COMPARISONS OF COMPUTER-BASED PROPAGATION MODELS WITH EXPERIMENTAL DATA COLLECTED IN AN URBAN AREA AT 1800 MHz

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Approval of the Graduate School of Natural and Applied Sciences, Atılım University.

____

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I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

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ABSTRACT

COMPARISONS OF COMPUTER-BASED PROPAGATION MODELS

WITH EXPERIMENTAL DATA COLLECTED

IN AN URBAN AREA AT 1800 MHz

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M.S., Electrical & Electronics Engineering Department
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Nowadays a lot of models are set for the efficient and economic usage of frequency band which is a limited source. In this thesis, propagation models, developed and accepted in literature for this purpose, were studied. These are Free Space Path Loss (Fspl) + RMD (Epstein-Peterson), COST-HATA and COST-WI models. The district chosen for the model application has an irregular structure style. In the application of Free Space Path Loss (Fspl) + RMD (Epstein-Peterson), RTV Plan software is used; the other models were applied by calculations. In order to compare the success of the models, electric field strength measurements were taken in the chosen district (Mustafa Kemal Mahallesi-ANKARA), firstly at the random coordinate and secondly coordinates tracking on a single line. As a conclusion, measured values were compared with the results which were taken from the mentioned models with graphical presentations and the most appropriate model is tried be found and as another aim of the thesis study, a correction factor was generated as a modification for COST – HATA propagation model.

ÖZ

KENTSEL BİR ALANDA 1800 MHz'de BİLGİSAYAR TABANLI YAYILIM MODELLERİNİN TOPLANAN DENEYSEL VERİLERLE KARŞILAŞTIRILMASI

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Frekansın kıt kaynak olduğu günümüzde frekans bandının verimli ve ekonomik kullanımı için birçok model oluşturulmuştur. Bu tez çalışmasında, bu amaç için geliştirilmiş ve bilimsel kaynaklarda kabul gören yayılım modellerinin uygulanması konusunda çalışılmıştır. Bu modeller Serbest Uzay Yol Kaybı (Fspl) + RMD (Epstein-Peterson), COST - HATA ve COST - WI modelleridir. Modellerin uygulanması için seçilen bölge ise düzensiz şehir yapısına sahip bir bölgedir. Modeller uygulanırken Serbest Uzay Yol Kaybı (Fspl) + RMD (Epstein-Peterson) modeli için RTV Plan yazılımı kullanılmış, diğer modellerin ise hesaplamaları tek tek yapılmıştır. Modellerin başarısının karşılaştırılması için seçilen bölgede değişik koordinatlarda elektrik alan şiddeti ölçümleri alınmıştır. İlk olarak karışık koordinatlardan, ikinci olarak tek bir doğrultu takip edilerek ölçüm verileri toplanmıştır. Sonuç aşamasında ise; bahsi geçen yayılım modelleri kullanılarak alınan sonuçlar ile ölçüm sonuçları grafiksel karşılaştırmalar yapılarak kıyaslanmış ve seçilen bölge için en doğru model belirlenmeye çalışılmıştır. Bunun yanı sıra, COST – HATA yayılım modelini geliştirmek için bir düzeltme faktörü belirlemek bu tez çalışmasının diğer bir amacını oluşturmuştur.

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LIST OF ABBREVIATIONS

COST -	European Cooperation in Science and Technology
BSC -	Base Station Center
BSS -	Base Station System
BTS -	Base Transceiver Stations
E.I.R.P -	Effective Isotropically Radiated Power
E.R.P -	Effective Radiated Power
GSM -	Global System for Mobile Communications
ICTA -	Information and Communications Technologies Authority
LOS -	Line of Sight
MSE	Mean Square Error
NLOS -	Non-Line of Sight
RF -	Radio Frequency
RMD -	Reflection Multipath Diffraction
SUI -	Stanford University Interim
TCU -	Transcoding Unit
TV -	Television
UHF -	Ultra High Frequency
VHF -	Very High Frequency
WI -	Walfisch Ikegami

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CHAPTER ONE

1. INTRODUCTION

Communication has always been the social need of mankind and many revolutions have been carried on to communicate. Communication on voice transfer first started with long wave radio transmission. Radio and television broadcasting use electromagnetic waves. Wireless communications technology has become very popular in the context of mobile cellular telephone system. This technology supports your freedom of movement while keeping people in touch with others. But all electromagnetic ways of communication, get influenced by the geographical position and physical structures of the earth's boundaries. The effect of environment as being rural, suburban, urban, forest region or highlands has effect on electromagnetic waves.

For different communication facilities, radio spectrum is divided into different bands, which is in the form of ground wave and sky wave for the radio propagation mechanisms of these bands. Continental communication is possible with the reflections from the ionosphere.

Communication with the transmitter and receiver antenna is related to the strength of the signal at the receiver. Radio wave propagation studies give data about suitable frequencies for optimum transmission, taking into consider the absorption mechanisms and the signal power or field strength. By this way, frequency planning can be done by simulation of propagation for many transmitters.

A limited source, Frequency Spectrum, has become scarcer by the wireless communication technology developments. Re-usage of the same frequency is a crucial subject, which means using the same frequencies as long as they do not interfere with each other. So, simulation studies of the transmitters are needed to plan the reuse of the frequencies.

Most of the cellular communication takes place in urban areas that planning and propagation simulation should be studied to design an efficient cellular network. In urban districts propagation mechanism takes its bases from the reflection and diffraction from buildings.

In this thesis, three propagation simulation models were studied and compared with the measurement values in urban environment. The three propagation models were COST - Hata, COST - Walfisch-Ikegami and Free Space Path Loss + RMD (Epstein-Peterson) [1, 2]. COST 231 Hata is the reproduced version of Hata-Okumura Model, which is one of the most general models used for signal prediction, working in the frequency band of 1500–2000 MHz. Four parameters are used for estimation of the model; frequency, distance, base station antenna height and the height of the mobile antenna and the model contains corrections for urban, suburban and rural (flat) environments [3, 4]. COST - Walfisch-Ikegami is based on measurement data and loss formulas like other models. The model considers more data to describe the character of the urban environment like height of buildings, width of roads, building separation and road orientation with respect to the direct radio path for line-of-sight and non-line-of-sight, but does not consider topographical data base [4]. Free space path loss (Fspl) which is the ratio of transmitted and received power ratio, estimates that there is no reflecting or scattering object between transmitter and receiver [5]. In this study Fspl and reflection multipath diffraction which is called RMD were used together and simply it is called Fspl + RMD method. Epstein-Peterson propagation model was chosen as RMD method. This method takes geographical structures into consideration by this way, it calculates the path losses due to reflections and diffractions on the terrain.

Results of calculations and simulations can be used basically to find field strength values by studying on path losses. This thesis puts forward the most useful model in the chosen district, comparing the results of measured values with calculation and simulation results.

CHAPTER TWO

2. BACKGROUND INFORMATION AND LITERATURE SEARCH

2.1 Background Information

2.1.1 Electric, Magnetic and Electromagnetic Field

There are two time domain fields generated on electromagnetic plane. Each has different properties according to their propagations. These are electric and magnetic fields [5].

2.1.1.1 Electric and Magnetic Fields

Electric and magnetic fields are forces surrounding all devices which are working with electric. The strength of electric field's unit is volts per meter (V/m), magnetic fields unit which is caused by electric current is amperes per meter (A/m). Electric field depends on the charges in the field; magnetic field depends on the movement of these charges. Electric and magnetic fields are vectorial quantities which have both strength and direction [6]. Even if there is no current on wire, electric field appears [7].

2.1.1.2 Electromagnetic Field and Electromagnetic Wave

The current which is generated by the motion of both positive and negative charges is the main source of magnetic field. An electromagnetic field is produced, when the velocity of a charged particle changes. So, electric and magnetic fields accompany to each other [7]. The cross product of electrical and magnetic fields gives a vector in the direction of propagation which is shown in Figure (2.1) [5].

Electric and magnetic planes are perpendicular to each other in far field. Far field means that; the distance more than $2D^2/\lambda$ where D equals antenna's maximum height and λ equals c/f (c: speed of light, f: frequency). Waves which occur during the movement of each plane are called electromagnetic wave. Electromagnetic waves occurring direction is the movement way of plane.

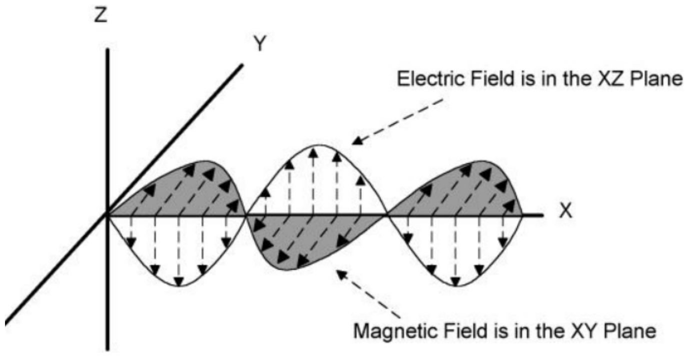


Figure 2.1 – Electric and magnetic planes are perpendicular to each [8]

At the point of radiation source, each electromagnetic wave has an amount of energy. As total energy distributed over large areas energy levels stand same like in the beginning but the strength of the wave decreases during the travel of the wave.

2.1.2 Transmission Sources

All the radio, radars, satellite, receivers, television, telephones, transmitters, power lines and transformers besides that, integrated parts mobile communications systems like cellular phones, base stations are transmission sources. In this thesis 2G mobile communication system is studied on. Base stations transmitters and Radio-TV transmitters mostly use RF transmission system [9].

2.1.2.1 Radio TV Transmitters

Radio and TV antenna transmitters are working using RF technology. So, these transmitters are a member of EM spectrum. The energy amounts which are spreading out from these depend on; station type, antenna type, power and antenna height. In our country Radio - TV broadcasting; 88-108 MHz in FM, 174-230 MHz in VHF and 470-854 MHz in UHF bands. Although, Radio - TV transmitters have high output powers, generally Radio - TV transmitters construct top of the high masts which are located outside the city centers. By this way, the electromagnetic field effects (pollution) which generate by these transmitters have minimum levels at the city centers. In Ankara city center and around city center (county) radio-TV station number is totally 336 and 99 of them are in Çankaya region [10].

2.1.2.2 GSM Transmitters

In cities, there are lots of Base Station (Base Transceiver Stations) (BTS) generates dense electromagnetic field. But, even though BTS's that are working with RF base, exist in non-ionizing side of the EM spectrum.

In our country, GSM cellular systems are working at frequencies 900, 1800 and 2100 MHz. But transmit power levels are changeable according to the areas like indoor, outdoor etc. Due to the 2014 data in Ankara city center and around city center (county) there are totally 9553 BTS located, 3258 of them are in Çankaya region. If these numbers are classified according to operator X's data (this study based on operator X data base, which is one of the Turkey's most popular GSM service operator), these numbers decrease to; 3502 in Ankara and 1147 in Çankaya region (Table-2.1) [10].

Table 2.1 - BTS numbers in Ankara and Çankaya

Number / Region	Ankara	Çankaya	%
Total	9553	3258	34,10
Operator X	3502	1147	32,75

At that point before continuing with the GSM architecture and thesis methodology parts, for a clear understanding, some briefs about international and national electromagnetic limits and electromagnetic health effects concept can be useful.

2.1.3 GSM Architecture

Whole GSM construction period is naturally based on GSM technology and its architectural structures. Besides, different from other countries in our country out of the electric field strength limits, construction of a base station depends on some strict procedure rules which were set up by governmental units. The reason of these rules are human health protection.

2.1.3.1 GSM Main Structures

GSM system has main structures and substructures Figure (2.2). These structures combine each other's and can observes in 3 main parts; MS (mobile station), BSS (base station systems) and NSS (networking switching systems) [11].

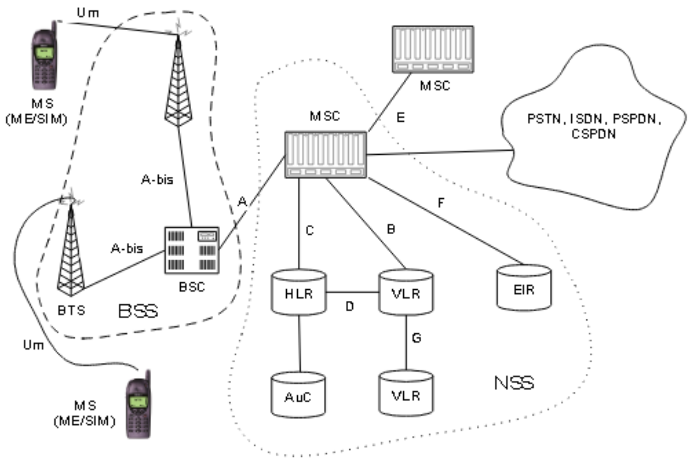


Figure 2.2 – GSM structures and substructures [12]

In this thesis, the focus point is BSS's antennas electromagnetic wave propagations and BSS's coverage areas. Because of that, BSS part of the GSM, its cellular and frequency structure is prior than the other parts of this architecturally complex communication technology.

2.1.3.1.1 Base Station System (BSS)

This system includes 3 subsystems: Base Transfer Station (BTS), Base Station Center (BSC) and Transcoding Unit (TCU).

2.1.3.1.1.1 Base Transfer Station (BTS)

These stations, in the GSM telecommunication, connects the mobile phones to the network. For increasing the GSM coverage area, generally these devices are constructed on top of the roofs. Forms of these devices are generally; 3-4m white boxes, 2 whip antennas and one dish satellite antenna. The electromagnetic wavelength is 0.1-100 cm and frequency is 0.3-300 Gigahertz of these antennas. As a working principle, the whip antennas collect microwave signals and transfer to the dish satellite antenna then this antenna transmits these waves 16 different frequencies on the Ultra-High Frequency (UHF) band. Due to the set locations, BTSs are called with two names; indoor and outdoor. One other mission of these devices is channel coding and decoding. A BTS generally has 3 sectorial antennas and these 3 antennas are located with 120^0 degree to each other. But this angular situation can be changed according to coverage necessity.

Figure 2.3 - An example of three sector base station antenna types

2.1.3.1.1.2 Base Station Center (BSC)

These centers control the power limits of approximately 80 BTS at the same time, due to the necessity. Beside, these devices control the frequency hopping of the BTSs between each other.

2.1.3.1.1.3 Transcoding Unit (TCU)

These units enables transformation, between the transmission types used in GSM's and general communication systems. In GSM systems transmission value is 16Kbit/sec for high efficiency. But for normal data transmission, this value is 64 Kbit/sec. The TCU is doing this conversion from 16 to 64 or from 64 to 16 Kbit/sec.

2.1.3.1.2 Cellular and Frequency Structure of GSM

In GSM system, the lower layer is cellular layer. This layer occurs from combining lots of BTS's. Each cell represents a BTS. Operator coverage area is divided into cells Figure (2.4). A transmitter or transmitters in the coverage area of a cell is associated with a group. The overall objective of the cellular system using low-power transmitter in a narrow frequency range used many times is to use the same frequency. The reason for this, if there is used more powerful transmitters, the same frequencies cannot be used again in an area several kilometers wide. The frequency bandwidth, allocated to cellular mobile radio system is distributed among a group of cells, and this distribution repeats itself in the operator's coverage area. So, a cell is used to power the transmitter in order not to intersect with one another. Because of that reason, the power must be limited [13, 14]. This situation is one of the reasons of power limitation and the other reason had been shown in title 2.1.5. The transmitters' distances to each other, should be 2,5 or 3 times bigger than cells circumferences. Neighbor cells cannot use same channel and the frequencies within a certain rule, to repeat itself.

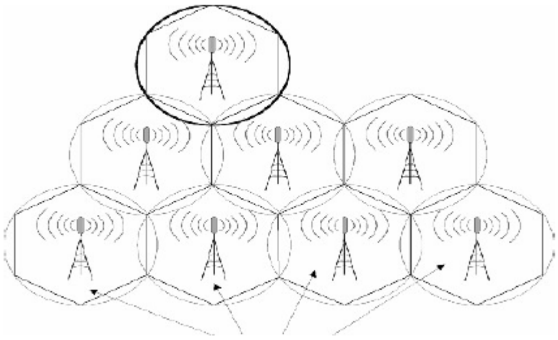


Figure 2.4- Operator coverage area is divided into cells [14]

The cells due to its location and output powers divided into 3 parts macro, micro and pico cells.

2.1.3.1.3 Macro, Micro and Pico Cells

Macro cells' radii is generally 1-30 km. But, when there are buildings, trees and hills in the region then the macro cells' radii is smaller than it is supposed to be.

Micro cells are generally used in urban places where there are more population. These types of cells are constructed for coverage area development and supplement of macro cellular systems. Micro cells generally used in as malls, airports central places; these cellular systems approximately have a 0–2 km diameter.

Pico cells coverage areas less than the other cellular types. These types of cell coverage methods generally used in indoor. As an example it's used in conference rooms or hotel lobbies. These cells have 0-0,5 km range coverage areas.

As known, like all wireless or mobile communication system, GSM is an antenna and it has propagation too. In this respect, BTSs' antennas propagation is the main point of field construction. Before continuing to field construction, information about propagation models and its relation with BTSs' is given in the following parts.

2.1.4 Propagation Models

The models are used for estimation of the signal value propagating from transmitter to receiver. These models, when making these estimations, calculate propagation losses, due to the changes undergone by the signal, the cause of the physical barriers between the transmitter and receiver. The effects of these changes are *multipath propagation* and *fading channel* effects. According to these propagation models used, the locations of transmitters are determined and so the cellular planning be made by an effective way. Besides, the geographical structures (land and ground) have an important role for propagation. Correction factors are used due to these structural situations.

For mobile communication, propagation calculation simply means finding the field strength values received. During the propagation of electromagnetic wave if a loss occurs it is called propagation path loss. By the antenna parameters, received power and field strengths can be found. In general the dB is used to express path loss. The formulations of unit changes are shown in equation (2.1) and the relation between dBmV, dBm and dBμV in equation (2.2) and (2.3) [15].

$$X\ (dB) = 10\log x \qquad \text{(Eq. 2.1)}$$

$$dBmV = 46.9897 + dBm \qquad \text{(Eq. 2.2)}$$

$$dB\mu V = 20\log_{10}(10^3) + dBmV \qquad \text{(Eq. 2.3)}$$

2.1.4.1 Free Space Propagation

The ratio of transmitted and received power ratio is simply free space path loss. Free space propagation estimate there is no reflecting or scattering object between transmitter and receiver. The principle path for free space loss is formally calculated by using the Friis free-space loss formula given in equation (2.5) [5]. If transmitted antenna power and its gain are multiplied it gives effective isotropically radiated power (E.I.R.P). This means power radiation at a specific angle to the isotropic antenna. But because of isotropic antenna is an imaginary antenna, when half wave-dipole antenna is used effective isotropic power (E.R.P) takes place of E.I.R.P. The relation between E.I.R.P and E.R.P can be written as E.I.R.P = E.R.P+2.15 (dBW) since dipole antenna gain is 2.15 dBi or E.R.P can be expressed as equation (2.4). When assuming the transmitter and receiver antenna gains are unity, the free space loss can be shown at equation (2.6), as just related with the distance (d) and frequency (f (MHz)), between transmitter and receiver:

$$E.R.P = P_0\,(dBW) + gain\,(dBi) \quad \text{(Eq. 2.4)}$$

$$L_{bf}(dB) = -\,G_{TdB} - G_{RdB} - 20\log(\lambda) + 20\log(d) + 22 \quad \text{(Eq. 2.5)}$$

$$L_{bf}(dB) = 32.45 + 20\log(d) + 20\log f\,(dB) \quad \text{(Eq. 2.6)}$$

2.1.4.2 Line of Sight (LOS) and Non-Line of Sight (NLOS) Concepts

NLOS is the situation where there is no direct seen between the transmitter and receiver and it takes into consider the reflection, diffraction and attenuation because of the barriers between the transmitter and the receiver. If the transmitter does not intersect with any obstacle and directly sees the receiver, it is called line of sight (LOS).

2.1.4.3 Multipath Propagation

In mobile communication, electromagnetic waves cannot reach to the receiver antenna because of barriers of the line of sight. *Facing reflection, diffraction and scattering* situations occurs with the effects of barriers (buildings, trees) on the waves, which are transmitted. Because of these three situations, the received wave is taken as combination of the wave which comes from different directions.

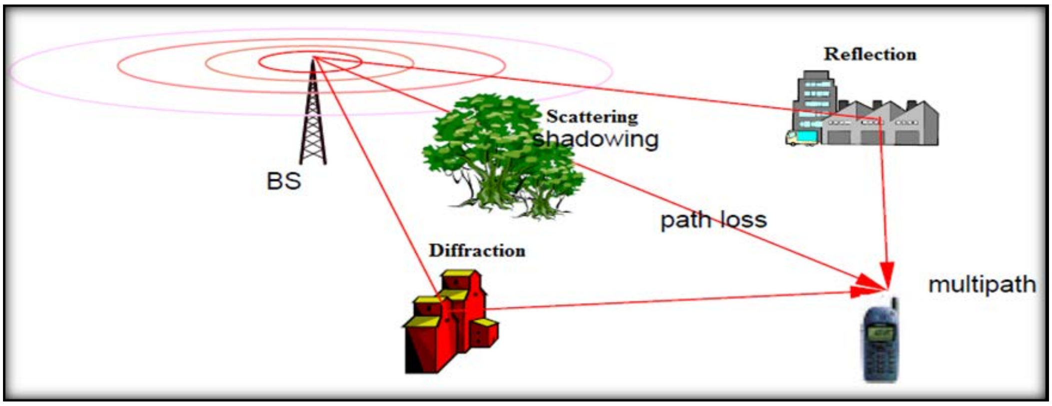


Figure 2.5 - Multipath Propagation [16]

In Figure (2.4) the multipath propagation illustrated for, base station propagation wave, for just three probable ways as an example (the number of ways can be more than three in real). The wave, which is propagated from base station, goes on a single line or it scatters from buildings or other things. Besides with the effects of multipath propagation, the receiver takes the different signals in different times, so multipath propagation has an effect, it is called propagation delay.

2.1.4.4 Doppler Spread

One of the signal transmission effects is Doppler spread. It affects mobile radio transmission channels negatively. Because of moving of the receiver, Doppler spread, shifts the frequencies of each partial waves. When Doppler spread is formulized;

Δ*l*: Movement time of x point to y point

Θ : The angle of x and y points with source at the same time. (Estimate as the source is located in far field)

$$\Delta l = d \cos\theta = v \, \Delta t \cos\theta \qquad \text{(Eq. 2.7)}$$

Due to difference between road lengths, the received signal phase's differences changes.

$$\Delta\varnothing = 2\pi\Delta l / \lambda = 2\pi v\Delta t / \lambda \cos\theta \qquad \text{(Eq. 2.8)}$$

As a result, frequency changes (Doppler spread) shown as f_{d};

$$f_{d} = \Delta\varnothing / 2\pi\Delta t = v / \lambda \cos\theta \qquad \text{(Eq. 2.9)}$$

Because of Doppler spread the spectrum of transmitted signal, during the transmission, is exposed to enlargement of frequency. This situation is called frequency distribution.

2.1.4.5 Fading Channel

The reason of fading is propagation conditions. These conditions are not fixed, due to the continuous change of them, the amplitude of the wave changes. Many physical factors in the propagation channel affect signal attenuation. These factors are; multipath spreading, speed of receiver, environmental things, signal band width, time delay of received signal, random phase and random amplitude.

As it is mentioned models have been generated for different environments to predict the path loss between the transmitter and receiver. All models are composed to find how much power is needed to transmit signal from BTS, considering the losses, in order to obtain the MS receive the signal. The complexity of the model affects the applicability as well as the efficiency.

2.1.4.6 The Propagation Models which are used in Thesis

As known, field construction depends on radio wave propagation concept. In literature there are famous wave propagation models; Okumura-Hata and Walfish-Ikegami. It is developed for micro cells (rural and suburban places) [17].

In this thesis the propagations losses calculated with COST-Walfish-Ikegami, COST-Hata model and simulated Fspl + RMD (Reflection plus Multiple Diffraction) models. Because of that, these three models are defined with their parameters.

2.1.4.6.1 COST-Hata Model

This model accepts physical barriers between transmitter and receiver antennas as homogeny. The real specification of the barriers is ignored in Okumura-Hata model. In this model, the Doppler spread, multipath propagation and fading effects are disregarded.

Four parameters used in Okumura-Hata model are listed below (Figure 2.6):

- Frequency (f) : 150 – 1500 MHz
- Distance between transmitter and receiver (d) : 1 – 20 km
- Transmitter antenna height (hTX as h_{Base}) : 30 – 200 m
- Receiver antenna height (hRX as h_{mobile}) : 1 – 10 m

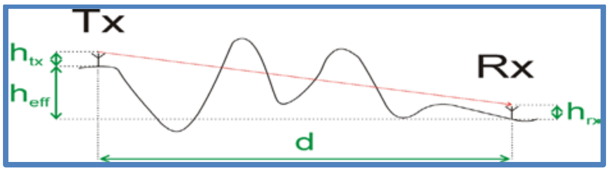


Figure 2.6 - Okumura-Hata Model Parameters [18]

Because of the frequency band limitation (150 – 1500 MHz) of the Okumura-Hata model, the original model was later reproduced by the European CO-operation in the field of Scientific and Technical research (COST 231) to the frequency band of 1500–2000 MHz This product is called COST-Hata-Model [19]. According to these, loss equations are for urban and suburban places:

L_b= 46.3 + 33.9 log (f/MHz) – 13.82 log (h_{Base}/m) – a(h_{mobile}) + ((44.9 – 6.55 log (h_{Base}/m)) log(d/km) + C_m (Eq. 2.10)

Where;

a(h_{mobile}) = (1.1 log (f/MHz) – 0.7) (h_{mobile}/m) – (1.56 log (f/MHz) – 0.8) (Eq. 2.11)

log = $\log_{10}$

C_m =
- **0 dB** for medium sized city and suburban centers with medium tree density
- **3 dB** for metropolitan centers (urban)

COST-Hata-Model is applicable for large and small macro-cells. It is not be used for micro-cells [20].

2.1.4.6.2 COST 231 - Walfisch-Ikegami Model (COST-WI)

The model is, as a combination of Walfisch and Ikegami models, the COST 231 project further developed the model and now it is called COST-WI Model. The model is provided the path loss estimations by using environmental data like; heights of buildings, widths of roads, road orientation, etc. But, in this model as differ from Epstein-Peterson the topographical structures is ignored.

- Frequency (f) : 800 – 2000 MHz
- Distance between transmitter and receiver (d) : 0,02 – 5 km
- Transmitter antenna height (hTX as h_{Base}) : 4 – 50 m
- Receiver antenna height (hRX as h_{mobile}) : 1 – 3 m

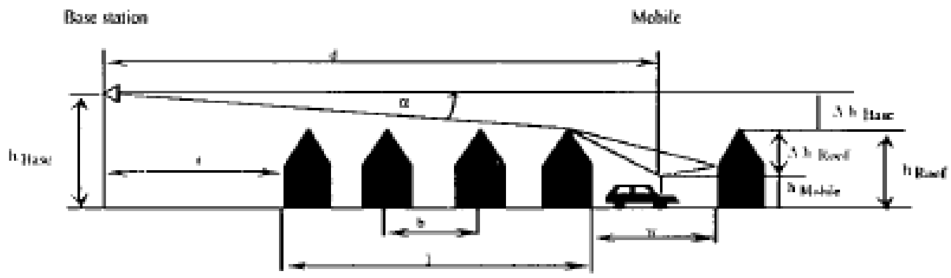


Figure 2.7 - A Typical Walfisch Ikegami Model parameter Figure [18]

The model working principle is changing in LOS and NLOS situations. In the LOS situation if the d value (distance between Tx and Rx) is smaller than the 20m the L_b equation (2.11) can be enough for finding the losses. Equation (2.12) is the free space formula for this model.

$$\mathbf{L_b\ (db)} = 42.6 + 26\log(d/km) + 20\log(f/MHz) \qquad \text{for } d \geq 20m \qquad \text{(Eq. 2.12)}$$

In the NLOS situation the equation (2.13) changes according to these functions; the free space loss is L_o (Eq 2.6), multiple screen diffraction loss (L_{msd} (Eq. 2.18)) and roof-top-to-street diffraction and scatter loss is L_{rst} (Eq 2.14)

$$\mathbf{L_b} = \begin{cases} L_0 + L_{rst} + L_{msd} & \text{for } L_{rst}+L_{msd} > 0 \\ L_0 & \text{for } L_{rst}+L_{msd} \leq 0 \end{cases} \qquad \text{(Eq. 2.13)}$$

$$\mathbf{L_{rst}} = -16.9 - 10\log w/m + 10\log f/MHz + 20\log \Delta h_{mobile}/m + L_{Ori} \qquad \text{(Eq. 2.14)}$$

COST-WI Lori function is different from the original (WI) one. This difference comes from the incident wave measurement.

$$\mathbf{L_{Ori}} = \begin{cases} -10 + 0.354\ \varphi/deg & \text{for } 0° \leq \varphi < 35° \\ 2.5 + 0.075\ (\varphi/deg - 35) & \text{for } 35° \leq \varphi < 55° \\ 4.0 - 0.114\ (\varphi/deg - 55) & \text{for } 55° \leq \varphi < 90° \end{cases} \qquad \text{(Eq. 2.15)}$$

The measurement technique is shown in Figure (2.8) for a clear comparison (a: original WI and b: COST-WI).

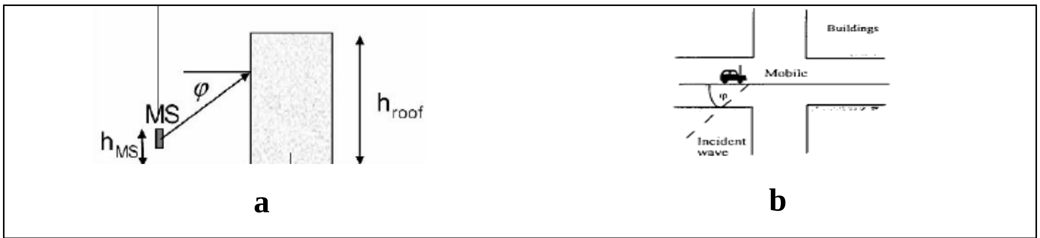


Figure 2.8 - COST-WI Lori function is different from the original one [17, 20]

These two equations (2.15) and (2.16) are used in all functions as a parameter without L_{ori}.

$$\Delta h_{mobile} = h_{roof} - h_{mobile} \quad \text{(Eq. 2.16)}$$

$$\Delta h_{base} = h_{base} - h_{roof} \quad \text{(Eq. 2.17)}$$

The multiple screen diffraction loss (L_{msd}) formula is used d, f and b parameters. These parameters were shown in Figure 2.6.

$$L_{msd} = L_{bsh} + k_a + k_d \log d/km + k_f \log f/MHz - 9 \log b/m \quad \text{(Eq. 2.18)}$$

L_{bsh} equation (2.19) is used to find the loss, according to relation of base station and roof heights, which is used as a parameter in L_{msd} formula.

$$L_{bsh} = \begin{cases} -18 \log (1 + \Delta h_{base}/m) & \text{for } h_{base} > h_{roof} \\ 0 & \text{for } h_{base} \leq h_{roof} \end{cases} \quad \text{(Eq. 2.19)}$$

As seen in equation (2.18) some parameters is used as k_a, k_f and k_d. The equations of these parameters are shown below.

$$k_a = \begin{cases} 54 & \text{for } h_{base} > h_{roof} \\ 54 - 0.8\, \Delta h_{base}/m & \text{for } d \geq 0.5 \text{ km and } h_{base} \leq h_{roof} \\ 54 - 0.8\, \Delta h_{base}/m\ (d/km)/0.5 & \text{for } d < 0.5 \text{ km and } h_{base} \leq h_{roof} \end{cases} \quad \text{(Eq. 2.20)}$$

As seen on equation (2.21) the k_f parameter is related to frequency.

$$k_f = -4 + \begin{cases} 0.7\ (((f/MHz)/925) - 1) & \text{for medium sized city and suburban centers with medium tree density} \\ 1.5\ (((f/MHz)/925) - 1) & \text{for metropolitan centers} \end{cases} \quad \text{(Eq. 2.21)}$$

The k_d term which is used for controlling the dependence of the multi-screen diffraction loss versus distance, is the other different term of the COST-WI.

$$k_d = \begin{cases} 18 & \text{for } h_{base} > h_{roof} \\ 18 - 15 \Delta h_{base} / \Delta h_{roof} & \text{for } h_{base} \leq h_{roof} \end{cases} \quad \text{(Eq. 2.22)}$$

If the height of roofs, b, w and incident wave angle are unknown, the equations 2.22 and 2.23 can be useful.

$$h_{roof} = 3m \times (\text{number of floors}) + \text{roof-height} \quad \text{(Eq. 2.23)}$$

b = 20 … 50m
w = b/2 (Eq. 2.24)
φ = 90^0

2.1.4.6.3 Epstein-Peterson and Knife Edge Loss Model

In order to model this single knife edge, ideal barrier, Fresnel-Kirchoff Diffraction parameter υ is used. It is calculated with:

$$\upsilon = h\sqrt{2\,(l_1 + l_2)/\,l_1\,l_2\,\lambda} = \theta\,\sqrt{2\,l_1\,l_2\,/(l_1+l_2)\lambda} \qquad \text{(Eq. 2.25)}$$

The Figure which belongs to the model is given below. As seen l_t is the distance between transmitter and the barrier, l_r is the distance between receiver and the barrier, l_1 is the distance between the transmitter and the highest point (vertex) of the barrier, l_2 is the distance between the receiver and the highest point (vertex) of the barrier and *h* is the height of the barrier (Fig. 2.9).

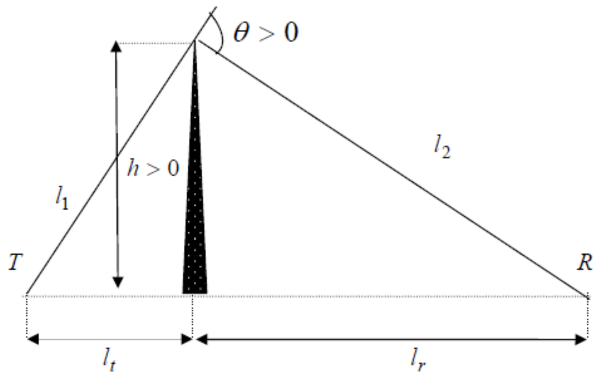


Figure2.9- Single Edge Diffraction Model [19]

If it is considered, diffracted wave because of the barrier electric field strength at the receiver E_d, and electric field strength of the wave which is transmitted E_0, the ratio E_d/E_0 is:

$$E_d/E_0 = F(\upsilon) = (1+j)\,/\,2\,\int_{\upsilon}^{\infty} \exp\,(-j\pi t^2\,)/2)dt \qquad \text{(Eq. 2.26)}$$

F(υ) is the complex part of the Fresnel integral (Eq. 2.26). Diffraction loss (L_b) generally evaluated with parameter υ (Fig 2.10). The formulation for this is below (Eq. 2.26) [21].

$$L_b(db) = 20\log|F\,(v)| \qquad \text{(Eq. 2.27)}$$

The Fresnel diffraction parameter υ versus knife edge diffraction loss graph is shown in Figure (2.10).

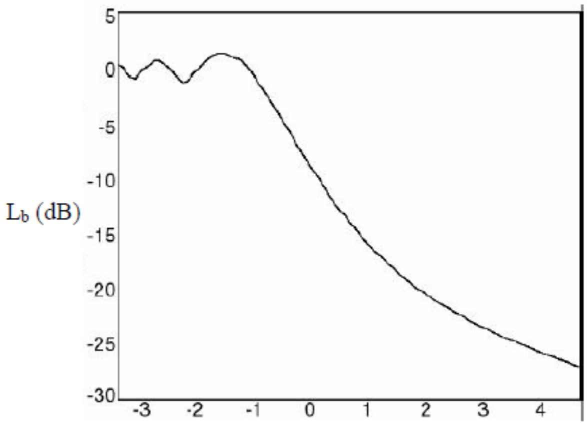


Figure 2.10 - Graphical representation of L_b to υ [21]

Practically there used to be five equations according to υ value changes. These equations are adapted due to the υ values boundaries.

L_b (db) = 0	$\upsilon \leq -1$	(Eq. 2.28)
L_b (db) = 20 log(0.5 – 0.62υ)	$-1 \leq \upsilon \leq 0$	(Eq. 2.29)
L_b (db) = 20 log (0.5 exp(-0.95 υ))	$0 \leq \upsilon \leq 1$	(Eq. 2.30)
L_b (db) $=20 \log(0.4- \sqrt{0.1184-(0.38-0.1\upsilon)}^2$	$1 \leq \upsilon \leq 2.4$	(Eq. 2.31)
L_b (db) = 20 log(0.225/υ	$\upsilon > 2.4$	(Eq. 2.32)

Calculation of diffraction losses truly on a single communication line with the two different barriers is started with Millington and continued with Bullington in 1947. Bullington considered [22].

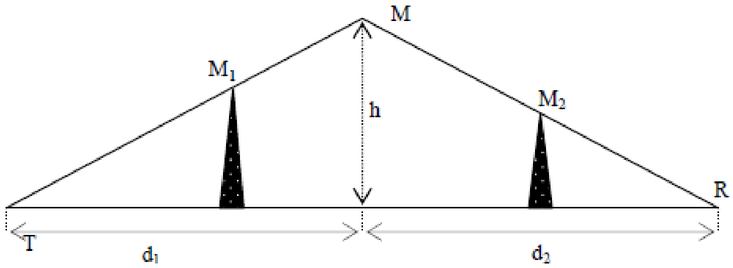


Figure 2.11 -Bullington's two knife edge diffraction loss model [22]

Bullington, reduced diffraction caused by two barriers (M_1 and M_2) into one barrier (M) in his model (Fig. 2.11). He calculated the loss according to one barrier situation.

But this calculation method was considered very complex by ITU then Epstein-Peterson and Deygout models were approved by ITU as these are simple and successful.

Epstein-Peterson differ from Bullington's studies, in 1953, in their models two different barriers are not thought to be one barrier, they calculated diffraction of each barrier separately. In this model, one diffraction loss is calculated for two barriers in return. For this, top of the first barrier is considered as the position of the transmitter for the calculation of the diffraction loss from the second barrier (Fig 2.12).

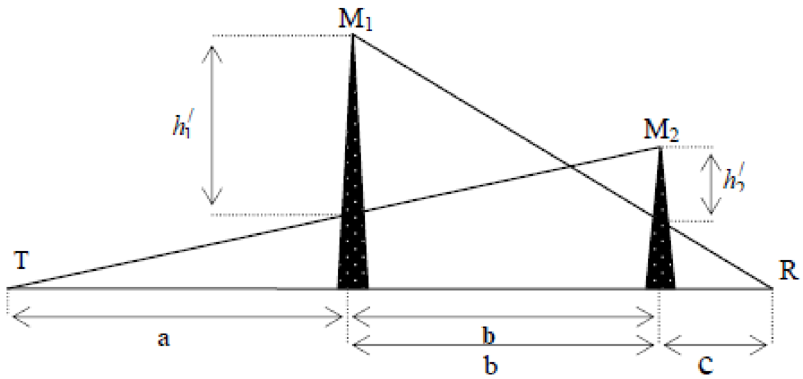


Figure 2.12 - Epstein-Peterson Model [22]

Diffraction loss of Epstein-Peterson Model is represented with $LEPS_{-PET}$, where diffraction loss caused by M_1 is with L_{M1} and the loss caused by M_2 is with L_{M2}

$$\mathbf{L_{EPS\text{-}PET}} = L_{M1} + L_{M2} \quad \text{(Eq. 2.33)}$$

To calculate L_{M1}, the distances between the transmitter and the receiver with the barrier a and b, and the height of the barrier h_1^l is used. With these parameters Fresnel-Kirchoff diffraction parameter υ is calculated. L_{M1} is calculated with the υ values according to the appropriate equations (2.28), (2.29), (2.30), (2.31), and (2.32). Same calculation is done for L_{M2} by using b and c distances and h_2^l height which are shown in Figure (2.12).

For Epstein-Peterson model Fresnel-Kirchoff parameters are calculated with these formulas:

For L_{M1} $\upsilon_{M1} = h_1{}^{l}\sqrt{2\,(a+b)\,/ab\lambda}$ (Eq. 2.34)

For L_{M2} $\upsilon_{M2} = h_2{}^{l}\sqrt{2\,(b+c)\,/b\,c\lambda}$ (Eq. 2.35)

The main point of Epstein-Peterson model is that, if the diffraction losses of two knife age barrier are close to each other, it can be said that this model is successful.

To simulate Fspl + RMD (Epstein-Peterson) propagation model, RTV plan simulation software is used. During the use of COST-Hata Model, COST-WI MODEL, path losses and result values are calculated. In this respect the general antenna parameters, the loss terms and its definitions, with associating to the calculations and simulation software, is given in methodology title 4.2.2.2 and 4.2.3 part of the thesis study.

2.1.5 Base Station Construction Secure Distance and Governmental Control

There is not a standard network planning process. The network planning process itself is not standard also. The process depends on the type of the project criteria and targets; there may be some common steps also [17].

GSM companies' base station construction processes and replacement locations surely is done to get full coverage (cover the dark places) but also depends on customer requests and users complaints.

Procedurally, GSM companies have some responsibilities during the station construction period. After planning the construction point, the company must prepare some documentation and make measurement for taking permission, for construction, from Information and Communications Technologies Authority (ICTA).

ICTA, controls whether the devices used by personal telecommunication facilities are on the standards, convenient to telecommunications regulations and spectrum control and auditing functions are carried.

The main point of these measurements and documentation is public health. 'Secure distance' is the main topic of public health. Secure distance is important for two reasons, according to ICTA regulations, first of all there must not be a living space in the secure distance in the direction of the antenna propagation and second electric field measurements must be taken from the end point of secure distance. So, the GSM operators must prepare the document about this situation as seen on the Figure (2.14).

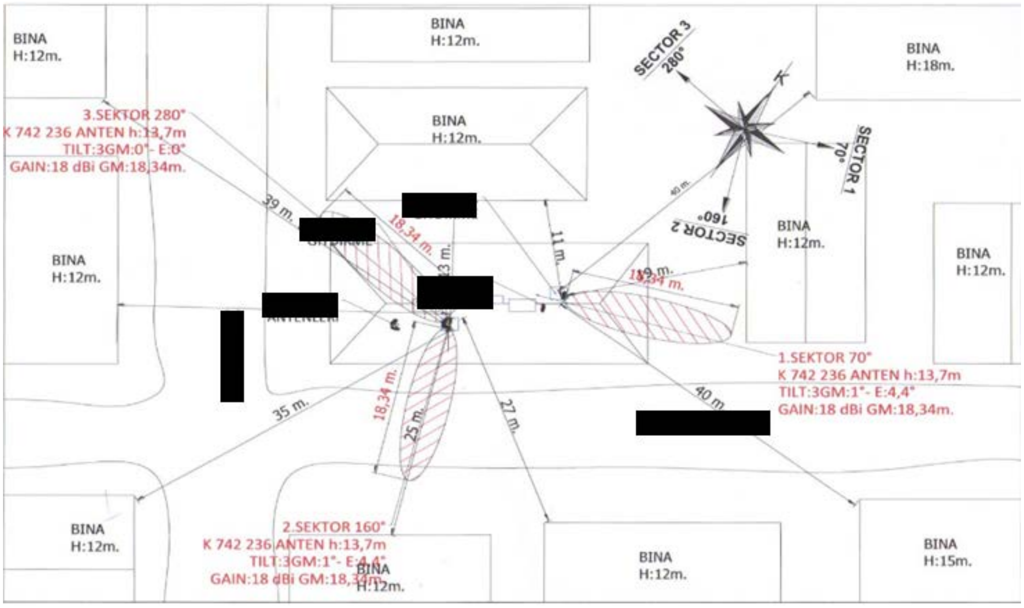


Figure 2.13 - Base Station Field Construction Overlay (GSM Company) [10]

Secure distance (D) is calculated with this formula (Eq. 2.36):

where;

P: Output power (Watt)

G: Antenna gain (dBi)

E: Electric field limited value (V/m) (from Table

2.2) D: Secure distance (meter)

$$D = \frac{\sqrt{30.P.10^{\frac{G}{10}}}}{E} \quad \text{(Eq. 2.36)}$$

As seen on Figure (2.13) there is a base station which has three sectors. For each sector secure distance is calculated (18, 34 meter). Beside these calculations, antennas propagations, tilt angles and azimuths are given sector by sector.

Table 2.2: Electric Field Limits in Turkey [10]

	Electric Field Intensity Limit (V/m)	
Limit Specification	**Device base limit**	**Environmental Base Limit**
Formula	0,341 $f^{1/2}$	1,375 $f^{1/2}$
900 (MHz)	10,23	41,25
1800 (MHz)	14,46	61

2.2 Literature Search

The studies which were examined in literature search were chosen from very similar subjects directly related to the main focus point of this thesis study. Comparable experimental studies are about the propagation models, which is mentioned in the thesis background information part, has an important role in literature.

A study was carried to find a suitable model to provide guidelines for the deployment of GSM networks in 2012 by Nivamat, V.D. and Kulkarni, G.R. For initial deployment of wireless network and cell planning it is important to reveal the path loss. Taking into consider the potential success of GSM operating in the 900 MHz or 1800 MHz bands in its line-of-sight (LOS) and non-line-of-sight (NLOS), researchers tried to estimate path losses. They compared and analyzed, COST 231 Hata model, Stanford University Interim (SUI) model, Ericsson model and COST 231 Walfish-Ikegami (COST WI) model in rural, urban and suburban environments in NLOS situations (except in rural areas) for different receiver antenna heights. As NLOS conditions did not provide any specific parameters in rural areas for COST 231 Walfish-Ikegami model, LOS condition was considered for it. The study was carried at 900 MHz frequency, distance between transmitter and receiver is 5 km, transmitter antenna heights urban-suburban as 30 m and rural as 20 m, receiver antenna heights 3m, 6m and 10 m. the average building height is fixed at 15 m, the distance between buildings is 50 m. As a result they conclude that path losses were higher in urban than in suburban and rural. In urban, Ericsson model gave the lowest and Stanford University Interim (SUI) model the highest path loss. In suburban, SUI model showed the lowest where Ericsson model the highest loss. In rural, COST WI model showed lowest loss and Ericsson model highest [23].

In another study in 2010 by Sharma et al., examined many propagation models to calculate path loss in different models on their survey article as it is important to understand system dynamics and analyze the performance of wireless networks. A network for communication has to be designed by minimizing the preventive effects. So it should be taken into consider that received powers decrease because of path losses and shadowing. Shadowing comes from the obstacles and path losses from the distance between the transmitter and the receiver. According to the study obstructions and reflecting surfaces around the antenna have a considerable effect on the propagation path. There are many propagation models to calculate the loss and shadowing: Simple Path Loss Model, Stanford University Interim (SUI) Model, Okumura's Model, Hata Model, COST 231 Extension to Hata Model, Walfisch-Ikegami Model, and Epstein-Peterson Model etc. Every model has its specific parameters and gives accurate results in different city types, distances, heights etc. For example Okumura-Hata Model has widespread usage on open environments but it is limited in urban areas. Walfisch-Ikegami model gives accurate result values in urban and suburban districts. As a result they concluded that appropriate propagation model gives the answer of how many base stations is required for full coverage [3].

In a study done in urban and suburban areas of Japan by Medesis and Kajackas in 2000, showed the applicability of the most widely used empirical propagation model, Okumura-Hata Model in various VHF/UHF freqency bands. Measurement results in different frequencies in the bands 160 MHz, 450 MHz, 900 MHz, and 1800 MHz compared with the model. Field strength was measured from a set of points in the coverage area randomly. In the study it appears that Okumura-Hata gave significant errors in rural districts, but gave good approximation in urban/suburban areas. The best result in accuracy was achieved in the 900 MHz in urban areas with the model [24].

COST-231 Walfish-Ikegami method studied in Ordu to investigate the consistency the measurement results for one base station by Mutlu, M. and Çavdar, İ.H. in 2010. The survey carried in 900 MHz frequency showed that the method and measurement results (which are taken non line of sight) are consistent when the distance between buildings is regular and antenna height is higher than the building. The researchers concluded that the method is one of the appropriate methods to measure the received power [25].

Another study was carried by Rahman A. A. and Kian J.T. in 2005 in Malaysia where total Global System for Mobile Communications (GSM) subscribers were 1266,4 million and base transceiver stations were 10673 in number by the year 2004. In this study measurements were taken according to the distance and time of the day to get the real electrical field strength (for 900 and 1800 MHz frequencies). Measurements for survey site I were taken in a rural residential area for public. The measurement distances for residential area were 60, 100, 150, 200 meters. Measurement at survey site II was connected on the roof tops for occupational. The measurement distances were 10, 15, 20, 25 meters and time 9:00 am, 12:00 pm, 3:00 pm. So, the measurement results have shown that for survey I is 0,4 V/m . And for survey II exposure levels was found to be 0,56 V/m field strength [26].

A model prediction about radiation level from mobile base stations using electromagnetic field simulation studied by Chio and friends in 2012. The study carried at 900 MHz frequency and a residential apartment was chosen and simulation values were compared with the data collected from the survey area. The simulation results were parallel with the measured data. In simulation session the model which is selected are observed in four points (analytical coordinates). The GSM 900 simulated antenna propagated to these points is chosen from a real manufacturer website (Power wave). According to the speciation's of the manufacturer antenna, the modeled antenna specifications are 944MHz frequency, polarization $+45^0$ and -45^0, front-to-back ratio ≈ 37dB, gain 15,7dBd, 3dB horizontal BW 660, 3dB vertical BW 14,20. As a conclusion, the simulated and measurement values of apartment's indoor locations (four points) were found approximately 0,5 V/m. Moreover, electric field strength levels of simulation model were found approximately 0,5 V/m too and on-site measurement values were 0,3 V/m [27].

A study which was carried in two districts of Mosul City using Walfish-Ikegami and Okumura-Hata models taking into consideration the structural facilities of the districts was done by Mahmood, F.E. in 2012. The district which has many similar and uniform buildings was analyzed with Walfish-Ikegami, the district which has dissimilar and irregular buildings was analyzed with Okumura-Hata. In order to calculate path losses simulations were used for both models by MatLab programing. Using Okumura-Hata model, path losses were calculated with distance for four antenna heights (10, 50, 70 and 100 meters). By this way, the path losses were found in kilometers. When using Walfisch-Ikegami model, different from Okumura-Hata, the base stations located due to the roof height (25m>h roof, 9m = hroof and 5m<hroof). After that as the previous one simulation process repeated for Walfish-Ikegami (path loss versus km). Comparable result shows that, the district which was modeled with Walfisch-Ikegami model has larger path loss than the district modeled with Okumura-Hata about 7-10 dB, as of multiscreen effects and roof tops that makes more diffraction in the first district [16].

CHAPTER THREE

3. METHODOLOGY OF MEASUREMENT, SIMULATION AND CALCULATIONS

Coverage area analyzes and electric field measurements of Mustafa Kemal District are done. During measurements, Narda Selective Radiation Meter (SRM) 3000 device is used. Coverage area and electric field analyses are done with simulation software which includes Fspl + RMD (Epstein-Peterson) propagation models. Besides COST (Okumura) - Hata model and COST - WI electric field strength calculations are done with directly help of its formulas.

3.1 Methodology of Measurement

This part gives the details about the device which is used to get the exact data from the chosen district and the measurement methodology.

3.1.1 Measurement Device

As shown in Figure (3.1) Narda SRM 3000 and its isotropic100 kHz to 3 GHz probe (receiver antenna), is a portable measuring device for analysis of RF and microwave electric and electromagnetic fields. This device has many usage areas; radio network operator, broadcasters etc. With its compact structure, the device's most useful specifications are; showing the electric (V/m), magnetic field (A/m) values or power (dB) values of the selected frequency ranges [28].

Figure 3.1 - Narda SRM 3000 and its isotropic 100 KHz to 3 GHz probe

Besides, it can show the frequencies spectral changes with a high sense Figure (3.2) so; SRM 3000 can be used as a spectrum analyzer. In this thesis, as the other portable devices generally measure only environmental electric field (averaging electric field values of Radio-TV transmitters, walkie-talkie, wireless telephone sets etc.), SRM 3000 device can analyze 100 KHz to 3 GHz full band spectrum and it can divide the band (in this study the GSM 1800 MHz downlink frequency band (1,805.2–1,879.8 MHz) is used) result according to the specific frequency ranges and it shows the results on a table on its LCD Figure (3.3), or the device can track just a single frequency, so SRM 3000 is preferred.

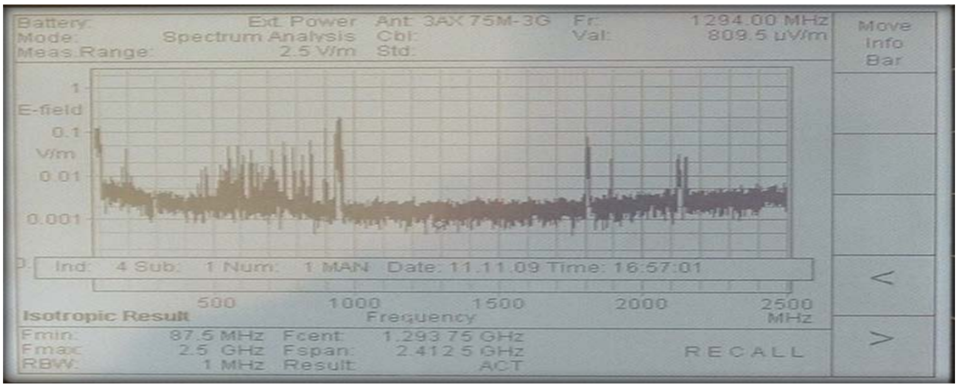


Figure 3.2- Screen shot of Spectral Changes 87.5 to 2500 MHz

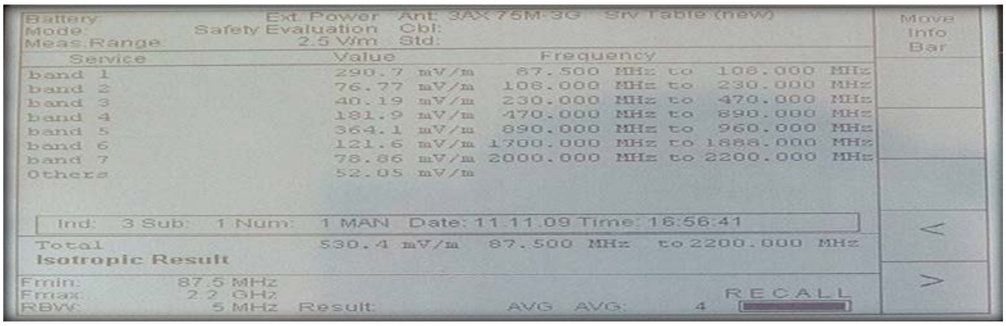


Figure 3.3 - Screen shot of Frequency Electric Field Table

3.1.2 Measurement Method

In the study, as magnetic field and electrical field are not perpendicular to each other in near field, measurements were taken in far-field where the distances were more far than $2D^2/\lambda$ (11,42 meter) to the antenna (D: maximum antenna diameter).

The measurements were taken for a GSM operator's base station which is used for micro cell coverage. This base station has three sectors and each sector corresponds as a directional antenna. Its specifications like azimuth angle, output power and downlink frequency were given in Table (3.2). The measured points and are shown in Figure (3.4). The measurements were done within the ICTA electrical filed strength measurement rules.

In this study, electric filed strength is measured on the coordinates, which were selected first randomly and secondly on a linear direction within the predicted propagation model where one of the antennas was directed with 230^o north angle.

Figure 3.4 - A screen shot of measured (linear and random) points from Google Earth

230^o north angled sector direction was chosen for the linear measurements because of the high density of the buildings in the district. The area was predicted taking into consider the probability of another antenna which is transmitting at the same frequency according to cell coverage architecture principles. During the field survey high values of electric field strength were seen on the average spectral changes at the measurements which were taken very far from the station. Electric field strength is measured on the roads and branch roads (outdoor) of the selected district in order to maintain the successful comparison of simulation module with the actual values as modules were based on land forms.

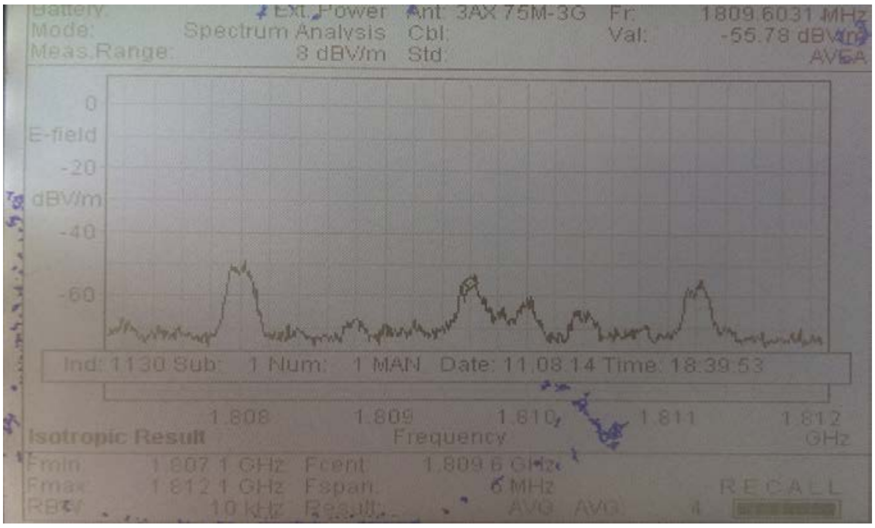


Figure 3.5 - SRM 3000 Measurement in 1808 to 1812 MHz

3.2 Methodology of Simulation and Calculation

The theoretical study was done in simulation and calculation parts as three propagation models were being examined. Firstly, simulation software was used for propagation simulation of Fspl + RMD (Epstein-Peterson) Model in dBµV/m. Then COST-Hata Model and COST-WI were used to calculate the path losses with its formulas and 3 dB value was chosen as C_m constant in the equation (3.1).

3.2.1 The Simulation Software

For the simulation session, RTV Plan mobile communication common engineering analyzing tool is used. It is developed by Communications and Spectrum Management Research Center which was established in 1994 as a research center. This tool working with 10 kHz to 40 GHz consists of the full set of the most probable propagation estimation modules. The models which are used in this thesis are two of these models [29].

3.2.2 Simulation

In the coverage area, analyzes was done by using RTV Plan; estimated field strengths were calculated in every point of the area which was covered by the transmitter antennas (base) direction.

The simulation was studied with the help of ICTA, which use Fspl + RMD (Epstein-Peterson) Model. Before starting the simulation software, the propagation model and the other parameters (RMD method, tropospheric parameters, city type etc.) were set. The selected parameters were given below with their definitions.

3.2.2.1 Simulation Model Parameters

Troposphere Diffraction Index: Troposphere is the nearest atmospheric level to the earth. Electromagnetic waves which propagate in some frequencies diffract at this layer of the atmosphere [30]. This diffraction needs to be used in propagation model analysis. In this simulation program, this diffraction index is calculated by the program according to the other parameters.

Table 3.1 - Simulation Parameters

Parameters (Fspl **+RMD Epstein-Peterson)**	**Values**
k factor	1,33
City type	Urban
Troposphere diffraction index	315,0
Troposphere height	7,35
Time percentage	1%
Field percentage	50%
Ground structure	Land
Coordinate system	Longitude and Latitude

Troposphere Height: It changes according to the coordinates of the place model applied. Because of that the software takes the average values.

City Type: This selection is done according to the chosen district for this study. Mustafa Kemal District in Ankara is chosen and it is an urban type of city.

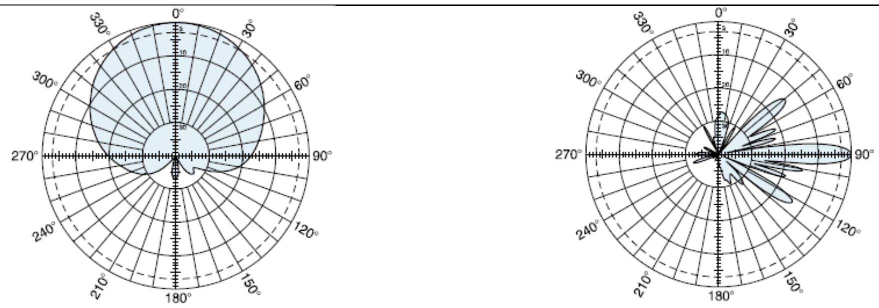
k factor: This parameter is the ratio of the electric field strength in the air and potential difference of the input of the spectrum analyzer [15].

3.2.2.2 Antenna and Antenna Parameters

As known, in a simple form, antennas are the specially constructed elements which make transmitting or receiving mission with converting the electric signals to electromagnetic waves or vice versa [15].

As it is mentioned antennas have some important parameters these are; propagation model, gain, pattern, effective EIRP [15].

Directional Antenna: Generally the antennas, which are used in telecommunication systems are directional aerials. They transmit and receive the electromagnetic energy in the specific direction than the other directions. The GSM operator X is using the pattern as shown in Figure (3.6).



Horizontal Pattern Vertical Pattern

Figure 3.6 - Directional antenna patterns used in the thesis [31]

The parameters which are used in the thesis according to the properties of the transmitter antenna are shown in Table (3.2). Besides the receiver antenna height used in simulation is 2 meters.

Table 3 2- Transmitter Antenna Parameters of Simulation [10]

Transmitter Antenna Parameters	**Value (Sector 1)**	**Value (Sector 2)**	**Value (Sector 3)**
Azimuth angle	230º	130º	30º
Down tilt angle	2º	4º	2º
Coordinates	N 39^0 54’’ 49.8’ E 32^0 46’’ 04.5’	N 39^0 54’’ 49.8’ E 32^0 46’’ 04.5’	N 39^0 54’’ 49.8’ E 32^0 46’’ 04.5’
Height from ground level	17,6 meters	17,6 meters	17,6 meters
Uplink frequency	1809,6 MHz	1806,8 MHz	1805,6 MHz
Output power	15 W = 11,76 dBW	20 W = 13,01dBW	15 W = 11,76dBW
Antenna gain	17,5 dBi	17,5 dBi	17,5 dBi
E.R.P	29,76dBW	30,51dBW	29,76dBW
Polarization	Horizontal	Horizontal	Horizontal

In the simulation application MapInfo tool and RTV Plan were used together.

3.2.2.3 MapInfo Tool

MapInfo Vertical Mapper is an advanced analytical and visualization tool. It allows working on the data related to coordinates which can be exported to Google Earth as Keyhole Markup Language (KML) file. RTV Plan program result data are available to use in MapInfo.

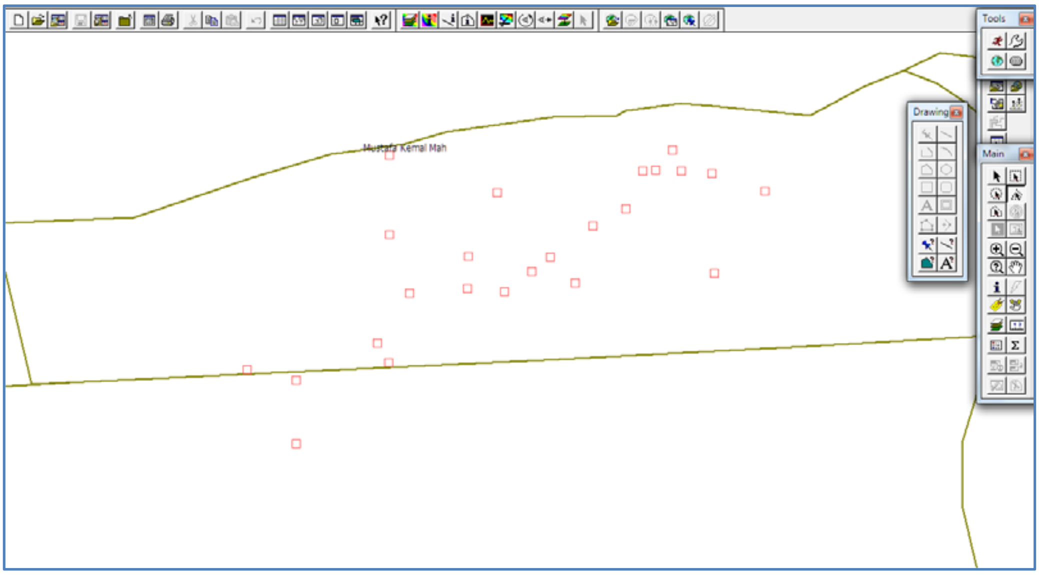


Figure 3.7 - MapInfo screen shot

As MapInfo includes district map data and coordinate values can be exported to Google Earth, it is preferred in this thesis. These properties allow us to see the coordinates on the map which has all components of the chosen district with its buildings, roads and etc.

3.2.2.4 Application of Simulation

The selected parameters were used in order to start the simulation by choosing the output unit dBμV/m and results were taken for each coordinate on Figure (3.4). After calculating the results, the software, using the map data from its library, puts the results on the maps as a propagation model output. Then the contours were drawn for 32 dBμV/m, so this means -104 dBm boundaries (Fig 3.9) according to base station antennas. As the cellular mobile phones cannot receive signal lower than (approximately) -104 dBm power value, this value was chosen in this survey study. These boundaries were drawn to give an idea about the coverage of the base station antennas according to the simulated propagation model.

Figure 3.8 - Screen shot of 32 dBμV/m boundaries

3.2.3 COST-HATA and COST-WI Calculations

COST - Hata Model was used to calculate electrical field strength by Microsoft-excel. Coordinates of the measured values were used in COST-Hata and COST-WI calculations and Google Earth height profiles were taken into consider. The receiver antenna heights are chosen 2m for whole calculations for an exact result compare in thesis study.

In COST - WI calculation session due to the complexity of the model b (distance between the buildings), w (distance between receiver and nearest building) and incident wave angle parameters were collected by using Google Earth's properties (ruler, miter etc.) (Figure 3.10). The redesigned parameter of Walfisch-Ikegami by COST, the incident wave, showed its efficiency in data collection part.

Figure 3.9 - Screen shot of Google Earth's properties

After the data collection process the path losses were calculated for each coordinate and differences were taken between transmitted power and path losses in dB. Then the measurement results (dBuV/m) were converted into dBm with the equation (3.8) to compare the calculation results. The reason of that, the simulation software data output is in dBµV/m unit, but the COST-Hata and COST-WI propagation models are not interested in electrical field strength. The models' output data is related with the power losses. The method used for this conversion was shown below.

3.2.3.1 Converting dBuV/m to dBm

As known a field strength value at a certain point in space is called E in units of V/m. Then the power density is Pw/m2 in watts per meter squared at that same point in space by squaring the field strength and dividing by free space impedance.

$$P_W/m^2=E^2/\eta=E^2/120\pi \qquad \text{(Eq. 3.1)}$$

The power collected by an antenna at that point would be equal to the multiplication of power density and the antenna's effective area (A_e).

$$P_W = A_e P_W/m^2 \qquad \text{(Eq. 3.2)}$$

If the antenna effective area is written in antenna gain term (G). As c is speed of light and f is the frequency.

$$Ae=\lambda^2 G/4\pi, \quad \text{where } \lambda=c/f \qquad \text{(Eq. 3.4)}$$

So the received power (P_W) can be written as;

$$P_W= (c^2G / 4\pi f^2) (E^2 / 120\pi) = (1 / 480) (c\pi / f)^2 GE^2 \qquad \text{(Eq. 3.5)}$$

Both sides are taken 10 log for writing the P_w in dB.

$$P_{dbW}=10\log(1 / 480) (c\pi)^2 – 20\log f+G(dBi)+20\log E \qquad \text{(Eq. 3.6)}$$

After the calculations due to the 10 log;

$$P_{dbW}=E_{dB}V/m – 20\log f \text{ (Hz)}+G(dBi)+132.8 \qquad \text{(Eq. 3.7)}$$

Then with the help of these relations; $E_{V/m}=E_{\mu V/m}/10^6$, f (Hz)=f (MHz)*10^6 and $P_{dBW}=P_{dBm}-30$

Finally the conversion of dBuV/m to dBm formula is found;

$$P_{dBm}=E_{dB\mu V/m}-20\log f\ (MHz)+G(dBi)-77.2 \qquad \text{(Eq. 3.8)}$$

The data collected from field measurements, COST-HATA and COST-WI calculations and simulation (RTV Plan analyze) results were compared using Microsoft-excel.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

The simulation and calculations results were compared with measurement values, as electrical field strength (dBµV/m) for simulation (Fspl + Epstein-Peterson) and as dBm term for calculations (COST-Hata, COST-WI), shown one by one. The tables and graphs were prepared due to the changes of electrical field strength and the distances between T as base and R as mobile. The results were examined in two parts as randomly and one single linear due to the field survey in methodology. The measurements of electrical field strengths (dBµV/m) results were shown for all points in Figure (4.1).

Figure 4.1 - A screen shot of measured values of linear and random points

4.1 Random Coordinates

The measurements, simulation and calculation of field strength results shown in two graphs to examine in a comparative way, one is simulation versus field measurements (dBµV/m) and the other is calculations versus field measurements. (dBm). The reason of this comparison method (unit differences), different from the simulation software the other models are not interested in electrical field strengths but they are interested in power.

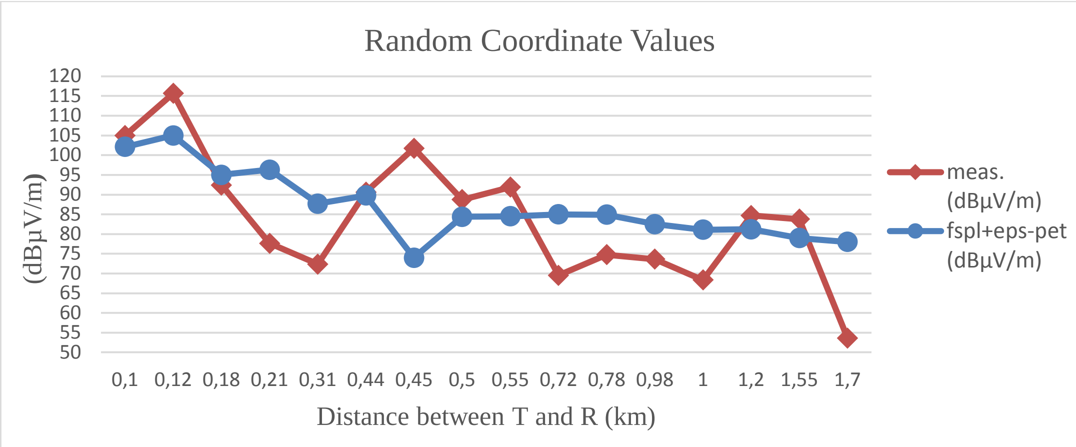


Figure 4.2 – Simulation results vs. measurements for random coordinate

Firstly as seen on Figure (4.2) (graph) the propagation model simulation results (Fspl + Epstein-Peterson) are not so much different from the field survey values. So, due to this situation it could be supposed that, this propagation model nearly succeeded according to the random point's comparison.

But when a deep survey is made some specific points should be analyzed. Especially for the points which has different curves or the points which has so different values. The points which are on 0,21 kilometers can be given as example. As seen on the random coordinate values graph, the simulation and the measured values have differences in some points.

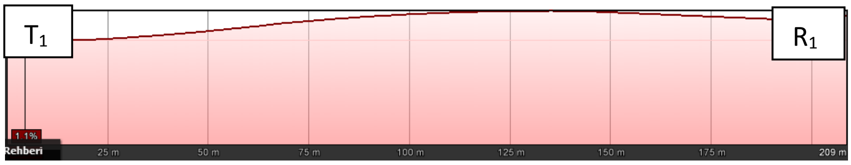


Figure 4.3 - The terrain specifications for point on 0,21 kilometers.

When the Figure (4.3) is examined, (T_1 as transmitter and R_1 as receiver) according to the geographical situation, it seems like it is suitable for free space propagation. But when the buildings or the roof materials were taken into consider the reason of the difference can be seen easily.

Figure 4.4 - A Google Earth screen shot to show buildings or the roof materials

As seen on Figure (4.4) (AN2887 is the base station) the measured point is surrounded by buildings and there is a metal roof top. These buildings and their construction materials affect the signal power with the negative way.

For the curve difference situation, the point 0,45 kilometers was analyzed as an example. This is explained again with the help of Google Earth properties.

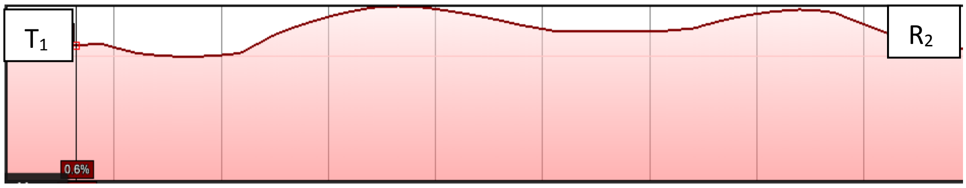


Figure 4.5 - The terrain specifications for point on 0,45 meters

As seen on Figure (4.5) (R_2 as a receiver) the topography has hills, due to these geographical situation the simulation and measurement values have a different curve for this point. But this time structural situation has different effects on measurement values. When the Figure (4.6) is examined, at the near side of the measured points there are some metal roofs and the points' environmental situation is open area.

Figure 4.6 - Google Earth Screen shot for the point on 0,45 meters point

In the Mustafa Kemal district there are two business centers which are called (two twin towers) TOBB and Tepe Prime, besides, in the Eskişehir Road region of that district there are some governmental buildings (ministerial buildings). These structures have lots of indoor GSM antennas which they own. According to the graph these points corresponds to the 1 kilometer to the 1,7 kilometers ranges. Because of that, the measurement values of these points most probably were affected from these antennas. This situation is valid for all graphical comparisons.

The comparison of the calculation between COST-Hata and COST-WI is done with the help of the graphical presentation. The conversion results of the measurement values dBμV/m to dBm unit were shown at Figure (4.7) one by one.

Figure 4.7 - Conversion results of the measurement values dBμV/m to dBm unit

The result can be seen in Figure (4.8), due to the dBm unit.

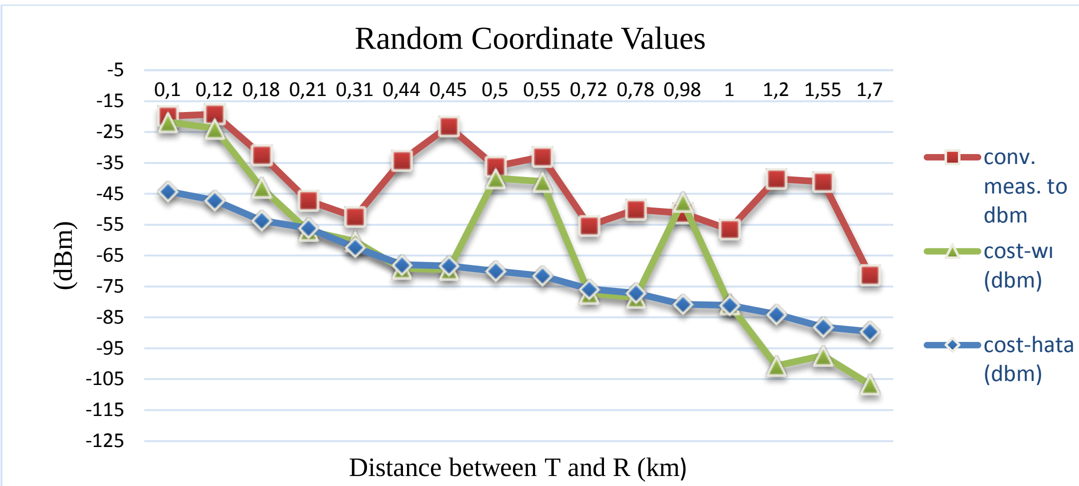


Figure 4.8 - Comparison graph of calculation results and measurement values

In the graph Figure (4.8) first notable situation is linearity of Cost - Hata results. That situation is coming from the Cost - Hata model formulation. As known Cost - Hata model depends on distance and frequency. But Cost - WI model considers lots of effects; like roof heights, incident wave angle etc. Because of that the Cost - Hata curve is nearly linear but the cost-wı curve is changing according to the points. Besides, first 5 points in the graph is nearly closed to the measurement values especially for Cost - WI results. These points are located near to the base station so, it could be understood that; with the effects of the environmental structures, Cost - WI model in the farer points from the transmitter antenna the accuracy of the results can decrease.

The other important situation is about the LOS and NLOS. In the selected area, there are two LOS points according to the base station antennas. These two points are 0,1 km and at 0,55 km. In the Figure (4.9) the LOS situation can be seen easily. This shows the LOS formula of Cost - WI is working.

Figure 4.9 - LOS situation of two points

In the random coordinates study the effects of main beam of the antennas was ignored. Because of that the linear coordinate study was done for one of the base station (AN2887) antennas which has 230^o azimuth.

4.2 Linearly Coordinates

The linearly collected data, simulation and calculation part was examined in this session. Linearly means, the points which were selected as a line according to the antenna which have 230^o azimuth. These points with theirs measured values in dBμV/m and the blue line which represents the linearity of the measured points were shown in Figure (4.1).

Comparisons of simulation (Fspl + Epstein-Peterson) results and the data which were collected from field were shown in Figure (4.10).

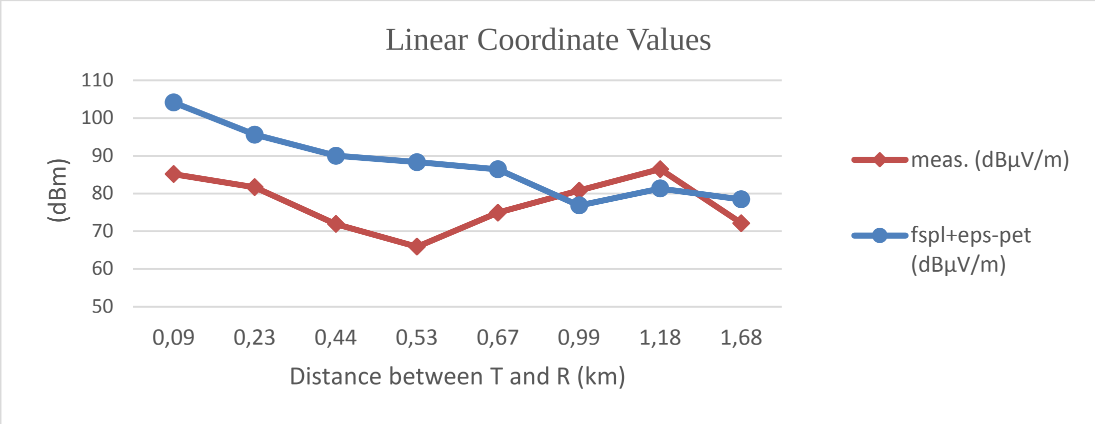


Figure 4.10 - Simulation results vs. measurements for linear coordinate

As seen on Figure (4.10) even if the values are not equal, the slopes of the graphs are nearly same. The effects of the indoor GSM antennas can be seen at the points after 1 km distance.

The other propagation methods COST - Hata and COST - WI were analyzed in linear situation shown in Figure (4.11).

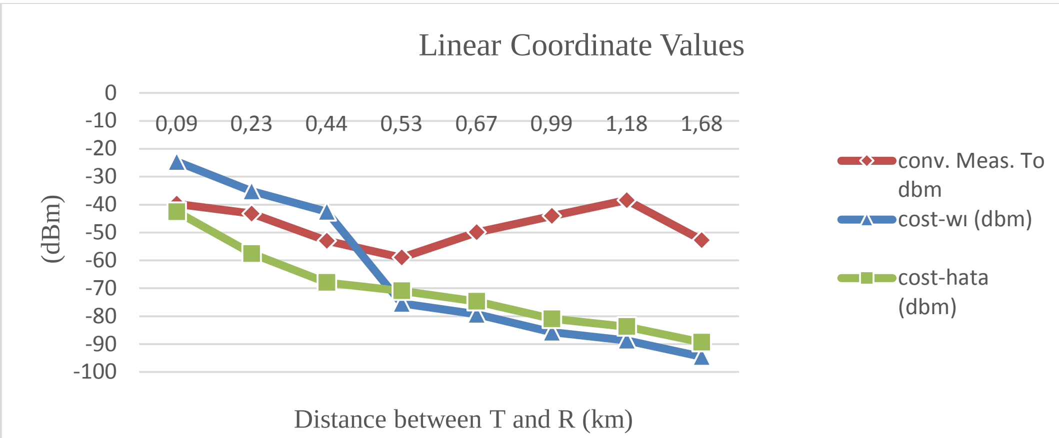


Figure 4.11 - Comparison graph of calculation results and measurement values

As seen on Figure (4.11) (graph) the values of the points which are located nearly to the base station antenna are close to the measured values.

Looking at the results with an overall view, as seen the models have advantages and disadvantages. The Fspl + Epstein-Peterson model seems to be successful, than the other models, which is used in thesis, in the selected area. This observable result can be supported with the Mean Square Error (MSE) equation (4.1) [32].

$$MSE = \sqrt{(\sum (Pm\text{-}Pr))^{2} / (N-1)} \quad \text{(Eq. 4.1)}$$

where;

Pm: Measured value

Pr: Calculated value

N: Number of measured points

The MSE results are shown in Table (4.1) one by one due to the propagation methods as linear and random.

Table 4.1 MSE values of propagation models

Method	**Random**	**Linear**
Fspl + RMD	13,585 dBµV/m	10,3277 dBµV/m
COST-WI	30,23749 dBm	20,81903 dBm
COST-Hata	31,51792 dBm	19,90329 dBm

As known Fspl + Epstein –Peterson model is interested in geographical structures. The geographical situations are more efficient than the buildings effects. But at the near points to the antennas the COST-WI model is more appropriate from the Fspl + Epstein-Peterson propagation model. This comes from the theoretical parameters of the models. So, for a better prediction in the propagation model studies, the topography and the building effects should be evaluated together.

COST - Hata should be examined from a different point of view. As known from the studies in literature, this model is working after 1 km distance from transmitter and working with the 30 or higher meter receivers. In this case with the help of the MSE results the Okumura-Hata's formulation was modified due to the parameters which were used in thesis for the selected area. These parameters were shown below.

Four parameters used in Okumura - Hata model are listed below:

- Frequency (f) : 1500 – 2000 MHz
- Distance between transmitter and receiver (d) : 0,1 – 2 km

- Transmitter antenna height (hTX as h_{Base}) : 20 – 200 m
- Receiver antenna height (hRX as h_{mobile}) : 1 – 10 m

By this way, the MSE value can be added to the Okumura - Hata formula as a correction factor the modified formula will be;

$$Lb_{\text{modified}} = Lb\,(\text{okumura - hata}) + k \qquad \text{(Eq. 4.2)}$$

where;

Lb (okumura - hata)	Cost - Hata formula
k= 31,52	urban - suburban

Results of the application of the modified equation (4.2), was shown in the graph.

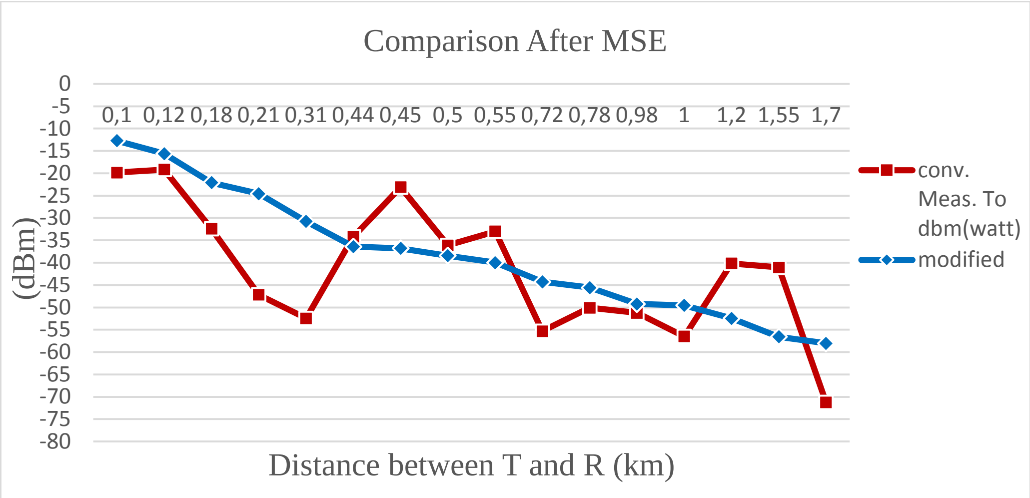


Figure 4.12 – Comparison of the measured and modified values

CHAPTER FIVE

5. CONCLUSIONS

In the mobile communication transmission, the main point is path loss, as frequency band is the limited source. Especially the developing cellular systems (GSM) loss in the power of transmission increased its necessity. Before field constructions right modeling should be done. As it is important to determine the probability of satisfactory performance of the communication system. This is the core of the all field strength studies. By this way it can be possible to predict the signal strength at the end of the communication line.

According to these, the aim of this thesis study is to find proper propagation model for the cities which are constructed unregularly or under construction. As an example a city cannot be able to construct regularly due to the terrain. Apartment towers or parking areas can be located in same place. Because of that in this thesis study an area is selected according to these conditions and the famous propagation models were applied on this area. These models are Free Space Path Loss + RMD (Epstein-Peterson), COST-HATA and COST-WI.

As a result of the application of the models it was clearly seen that the Fspl + RMD (Epstein-Peterson) model is more successful than the other models. This success is approved by MSE. So, the most proper propagation model for the selected area is Fspl + RMD (Epstein-Peterson).

Besides with the help of the MSE, the Okumura-Hata model was modified adding a correction factor to its formula (COST-Hata) as ‘k’, in order to adapt the model to the parameters of the selected area.

In addition, there is an important point in GSM. During making propagation or coverage planning there has some governmental rules. These rules are related with the transmitter location point. The transmitter should not be located to near a house or rooftop.

As it is known the propagation models can able us to predict the signal strength at the end of the communication line in the field strength studies and it can be concluded in this study that, although COST-WI propagation model is interested in building structures it is successful in near points where the Epstein-Peterson RMD method is more successful in far field points from the transmitter as it is interested in topography.

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