
				10log(d)	L=Pt-Pr	z=20log(f)	x=L-z+28		
1	481.23	43	-48.1696	26.824	91.16962	59.6236827	59.545939	719.527	1597.26
2	480.59	43	-36.3156	26.82	79.3156	59.6236827	47.691915	719.3124	1279.097
3	479.95	43	-39.7325	26.81	82.73247	59.6236827	51.108787	718.7761	1370.227
4	479.31	43	-36.0383	26.8	79.03826	59.6236827	47.41458	718.24	1270.711
5	482.25	43	-41.3821	26.83	84.38214	59.6236827	52.758456	719.8489	1415.509
6	481.6	43	-48.9419	26.82	91.94187	59.6236827	60.318189	719.3124	1617.734
7	480.96	43	-48.3226	26.82	91.32256	59.6236827	59.698875	719.3124	1601.124
8	480.33	43	-44.1037	26.815	87.10373	59.6236827	55.480051	719.0442	1487.698
9	483.77	43	-45.4732	26.846	88.47318	59.6236827	56.849497	720.7077	1526.182
10	482.81	43	-48.5265	26.837	91.52647	59.6236827	59.902791	720.2246	1607.611
11	481.85	43	-45.8525	26.829	88.85247	59.6236827	57.228783	719.7952	1535.391
12	484.08	43	-56.9648	26.849	99.96484	59.6236827	68.341156	720.8688	1834.892
13	483.13	43	-53.9872	26.84	96.98719	59.6236827	65.363508	720.3856	1754.357
14	486.77	43	-56.0307	26.873	99.03065	59.6236827	67.406971	722.1581	1811.428
15	485.37	43	-51.643	26.86	94.64297	59.6236827	63.019287	721.4596	1692.698
16	489.08	43	-47.2523	26.893	90.25234	59.6236827	58.628655	723.2334	1576.7
17	487.51	43	-54.7092	26.879	97.70919	59.6236827	66.085512	722.4806	1776.312
18	492.22	43	-57.908	26.922	100.908	59.6236827	69.284303	724.7941	1865.272
19	490.66	43	-62.4327	26.907	105.4327	59.6236827	73.809033	723.9866	1985.98
20	492.38	43	-68.222	26.923	111.222	59.6236827	79.598359	724.8479	2143.027
21	490.81	43	-68.5564	26.909	111.5564	59.6236827	79.932735	724.0943	2150.91

$$n = \frac{X*Y}{Y^2} = 34900.12/15142.41=2.3047.$$

To calculate the measured Path lossexponent (n) we will plot Pr. Vs. 10 log (d_{red}), whered_{red} represents the minimum distance at which the measured n becomes very close to n calculated by using error functionwhich is equal to 2.3047),hence we will reducethe original distance d* untilthe slope of the line gets closer to n=2.3047. This is shown in the following table.

Table 7.3: Calculating d_{red} at which n measured will be equal to that calculated by error function analysis

				$d_0=2.88\text{ m}$		
Point	d^*	Pt (dBm)	$10\log(d^*)$	$d_{red}=d^*-478.35$	$10\log(d_{red})$	Pr (dbm)
1	481.23	43	26.82353	2.88	4.593924878	-48.169621
2	480.59	43	26.81775	2.24	3.502480183	-36.315598
3	479.95	43	26.81196	1.6	2.041199827	-39.732469
4	479.31	43	26.80616	0.96	-0.17728767	-36.038263
5	482.25	43	26.83272	3.9	5.91064607	-41.382138
6	481.6	43	26.82686	3.25	5.11883361	-48.941871
7	480.96	43	26.82109	2.61	4.166405073	-48.322558
8	480.33	43	26.8154	1.98	2.966651903	-44.103734
9	483.77	43	26.84639	5.42	7.339992865	-45.47318
10	482.81	43	26.83776	4.46	6.493348587	-48.526474
11	481.85	43	26.82912	3.5	5.440680444	-45.852466
12	484.08	43	26.84917	5.73	7.58154622	-56.964838
13	483.13	43	26.84064	4.78	6.794278966	-53.987191
14	486.77	43	26.87324	8.42	9.253120915	-56.030654
15	485.37	43	26.86073	7.02	8.463371121	-51.64297
16	489.08	43	26.8938	10.73	10.30599722	-47.252338
17	487.51	43	26.87984	9.16	9.618954737	-54.709195
18	492.22	43	26.92159	13.87	11.42076461	-57.907986
19	490.66	43	26.90781	12.31	10.90258053	-62.432716
20	492.38	43	26.923	14.03	11.47057671	-68.222042
21	490.81	43	26.90913	12.46	10.95518042	-68.556418

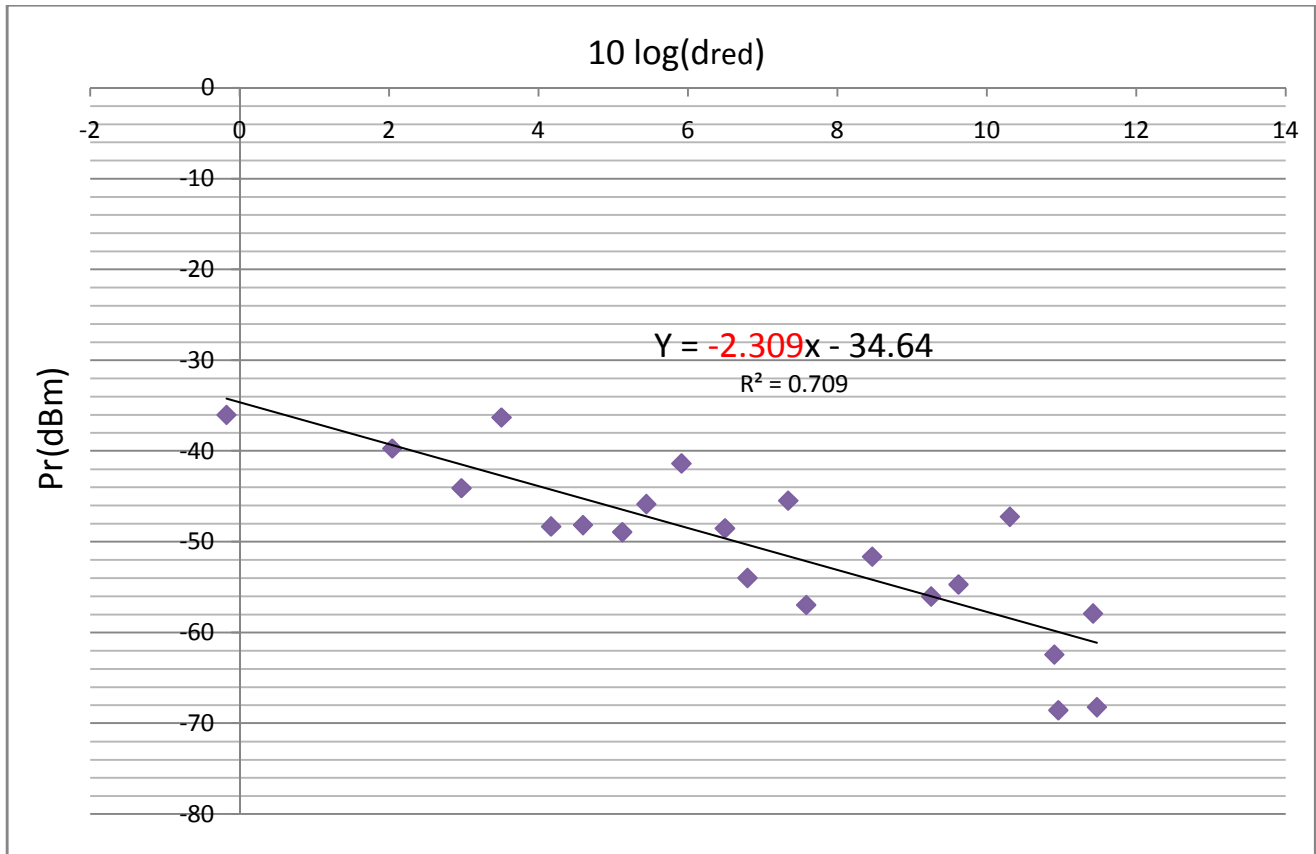


Figure 7.4: Plot of the received Power in dBm (Pr) vs. $10\log(d_{red})$ at 900 MHz

The equation of the line as shown is

$$Y = -2.309x - 34.64 \quad (7.4)$$

The slope of this line represents the measured value of the path loss exponent $n=2.309$.

The y-intercept of the line $B=-34.64$, However this y-intercept represents the value:

$$B = P_t - 20\log(f) + 28, \text{ From which:}$$

$$P_t = B + 20\log(f) - 28$$

$= -34.64 + 59.63 - 28 = -3.01$ dBm. So this is equivalent to having a transmitter at a distance of $d_0=2.88$ from the outer wall transmitting at a power of **-3.01 dBm**.

Applying the same procedure to the 2.4GHz results:

Table 7.4: Calculating path loss exponent (n) by using Error function analysis at 2.4 GHz

				Y	L	F=2447 MHz	X		
Point	d*	Pt(dbm)	(Pr)	10log(d*)	L=Pt-Pr	z=20log(f)	x=L-z+28	Y^2	X*Y
1	17.7	30	-56.448	12.47973	86.4484	67.77267939	46.67572	155.7437	582.5005
2	17.4	30	-54.239	12.40549	84.2394	67.77267939	44.46672	153.8962	551.6316
3	17.3	30	-53.096	12.38046	83.0955	67.77267939	43.32282	153.2758	536.3565
4	17.33	30	-54.906	12.38799	84.9061	67.77267939	45.13342	153.4622	559.1122
5	18.86	30	-55.871	12.75542	85.8713	67.77267939	46.09862	162.7007	588.0071
6	18.61	30	-55.558	12.69746	85.5579	67.77267939	45.78522	161.2256	581.3562
7	18.5	30	-60.032	12.67172	90.0323	67.77267939	50.25962	160.5724	636.8757
8	18.52	30	-58.095	12.67641	88.0947	67.77267939	48.32202	160.6914	612.5497
9	20.6	30	-53.199	13.13867	83.1988	67.77267939	43.42612	172.6247	570.5616
10	20.33	30	-50.824	13.08137	80.8237	67.77267939	41.05102	171.1223	537.0037
11	20.32	30	-57.743	13.07924	87.7428	67.77267939	47.97012	171.0664	627.4126
12	20.97	30	-71.869	13.21598	101.8685	67.77267939	62.09582	174.6622	820.6574
13	20.71	30	-68.436	13.1618	98.436	67.77267939	58.66332	173.233	772.115
14	24.08	30	-71.259	13.81656	101.259	67.77267939	61.48632	190.8975	849.5297
15	23.89	30	-68.352	13.78216	98.3515	67.77267939	58.57882	189.948	807.3428
16	26.78	30	-74.19	14.27811	104.1895	67.77267939	64.41682	203.8643	919.7502
17	26.57	30	-66.803	14.24392	96.80282	67.77267939	57.03014	202.8891	812.3325
18	30.44	30	-72.189	14.83445	102.1895	67.77267939	62.41679	220.0608	925.9185
19	30.26	30	-75.719	14.80869	105.7186	67.77267939	65.94592	219.2973	976.5726
20	30.62	30	-82.263	14.86005	112.2632	67.77267939	72.49048	220.8211	1077.212
21	30.45	30	-83.2206	14.83587	113.2206	67.77267939	73.44791	220.1031	1089.664

$$n = \frac{X*Y}{Y^2} = 15434.46/3792.158=4.0701$$

Table 7.5: Calculating d_{red} at which (n) measured will be equal to that calculated by error function analysis at 2.4GHz

Point	d*	10log(d)	d0=4.9m		
			dred=d*-12.8	10log(d)	(Pr)
1	17.7	12.4797	4.9	6.9019608	-56.448
2	17.4	12.4055	4.6	6.627578317	-54.239
3	17.3	12.3805	4.5	6.532125138	-53.096
4	17.33	12.388	4.53	6.56098202	-54.906
5	18.86	12.7554	6.06	7.824726242	-55.871
6	18.61	12.6975	5.81	7.641761324	-55.558
7	18.5	12.6717	5.7	7.558748557	-60.032
8	18.52	12.6764	5.72	7.573960288	-58.095
9	20.6	13.1387	7.8	8.920946027	-53.199
10	20.33	13.0814	7.53	8.767949762	-50.824
11	20.32	13.0792	7.52	8.762178406	-57.743
12	20.97	13.216	8.17	9.122220565	-71.869
13	20.71	13.1618	7.91	8.981764835	-68.436
14	24.08	13.8166	11.28	10.523091	-71.259
15	23.89	13.7822	11.09	10.44931546	-68.352
16	26.78	14.2781	13.98	11.45507171	-74.19
17	26.57	14.2439	13.77	11.3893394	-66.803
18	30.44	14.8344	17.64	12.46498581	-72.189
19	30.26	14.8087	17.46	12.42044239	-75.719
20	30.62	14.8601	17.82	12.509077	-82.263
21	30.45	14.8359	17.65	12.4674471	-83.2206

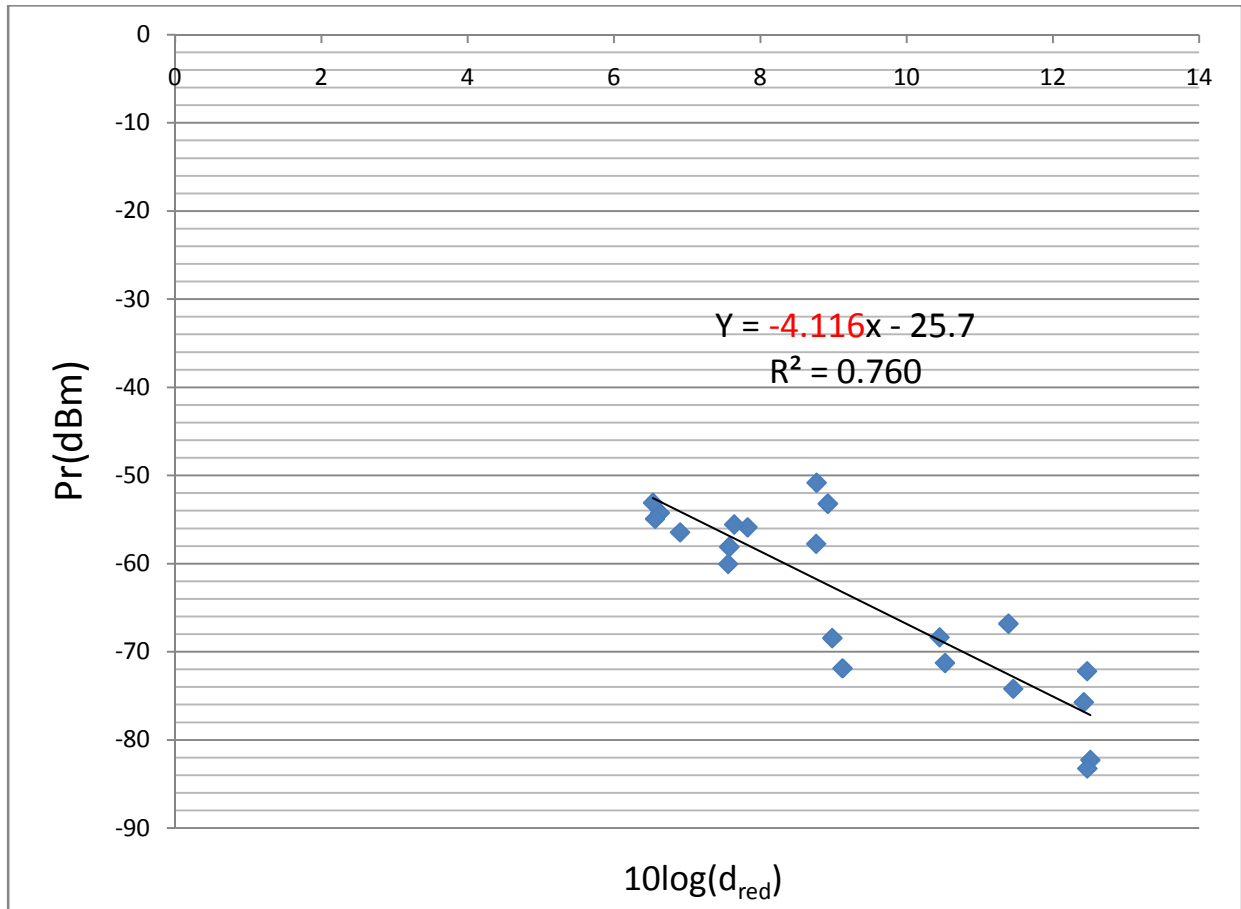


Figure 7.5: Plot of the received Power in dBm (Pr) vs. $10\log(d_{red})$ at 2.4GHz

The equation of the line as shown is

$$Y = -4.116x - 25.7 \quad (7.5)$$

The slope of this line represents the measured value of the path loss exponent $n=4.116$.

The y-intercept of the line $B=-25.7$, However this y-intercept represents the value:

$$B = P_t - 20\log(f) + 28, \text{ From which:}$$

$$P_t = B + 20\log(f) - 28$$

$= -25.7 + 67.77 - 28 = 14.07 \text{ dBm}$. So this is equivalent to having a transmitter at a distance of $d_0=4.9\text{m}$ from the outer wall transmitting at a power of **14.07 dBm**

Additional comparison between the 900MHz and 2.4GHz frequency bands is shown in the following figures:

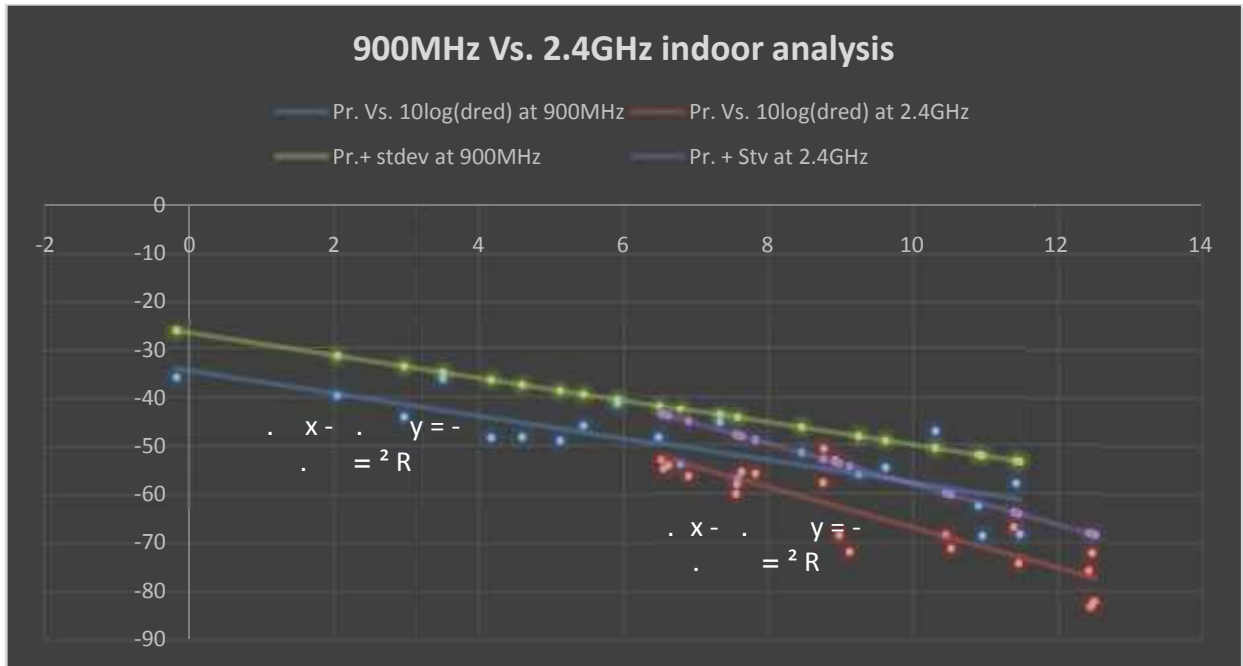


Figure 7.6:900MHz Vs. 2.4GHz indoor analysis

The total number of samples for each class at both frequencies is shown in the figure below :

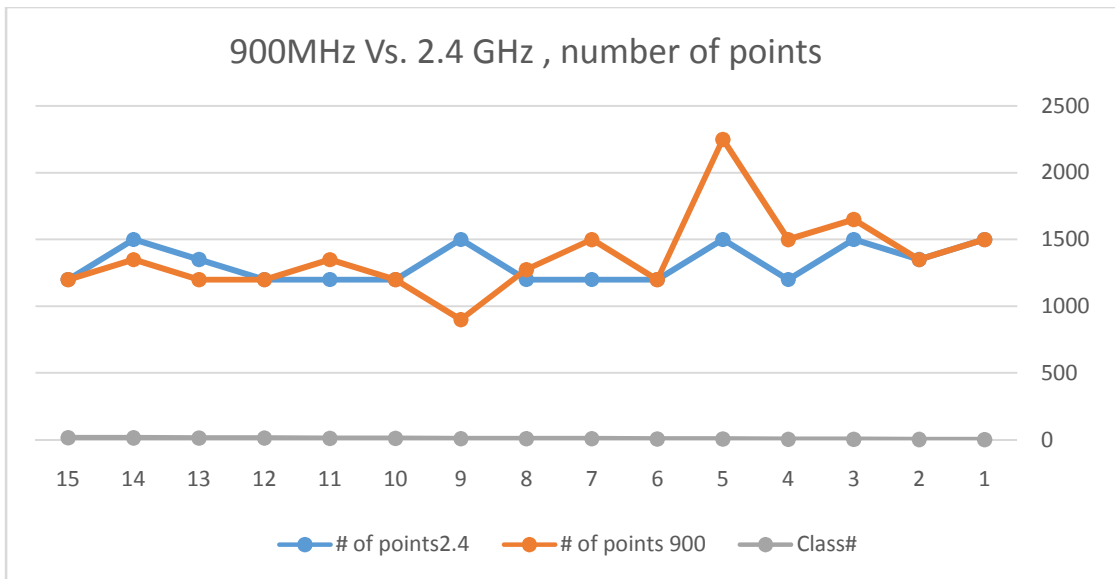


Figure 7.7: Total number of samples at both frequencies

The following two figures compare between the standard deviation at both sides of each class for the 900MHz and 2.4GHz

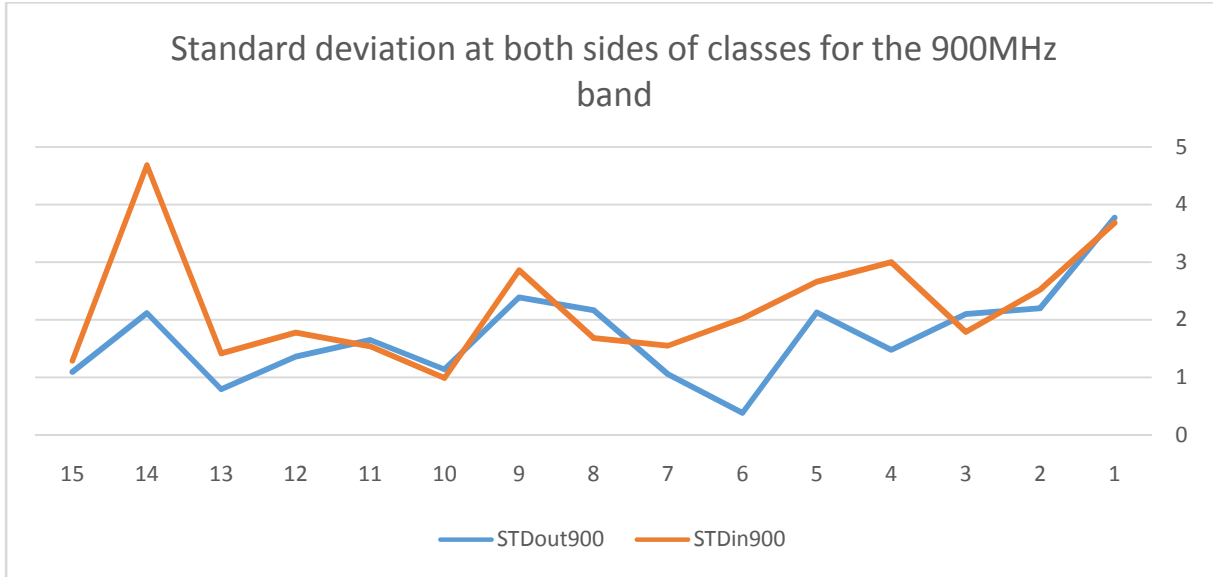


Figure 7.8: Standard deviation at both sides of each wall for the 900MHz band

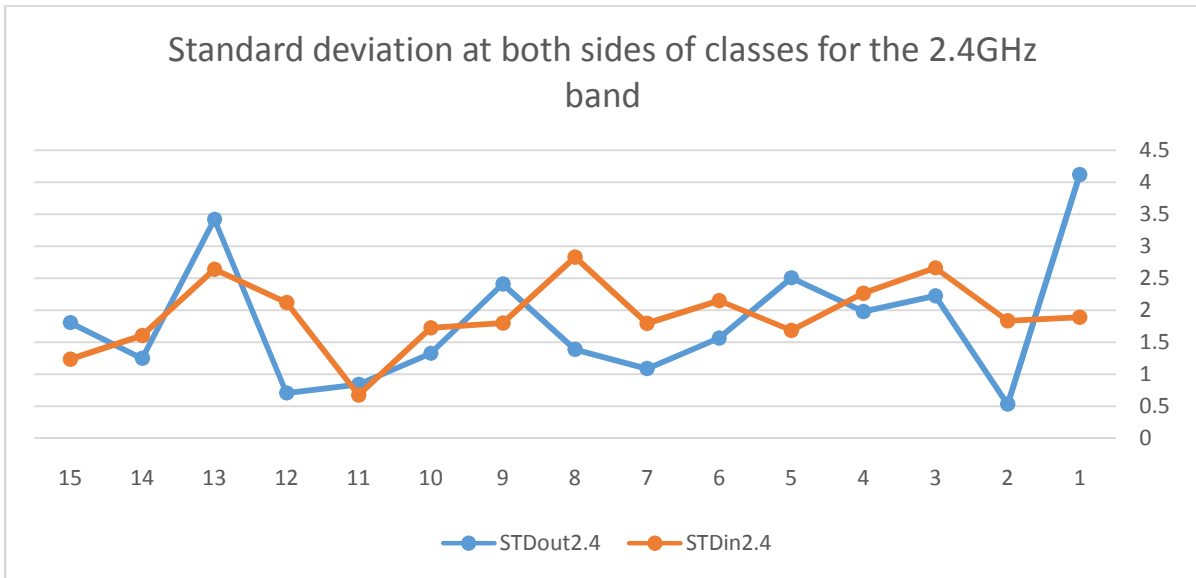


Figure 7.9: Standard deviation at both sides of each wall for the 2.4GHz band

Appendix 1

Equipment and software

The features of Equipment we will use in our Project are listed below:

📊 Spectrum analyzer (AaroniaSpectran HF60105 V4)



Figure 1: Spectrum analyzer HF60105

The HF-60105 V4 is a high-frequency RF spectrum analyzer that provides simplified measurement of RF signals for Interference and exposure applications. It's used many applications like finding the radiation sources in the surroundings. The respective frequencies and signal strengths, including direct display of exposure limits. The highly complex calculations required for exposure limit calculations are performed automatically by a high-performance DSP (digital signal processor). Exposure levels for various standards are displayed as a practical bar graph display (including convergence display in percent) while the measurement is running.

HF 60105 V4 Features:

- Frequency range: 1MHz to 9.4GHz
- Input connector: SMA(f) 50 ohms
- Display: dBm, V/m, A/m, dBiV, W/m²
- Exposure limits with percentage display
- RBW: 200Hz to 50MHz
- Maximum Level: +40dBm with external attenuator
- Option 020 internal 15dB RF preamplifier
- Extended full ICNIRP range (with external attenuator)
- Internal data logger
- Time-slot analyzer
- Internal speaker and audio output (internal AM/FM demodulation)
- Configurable antenna and cable calibration data

Bullet M2HP wireless radio transmitter

Bullet M is the latest version of the popular Ubiquiti Bullet. Bullet M is a wireless radio with an integrated Type N RF connector that can be directly plugged in to any the sector Antenna to create a powerful and robust outdoor Access Point, Client, or Bridge. The Bullet M features a signal strength LED meter for antenna alignment, a low-loss integrated N-type RF connector, and a robust weatherproof design. With up to 600mW of power and enhanced receiver design, the Bullet M is ideal for long-distance links, capable of 100Mbps+ real TCP/IP speeds over multi-km distances.



Figure 2: The bullet 2.4 transmitter

Features:

- Zero-Variable Wireless Infrastructure Deployment.
- No radio card / host board issues
- No RF cable quality concerns
- No mechanical stability concerns
- No enclosure mounting requirements
- Just Plug and Go.
- Processor Specs: Atheros MIPS 4 KC, 180MHz
- Memory Information: 16MB SDRAM, 4MB Flash
- Networking Interface: 1 X 10/100 BASE-TX (Cat. 5, RJ-45)
- Ethernet Interface Approvals: FCC Part 15.247, IC RS210, CE
- RoHS Compliance: YES
- RF Connector: Integrated N-type Male Jack (connects directly to antenna)
Power Method: Passive Power over Ethernet (pairs 4,5+; 7,8 return) 10vdc to 24vdc

The ASA-2416 Sector Antenna

The ASA-2416 is designed for the 2.4GHz ISM band, supporting 2.4 to 2.5 GHz and provides superb performance in IEEE 802.11b/g/n WiFi and Bluetooth applications. ASA-2416 includes mounting bracket and hardware for up to 2" OD masts. Made with fiberglass.

Application:

- 2.4 - 2.5 GHz ISM Band
- IEEE 802.11b, 802.11g, 802.11n Wireless LAN
- Directional and multipoint applications
- Bluetooth
- Public Wireless Hotspot
- WiFi, RFID
- Wireless Video Systems
-

Specification:

- Model : ASA-2416
- Frequency: 2.4-2.5GHz
- VSWR : 1.5
- Gain: 13-16dBi
- Polarization: Vertical
- Power Handling: 50 Watts
- Impedance : 50
- Beamwidth H: 45-120° / V: 7-12°
- Connector : N-Female

- Operating Temp. : -40 ~ +80
- Dimension (mm*mm) : 500*110
- Mounting : 32 ~ 45 mm
- Weight : 2030g

Vistumbler©

Vistumbler is an excellent, free tool for finding nearby wireless access points, and giving you a great deal of information about each. It's much like the popular NetStumbler program, except appears to work with a wider variety of hardware. It gives you a comprehensive report, including the name, signal strength, kind of encryption, Mac Address, channel the network is using, manufacturer, and more. It will also graph the traffic for each network as well. The software allows you also to record logfiles of signal strength for any access point available in the area which might be valuable for further processing and evaluation.

Vistumbler is available free of charge on the company's online website, however if you want to use the most sophisticated features of the program, you'll need a GPS attachment for your laptop and thus you need to pay for any extra features. Screenshots of the software and the methodology to use it are available in Ch5.

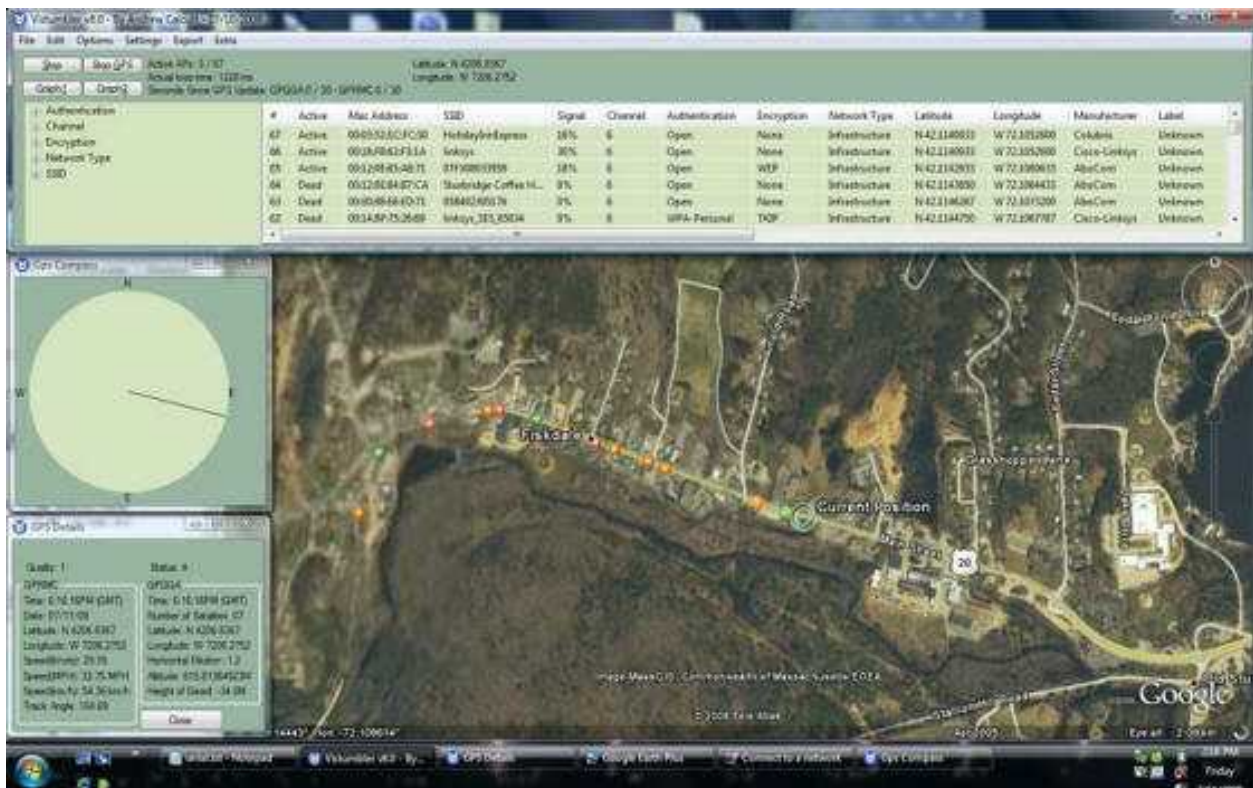


Figure 3: Vistumbler FrontPage with GPS activated

Encoding Errors

Due to the limitations of the supported zip file format, the following file(s) had to be renamed.

Original File Name	->	New File Name
اهداء.docx	->	File1.docx

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