MICROWAVE PROPAGATION PREDICTIONS ON RADIO COVERAGE OF UMTS

by

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ABSTRACT

MICROWAVE PROPAGATION PREDICTIONS ON RADIO COVERAGE OF UMTS

The success story of GSM system is very well known throughout the world. The reason for its success is due to its ability to give services to its users anywhere and anytime. In fact, GSM basically gives speech services. Now, GSM operators also want to give data services by taking advantage of their existing network infrastructure. Although there are many ongoing studies over GSM in order to improve data service capabilities, none of them can lead GSM to GSM operators' data rate goals.

Now, GSM operators are completely changing the air interface of the GSM, while still keeping the rest of the network. Instead of GSM TDMA air interface, WCDMA air interface technology is being used. Changing the air interface technology means changing the type and the number of base stations. Operators try to find the optimum positions and the optimum numbers for their new base stations.

This study deals with microwave propagation models. These are used to find the number of needed base stations to provide the coverage requirements for the networks in WCDMA networks. They also help to determine where the cell sites should be located to achieve an optimum position in the network.

This study concentrates on comparative parametric analysis for propagation path loss prediction models considering the macrocell region. It uses three different models. Model prediction results were compared with the real measurements obtained from a UMTS based network for city İstanbul. The study concludes which of the models is best suited for İstanbul.

ÖZET

UMTS KAPSAMA ALANI ÜZERİNDE MİKRODALGA YAYILIM ÖNGÖRÜSÜ

GSM sistemin başarı hikayesi bütün dünyada çok iyi bilinmektedir. Başarısının nedeni kullancılarına her an ve her yerde hizmet verebilmesidir. Aslında, GSM kullanıcılarına en temelde konuşma hizmeti verir. Şimdilerde, GSM operatörleri, mevcut ağ altyapılarından yararlanarak, data hizmetini de kullanıcılar sunmak istiyorlar. GSM'in data hizmet kapasitesini arttırmak için yapılmakda olan bir çok çalışma olmasina rağmen, bunların hiçbiri GSM'i, GSM operatörlerinin data hız hedeflerine ulaştıramamıştır.

Şimdilerde, GSM opertörleri, hava arayüzü haricindeki ağlarını koruyarak, GSM hava arayüzünü tamamen değiştiriyorlar. GSM TDMA hava arayüzü yerine, WCDMA hava arayüzü teknolojisi kullanılmaktadır. Hava arayüzü teknolojisinin değişmesi baz istasyonlarının şeklinin ve sayısinin değişmesi anlamına gelir. Operatörler yeni baz istasyonları için optimum konumu ve optimum baz istasyonu sayısını bulmaya çalışıyorlar.

Bu çalışma mikrodalga yayılım modelleriyle ilgilidir. Bu modeller, WCDMA ağlarında yeterli kapsama alanı sağlamak için gerekli olan baz istasyonu sayısını bulmak için kullanılır. Bu modeller, ayrıca, ağda en uygun baz istasyon konumu için baz istasyonunun nereye yerleştirimesi gerektiğini belirlemeye yardımcı olur.

Çalışma, makrohücre alanlarında, yol kaybı dalga yayılım modellerin parametrik karşılaştırmalı analizi üzerine yoğunlaşmıştır. Çalışma üç farklı model kullanır. Model öngörü sonuçları İstanbul için WCDMA ağından elde edilen gerçek ölçümlerle kıyaslanmıştır.

Çalışma modellerden hangisinin İstanbul için en uygun olduğu ile son bulur.

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LIST OF SYMBOLS/ABBREVIATIONS

A_0, A_1, A_2, A_3	Model tuning parameters for Algorithm 99999 path loss model
A_e	The effective area of an antenna
$a(h_m)$	Correction factor in Okumura-Hata path loss model
d	Distance between transmitter and receiver
f	Frequency of the radio wave
G_r	Receiver antenna gain
G_t	Transmitter antenna gain
H	Height of buildings
h	Antenna height of Base station
h_b	Effective height, the difference between the altitude and the average terrain height
h_{eff}	Effective base station antenna height
h_m	Antenna height of mobile station
L_{bsh}	Base station height loss
L_{KE}	Knife edge diffraction loss
L_{msd}	Multiple blocking diffraction loss
L_{mul}	Multiple screen loss
L_{ori}	Orientation loss
L_{rts}	Diffraction loss and scattering loss from rooftop to streets
L_{sp}	Free space loss
PL	Path Loss
PL_{LOS}	Path loss in LOS
PL_{NLOS}	Path loss in NLOS
P_r	Received power
P_t	Transmitted power
$W_1 - W_9$	Semiempirical parameters in Walfisch-Ikegami Model in TCPU
λ	Wavelength of the radio wave

μ	Mean error
σ	Standard deviation of error
1G	First generation
2G	Second generation
3G	Third generation
3GPP	Third Generation Partnership Project
ADSL	Mega chips per second
AMPS	Advanced Mobile Phone Services
AUC	Authentication Center
BS	Base Station
BSC	Base Station Controller
BTS	Base Transceiver Station
CDMA	Code Division Multiple Access
CLPC	Closed Loop Power Control
CN	Core Network
CPICH	Common Pilot Channel
CPLM	Composite Pathloss
CS	Circuit Switched
DL	Downlink
DPCH	Downlink Dedicated physical channel
DS	Direct sequence
EDGE	Enhanced Data Rates for Global Evolution
EIR	Equipment Identity Register
EIRP	Equivalent Isotropic Radiated Power
EM	Electromagnetic
ETSI	European Telecommunications Standards Institute
FDD	Frequency division duplex
FDMA	Frequency division multiple access
FDTD	Finite-difference time-domain
FSK	Frequency shift keying

GGSN	Gateway GPRS Support Node
GIS	Geographic information system
GMSC	Gateway MSC
GMSK	Gaussian Minimum Shift Keying
GMSK	Gaussian Minimum Shift Keying
GPRS	General Packet Radio Services
HIPERLAN	High Performance Radio Local Area Network
HHO	Hard handover
HLR	Home Location Register
HSCSD	High speed circuit switched data
HSPA	High-Speed Packet Access
HSOPA	High-Speed OFDM packet access
HSxPA	High Speed Downlink/Uplink packet access
IS-95	Interim Standard 95
ISDN	Integrated Services Digital Network Home Location Register
IP	Internet protocol
ITU	International Telecommunications Union
LoS	Line-of-sight
MAPL	Maximum allowable pathloss
Mbps	Megabits Per Second
Mcps	Mega Chips Per Second
NLoS	Non Line-of-Sight
NMC	Network Management Center
Node B	BTS in UMTS
MT	Mobile terminal
OFDM	Orthogonal Frequency Division Multiplexing
OLPC	Open loop power control
OMC	Operation and Maintenance Center
OVSF	Orthogonal Variable Spreading Factor
RCU	Remote Control Unit
PDF	Probability Density Function

PLMN	Public Land Mobile Network
RNS	Radio network sub-system
RRM	Radio Resource Management
PSTN	Public Switched Telephone Network
SGSN	Serving GPRS Support Node
SHO	Soft handovers
SMS	Short Message Service
SPM	SPM Standard Propagation Model
TCPU	TEMS Cell Planner Universial
TEMS	Test Mobile System
SQL	Structured query language (Database query lanquage)
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
UE	User equipment
UHF	Ultra High Frequency
UL	Uplink
UMTS	Universal Mobile Telecommunications System
USIM	UMTS Subscriber Identity Module
UTRAN	UMTS Terrestrial Radio Access Network
VHF	Very high frequency
VLR	Visitor Location Register
WCDMA	Wide band code division multiple access
WLAN	Wireless Local Area Network

1. INTRODUCTION

1.1. Brief History of Mobile Cellular Systems

Wireless and mobile technology have a very well known success story. In some countries the penetration of mobile communications is around % 100. This is especially in the European countries, that means virtually everyone capable of using a mobile phone (at least one) [1].

The reasons for this huge success, and how we got here have been the subject of many studies since the times of first generation mobile cellular systems. No one can tell the exact reasons behind this huge success, but a common idea is that the success of the system is very closely related to its ability to connect people "anywhere and anytime".

1.1.1. First Generation

The first generation of mobile cellular telecommunications systems appeared in the 1980s. There was no dominant standard but there were several competing ones. The most successful standards were Nordic Mobile Telephone (NMT), Total Access Communications System (TACS), and Advanced Mobile Phone Service (AMPS).

The first generation used analog transmission techniques for traffic, which was almost entirely voice. Analogue technology can only offer a limited degree of reuse before interference starts to cause dropped calls and crossed lines. However, digital technology could allow much greater reuse and, at the same time, offer more capacity with higher security through digital speech coding [2].

Although the world is now busy with moving into 3G networks, these first-generation networks are still in use. Some countries are even launching new first-generation networks, and many existing networks are growing. However, in countries with more advanced telecommunications infrastructures, these first-generation systems will soon be, or already have been, closed, since they waste valuable frequency spectrum that could be used in a more effective way for newer digital networks [3].

1.1.2. Second Generation

The rapid development of second generation mobile telecommunication systems was one of the most notable success stories of the 1990s. The first GSM network was launched in Finland in 1991, since then GSM and other second generation systems have been expanding and evolving continuously.

Today, there are 2.5 billion subscribers in the world and 850 subscribers are added in a minute all over the world. Tendency of new subscriber is toward data communication and wide band mobile services [4].

The boundary line between the first and the second generation systems is very clear: From the analog to digital split.

The 2G networks offer much higher capacity than the first-generation systems. Because unlike first generation systems, in second generation, one frequency channel is simultaneously divided among several users (either by code or time division). Using hierarchical cell structures in which the service area is covered by macrocells, microcells, and picocells enhance the system capacity even further.

The digital systems currently in use, such as GSM, PDC, cdmaOne (IS-95) and US-TDMA (IS-136), are second generation systems. These systems have enabled voice communications to go wireless and some extent data communication is possible.

1.1.3. 2.5. Generation

2.5 is a stepping stone between 2G and 3G cellular wireless systems. The term "second and a half generation" is used to describe 2G systems that have implemented a packet switched domain in addition to the circuit domain. The aim of these upgrades is to increase data capabilities of the existing networks. The boundary line between 2G and 2.5G is a not clear. It is difficult to say when a 2G becomes a 2.5G system in a technical sense [3].

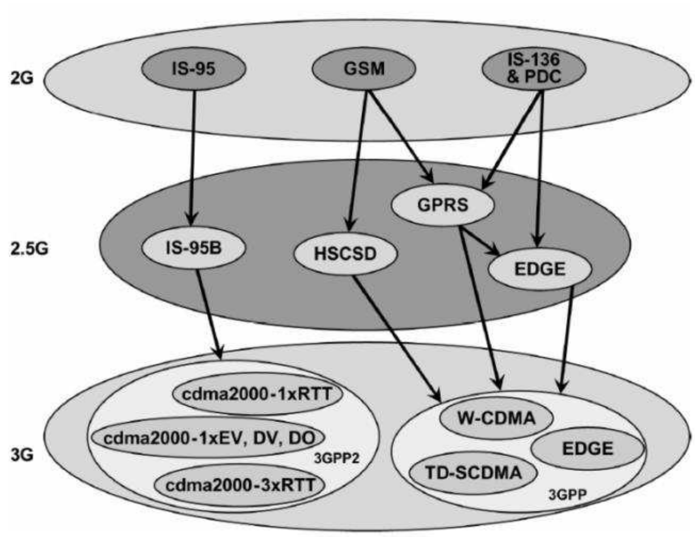

Figure 1.1. Upgrade paths for 2G systems,[5]

Figure 1.1 shows upgrade paths for 2G systems, a 2.5G GSM system includes at least one of the following technologies: High-speed circuit-switched data (HSCSD), General Packet Radio Services (GPRS), and Enhanced Data Rates for Global Evolution (EDGE). An IS-136 system becomes 2.5G with the introduction of GPRS and EDGE, and an IS-95 system is called 2.5G when it implements IS-95B, or CDMA2000 1xRTT upgrades.

1.1.4. Third Generation

In the same year that GSM was commercially launched, ETSI had already started the standardization work for the next-generation mobile telecommunications network. This new system was called the Universal Mobile Telecommunications System (UMTS).

The 3G development work was not done only within ETSI. There were other organizations and research programs that had the same purpose.

Later the most important companies in telecommunications joined forces in the 3GPP program from Europe, Japan, Korea, the USA and China, with the goal of which is to produce the specifications for a 3G system based on the ETSI Universal Terrestrial Radio Access (UTRA) radio interface. In these forums, WCDMA technology has emerged as the most widely adopted third generation air interface. UMTS takes advantage of the existing GSM and GPRS networks, which serve as a core network in the UMTS infrastructure [6].

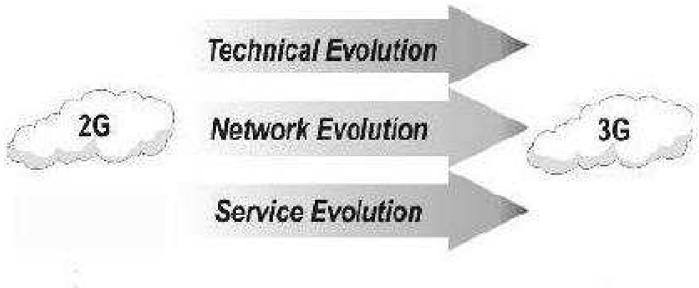

Figure 1.2. Technical, network and service evolution, [6]

Third generation systems are designed for multimedia communications, with them communication will be enhanced with high quality images and videos. Moreover, access to information and services on public and private networks will be enhanced by the higher data rates and new flexible communication capabilities. This, together with the continuing evolution of the second generation systems, will create new business opportunities not only for manufacturers and operators [6].

In Figure 1.3, basic properties of each mobile telecommunication generation is shown.

1.2. Future Trends

In future, it is expected that mobile and wireless applications and services will become more and more common, also the variety of devices will increase. Furthermore, computation and communication facilities of these devices will be more advanced.

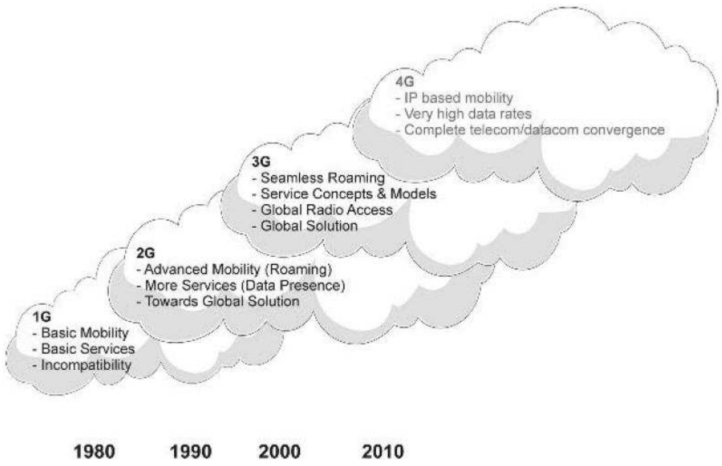

Figure 1.3. Cellular generation,[7]

Cards, rings, watches, eyeglasses can be used as communication and computation device.

The size of devices will be pocket sized, and walls or table screen will be working areas. The technology will undergo a transformation, from an expensive, highly visible, hi-tech technology as in early mobile phones, over the current situation where almost everyone owns a mobile phone, to a disappearing technology that is present everywhere and taken for granted [1].

Moreover, there is clearly the need to invent new access techniques and network architectures, so that future use of mobile and wireless communications can be made in an effective way [1].

The probability of increased success can be measured by the way this vision creates a disruption with the existing networks or systems. The old vision of anywhere, anytime could easily be replaced by, any network, any device, any content. Basically, this vision carries many implications, some of which are discussed in what follows.

It is also very unusual to expect from users make a decision on the network to be used on their common use of system. From that reason, the complexity of systems and networks should be concealed to users.

The use of the system should be independent of the device. For example, users will just carry a kind of Radio Frequency Subscriber Identity Module (RF SIM), i.e. simply a small card that carries all their information. This small card communicates via RF with all the devices available in its range. This will enable users to take advantage of many types of devices which is available for them [1].

A future vision cannot be complete without the definition of the future application scenarios and users. A good starting point from which one should draw trends is to look at users as our children/grand children who will be the active population in 1520 years time. Moreover, content needs to be meaningful, since, on the one hand, non-desired information (e.g. advertisement, spam, virus, etc.) and privacy are proving problematic in todays communications, as is evident in computing (e.g. e-mail, and intrusive and destructive Internet access); on the other, it also means that filtering of information is very important, so that users get what they really want [1].

Finally, the information should be multisensory making use of all five human basic senses. It is very clear that the realization of the future vision of mobile and wireless communications demands requires multidisciplinary research and development. [1]

Is there any limitation of the development of wireless communication? The answers for this question is yes due to following limitating factors: Limited electromagnetic spectrum, the storage of electrical energy within stringent size, the amount of money and time spent by people on mobile communication. Moreover, the size of the mobile satiation is again a limitation. Mobile phones should be light and small enough to be easily carried, and they should be large enough to use it in everyday life [8].

If all the factors which were mentioned above are evaluated, it can be seen that frequency limiting is one of the most critical limitation factors. Because radio wave communication is only possible a relatively narrow band, approximately between 0.1 GHz to 5 GHz. For the lower frequencies, there is no available free spectrum for mobile communication. Moreover, below 0.1 GHz, the size of the electronic devices and antennas becomes too large to carry. After 5 GHz, wave attenuation becomes too fast and deep to allow for the deploying the cost-effective networks [8]. In the frequencies between 0.1 Ghz to 5 GHz, there are many other applications such as radio, television, radio navigation, weather satellites, military radios, radio links, private radio for officials, remote controlling, remote sensing, satellite navigation etc. For these reasons; the best thing to do is using the available spectrum in a very wise manner in a given geographical area, while bearing in mind that interference among system will create decrease in performance. The propagation environment has a large influence on interference [8], [9] and this is what the study is about: studying the usage of environment specific propagation models within the area of mobile radio system design.

The study is organized as follows. A brief description of GSM and UMTS as concerning spectrum allocation, network architecture, multiple access techniques, modulation and power control, are given Chapter 2 and Chapter 3, respectively. Throughout these two chapters, basic network architecture of GSM and UMTS systems are discussed. A brief comparison between UMTS and GSM in terms of air interface, transmitted and received power, data and service capabilities, user devices, network planning, propagation prediction models and antennas, are presented in Chapter 4. Wave propagation phenomena is described in Chapter 5. Path loss models for outdoor environments are presented in Chapter 6. In Chapter 7, used toolkit during this study, namely TCPU, Tems Investigation and MapInfo softwares, their basic and important features are mentioned. Finally, in chapter 8, applied path loss models and path loss maps for WCDMA sites in İstanbul and their comparison with measurements are presented. A brief literature survey about path loss models is given. In Chapter 9, there is a very brief conclusion of this study.

2. GLOBAL SYSTEM FOR MOBILE COMMUNICATION (GSM)

2.1. Introduction

GSM was the first developed in the 1980s. Unlike first generation, GSM system uses digital technology and a narrow band TDMA solution. The modulation scheme of GSM is Gaussian minimum shift keying (GMSK). After some the technical consideration, in 1991, GSM was the first commercially operated digital cellular system in Finland. GSM is by far the most popular and widely implemented cellular system with more than a billion people using this system.

GSM system has been based on open standardization. Network operators can take advantage of deploying equipment from different vendors because the open standard allows easy interoperability. Another important feature of GSM is that GSM allows much greater reuse factor, when we compare it with first generation system, in the second generation systems, capacity of the network is increased. Moreover, it provides higher security through digital speech coding. [10]

This section briefly summarized network architecture of GSM system.

2.2. Spectrum Allocation

As GSM has grown worldwide, it has expanded to operate at three frequency bands: 900, 1800 and 1900 MHz. The uplink frequency band in the 900 MHz band is 935-960 MHz and the downlink frequency is 890-915 MHz. Thus, in both the uplink and downlink the band is 25 MHz, which is subdivided into 124 carriers, each being 200 kHz apart. Each radio frequency channel contains eight speech channels.

2.3. GSM Network Architecture

As shown Figure 2.1, the network components GSM system can be divided into two subsystems. Each of these systems are comprised of a number of functional units which are individual components of the mobile network. These systems are [11]:

- Switching System (SS)
- Base Station System (BSS)

In addition to these systems, there are computerized centers for maintaining, operating and managing all the network.

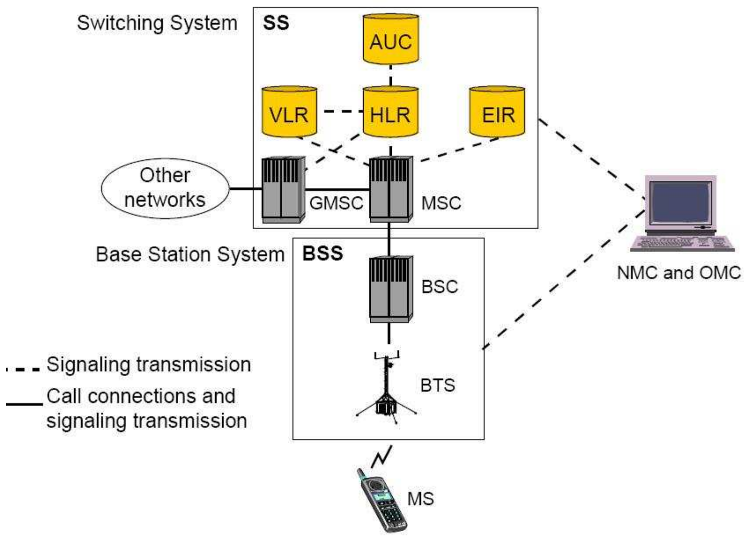

Figure 2.1. System model, [11]

2.3.1. Switching System (SS)

The SS is basically responsible for performing call processing and subscriber related functions. It includes the following functional units:

<u>2.3.1.1. Mobile services Switching Center (MSC).</u> The MSC performs the telephony switching functions for the mobile network. It controls calls to and from other telephony and data systems, such as the Public Switched Telephone Network (PSTN), Integrated

Services Digital Network (ISDN), public data networks, private networks and other mobile networks.

2.3.1.2. Home Location Register (HLR). The HLR is a centralized network database that stores and manages all mobile subscriptions belonging to a specific operator. It acts as a permanent store for the subscription information of a person until that subscription is canceled.

The HLR can be implemented in the same network node as the MSC or as a stand-alone database.

2.3.1.3. Visitor Location Register (VLR). The VLR database contains information about all the mobile subscribers currently located in an MSC service area. Thus, there is one VLR for each MSC in a network. The VLR temporarily stores subscription information so that the MSC can service all the subscribers currently visiting that MSC service area. The VLR can be regarded as a distributed HLR as it holds a copy of the HLR information stored about the subscriber. When a subscriber roams into a new MSC service area, the VLR connected to that MSC requests information about the subscriber from the subscribers HLR. The HLR sends a copy of the information to the VLR and updates its own location information. When the subscriber makes a call, the VLR will already have the information required for call set-up [11].

2.3.1.4. Authentication Center (AUC). The main function of the AUC is to authenticate the subscribers attempting to use a network. In this way, it is used to protect network operators against fraud. The AUC is a database connected to the HLR which provides it with the authentication parameters and ciphering keys used to ensure network security [11].

2.3.1.5. Equipment Identity Register (EIR). The EIR is a database containing mobile equipment identity information which helps to block calls from stolen, unauthorized, or defective MSs. It should be noted that due to subscriber-equipment separation in GSM, the barring of MS equipment does not result in automatic barring of a subscriber [11].

2.3.2. Base Station System (BSS)

2.3.2.1. Base Station Controller (BSC). The BSC manages all the radio-related functions of a GSM network. It is a high capacity switch that provides functions such as MS handover, radio channel assignment and the collection of cell configuration data. A number of BSCs may be controlled by each MSC.

2.3.2.2. Base Transceiver Station (BTS). The BTS controls the radio interface to the MS. The BTS comprises the radio equipment such as transceivers and antennas which are needed to serve each cell in the network. A group of BTSs are controlled by a BSC.

2.4. Network Monitoring Centers

2.4.1. Operation and Maintenance Center (OMC)

An OMC is a computerized monitoring center which is connected to other network components such as MSCs and BSCs via X.25 data network links. There may be one or several OMCs within a network depending on the network size.

2.4.2. Network Management Center (NMC)

Centralized control of a network is done at a Network Management Center (NMC). Only one NMC is required for a network and this controls the subordinate OMCs. The advantage of this hierarchical approach is that staff at the NMC can concentrate on long term system-wide issues, whereas local personnel at each OMC can concentrate on short term, regional issues. OMC and NMC functionality can be combined in the same physical network node or implemented at different locations.

2.5. General outlook at GSM System

2.5.1. Multiple Access Techniques

The radio interface of GSM is a combination of FDMA (Frequency Division Multiple Access) and TDMA (Time Division Multiple Access). T 890-915 MHz and 935-960 MHz bands are allocated for GSM system. The first 25 MHz band is used for the uplink connection and the second 25 MHz band is used for downlink connection. The central frequencies are separated evenly every 200 kHz within these bands, starting 200 kHz away from the band borders. Therefore 124 different frequency slots are defined in 25 MHz. Each 200 kHz frequency slot is divided into some equal pieces in time, each called as a time slot. Eight full rate time slots or sixteen half rate time slots are used in one frequency carrier.

2.5.2. Modulation

GSM uses Gaussian Minimum Shift Keying (GMSK) modulation with a bandwidth time product of 0.3 at a data rate of 271 kbit/s.

2.5.3. Power Control

Power control refers to the possibility to modify the transmission power on the radio, both for the mobile station and the base station. The main goal of power control is improving the spectral efficiency and to some extent, saving the battery life for the mobile station.

2.5.4. Services

The GSM became more user friendly with many services, apart from just making calls. These services included voice mail, SMS, call waiting, etc. SMS was a phenomenal success, with almost 15 billion SMS sent every month by the year 2000. The key advantage of GSM systems has been higher digital voice quality and low cost alternatives to making calls, such as text messaging. Features such as prepaid calling, international roaming, etc., enhanced [10].

2.5.5. Handover

In dedicated mode, the process of automatically transferring a transaction in a progress from one cell to another is called handover. Handover is always initiated by the network evaluating the measurement reports sent by the mobile station. Handover within BTSs, among BTSs, and even among PLMNs is possible.

3. UNIVERSAL MOBILE TELECOMMUNICATIONS SYSTEM (UMTS)

3.1. Introduction

The UMTS is the one of the third generation mobile communication systems which has been standardized by the 3GPP (Third Generation Partnership Project) organization. UMTS provides fully integrated digital communication with maximum data throughput up to 2 Mbit/s. High data transfer and compression techniques make it possible pretty good access to web servers and high quality video streaming. UMTS became perfect tool for providing wireless video calls and video conferences. It was possible until now only fixed digital communications. UMTS uses packet switched connection, which are integrated part of this network. WCDMA access technology was chosen for air access technology for UMTS. Even though, UMTS was meant to be a universal system, the different spectrum allocations for different parts of the world complicates its straightforward usage [12].

In this section, basic network infrastructure of UMTS system is presented. More detailed description can be found in [7] or [13], for the UMTS system and [14] for mobile communication systems in general.

3.2. Spectrum Allocation

The WCDMA-FDD uses frequencies of 2110-2170 MHz for downlink (from the BS to the UE) and 1920-1980 MHz for uplink (from the UE to the BS). Air interface transmission directions are separated by different frequencies and the duplex distance is 190 MHz. The TDD variant of the WCDMA uses a frequency band located at both sides of the WCDMA-FDD uplink. The lower frequency band offered for the TDD variant is 20MHz and the higher one is 15 MHz [7].

3.3. UMTS Radio Interface

The radio interface of a mobile radio system is generally interpreted as the interface between the mobile station and the base station. In the UMTS standard, it is also referred to as the U_u interface.

UMTS uses WCDMA as radio interface technology. Although UMTS compatible with GSM in terms of the core network, it is incompatible with GSM in terms of radio interfaces. This chapter introduces the principles of the WCDMA air interface.

3.3.1. Duplex Procedures

A duplex procedure generally separates the transmit and receive signals of a station. UMTS specifications include two different duplexing modes: FDD (Frequency division duplex) and TDD (Time division duplex). Deployment of the FDD mode is by far the more widespread than TDD mode, since FDD is more suitable for fulfilling outdoor and large area coverage requirements. The usage of the UMTS TDD mode has been considered for indoor usage only [15].

The physical parameters in UTRA TDD and UTRA FDD modes are shown in Table 3.1.

3.3.2. Multiple Access Method

Within a transmission direction, a multiple access technique distributes the available transmission bandwidth among the individual users or connections. The multiple access technique defines the so-called physical channels. A physical channel is characterized by different physical parameters, e.g., by a period of time or a frequency range. Two stations communicate over a physical channel. These physical channels should be defined so that various connections do not cause mutual interference [13].

There are various techniques of sharing the radio interface by the simultaneous

Table 3.1. Comparison of UTRA TDD and UTRA FDD physical layer parameters, [12]

	UTRA TDD	**UTRA FDD**
Multiple access method	TDMA, CDMA (inherent FDMA)	CDMA (inherent FDMA)
Duplex Method	TDD	FDD
Channel Spacing	5MHz	
Carrier Chip Rate	3.84Mcps	
Time slot structure	15 slots/frame	
Frame length	10ms	
Multirate concept	Multicode, multislot, and orthogonal variable spreading factor (OVSF)	Multicode and OVSF
Interleaving	Inter-frame (10,20,40,and 80 ms)	
Modulation	QPSK	
Dedicated channel power control	Uplink : open loop; 100 Hz or 200 Hz, Downlink : closed loop; rate $\leq$ 800Hz	Fast closed loop; rate=1500 Hz
Intra-frequency handover	Hard Handover	Soft Handover
Inter-frequency handover	Hard Handover	Soft Handover
Spreading factors	1..16	4...512

communicating multiple users. There are three methods which is used in cellular systems. These are TDMA (Time Division Multiple Access), FDMA(Frequency Division Multiple Access), and CDMA (Code Division Multiple Access).

In Figure 3.1, multiplexing schemes are shown. In CDMA scheme, the simultaneous users use the same frequency, but they are separated by different codes. FDMA technology divide whole band to sub-bands and then assigns each subscriber to a unique

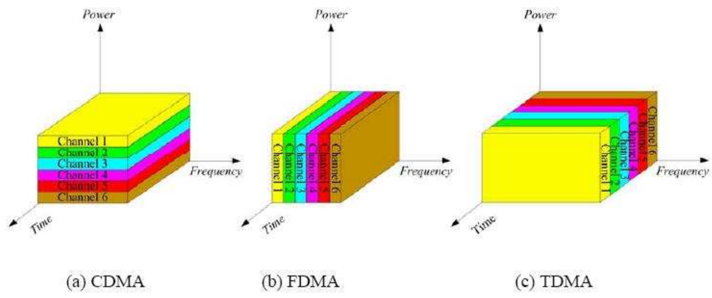

Figure 3.1. Multiple Access Schemes: (a) CDMA, (b)FDMA (c)TDMA, [12]

frequency. TDMA allows subscribers to use the same frequency, but separates them by time slots.

3.3.3. Scrambling and Spreading Codes

In CDMA, user information bits are spread over a wide bandwidth and each channel uses of all the available bandwidth all of the time. Therefore, in order to distinguish a wanted channel from the many other channels that share the same bandwidth, a layer of coding is needed. These code layers enable to differentiate between base stations and so provide a degree of separation between cells on the downlink. These codes are called scrambling codes. Each call is separated by a set of scrambling code and each receiver unscrambles the code it needs. Scrambling codes are different from spreading codes, which use code bits called chips to multiply the user information. Each user has a different spreading code, enabling to differentiate one user from another on the same cell by spreading them recovering the original information through subsequent processing [16].

The Figure 3.2 shows the relationship between spreading and scrambling codes:

3.4. Network Architecture

UMTS system uses existing GSM and GPRS networks as a core network. Figure 3.3 shows UMTS radio network architecture.

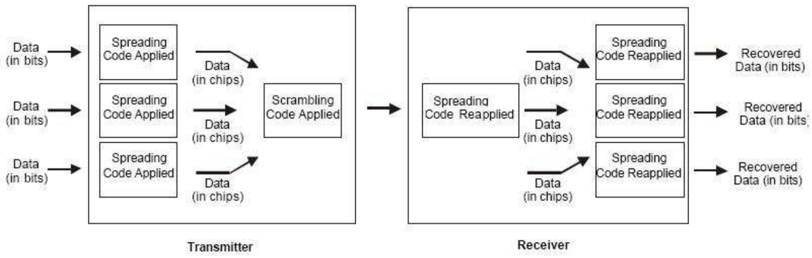

Figure 3.2. Spreading and scrambling codes, [17]

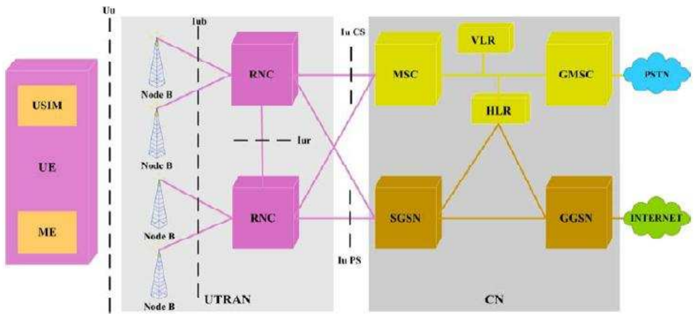

Figure 3.3. UMTS network architecture, [12]

There are three main element in this infrastructure namely User Equipment (UE), UMTS Terrestrial Radio Access Network (UTRAN) and Core Network (CN).

3.4.1. User Equipment

UE is a 3GPP terminology and refers to mobile station (MS) in second generation system. User equipment consist of two part:

-Mobile Equipment (ME): Mobile equipment connects subscriber to the UTRAN via U_u.

-UMTS Subscriber Identity Module (USIM): This is a smart card which is similar SIM card in GSM system. This card contains information about subscriber such as subscriber identity, and also contains authentication algorithms, authentication and encryption keys etc.

3.4.2. UMTS Terrestrial Radio Access Network (UTRAN)

This system basically manages the radio packet transmission and resource management. A UTRAN consists of one or more RNSs (Radio network sub-systems), which in turn consists of base stations (Node B) and their controllers (RNC). The RNS performs all of the radio resource and air interface management functionalities.

-Node B (BS in GSM): Node B performs physical layer processing such as data interleaving, rate matching, channel coding, modulation etc. Node B converts data between U_u radio interface and I_{ub} interface.

-Radio Network Controller (RNCs): Every RNC has one or more Node B. First duty of RNC is to control Node B which is attached to itself and manege radio resources assigned to them. From this perspective, RNCs perform the data link layer processing in the handover procedures. The RNC is considered as a service access point of UTRAN for the core network. It is connected to a single MSC/VLR to route circuit switched traffic and to a single SGSN to route packet switched data [12].

3.4.3. Core Network

The core network handles call control and mobility management functionalities. As mentioned, UMTS uses GSM and GPRS infrastructure as a core network. For this reason the elements of this system are the elements of GSM and GPRS.

-Mobile Switching Center (MSC)/Visitor Location Register (VLR): This system handles circuit switched traffic.

-Home Location Register (HLR): Performs similar functions to those in the GSM and GPRS systems.

-Gateway MSC (GMSC): GMSC connect UMTS systems with external circuit switched networks.

-Serving GPRS Support Node (SGSN): Similar to the GPRS system, SGSN serves the packet switched traffic.

-Gateway GPRS Support Node (GGSN): Similar to the GPRS systems, GGSN connect UMTS systems with other external Packet Switched Network.

3.5. Radio Resource Management in WCDMA

3.5.1. Power Control

The UMTS is an interference-limited system. In order to support maximum capacity and the best quality of service, appropriate signal coverage should be granted. For these reasons, the main goal is the optimization of transmission power level. This also means that interference introduced by additional users and introduced by high throughput should be minimized. The role of the power control is keeping the power strength at appropriate level. Approximately 200 MHz band separates transmission in uplink and down-link direction in frequency domain. For this reason, path loss in uplink and down-link is different. So, different uplink and down-link power control is needed. Especially in uplink direction effective power control mechanism is vital. Because in this direction near-far problem occurs.

In the downlink direction, the power control is done in order to reduce intercell interference. There are three types of power control used in UMTS networks: Open loop power control, inner loop power control, and outer loop power control. More detail information about power control in UMTS can be found in [13] and [18].

3.5.2. Handover

When mobile user are moving, deep variations in signal level and interference can be observed. Especially from one cell edge to the other, signal from serving base station is worsening. In these case, it will be more convenient for mobile user to change its base station. This process is known as handover.

In GSM, there is only so called hard handovers (HHOs) exists. In a hard handover, old radio link is released before new radio link is established. In WCDMA technology, there are also different kinds of handovers: Soft handovers (SHOs) and softer handovers (SfHOS). These handovers can only be possible in FDD mode. WCDMA also supports hard handovers, which can be classified as intra-frequency, inter-frequency, and inter-system handovers. These types are supported by UTRA FDD and UTRA TDD modes.

Handover procedure can cause drop calls. The reason of this may be signalling errors and lack of the radio resources. Handovers have to be very effective, because the access to the service has to be assured for users during ongoing call, and when the handovers are performed. The handover failure should be minimized especially in high performance networks like UMTS.

3.6. UMTS Services

The UMTS is best known for its ability to support higher user bit rates. Second generation systems like GSM, were originally designed for efficient delivery of voice services. UMTS networks are, on the contrary, designed from the beginning for flexible delivery of any type of service, where each new service does not require particular network optimization. In addition to the flexibility, the WCDMA radio solution brings advanced capabilities that enable users new services.

Such capabilities are [18]:

- High bit rates theoretically up to 2 Mbps in 3GPP Release 99, and beyond 10 Mbps in 3GPP Release 5. Practical bit rates are up to 384 kbps initially, and beyond 2 Mbps with Release 5;
- Low delays with packet round trip times below 200 ms;
- Seamless mobility also for packet data applications;

- Quality of Service differentiation for high efficiency of service delivery;
- Simultaneous voice and data capability;
- Interworking with existing GSM/GPRS networks.

3.7. Interference in WCDMA

The behavior of cellular CDMA mobile radio networks differ considerably from that of cellular TDMA/FDMA networks. The reason for this is a basically different interference situation: In CDMA networks, all users utilize the same frequency channel. Consequently, the resulting co-channel interference is comparatively high whereas the carrier-to-interference ratios are appropriately low. Added to this is that co-channel interference in TDMA/FDMA networks always originates in other cells; in CDMA networks all users of the same cell also cause interference to one another. Interference power caused by users of the same cell is called intracell interference. The interference power resulting from connections in co-channel cells is called intercell interference. CDMA networks typically have the cluster size one, which means that all senders in the network are causing mutual interference. Due to the close proximity of intracell interferers, the intracell interference is usually greater than the intercell interference. Consequently, many of the effects noticeable in cellular CDMA networks are essentially caused by intracell interference. Intracell co-channel interference does not occur in TDMA/FDMA networks, which is a key reason for the different behavior between TDMA/FDMA and CDMA networks [18].

3.8. HSPA

High-Speed Packet Access (HSPA) is a collection of mobile telephony protocols that extend and improve the performance of existing UMTS protocols. Two standards HSDPA and HSUPA have been established and a further standard HSOPA is being proposed.

The two existing standards (HSDPA and HSUPA) in this family provide increased performance by using improved modulation schemes and by refining the protocols by which handsets and base stations communicate. These improvements lead to a better utilization of the existing radio bandwidth provided by UMTS.

4. GSM VERSUS UMTS

GSM is very good at delivering voice services to its subscribers, and is the most common 2G system in all over the world. However, when data services is concern, the situation is not the same. It can be seen from Figure 1.1, there are some upgrade studies on existing GSM system in order to support more efficient data services. In Turkey, for example, GPRS and EDGE are deployed. However, neither GPRS nor EDGE directs subscribers to the expected data rates (like ADSL data rates). Nowadays, totally new air interface, namely WCDMA air interface system is being deployed on existing GSM core network in Turkey. The use of totally new air interface entails totally new, different base stations and base station controllers, which means a huge cost for operators.

From the subscriber side, 3G means also cost. Because seamless operation for end users is achieved through the use of dual-mode GSM/CDMA handsets [19].

This chapter briefly summarizes basic differences between UMTS and GSM in terms of air interface, transmitted and received power, data and service capabilities, user devices, network planning, propagation prediction models and antennas.

4.1. Air Interface

UMTS air interface WCDMA is quite different from the air interface used in GSM networks. The quality (and delay) requirement is much higher in UMTS networks as compared to GSM networks. The bit rates are higher (up to 2 Mbps with Release 99 and up to 10 Mbps with HSDPA), which means that a larger bandwidth of 5 MHz is required to support these higher bit rates. The possibility of offering subscribers variable bit rates and bandwidth on demand is an attractive feature in UMTS networks. Asymmetric traffic is supported. Transmit diversity can be used to improve downlink capacity in WCDMA networks. Packet data scheduling is load based as compared to timeslot based as in the GSM network, thus making the system more efficient. The algorithms that are used for Radio Resource Management (RRM) functionality are more advanced as compared to GSM networks [10].

Although, WCDMA is designed to provide backward compatibility and interoperability for all GSM, IS-136/PDC, GPRS and EDGE switching equipment and application as shown Figure 1.1, however, wider air interface bandwidth of WCDMA requires a complete change out of the RF equipment at each base station [5].

Table 4.1. Main differences between WCDMA and GSM air interface

	WCDMA	**GSM**
Carrier Spacing	5 MHz	200 kHz
Frequency Reuse Factor	1	1-18
Power Control Frequency	1500 Hz	2 Hz or lower
Quality Control	Radio resource management algorithms	Network planning (frequency planning)
Frequency Diversity	5 MHz bandwidth gives multipath diversity with Rake receiver	Frequency hopping
Packet Data	Load-based packet scheduling	Time slot based scheduling
Downlink Transmit Diversity	Supported for improving downlink capacity	Not supported by standard, but can be applied

The move from second to third generation systems has introduced a further increase in channel bandwidth and an over the air chip rate of 3.84 Mcps for 3GPP. A layered code spreading method, as show Figure 3.2, is used to support both multiple users and variable traffic service rates in an efficient coding scheme [20].

Another important feature of 3GPP standard is that it takes additional advantage of the wideband channel characteristics to compensate for multipath signal components. In 3GPP the fundamental measurement resolution is significantly improved over GSM by using a wideband channel and a chip period of 260 ns. The separate multipath components seen in a highly reflective environment can be resolved and coherently

Table 4.2. GSM frequency bands, [21]

PARAMETER	VALUE/INTERVAL
GSM 900 UL frequency band [MHz]	[890, 915]
GSM 900 DL frequency band [MHz]	[935-960]
GSM 900 Duplex Separation [MHz]	45
Carrier Spacing [kHz]	200
GSM 1800 UL frequency band [MHz]	[1710, 1785]
GSM 1800 DL frequency band [MHz]	[1805, 1880]
GSM 1800 Duplex Separation [MHz]	95
Carrier Spacing [kHz]	200

combined in a RAKE receiver to gain a diversity improvement in signal quality. The same receiver method is also used in 3GPP to support soft handover from one cell to the next by combining separate rays from each cell that can be heard [20].

4.2. Frequency Bands

The radio interface of GSM uses a combination of FDMA (Frequency Division Multiple Access) and TDMA (Time Division Multiple Access). As mentioned Section 2.2, when GSM has grown worldwide, it began to operate at three frequency bands: 900, 1800, 1900 MHz.

As shown Table 4.2, GSM-900 uses 890-915 MHz to send information from the mobile station to the base station (uplink) and 935-960 MHz for the other direction (downlink), providing 124 RF channels (channel numbers 1 to 124) spaced at 200 kHz. Duplex spacing of 45 MHz is used.

GSM 1800 system uses frequencies of 1805-1880 MHz downlink (from the BTS to the MS) and 1710-1785 MHz uplink (from the MS to the BTS). Air interface transmission directions are separated from each other by different frequencies and the duplex distance is 95 MHz.

Table 4.3. UMTS frequency bands, [21]

PARAMETER	VALUE/INTERVAL
Chip rate [Mcps]	
FDD	3.84
TDD	1.28, 3.84
Nominal channel spacing[MHz]	
FDD	5.00
TDD (1.28 Mcps)	1.60
TDD (3.84 Mcps)	5.00
TDD frequency bands[MHz]	[1900,1920]
	[2010,2025]
FDD DL frequency bands[MHz]	[2110,2170]
FDD UL frequency bands[MHz]	[1920,1980]
FDD Tx-Rx frequency separation[MHz]	190

UMTS systems uses two Direct Sequence-Code Division Multiple Access (DSCDMA) technology for air interface: Wideband Code Division Multiple Access-Frequency Division Duplex (WCDMA-FDD) and Time Division Duplex -Code Division Multiple Access (TD-CDMA).

As shown Table 4.3, the WCDMA-FDD uses frequencies of 2110-2170 MHz downlink (from the BS to the UE) and 1920-1980 MHz for uplink (from the UE to the BS). Air interface transmission directions are separated by different frequencies and the duplex distance is 190 MHz. WCDMA-TDD uses frequency bands of 1900-1920 and 2010-2025 MHz.

UMTS cell size generally smaller than GSM cell size since UMTS uses higher frequency than GSM.

4.3. Transmitted and Received Power

In GSM, the Base Station (BS) and the Mobile Station (MS) are classified into different classes according to the output power and the frequency band, [21], as shown Table 4.4 and Table 4.5.

The lowest power level for all MSs, regardless of their power class, is 13 dBm (20mW) and the highest power level is equal to the maximum peak power corresponding to the class of the particular MS [21].

There are five different mobile class for the GSM 900 system. Classes 5 and 2 are vehicle mounted and they can be found very rare. Power class 3 and 4, specifically the mobile station with 2W transmission peak power are very common. Mobile station class 1 have been discussed but they are not widely supported at present [22].

GSM specification defines reference sensitivity level as -104 dBm for BTS and -102 dBm for MS.

Typical values for UMTS are presented in Table 4.6 and 4.7 for Equivalent Isotropic Radiated Power (EIRP), power control step size and reference sensitivity. According to Table 4.6, the transmit power and reference sensitivity level of Base station depend on the type of services, e.g., voice, real-time or non-real-time data. Link budget analysis must be made separately for each service class [21].

When a BTS in GSM and a BTS in UMTS are compared, it can be seen that there are improvements in UMTS BTSs (NodeBs) in terms of reference sensitivity level. For example, while Normal BTS in GSM -which is the best BTS class in GSM in terms of reference sensitivity level- can sense -104 dBm ($1.41\mu V,$ and smaller than$0.1pW$), UMTS BTS for 384 kbps non-real-time data -which is the worst BTS in UMTS in terms of reference sensitivity level-can sense -109.2 dBm (800 nV, and 0.01pW). That means BTSs in UMTS are at least ten times more powerful than BTSs in GSM in terms of sensing received signals. Also MS in UMTS is more powerful in terms of sensing

Table 4.4. GSM BS characteristics, [21]

Parameter	**Value/Interval**	
	GSM900	GSM1800
Maximum Transmission Power[dBm]		
Power class 1:	[55.0, 58.0[	[43.0, 46.0[
Power class 2:	[52.0, 55.0[	[40.0, 43.0[
Power class 3:	[49.0, 52.0[	[36.9, 40.0[
Power class 4:	[46.0, 49.0[	[33.9, 36.9[
Power class 5:	[43.0, 46.0[	
Power class 6:	[40.0, 43.0[	
Power class 7:	[36.9, 40.0[	
Power class 8:	[33.9, 36.9[	
Micro BTS Maximum Transmission Power [dBm]		
Power class M1	]19.0, 24.0]	]27.0, 32.0]
Power class M2	]14.0, 19.0]	]22.0, 27.0]
Power class M3	]9.0,14.0]	]17.0, 22.0]
Reference sensitivity level [dBm]		
Micro BTS M1	-97	-102
Micro BTS M2	-92	-97
Micro BTS M3	-87	-92
Normal BTS	-104	-104

Table 4.5. GSM MS characteristics, [21]

Parameter	**Value/Interval**	
	GSM900	GSM1800
Maximum Transmission Power[dBm] Power class 1: Power class 2: Power class 3: Power class 4: Power class 5:	 39 37 33 29 -	 30 24 36 - -
Reference sensitivity level [dBm]	Small MS:-102 Other MS: -104	Class 1/2/3:-102

Table 4.6. UMTS BS characteristics, [21]

Parameter	**Value/Interval**		
	Macro-Cell	Micro-Cell	Pico-Cell
EIRP[dBm]	[40.0, 43.0]	[30.0, 43.0]	[20.0, 43.0]
Power control step size [dB]	1.0 (0.5 optional)(FDD) (1.0, 2.0, 3.0)(TDD)		
Reference sensitivity level[dBm]	12.2 kbps (FDD) voice	144 kbps(FDD) real-time data	384 kbps(FDD) non-real-time data
	-120	-113	-109.2

Table 4.7. UMTS MS characteristics, [21]

Parameter	**Value/Interval**	
	FDD	**TDD**
EIRP [dBm]	[10,33]	
Output power[dBm] Power class 1: Power class 2: Power class 3: Power class 4:	 33 27 24 21	 24 21
Reference sensitivity level [dBm]	-106.7(CCPCH, etc) -117.0(DPCH)	-105.0(3.84Mcps) -108.0(1.28 Mcps)

signals. When the comparison is made in terms of BTS transmit power, which system sends more energy to the environment depends applied network plan.

When MS in two systems are compared in terms of transmit power, it can be seen that MS in UMTS sends less energy to the environment. The reason for this can be the improvement in BTS technology in UMTS and small cell sizes in UMTS. Small cell size means small distance between MS and BTS.

4.4. Power Control

The power control mechanisms used in the GSM are clearly inadequate for WCDMA and, thus, WCDMA takes a different approach to the matter. In the GSM, power control is applied to the connection once or twice per second, but, due to its critical nature, in WCDMA, the power used in the connection is adjusted 1500 times per second (i.e., the power control cycle is repeated for each radio frame in association with the DCH). Power control is at least 750 times faster in UMTS. Therefore, power adjustment steps are considerably faster than in the GSM. To manage power control properly in WCDMA, the system uses two different power control mechanisms, as defined in Figure 4.1. These power control mechanisms are: Open Loop Power Control (OLPC) and Closed Loop Power Control (CLPC), including inner and outer loop power control mechanisms [7].

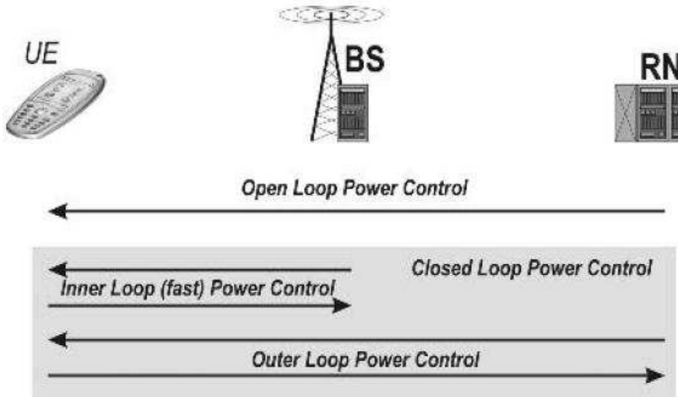

Figure 4.1. The main power control mechanisms employed in WCDMA, [7]

4.5. Data Capabilities and Services

Compared to GSM, the 3GPP standard achieves a higher cell capacity and also capability of supporting mixed traffic types ranging from broadband packet services to circuit switched voice [20].

The wider band makes it possible to insert some attractive features into the system, such as multimedia services with adequate bandwidth and macro diversity [7].

Comparisons of network capacity improvements from GSM to WCDMA are often made in both theory and practical measurements. A generally accepted multiplier of 2-3 can be used as a rough guide [20].

4.6. User Devices

Evolution to 3G will require dual mode or tri-mode cell phones that can automatically switch between existing TDMA based 2G technology, EDGE, or WCDMA based UMTS technology.

If a user wants to make a call, but it is out of a UMTS area, the device can use GSM. Even if this happens while on a call, the phone can be switched over to the GSM network, completely uninterrupted, transparently to the end user. Although the newer wave of 3G phones can be used on both networks, GSM phones can not be used on UMTS networks [23].

4.7. Network Planning

When we compare UMTS and GSM in term of network planning, it can be easily argued that UMTS network planning is easier than GSM due to lack of frequency planning, which is a tedious task in the GSM networks [9]. Frequency reuse factor in UMTS is 1, while in GSM, reuse factor is 1-18.

In Figure 4.2, there is an example of one-seven and one-one Frequency Reuse (FR) patterns, respectively. In terms of planning frequency reuse map, UMTS is easier. All cell uses the same frequencies [9].

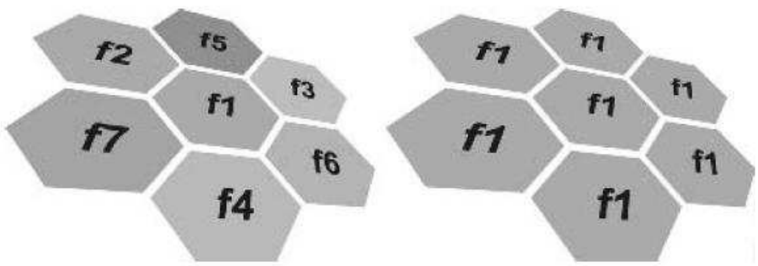

Figure 4.2. An example of frequency re-use pattern, FR=7 and FR=1

In CDMA based system like UMTS, all the mobile station in a cell uses the same frequency at the same time. This situation causes the interference between users in the same cell and neighboring cells. In order to suppress this interference, user signals are spreaded to available frequency band by using spreading and despreading technique. In the UMTS network, user signals spreaded over 5 MHz frequency band. The level of suppression is called the system processing gain. The processing gain can be defined as:

$$ProcessingGain = \frac{CDMAChipRate}{UserDataRAte} = \frac{BitPeriod}{ChipPeriod}$$

The processing gain will be different according to the current service demand. When the load of a cell is increased, the BS receiver noise floor appears to rise. In order to continue to communication, mobile station should rise its transmit power, as a result, the maximum path loss that can be tolerated will decrease and the cell effectively shrinks and this is called as cell breathing. The aim of cell breathing is to balance the load of a cell. As a result of cell breathing, some users especially near the boundary of the cell are transferred neighboring cells. However, it is important to plan for sufficient cell overlap to ensure that coverage holes do not occurs.

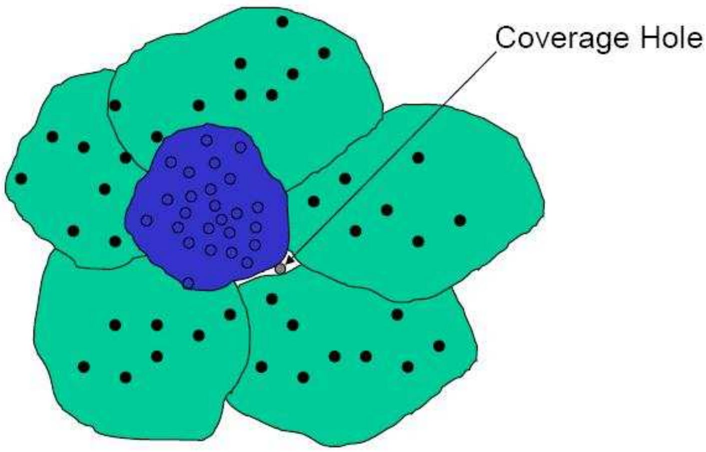

Figure 4.3. Planning the cell overlap

The effect of cell breathing can be minimized by using call admission control. This control mechanism decide when a new call can be accepted. Capacity extension by adding a second frequency is easier to implement in 3GPP, allowing an overlay mapping of macro and micro cells without replanning the local network [20].

From this point, it is clear that network coverage and call blocking should be taken into account when planning a CDMA network [24].

Briefly, 3G network planning is different from 2G network planning. In UMTS, network coverage depends on traffic load. Therefore different services could have different coverage and service area. In GSM network, the coverage area is limited by wave propagation and capacity is limited by available channels, which is interpreted as hard capacity. In WCDMA, network coverage is limited by the type of services and user distribution. The capacity is limited by available channels and traffic load on the cells. Therefore a new approach for WCDMA network simulation, Monte Carlo simulator, has been introduced [20].

4.8. Propagation Prediction Models

In the case of UMTS based on Wideband Code Division Multiple Access (WCDMA), where network coverage and capacity are interrelated, an important requirement for good radio network planning is accurate outdoor path loss estimation. Currently, these losses are predicted with path loss models based on measurements and statistics.

WCDMA is spectrally more efficient than GSM, but it is the wideband nature of WCDMA that provides its greatest advantage- the ability to translate the available spectrum into high data rates. This results in flexibility to manage multiple traffic types, including voice, narrowband data, and wideband data.

Since a GSM radio network is expected to be more robust due to its TDMA/FDMA scheme and its relative simplicity, especially in terms of services, it can be easily argued that UMTS network planning requires even more accurate radio predictions. The effects however remain to be investigated in some details [9]. Path loss models for GSM 900/1800 are not one to one applicable to the UMTS systems [25].

4.9. Antennas

Antennas are designed to function in a single band, dual band or multi band. Single band antennas are easier to manufacture, whereas dual/multi band antennas are produced for specific purposes [22].

There are now plenty of UMTS single band panel antennas. Dual band antennas for GSM 900 and GSM 1800 are currently available in market. Now, several antenna suppliers have plans for dual band antenna that can be used both GSM900/UMTS and GSM1800/UMTS and multi band antennas for GSM900/GSM1800/UMTS. Generally multi-band antennas used in order to minimize physical impact of sharing. However, generally using multi band antennas give reduced performance compared to single band antennas. Nevertheless, in some cases using multi-band antenna would be the economical solution as only one antenna and cable has to be installed [26], [22].

In Figure 4.4, a panel antenna from KATHREIN-Werke KG (the world's largest antenna producing enterprise [27]) is shown. This antenna is one of the preferred UMTS system antennas in Turkey. More detailed description for Kathrein 742236 antenna can be found in [27].

Antenna arrays and intelligent beam forming antenna systems have been coming for a while, but traditional, cheap and trusted panels seem to be the antennas of choice for most 3G operators.

4.10. Interference

Assume a cellular system with asynchronous users sharing the same radio bandwidth and served by the same radio base station in each coverage area or cell, each base station not only receives interference from mobiles in the home cell but also from terminals and base stations located in neighboring cells. Depending on the source of interference, they can be classified as intra-cell/co-channel interference, inter-cell/adjacent cell interference and interference due to thermal noise [7].

Unlike bandwidth-limited multi-access, such as FDMA and TDMA, that suffers mainly from co-channel interference due to the high range of frequency reusing, in the CDMA systems inter-user uplink interference is the most crucial type of the interference. One basic reason is that inter-user uplink interference increases on an accumulated power basis, and the performance of each user becomes poorer as the

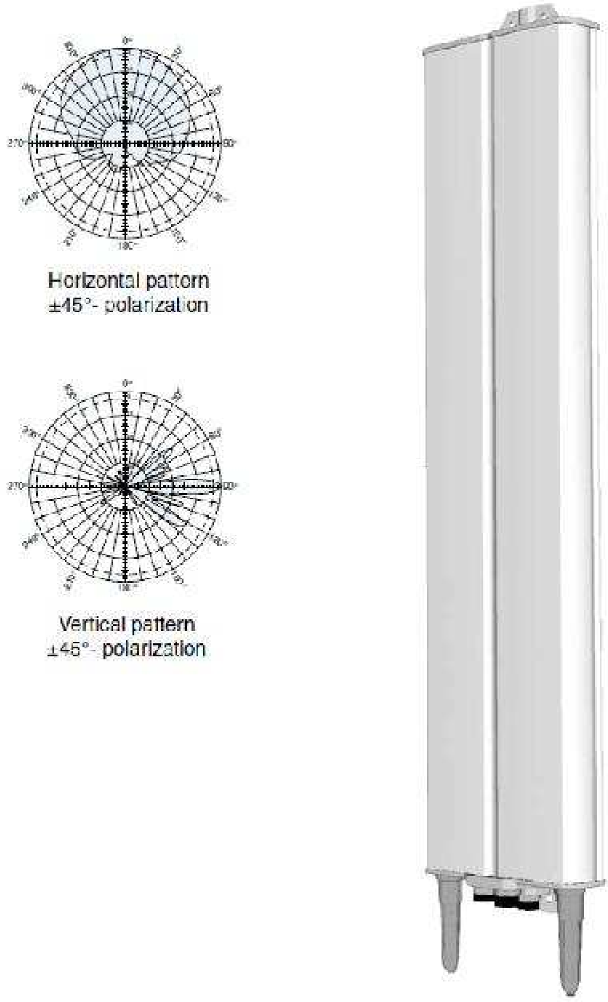

Figure 4.4. Kathrein 742236 panel antenna, and its radiation pattern [27].

number of simultaneous users increases in a single cell [7].

5. WAVE PROPAGATION

Communication process involves the transmission of information from one location to another. In communication, information is encoded onto carrier wave by using modulation methods. It is only the characteristics of the carrier wave which determine how the signal will propagate over any significant distance. This chapter briefly describes the different ways of the propagation of electromagnetic waves.

5.1. Propagation Mechanism

The concept of propagation refers to the various ways by which an electromagnetic (EM) wave travels from the transmitting antenna to the receiving antenna. Propagation of EM wave may also be regarded as a means of transferring energy or information from one point (a transmitter) to another (a receiver).

5.1.1. Free Space Propagation

Free space means space with nothing at all in it, no electrical charge, carries no current. Free space is uniform everywhere and infinite extent in all directions.

In free space [28]:

- A radio wave launched from a point in any given direction will propagate outwards from that point at the speed of light.
- The energy will travel in a straight line, as there is nothing to prevent them doing so.

Free space does not exist in the know universe, but it is important to understand how the path loss can be calculated in the free space.

When we consider two antennas separated by a distance of d in free space, and transmitting antenna gain G_t, equation for received power flux density is [29]:

$$\frac{P_t G_t}{4\pi d^2} \tag{5.1}$$

To find the power received, power flux density should be multiplied by the effective area of the antenna:

$$P_r = A_e(\frac{P_t G_t}{4\pi r^2}) \tag{5.2}$$

The effective area A_e of an antenna is related to its gain and can be given as:

$$A_e = G_r \frac{\lambda^2}{4\pi} \tag{5.3}$$

So, using Equation 5.3 in 5.2, we can get:

$$P_r = G_r G_t P_t (\frac{\lambda}{4\pi r})^2 \tag{5.4}$$

For unity-gain (isotropic) antennas, $G_r = 1$ and $G_t = 1$, received power:

$P_r = P_t(\frac{\lambda}{4\pi r})^2$.

Propagation loss is usually expressed in dB;

$FreeSpaceLoss = 10log(\frac{P_t}{P_r})$ and when we use $\lambda = c/f$ in Equation 5.4, we can get:

$$FreeSpaceLoss[dB] = 32.4 + 20log(f) + 20log(d), \text{ f:Mhz and d:km} \quad (5.5)$$

However, in mobile communication, signal between a transmitter and a receiver is disturbed by environmental factors, such as terrain, buildings, and vehicles etc.. The signals also influenced by the motion of the terminal. As a result, signals arrive the receiver by a combination different propagation mechanisms.

The Figure 5.1 gives some idea of how various signal parameters are effected by propagation.

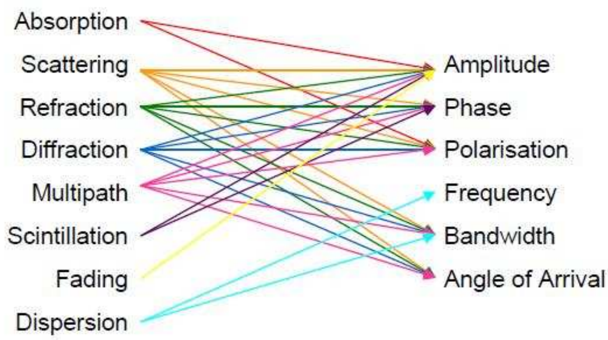

Figure 5.1. Propagation mechanisms and their effects,[28]

Figure 5.2 shows the relative importance of propagation mechanisms. This simulation of each mechanism versus frequency band illustrates some important points [28]:

- Line of sight coverage increases with frequency, because fresnel zones get smaller with frequency.
- Diffraction becomes less important at higher frequencies due to increased losses.

- Spectral reflections are more likely at lower frequencies.

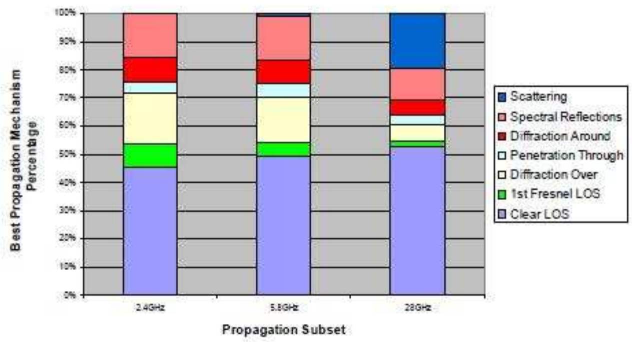

Figure 5.2. Relative importance of propagation mechanisms,[28]

In following section, some important propagation mechanisms are explained very briefly.

5.1.2. Reflection

Reflection occurs when a propagating wave faces an obstacle of large surface compared to the incident wavelength. A part of wave is reflected from the medium and a part of wave propagate in the new medium. The part, which has entered the new medium, is called transmitted or refracted wave and the other called reflected wave. The amount of energy, which is reflected or refracted, is related to the electrical properties of the boundary between the two mediums.

Reflected wave has a very simple rule governing its behavior, and makes the following construction:

The rule for reflection is simply stated as:

The angle of reflection = The angle of incidence.

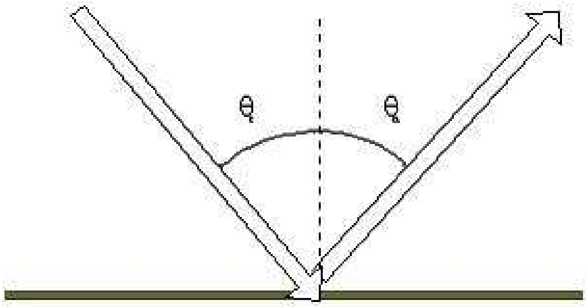

Figure 5.3. Reflection of propagating wave, [12]

5.1.3. Diffraction

Diffraction refers to the bending of waves around an edge of an object. Diffraction involves a change in the direction of waves as they pass through an opening or around a barrier in their path [12].

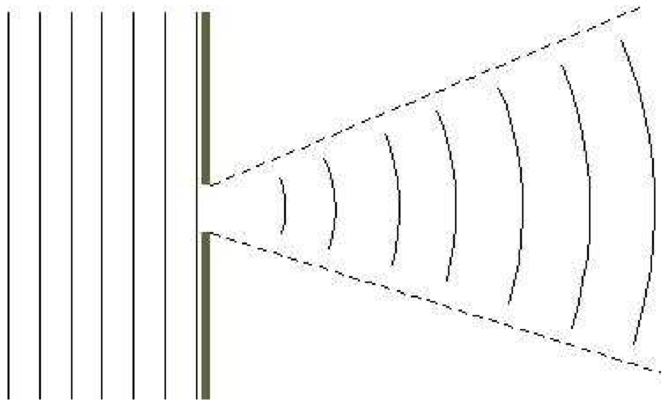

Figure 5.4. Diffraction of propagating wave

Diffraction depends on the size of the object relative to the wavelength of the wave.

5.2. Mobile Radio Channel

5.2.1. Multipath Propagation

In wireless telecommunications, multipath is the propagation phenomenon that results from radio signals' reaching the receiving antenna by two or more paths, which is illustrated in Figure 5.5. Causes of multipath include atmospheric ducting, ionospheric reflection and refraction, and reflection from terrestrial objects, such as mountains and buildings [12].

The effects of multipath include constructive and destructive interference, and the phase shifting of the signal.

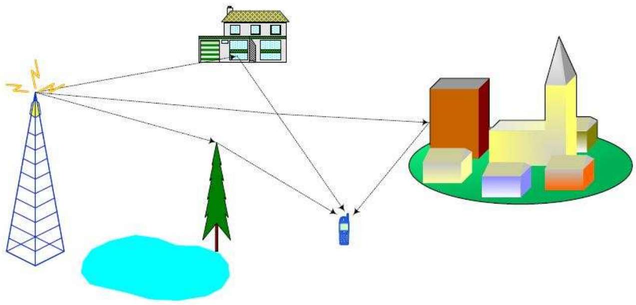

Figure 5.5. Multipath propagation,[12]

When measuring signal strength variations, a pattern like the one shown in Figure 5.6 occurs.

The mobile radio channel can in general be characterized by three distinct signal components [30]:

- Fast fading or Rayleigh fading
- Slow fading
- Path loss, the decrease of the global mean value with distance

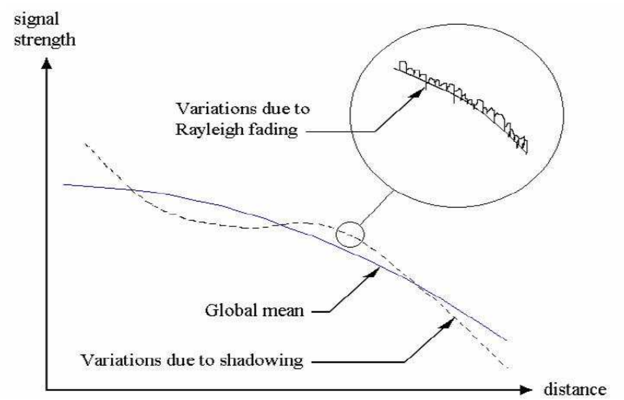

Figure 5.6. Signal strength variations,[30]

5.2.2. Rayleigh or Fast Fading

The reason of this phenomenon is the multipath propagation of the signal. Signals with the same amplitudes and opposite phase shifts superimpose and eliminate each other. This creates very distinguished fading dips in order of fractional wavelengths, and can be modeled mathematically by the Rayleigh distribution. This occurs at the spatial scale of the order of the carrier wavelength, and Rayleigh fading is frequency dependent.

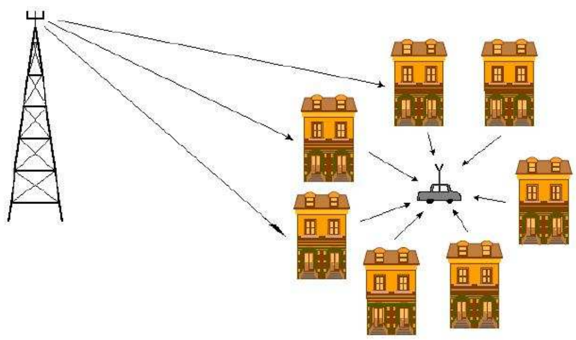

Figure 5.7. Rayleigh fading,[30]

5.2.3. Slow Fading

Slow fading can be caused by events such as shadowing, where large obstructions such as hills or large buildings obscure the main signal path between the transmitter and the receiver [31]. The slow fading can be described mathematically by the Gaussian distribution.

This occurs as the mobile moves through a distance of the order of the cell size, and slow fading is typically frequency independent [12].

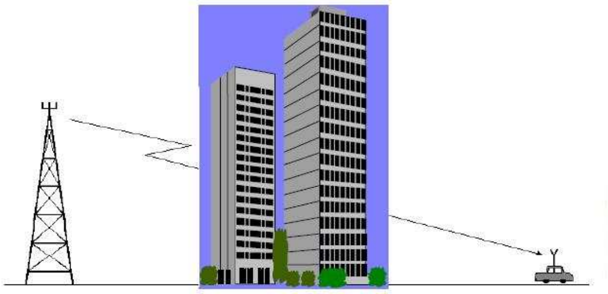

Figure 5.8. Shadowing from obstacles, [30]

6. MODELS FOR TRANSMISSION PATH LOSS CALCULATION

6.1. General Principia

6.1.1. Definition of Propagation Models

Propagation models are mathematical attempts to model the real radio environments as closely as possible. Models have been created for different environments to predict the path loss between the transmitter and receiver.

This chapter gives an answer following questions:

- Why are there many propagation models?
- Why are propagation path loss models so important?
- What is path loss model tuning and why model tuning is necessary?

The chapter continues with the classification of path loss models and some path loss models from literature and the comparison of path loss models.

6.1.2. Why There Are Many Propagation Models

Each individual telecommunication link encounters different terrain, path, obstructions, atmospheric conditions and other phenomena. For this reason, it is intractable to formulate the exact loss for all telecommunication systems in a single mathematical equation. As a result, different models exist for different types of radio links under different conditions. The models rely on computing the path loss for a link under a certain probability that the considered conditions will occur. Propagation models do not point out the exact behavior of a link; rather, they predict the most likely behavior of the link.

6.1.3. The Importance of Propagation Models

In radio network planning, the selection of propagation model directly affects the cell planning and the operator's ability to meet subscribers' needs with economic and reasonable capital expenditure. Therefore, engineers must check, analyze, and classify the features of propagation scenarios in the planning areas at the initial stage of planning so that they can select proper propagation model [32].

6.1.4. Why Model Tuning is Necessary

Most propagation models need to be tuned or calibrated by compared to measured propagation data, otherwise coverage predictions will not be able to obtained accurately. Carrier Wave measurements (survey data) help to produce an accurate prediction model that functions correctly. No model could be applied with a reasonable accuracy to every situations, and the choice of model is not as important as the fine tuning that is done according to the environment. Normally, this calibration process is carried out by a specialist. The validity of a propagation model will depend on the validity and significance of the survey data [16].

Figure 6.1 shows the flow for applying propagation model.

6.2. Classifying Typical Radio Propagation Scenarios

Typical radio propagation scenarios in mobile communication are listed in Table 6.1.

6.3. Classifying Propagation Models

Different models have been developed to meet the needs of realizing the propagation behaviors in different conditions. A propagation model is usually restricted by a frequency range and a scenario, so it serves only a particular frequency range and the scenario.

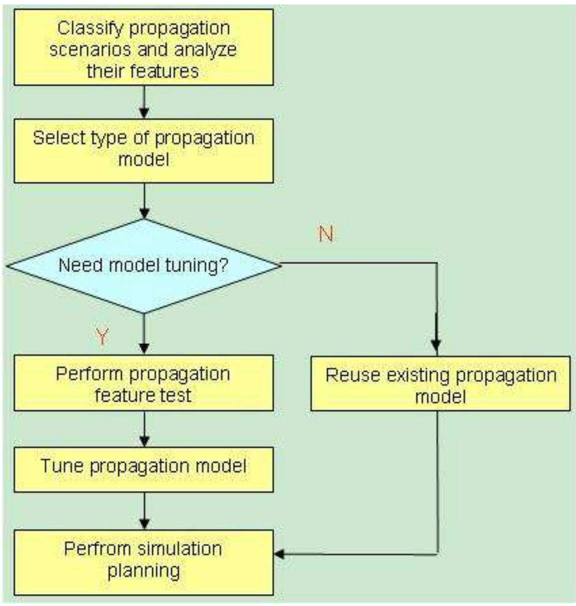

Figure 6.1. Flow for applying propagation model, [32]

We can classify models according the principle approach used to develop propagation models.

6.3.1. Deterministic Models (Theoretical Models)

The deterministic model is based on theoretical analysis, so it can be applied in different scenarios without affecting its accuracy. However, the realization of theoretical model is based on large database on the scenario features and an accurate 3D digital map [32].

Generally, the algorithms of theoretical models are complicated, moreover sometimes they have low efficiency. For this reason, its application is restricted in a small range, such as micro cell in dense urban areas and indoor scenarios. However, if a theoretical model is reasonably applied, its accuracy of prediction will improve greatly compared with an empirical model. The theoretical model uses ray tracing method and FDDI (Finite-difference time-domain). Some deterministic models help obtain, as can be seen from Table 6.5, delay and multipath features and channel impulse response of the channel [32].

6.3.2. Empirical Models (Statistical Model):

Empirical models are based on extensive measurement data. In these models, all the environment factors are implicitly considered. The accuracy of models depends on the following factors [32]:

- Accuracy of measured data,
- Similarity of the environment to be predicted and the measurement environment for modeling.

The empirical model usually uses 2D digital maps, so its usage is easy and its calculation is efficient. However, the accuracy of empirical model is low and the delay and multi-path features, as can be seen from Table 6.5, are beyond reach.

We can also classify models according to application scenarios:

- Models for indoor applications :
  Common indoor propagation models include: Keenan-Motley, ITU 529-3 etc.
- Models for outdoor applications:
  Common outdoor propagation models include: Okumura-Hata, Cost231-Hata, Cost231-WI, etc.
- Models for special scenarios, such as mountainous region, sea surface, and highway.

6.4. Propagation Loss in Free Space

The simplest model for wave propagation is the free space case. It is assumed that the transmitting and receiving antennas are placed at a long distance from each other. This is applicable for satellite communication but can also be used as a reference for comparison with other models [30].

Assume in free space, there are a Tx antenna and an Rx antenna with antenna gain G_t and G_r respectively and the distance between them is d,

In this case, the following formula represents the relation between the received power (P_r) of Rx antenna and the transmit power of Tx antenna (P_t):

$$P_r = \frac{P_t \cdot G_t}{4\pi d^2} \cdot \frac{\lambda^2}{(4\pi d)^2} = \frac{\lambda^2}{(4\pi d)^2} P_t \cdot G_t \cdot G_r \quad (6.1)$$

Previous formula can be written as;

$$P_r = \frac{P_t \cdot G_t}{4\pi d^2} \cdot \frac{\lambda^2}{(4\pi d)^2} = \frac{P_t \cdot G_t \cdot G_r}{PL}, \qquad PL = 1/(\frac{\lambda^2}{(4\pi d)^2}) \quad (6.2)$$

The PL is the propagation loss of free space, in the unit of dB. The following formula represents the propagation loss of free space:

$$PL = -10 \log \frac{\lambda^2}{(4\pi d)^2}(dB) = 32.45 + 20 \log(d_{km}) + 20log(f_{MHz})(dB) \quad (6.3)$$

The formula 6.1 can be represented with dB as below:

$$P_r(dBm) = P_t(dBm) + G_t(dB) + G_r(dB) - PL(dB) \quad (6.4)$$

Path loss formula for free space in Equation 6.3 and measurements show that [30]:

- The Path loss increases as the propagation distance d increases or as the frequency f increases.
- Path loss decreases with increasing base station and mobile antenna heights.
- Path loss is affected by clutter type, diffraction, weather conditions, the time of the year, proximity of other obstacles and street orientation.

When all these points are taken into account, more refined models are required for mobile environment. In the following, such models that can be used in different kinds of environments are described.

6.5. Okumura-Hata Related Models

6.5.1. Okumura Model

As the earliest propagation model, the Okumura model was mentioned by Yoshihisa Okumura in Field Strength and Its Variability in VHF and UHF Land-Mobile Radio Service in 1968. The Okumura method is semi-empirical and based on extensive measurements performed in the Tokyo area. The application scope for Okumura model is shown below [32]:

- Frequency range: 150-1920 MHz
- Propagation distance: 1-100 km
- Antenna height of NodeB: 30-1000 m
- Applicable terrain: urban and quasi-urban

The application scope for the Okumura model is wide all over the world. However, it is a pure experience statistical model, so its statistics are represented by curves without a specific formula. Therefore, its application is not convenient.

6.5.2. Okumura-Hata

The Okumura model was intended for manual use. Hata, in 1980, [30] made an attempt to derive semi-empirical formulas from Okumura's curves for computational use.

The Okumura-Hata model predicts the field strength based on quasi-flat terrain in urban areas. It does not consider the terrain between the Tx antenna and the Rx antenna, neglects the correction over terrain in Okumara model and the reflection and shadow effects. The formula of Okumura-Hata has only four variables, so its calculation is fast [32].

The path loss formula for Okumura-Hata model is as shown in Equation 6.5:

$$PL = 69.55 + 26.16\log(f) - 13.82(h_b) - a(h_m) + [44.9 - 6.55\log(h_b)]\log(d)dB \quad (6.5)$$

Wherein,
f : frequency, in the unit of MHz
h: antenna height of base station, in the unit of meter
h_m: antenna height of mobile station, in the unit of meter
$a(h_m)$: correction factor when the h_m is equal to 1.5 meter
d: distance with base station antenna, in the unit of kilometer

The h_b refers to effective height, namely, the difference between the altitude and the average terrain height. The Okumura-Hata model is based on test data, so its application scope is restricted. The following range for parameters should be met:

- Frequency range: 150-1500 MHz

- Antenna height of base station: 30-200 m
- Antenna height of mobile station: 1-10 m
- Distance: 1-20 km

$a(h_m)$ is a correction factor for the vehicular antenna height h_m.

In a medium small city,

$$a(h_m) = (1.1 \log f - 0.7)h_m - 1.56 \log f + 0.8 \quad (6.6)$$

In a large city,

$$a(h_m) = \begin{cases} 8.29[\log(1.54h_m)]^2 - 1.10 & f \leq 200, \\ 3.2[\log(11.75h_m)]^2 - 4.97 & f \geq 400. \end{cases} \quad (6.7)$$

All these formulas are valid for urban areas. In order to apply Okumura-Hata model in suburban and open areas, correction factors should be added to the path loss formula.

$$SuburbanArea : \begin{cases} K_r = 2[\log(\frac{f}{28})]^2 + 5.4 \\ L_{suburban} = L_{urban} - K_r \end{cases} \quad (6.8)$$

$$OpenArea : \begin{cases} Q_r = 4.78(\log f)^2 - 18.33 \log f + 40.94 \\ L_{open} = L_{urban} - Q_r \end{cases} \tag{6.9}$$

For equation 6.8 and 6.9, L_{urban} is given by equation 6.5.

The Okumura-Hata model applies well for large cells. In the configuration of large cells, the antenna of base station is usually higher than surrounding buildings or obstacles. The main propagation loss for Okumura-Hata model is the diffraction and scattering over rooftop near the mobile station. The radio waves propagate on rooftop, so the cell radius should be at least 1 km, usually over 3 km. The maximum frequency for Okumura-Hata model is 1.5 GHz [32].

6.5.3. The COST-231 Hata Model

COST is a European Union forum for cooperative scientific research. There are some subgroups of COST, such as COST 231, COST 259, and COST 273. COST 231 investigates different propagation mechanisms and develops new models.

COST 231 group extended the studies of Okumura-Hata. Okumura-Hata propagation model works frequencies below 1500 MHz and thus it does not work e.g the 2100 MHz band. Okumura's propagation curves have been analyzed in the upper frequency band to find a suitable expression for 2100 MHz [30].

As a result, the COST231-Hata model for 2100 GHz is developed. Path loss formula for COST231-Hata model is given in Equation 6.10:

$$PL = 46.30 + 33.90 \log(f) - 13.82 \log(h_b - a(h_m)) + [44.9 - 6.55 \log(h_b)] \log(d) dB - C_m \tag{6.10}$$

C_m is given as ;

$$C_m = \begin{cases} C_m = 0\text{dB} & \text{for medium sized cities and suburban centers with moderate tree density;} \\ C_m = 3\text{dB} & \text{for metropolitan centers.} \end{cases} \tag{6.11}$$

The formula of COST231-Hata model (Equation: 6.10) differs from that of Okumura-Hata model (Equation 6.5) in the constants and the coefficient of $\log(f)$.

6.5.4. The Okumura-Hata Model in TCPU

A variant of the Okumura-Hata model is implemented in TCPU for the purpose of detailed propagation predictions in cell planning [30].

In this model, path loss (L_p) is given as:

$$L_p = max(L_1, L_2) + L_3 + L_{clutter} \tag{6.12}$$

In Equation 6.12, L_1 is a variant of the equation for Okumura-Hata model [30].

$$L_1 = C_0 + \log d(C_1 - C_2 \log h_{eff} + C_3 \log d) - C_4 \log h_{eff} - C_5(\log f)^2 + C_6 + C_7 - L_m \tag{6.13}$$

In Equation 6.13, h_{eff} is the effective base station antenna height that takes into consideration the differences in ground height along the path between the mobile and the base station. C_1 to C_7 are semi empirical constants. L_m is the mobile height loss [30]:

$$L_m = \begin{cases} 3.2(\log(11.75h_m))^2 - 4.97 & \text{urban areas;} \\ h_m(1.1\log f - 0.7) - (1.56\log f - 0.8) & \text{other areas.} \end{cases} \tag{6.14}$$

L_2, in Equation 6.12, is the free space loss and given as:

$$L_2 = C_8 + 20\log f + 20\log d \tag{6.15}$$

In equation 6.15, C_8 is a semi empirical constant [30]. Equation 6.12 takes into account diffraction loss also by using L_3 parameter. L_3 gets positive value when there is no line of sight between transmitter and receiver.

L_3, diffraction loss parameter, can be calculated with the formula 6.16. Here, C_9 is a semi empirical constant and L_{KE} is knife edge diffraction loss.

$$L_3 = C_9 L_{KE} \tag{6.16}$$

Finally, in Equation 6.12, $L_{clutter}$ represents an extra term that can be set to different values for different land usage code types [30].

As stated before, $C_0 - C_9$ are semi empirical constants, and their values change according to environments. In the Table 6.2, suggested values of $C_0 - C_9$ are stated [30].

This model is valid for the following ranges:

- $150 \leq f \leq 2000$ MHz
- $1 \leq d \leq 100$ km
- $30 \leq h_b \leq 200$ m
- $1 \leq h_m \leq 10$ m

The implementation requires the following map data:

- Height information
- Clutter data

A more extensive description of this model is found in [30].

6.6. Algorithm 9999

There have been several suggestions for improving the Okumura-Hata and COST231-Hata models to take more propagation environment into account. One of the improved Okumura-Hata models is Algorithm 9999, which is Ericsson Implementation of Enhanced Okumara-Hata based model. Algorithm 9999 is implemented in Ericsson's RF planning tool for TEMS Cell Planner [30].

Algorithm 9999 is valid for the following ranges [30]:

- $150 \leqslant f \leqslant 2000$ MHz
- $0.2 \leqslant d \leqslant 100$ km
- $20 \leqslant h_b \leqslant 200$ m
- $1 \leqslant h_m \leqslant 5$ m

In Algorithm 9999 model, the path loss includes four parts as shown Figure 6.2.

- Free space loss based on Okumura-Hata model. Wherein, the coefficients A_0 to

A_3 are corrected.

- Diffraction loss due to obstacles in propagation path.
- Loss due to curvature of earth when the distance between the transmitter and the receiver is long enough.
- Loss due to clutter offset where the mobile station is.

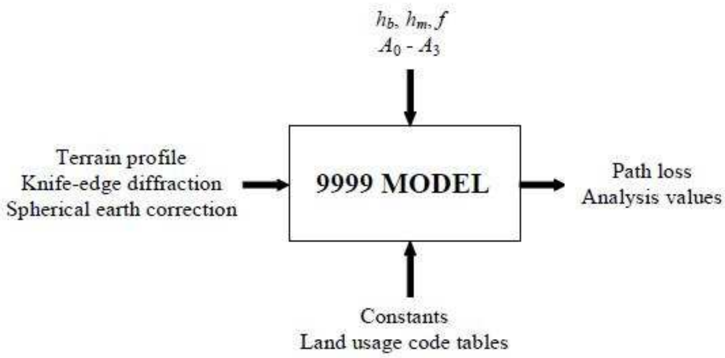

Figure 6.2. Basic concept of Algorithm 9999,[30].

The basic formula for Algorithm 9999 model is given in Equation 6.17:

$$L_p = A_0 + A_1 \log d + A_2 \log(HEBK) + A_3 \log(d) \log(HEBK) - 3.2[\log(11.75h_m)]_2 + g(f) + KnifeEdgeDiffractionLoss + SphericalEarthDiffractionLoss + LandUsageCode \quad (6.17)$$

The first part of this formula is the formula for Hata open space algorithm:

$$HOA(HataOpenArea) = A_0 + A_1 \log d + A_2 \log(HEBK) + A_3 \log(d) \log(HEBK) - 3.2[\log(11.75h_m)]^2 + g(f) \quad (6.18)$$

Wherein;

- d: the distance between the MS to the BS
- HEBK: effective antenna height
- $g(f) = 44.49 \log f - 4.78(\log f)^2$
- A_0, A_1, A_2 and A_3 are tuning parameters.

Default settings for $A_0 - A_3$ are given in Table 6.3. Values of $A_0 - A_3$ are used in order to tune Algorithm 9999 model. Algorithm 9999 requires land usage (clutter) and elevation data.

Even if the validity of the model here is stated to be up to 2 GHz, it is possible to adapt Algorithm 9999 to higher frequency bands by tuning the model against measurements.

A more extensive description of Algorithm 9999 is found in [30]

6.7. Walfisch-Ikegami Related Models

6.7.1. COST231-Walfisch-Ikegami Model (COST231-WIM)

In the urban areas with large population and densely located buildings, the cell radius is usually smaller than 1 km due to capacity restriction. The error to use Hata model in such mini cells is large. To enable Hata model to apply to the areas with densely located high buildings, Cost231 proposes the COST231-Walfisch-Ikegami model based on numerous on-site tests and model analysis [32]. COST231-Walfisch-Ikegami Model is a combination between the two models described in The Ikegami model [30] and The Walfisch-Bertoni model [30], including a line-of-sight component.

In the urban areas with large population and densely located buildings, the base station antenna is usually higher than the average height of surrounding buildings but lower than the tallest building. The COST231-Walfisch-Ikegami model, based on theoretical Walfisch-Bertoni model [30], [21] and [33] calculates the multiple screen forward diffraction loss of antenna of high base station. It uses the test-based data for antenna of low base station. The model considers the following aspects in details:

- Free space loss
- Diffraction loss on streets
- Direction factor of street
- Scattering loss on buildings

The COST231-Walfisch-Ikegami model applies to the network planning of small cells in dense urban areas. In such scenario, the typical range for cell coverage is 200 m to 3 km [32].

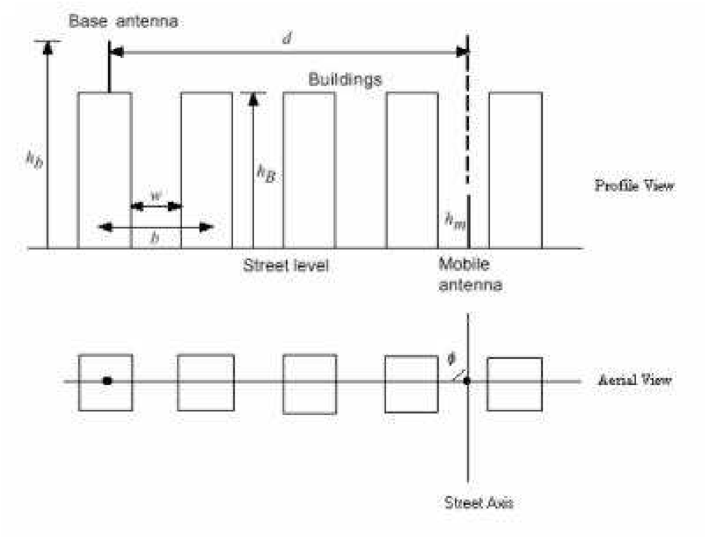

Figure 6.3. Definition of variables in Cost 231-WI model, [32].

6.7.1.1. NLOS Propagation Loss. When LOS is unavailable between the base station and mobile station, the propagation loss is given in Equation 6.19 [30]:

$$PL_{NLOS} = L_{sp} + L_{rts} + L_{msd} \tag{6.19}$$

Wherein,

- L_{sp} = Free space loss =$32.4 + 20\log(d) + 20\log(f)$
- L_{rts} =the diffraction loss and scattering loss from rooftop to streets = $-16.9 - 10\log(w) + 10\log(f) + 20log(H_B - H_m) + L_{ori}$

Wherein,

$$L_{ori} = -10 + 0.354\phi \qquad 0 \leq \phi < 35^\circ$$
$$L_{ori} = 2.5 + 0.075(\phi - 35) \qquad 35^\circ \leq \phi < 55^\circ$$
$$L_{ori} = 4.0 - 0.114(\phi - 55) \qquad 55^\circ \leq \phi < 90^\circ$$
$$\phi = \text{angle of arrival (degree)}$$

L_{ori} is the orientation loss, with the relation with the angle of incidence as Figure 6.4.

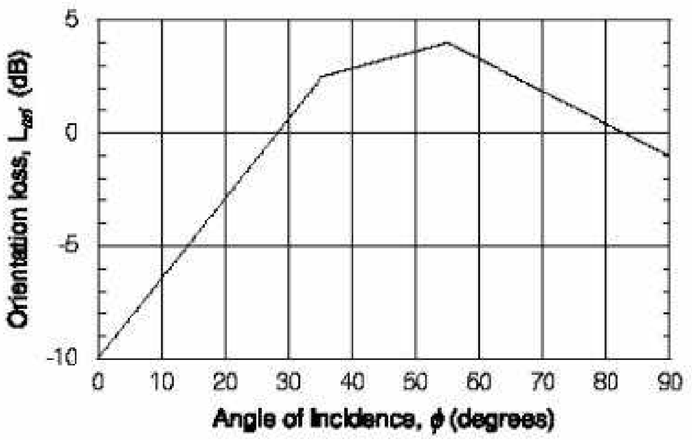

Figure 6.4. Relation between angle of incidence loss and orientation loss, [32].

L_{msd} multiple blocking diffraction loss and is based on the Walfisch-Bertoni expression, which can be found in [30]. When the base station antenna is higher than surroundings rooftops, L_{msd} can be written as [30]:

$$L_{msd} = 54 - 18\log(1 + h_b - H) + 18\log d + \\ [-4 + 0.7(\frac{f}{925} - 1)]\log f - 9\log b \tag{6.20}$$

There are extra terms added for short distances ($d < 0.5km$) and the case when base antennas lower than rooftops. However measurements shows that the accuracy of the prediction is the best for the case $h_b >> H$. (h_b is the height of base station antenna and H is the height of building)

6.7.1.2. LOS Propagation Loss. When LOS is available between the base station and mobile station, the propagation loss is given in Equation 6.21:

$$PL_{LOS} = 42.6 + 26\log(d) + 20\log(f) \qquad d \geq 0.020\text{km} \tag{6.21}$$

The application scope for the COST231-Walfisch-Ikegami model is below:

- Frequency range: 800-2000 MHz
- Antenna height of Base Station: 4-50 m
- Height of mobile station: 1-3 m
- Distance range: 0.02-5 km
- Flat ground
- Uniform building heights and building separations.

When the base station antenna is nearly as high as the rooftop of surrounding buildings, the path loss changes abruptly. Therefore, high accuracy of the antenna height of base station is required to avoid large prediction error. In addition, when the base station antenna is lower than surrounding buildings, the performance of Walfisch-Ikegami declines [32].

6.7.2. The Walfisch-Ikegami Model in TCPU

There have been several suggestions for improving Walfisch-Ikegami model to take more propagation environment into account. One of the improved Walfisch-Ikegami model is implemented in TCPU. This model works at the same physical condition as the COST-231 Walfisch-Ikegami model described before. Walfisch-Ikegami model in TCPU works as best when uniform building separation and building heights exist. It requires height information for the calculation of effective antenna height and knife-edge diffraction. The path loss is described below [30]:

$$L_p = L_0 + L_{mul} + L_{rts} + W_9 L_{KE} \tag{6.22}$$

Where L_{KE} is the knife-edge diffraction loss. W_1 to W_9 in Equation from 6.22 to 6.29 are semisatirical parameters. L_0 is the free space path loss equation:

$$L_0 = W_0 + 20\log f + 20\log d \tag{6.23}$$

L_{mul} is the multiple screen loss:

$$L_{mul} = L_{bsh} + K_a + K_d \log d + K_f \log f - 9logW_7 \tag{6.24}$$

L_{bsh} is the base station height loss:

$$L_{bsh} = \begin{cases} -18\log(1 + h_{eff} - W_8) & \text{if } h_{eff} - W_8 > 0 \\ 0 & \text{if } h_{eff} - W_8 < 0. \end{cases} \tag{6.25}$$

where K_a shows the raise of the path loss for base antennas below the rooftops of the surrounding buildings, h_{eff} is the effective base antenna height [m][30].

$$K_a = \begin{cases} W_1 & \text{if } h_{eff} - W_8 > 0 \\ W_1 - 0.8(h_{eff} - W_8) & \text{if } h_{eff} - W_8 < 0 \text{ and } d \geq 0.5. \\ W_1 - 1.6(h_{eff} - W_8) & \text{if } h_{eff} - W_8 < 0 \text{ and } d < 0.5. \end{cases} \tag{6.26}$$

K_f in Equation 6.24 represents the dependence of the multi-screen diffraction loss versus radio frequency:

$$K_f = -4 + 0.7(\frac{f}{925} - 1) \tag{6.27}$$

K_d in Equation 6.24 shows the dependence of the multi-screen diffraction loss versus distance.

$$K_d = \begin{cases} W_2 & \text{if } h_{eff} - W_8 > 0 \\ W_2 - 15(\frac{h_{eff}}{W_8} - 1) & \text{if } h_{eff} - W_8 < 0. \end{cases} \tag{6.28}$$

And L_{rts} is the rooftop-to-street diffraction loss:

$$L_{rts} = -8.2 - W_3 \log W_6 + W_4 \log f + W_5 \log(W_8 - h_m) \tag{6.29}$$

Here, the knife-edge diffraction loss L_{KE} and the effective antenna height h_{eff} are calculated using the same technique as for the Okumura Hata Model in TCPU.

These model can be tuned by adjusting W_2 and W_1 parameters according to measurements.

Recommended values by Ericsson for W_0 to W_9 are shown in Table 6.4:

6.8. Ray Tracing Models

The objective of the ray-tracing path loss models is to foresee the physical propagation process of the radio waves for a given environment. In ray tracing models, there are two techniques used, image theory and ray launching techniques [33].

Ray tracing technique requires 3D topographic databases with building data, which is very expensive in Turkey [32]. Moreover, these models have high computational demands and consequently, they are mostly used in microcells and picocells and they are not appropriate for macrocells.

Typically, ray-tracing propagation models are relatively slow compared empirical models, due to the fact that the calculation of the ray paths is computationally complex [8].

6.9. Comparison of the Models

Table 6.5 shows a comparison between several path loss models available in literature.

Table 6.6 collects common outdoor and indoor propagation models, their applicable band, applicable cell, applicable scenario.

6.10. Selecting Propagation Models

In practice, when propagation models are applied, the first two procedures is the classifying propagation scenarios and the selection of appropriate propagation models from propagation model library that best fit existing propagation scenarios [32].

The radio propagation scenarios are complicated, so it is difficult to master well the classification of propagation scenarios, selection and reuse of propagation models [32].

Different propagation scenarios require different propagation models. Table 6.8 shows the recommended propagation models in for each scenario [32];

More detailed description of SPA, Keenan-Motley, ITU-R P.1238, Volcano can be found in [32].

Table 6.1. Classified radio propagation scenarios, [32]

Scenario	**Description**
Micro cell in dense urban area	This clutter is usually densely located. There are numerous buildings with over 10 floors. The commercial centers and areas with dense office buildings in capital cities are of this scenario. The antenna is usually lower than the average height of buildings, or even installed on a wall of buildings. There are numerous obstacles around the antenna. The radio wave travels by being reflected and diffracted on the streets. The cell radius is usually shorter than 200 m.
Macro cell in dense urban area	Its clutter is usually densely located. There are numerous buildings with over 10 floors. The most part of capital cities and center of ordinary cities are of this scenario. The antenna is nearly as high as the average height of buildings. There are a few obstacles around the antenna. The radio wave travels by being diffracted on the rooftop. The cell radius is usually shorter than 500 m.
Urban area	The Buildings are separated clearly by streets or Greenfield. There are a small number of 10-floor or higher buildings sparsely distributed. Most part of capital cities, the center of ordinary cities, and developed towns in south China are of this scenario.
Suburban area	The buildings are sparsely distributed, and most of them are low. The out skirt of cities, most towns, and common industrial zone are of this scenario.
Rural area	The buildings are fairly sparsely distributed, and most of them are farmer houses. Most rural areas and some developing towns are of this scenario.
Indoor area	Indoor scenarios refer to various buildings, such as residential buildings, shopping centers, office buildings, factories, stadium, and airport. The transmitter is indoor.
Special scenario	Mountainous area, sea surface, highway, and tunnels.

Table 6.2. Suggested values of $C_0 - C_9$, [30]

Parameter	**Urban**	**Suburban**	**Rural**	**COST231 Urban**	**COST231 Suburban**
C0	69.55	59.96	28.616	49.3	46.3
C1	44.9	44.9	44.9	44.9	44.9
C2	6.55	6.55	6.55	6.55	6.55
C3	0.0	0.0	0.0	0.0	0.0
C4	13.82	13.82	13.82	13.82	13.82
C5	0.0	2.0	4.78	0.0	2.0
C6	26.16	31.95	44.49	33.9	33.9
C7	0.0	0.0	0.0	0.0	0.0
C8	32.44	32.44	32.44	32.44	32.44
C9	0.5	0.5	0.5	0.5	0.5

Table 6.3. Default parameter setting for Algorithm 9999,[30]

Parameter	**Default value**
A_0	36.2
A_1	30.7
A_2	-12.0
A_3	0.1

Table 6.4. Recommended parameter setting for the Walfisch-Ikegami model, [30]

Parameter	**Description**	**Value range**	**Default value**
W_0	Free space loss correction	20-60	32.4
W_1	Reduced base antenna height correction	30 -70	54
W_2	Range correction	5- 35	10
W_3	Street width correction	3-15	10
W_4	Frequency correction	3-25	10
W_5	Building height correction	10-30	20
W_6	Street width [m]	15 (fixed)	15
W_7	Distance between buildings [m]	30 (fixed)	30
W_8	Building height [m]	12 (fixed)	12
W_9	Knife edge diffraction loss correction	0-1	0.5

Table 6.5. Comparison of Prediction Models, [34]

		Empirical Models	**Dominant Path Model**	**3D Ray Tracing**
Scenario	Rural	✓	✓	
	Urban	✓	✓	✓
	Indoor	✓	✓	✓
Results	Field strength,Path loss, Power	✓	✓	✓
	Delay Spread			✓
	Angular Spread			✓
	LOS/NLOS	✓	✓	✓
	Channel Impulse Response			✓
Computation	Direct Ray	✓	✓	✓
	Reflection		included	unlimited
	Diffraction		unlimited	2
	Fl.& Differ.		✓	✓
	Fl.& Differ.& Transom.		✓	✓
	Multiple Propagation Paths			✓
	Channel Impulse Response			✓
Prediction Area	Large Area	✓		
	Medium Areas	✓	✓	
	Small Areas	✓	✓	✓
Accuracy	near Tx	satisfying	very high	very high *)
	far from Tx	limited	very high	medium *)
Computation time	Prediction	very short	short	short *)
	Preprocessing	none	none	medium *)

*) depending on model settings (e.g. number of interactions)

Table 6.6. Various propagation models, [32]

Model	**Applicable band**	**Applicable cell**	**Applicable scenario**	**Remarks**
Propagation model in free space	Any band			Ideal formula for propagation loss, also theoretical basis for all other propagation models
Okumura	150-1920 MHz	Macro cell		Represented in diagram, not convenient
Okumura-Hata	150-1500 MHz	Macro cell .	Radius:1-20 km Urban , suburban , and rural areas, and where the NodeB antenna is higher than the surrounding rooftop	Obtained by fitting the curve of Okumura model
COST 231-Hata	1500-2000 MHz	Macro cell	Radius: 1-20 km Urban , suburban ,and rural areas, and where the NodeB antenna is higher than the surrounding rooftop	Obtained by expanding the frequency range of Okumura-Hata to 2 GHz.

Table 6.7. Various propagation models (Table 6.6 continues)

Model	**Applicable band**	**Applicable cell**	**Applicable scenario**	**Remarks**
Propagation model in free space	Any band			Ideal formula for propagation loss, also theoretical basis for all other propagation models
COST-231 Walfisch-Ikegami	800-2000 MHz	Macro cell or Micro cell for dense urban area.	Radius:0.02-5 km	Dense urban area. The NodeB antenna is just above the average height of rooftop Its propagation path includes line of sight (LOS) and non-LOS (NLOS). It considers azimuth.
COST-231 Microchips	900, 1800 MHz	Micro cell. $Radius < 1km$	Micro cell in dense urban area, and the area where NodeB antenna is below rooftop.	It considers turning corner loss.

Table 6.8. Recommended propagation models for each scenario, [32]

Scenario	**Recommended propagation models**
Micro cell in dense urban area	Volcano Micro, Volcano Mini
Macro cell in dense urban area	Volcano Mini, Volcano Macro, SPA (for calculating clutter height)
Urban area	Volcano Macro, SPA
Suburban area	SPA, Cost231-Hata
Rural area	SPA, Cost-231-Hata
Indoor area	Keenan-Motley, ITU-R P.1238
Special scenario	Propagation model for special scenario

7. COMPUTER SIMULATION OF THE PATH LOSS MODELS

Operators, generally, before deployment of a network, try to mimic the network on a computer as vividly as possible. There are many planning tools developed for this aim by different companies. For an operator, the utilization of a network planning tool is economically and technically extremely beneficial. The usage of planning tools minimizes the costs and the effort for the operators, and moreover, fasten some processes [35].

Among well known planning tools, there are Asset from Arcos company, Odyssey from Logia, Atoll from Forks, Cellula, Planet etc [9]. The simulations in this study are performed by using TEMS Cell Planner Universal from Ericsson, but they could be done with the other tools as well. Apart from TEMS Cell Planer Universal, the two other softwares are used in this study.

This chapter presents the information about 3 softwares which were used in this study. Their basic and important features are described. Chosen two 3G sites in order to investigate propagation models are mentioned.

7.1. Used Toolkit

In order to simulate propagation models in PC, three softwares are used in this study, namely TEMS Cell Planner Universal (TCPU) 6.2.2, TEMS Investigation 8.1.1 and MapInfo Professional 9.0. Apart from these softwares, a digital map is used in order to take environmental effect into account in simulation. The map is used in TCPU software.

TEMS Cell Planner Universal (TCPU) 6.2.2 is used for computing path loss values with different models. After computation of path loss values, these values should be compared with real values to test quality of proposed model. Generally planning tools is used just for planning purposes, not for comparing simulation and real values. For this reason, after computation of path loss maps, these maps is converted into MapInfo (MIF/MID) format.

TEMS Investigation 8.1.1 is used for picking up and analyzing drive test data. In this study, TEMS Investigation is used for converting drive test data to MapInfo (TAB)format.

MapInfo Professional (9.0) is used for comparing simulation value and drive test value.

Basic properties of these programs with a short description and their features used are mentioned below.

7.1.1. TEMS CellPlanner Universal

TEMS CellPlanner Universal is a graphical PC-based application for designing, implementing, and optimizing mobile radio networks developed by Ericsson [36]. This program holds 510 MB space on disk.

This program assists engineers in a number of complex tasks, including network dimensioning, traffic planning, site configuration, and frequency planning.

TEMS CellPlanner Universal provides support for different technologies to simulate namely:

- GSM 850
- GSM 900
- GSM 1800
- GSM 1900
- WCDMA
- CDMA

- CDMA2000 1xRTT
- TDMA/AMPS
- NMT 450
- NMT 900
- TACS and E-TACS

TEMS CellPlanner Universal also provides support for GPRS and EGPRS (EDGE) implemented on GSM systems, HSDPA in WCDMA systems, and EV-DO implemented in CDMA systems.

TCPU is used to simulate propagation prediction models. In order to get path loss prediction in TCPU, a number of parameters should be defined and set, these are:

- Sites, UTRAN Cells, Antenna Systems, Antennas, Antenna System Controllers (ASC)
- Channel Parameters
- Propagation Prediction Model Parameters

The other tools developed by Ericsson for WCDMA portfolio are TEMS Investigation WCDMA, TEMS DeskCat, TEMS Light WCDMA, TEMS Pocket WCDMA, TEMS Automatic WCDMA, TEMS Modeler, TEMS LinkPlanner and TEMS CellSight [30].

7.1.2. MapInfo Professional 9.0

MapInfo Professional is a powerful Microsoft Windows-based mapping and geographic analysis application, and a commonly used desktop GIS (Geographic Information System) software package produced by the MapInfo Corporation [37]. This program holds 284 MB space on disk.

Important features of Mapinfo Professional were used for performing this study shown below .

<u>7.1.2.1. Ability to Show Different Map Layers on the Same Window.</u> By using this property, computer simulation of path loss model maps (created in TCPU and converted into MapInfo format) and drive test data maps (created in TEMS Investigation and converted into MapInfo format) are opened at the same window [37].

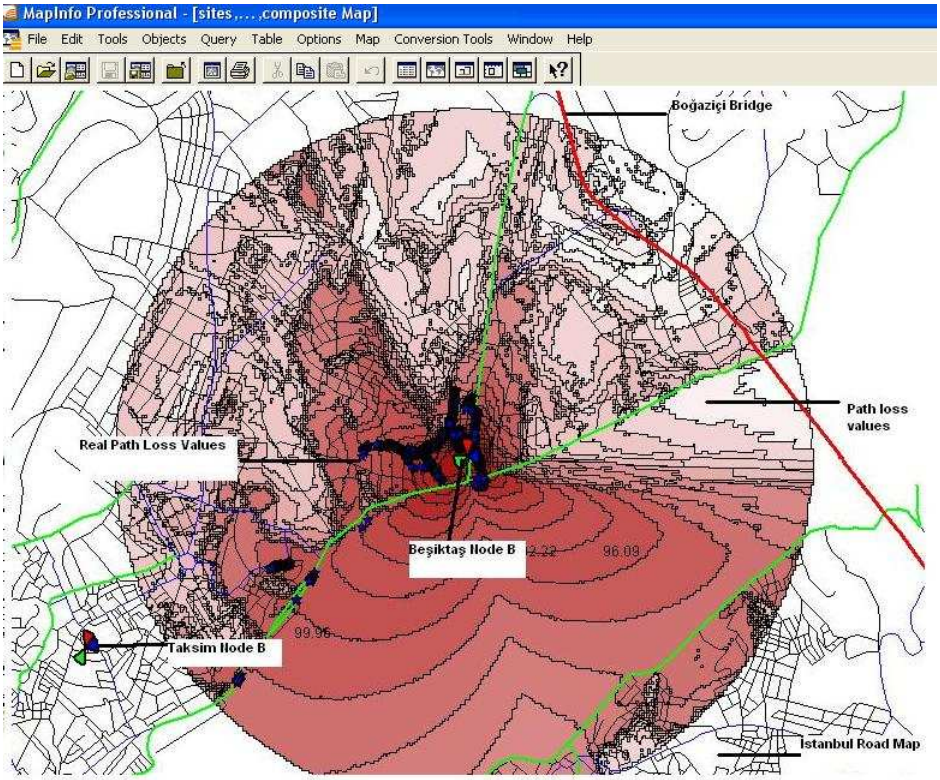

Figure 7.1. An example view of a study in Mapinfo Professional

In Figure 7.1, there are four different maps which are opened at the same window by using MapInfo layer control property. First map is road map of İstanbul, which only shows which area of the İstanbul the study on and stated black curves in the figure. Second map shows path loss map calculated using Walfisch-Ikegami model and stated red tones in the figure. Third map shows drive test data points and stated black and blue thick dots. And the last map shows two 3G sites which are the study on. 3G sites are stated as 3 triangles which refer to 3-sectorised cell sites.

In MapInfo, maps can have "browse windows" which holds information about map, for example for path loss maps, browse window holds the value of path loss at that coordinate. These browse windows are similar to Microsoft Excel sheets.

7.1.2.2. Table Maintenance. This property is used to create two new columns in the browse window tables. In this study two new columns are added to drive test data window. First column was used for holding simulation value at the same coordinate. Second row is used for holding error at that coordinate.

7.1.2.3. Calculate Statistics Property. This property is used for getting statistical data about error.

7.1.2.4. Update Column Property. One of the most useful property of MapInfo tool is its update column property. By using this property, for every coordinate, simulation value and drive test value can be picked up at the same browse window which is vital to calculating error. In this property, "sql" language is used.

7.1.2.5. SQL Select. In MapInfo, sql query script can be written for manipulation of data. In this study, simulation and drive test data were manipulated by using sql select scripts.

Drive test data for these specific sites were extracted from a drive test data collection picked up around Beşiktaş and Karaköy by writing a sql script using sites unique scrambling codes.

7.1.3. Tems Investigation 8.1 Data Collection and Route Analysis

TEMS Investigation is an air interface test tool for troubleshooting, verification, optimization, and maintenance of mobile networks [38]. This program holds 191 MB space on the disk.

This software can be run in two different modes, one for testing and recording, and one for replay and analysis.

In this study, log files for WCDMA networks is converted into MapInfo Tab file by using Tems Investigation export file property.

7.1.4. Used Map

Used map has a resolution 10 meter x 10 meter. Generally, for path loss calculation, the more resolution, the better performance. This map holds 49.3 MB on the disk. In literature, 5 meter x 5 meter resolution maps is used in a similar project [35].

Map Projection is Longitude/Latitude (NTF with Greenwich prime meridian). In this map, there elevation data, land usage (clutter) data, vector data and text data. But there are not building height information which is necessary for ray tracing models.

Elevation file, as the name suggests, holds elevation information of investigated area. Text data fila holds the names of roads, streets etc. Land usage file holds information about how area is used. Investigated area are grouped according the their similarities. For every map, clutter number varies according to application. Below, a list of land usage data available in the used map is shown:

- Buildings
- Dense block buildings
- Dense block buildings high
- Block buildings high
- Dense urban low
- Dense urban
- Dense urban high
- Industrial Commercial
- Low residential
- Tax area
- Mean urban
- Open land
- Parks
- Inland water

- Sea
- Openinurban
- High residential
- Semi open Area
- Sparse forest

The example definition of land usage (clutter) data refer to Appendix B, but all the maps should be evaluated in its own. A creation of land usage is shown in Figure 7.3 for Berlin city step by step.

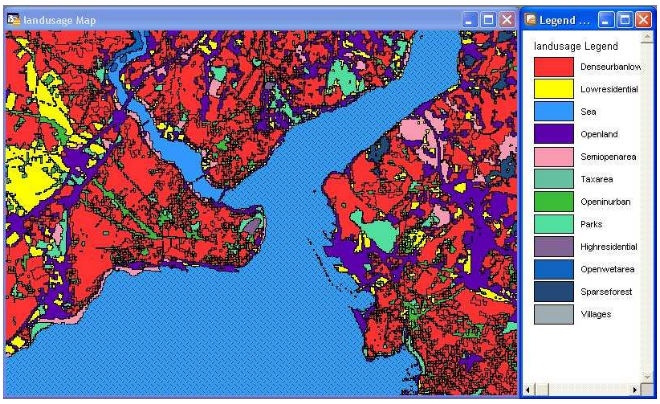

Figure 7.2. An example view of land usage map of Istanbul

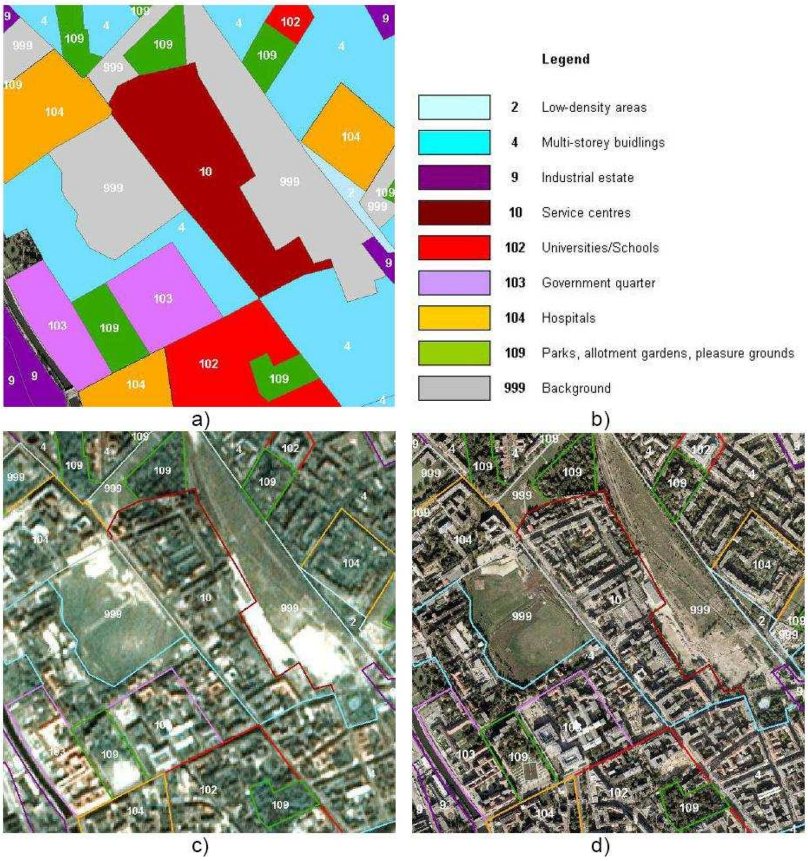

Figure 7.3. Berlin example from the country-wide urban clutter data, a) Urban classification b) Legend c) Subset of high resolution satellite image mosaic of Germany - EuroMaps (5 m) d) Subset of orthoimage (0,4 m) used for verification, [39]

A similar technique is used while creation of land usage map of Istanbul.

7.2. Investigated Area

The reference measurements for the comparison were conducted in pre-commercial UMTS FDD network deployed in urban environment. Two sites were selected for simulation of path loss models, namely Taksim and Beşiktaş sites. The propagation environment for investigation was chosen in a dense environment in İstanbul. In these sites, the average antenna height is close to the average roof top level, hence forms a combination of macro and micro-cellular environments. The site configuration consists of 3-sectored cells. Generally mechanical and electrical downtilting is used.

In order to make comment on predicted loss values of sites, Google Earth picture of sites and NodeB antenna and investigated area of Beşiktaş are shown below.

Figure 7.4. Google Earth wive of Beşiktaş

Figure 7.5. A picture of Beşiktaş Site

Figure 7.6. Another Picture of Beşiktaş Site

7.3. Beşiktaş and Taksim Sites Properties

- Both Beşiktaş and Taksim are 3-sectorized sites

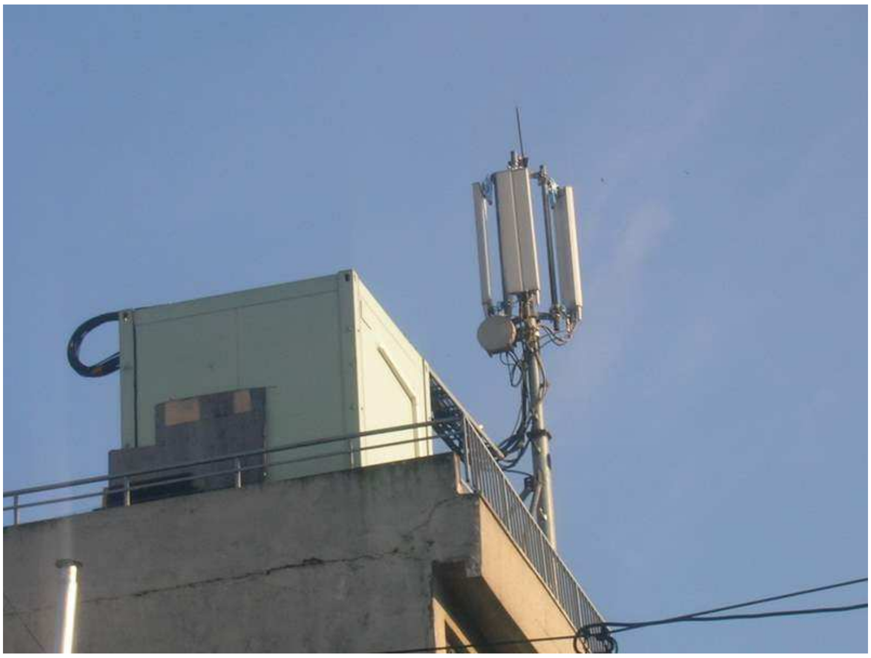

Figure 7.7. Beşiktaş Node B antenna and cabinet

Figure 7.8. Google Earth wive of Taksim

- All three Beşiktaş site antennas are 20 meters from ground, two of Taksim antennas are 12 meters and the other antenna of Taksim is 14 meters from ground.
- Base station maximum power for both sites are 43 dBm

- Pilot power is 30dBm
- Used antenna in simulation for both sites is Kathrein 742215 Multi-band Panel Dual Polarization Half-power Beam Width Adjust. Electrical downtilt can be set by hand or by optional RCU (Remote Control Unit), provides a gain of 18 dBi. For more information refer to Appendix C. In order to add antenna pattern into TCPU, imported antenna patterns files are added in EET format. For every electrical tilt, there is an antenna pattern file.
- For Taksim Site, all three antennas have two degrees electrical downtilt and a mechanical downtilt of 2 degree. For Beşiktaş all three antennas have 4 degrees electrical downtilt and a mechanical downtilt of 0 degree.
- For Beşiktaş site, the azimuth of the first antenna is 0 degree, the second antenna 90 degrees and the third antenna has 240 degrees azimuth angle. For Taksim site, the azimuth of the first antenna is 10 degrees, the second antenna 70 degrees and the third antenna has 210 degrees azimuth angle.

7.4. Path Loss Plots

In order to create a path loss table in TCPU, 3 path loss models are used; Algorithm 9999 which is Ericsson's implementation of the Okumura-Hata Model with empirical correction, the Okumura-Hata Model and the Walfisch-Ikegami Model in TCPU.

For all figures, maximum allowable path loss for calculation is 200 dB. Any path loss higher than this value is not included in the resulting pathloss calculation to limit analyzed area. Pathloss prediction was made within a circle with radius 2300 meters.

In TCPU, there are three plots in order to analyze path loss of a site. Pathloss by Cell (in 3D), Pathloss Cell Count, Pathloss Composite (Best Server).

Calculate Composite Pathloss: Calculating of composite pathloss combines the pathloss prediction from individual cells into a matrix to give an overview of pathloss for a project [36].

In TCPU, WCDMA composite pathloss matrix analysis window is used in order to create composite matrix.

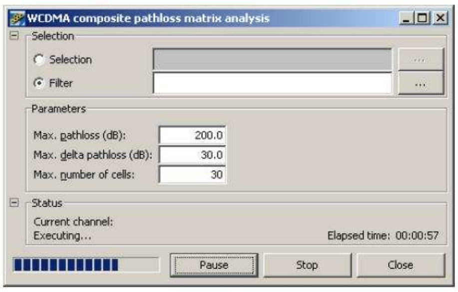

Figure 7.9. WCDMA composite pathloss matrix analysis

Pathloss by Cell: The color of the display shows the best serving cell, while the pathloss value is shown by changing hue and saturation of the selected color.

Pathloss Cell Count: The cell count displays the total number of cells, for which a pathloss value is available at any position in the network.

Pathloss by Cell (in 3D), Pathloss Cell Count, Pathloss Composite (Best Server) create a matrix of relevant values. Apart from these matrixes, by using status bar at the bottom of the map, we can learn the pathloss value of the selected point. As can be seen in following plots , path loss value can be high in the points near the site and it can be low in the points far away from sites. The reason of this is that diffraction, reflection or scattering increasing effect as some points while have a decreasing effects in other points according the features of environment.

At first the radio propagation model is computed, and then simulation result is converted MapInfo(MIF/MID)format in order to make a comparison between simulation and log data. There are two format in export mode in TCPU, one is Local East/North and the second is WGS84 Longitude/ Latitude. Second one is chosen since drive test data are also in the form of WGS84.

8. QUANTITATIVE RESULTS

In this thesis, three propagation path loss models were chosen in order to predict path loss in WCDMA system. Used path loss models are:

- Algorithm 9999
- Ericsson implementation of the Okumura-Hata Model
- Ericsson implementation of the Walfisch-Ikegami Model

Path loss formulas of these models can be found in Chapter 6. Prediction results of these three models are compared real measurements obtained from a WCDMA based network for the city İstanbul, and then prediction results are compared with literature. Prediction and comparison results are presented throughout this chapter.

8.1. Path Loss Prediction Maps

In the path loss prediction figures, path loss maps create a circle around base station with the tones of red. Base stations (ISH1204: Beşiktaş Site, ISH0040: Taksim Site) are shown as a point covered by three small lines. These three lines show antenna positions of base station. Behind the path loss map,the clutter map of İstanbul appears. Left side or sometimes right side of these maps, there are legend information. In legend part, there are two kind of information. First (upper side), WCDMA CPLM (Composite pathloss) is shown. This part of legend gives information about path loss values in path loss maps. Second (lower side), landuse codes of İstanbul are shown. For example, in Figure 8.1, green colored parts of display shows open urban areas in İstanbul. Definition of open urban can be found in Appendix B.

Path loss maps create a circle around base station. Because in TCPU setup, it was chosen for path loss maps to create a circle around the base station with radius 2.3 km. The density of the color in displays shows path loss value levels. For example, in Figure 8.1, there are seven different color tones of red. That means, there are seven different path loss values in this map. For instance, the darkest red tone shows the smallest path loss value, this smallest path loss value is between 53.69-63.91 dB for Figure 8.1. Generally the darkest tone or smallest path loss value in all displays is very close to base station, which makes sense according to path loss formulas.

Figures 8.1, 8.2, 8.3 show path loss maps for Beşiktaş site, and Figures 8.5, 8.6, 8.7 show path loss maps for Taksim site which were created by using Algorithm 9999, Ericsson implementation of the Okumura-Hata and Walfisch-Ikegami path loss models respectively.

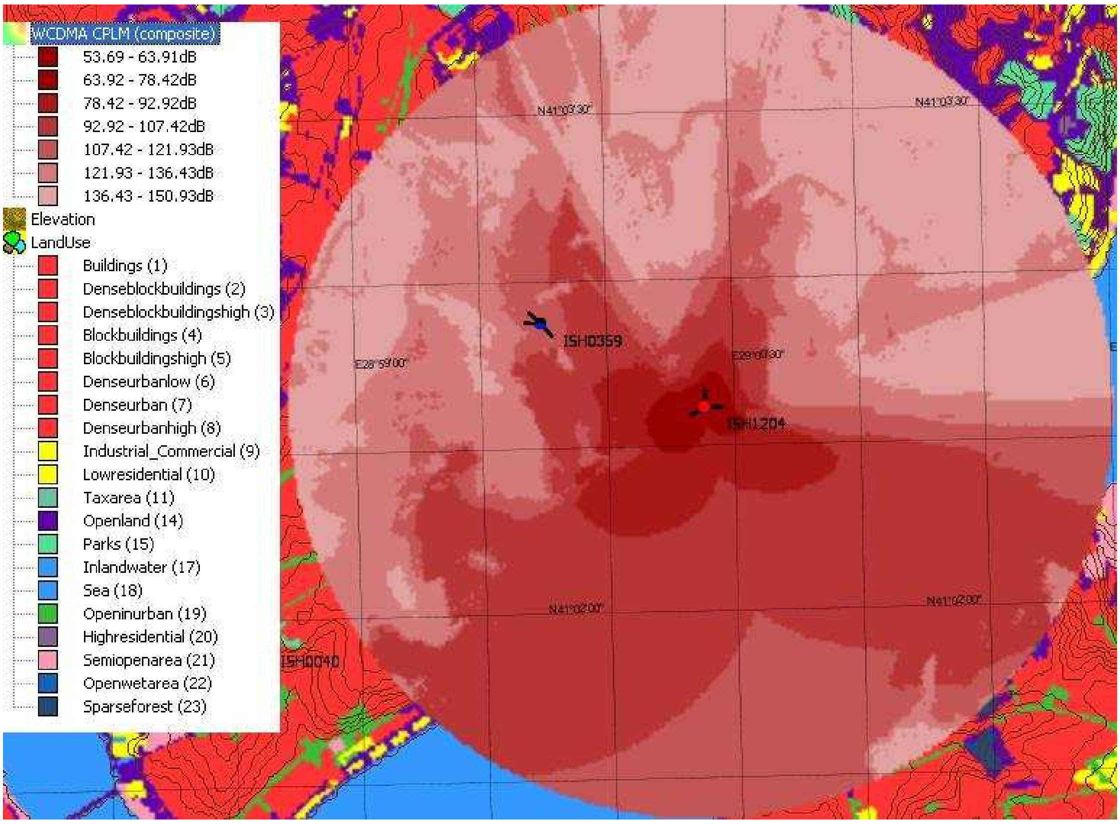

Figure 8.1. Path loss of map of Beşiktaş UMTS NodeB by Algorithm 9999

From all path loss maps, the three-sector antenna pattern are clearly seen from the shape of the results since none of the model do not take into account building information in prediction.

Generally Okumura-Hata based models works better in a little bit far from the

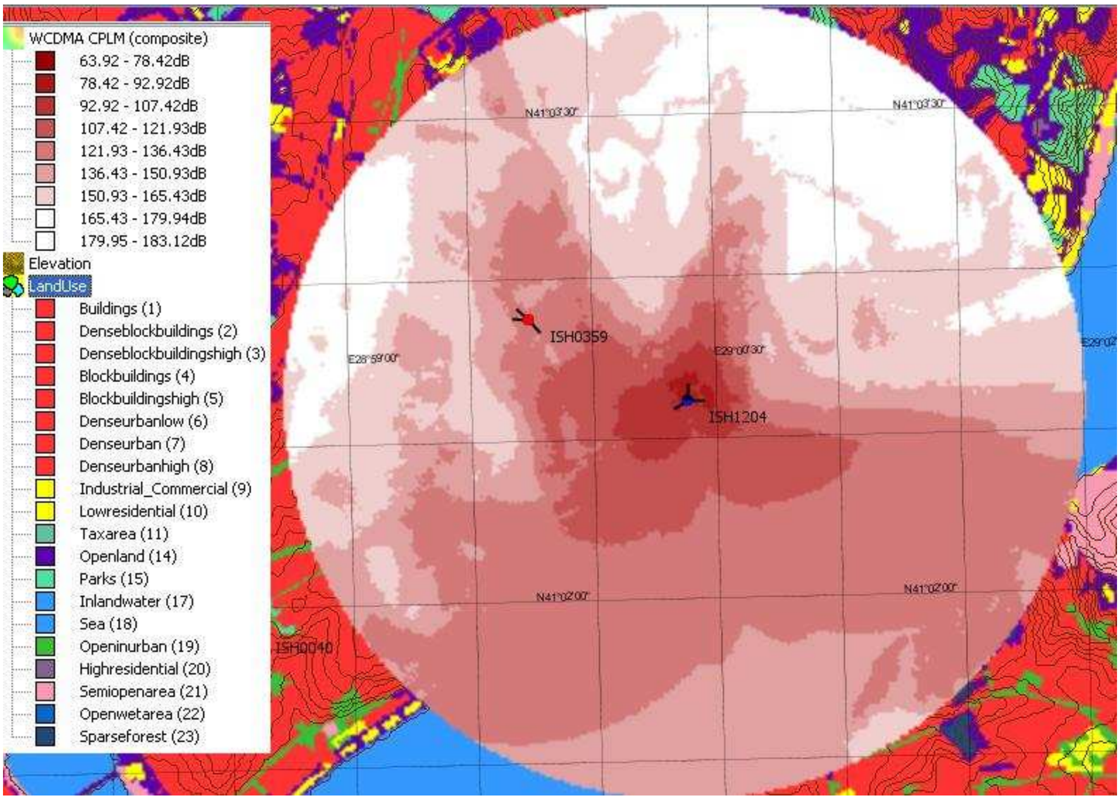

Figure 8.2. Path loss of map of Beşiktaş UMTS NodeB by Okumura-Hata

base station [36]. In order to test this fact, Beşiktaş Site is investigated within two part, namely Area1 and Area2 as shown in Figure 8.4. Area1 is a circle around base station which has a radius about 1 kilometers. Area2 is the area between 1 kilometer circle and 2.3 kilometers circle.

Table 8.1 shows mean prediction error, the standard deviation of the error which were calculated in Beşiktaş site by using Algorithm 9999, Ericsson implementation of Okumura-Hata and Ericsson implementation of Walfisch-Ikegami path loss models.

The definition of mean error and standard deviation of error stated in formula 8.2 and 8.3 respectively.

The prediction deviation is a difference of measured level and predicted level[16]:

$$E(i) = P_{measured}(i) - P_{predicted}(i) \tag{8.1}$$

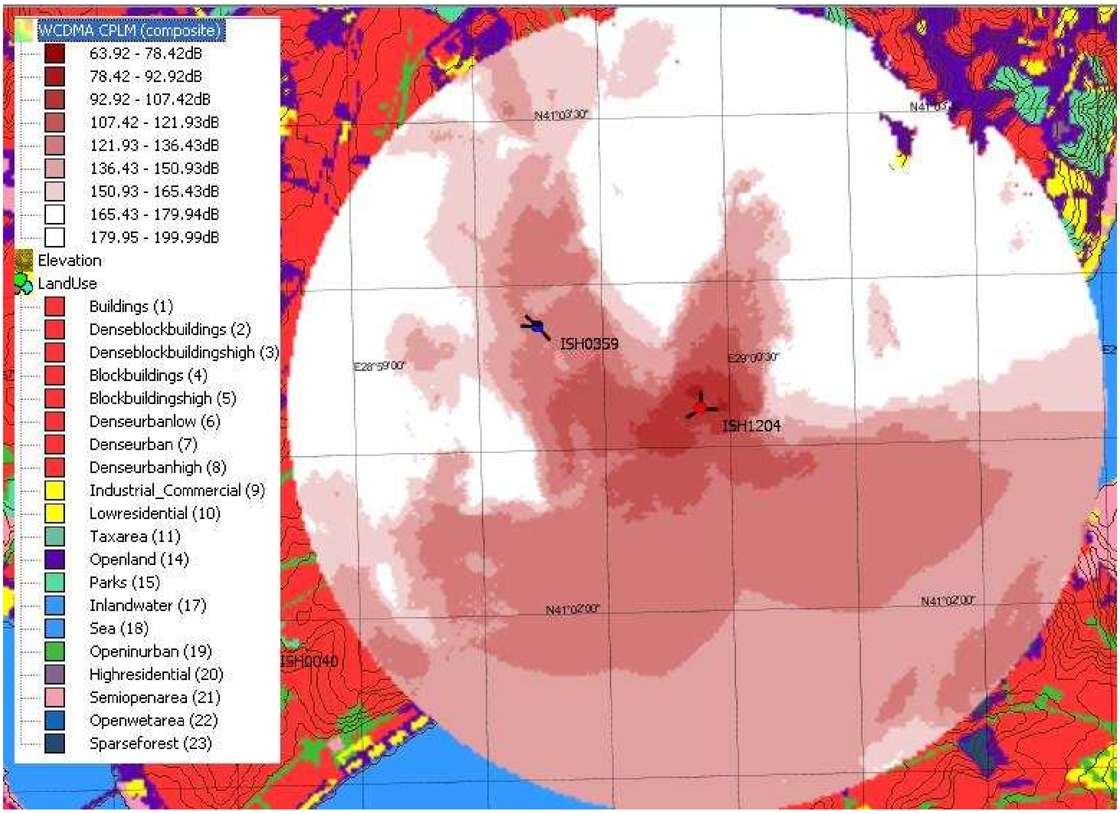

Figure 8.3. Path loss of map of Beşiktaş UMTS NodeB by Walfisch-Ikegami

The mean error is the difference of predicted mean level and measured mean level:

$$\mu = \bar{E} = \frac{1}{n}\sum_{i}^{n} E(i) \tag{8.2}$$

The standard deviation is the mean square error with mean error excluded:

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i}^{n}(E(i) - \bar{E})^2} \tag{8.3}$$

According to Table 8.1, it is observed that path loss values predicted by Algorithm 9999 model underestimates the path loss in most areas. The reason for this may be not tuning the model against measurement. There are four variable namely $A_0 - A_3$ that can be tuned or adjusted for a specific area in Algorithm 9999. But $A_0 - A_3$ are not adjusted in this study, just default parameter setting for Algorithm 9999. If

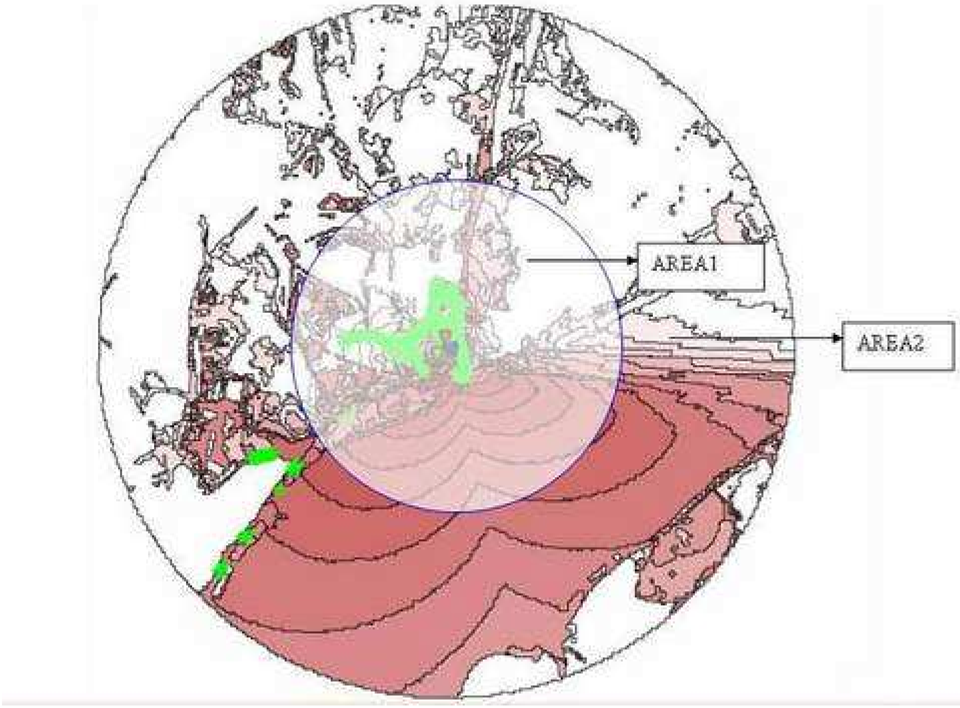

Figure 8.4. Beşiktaş Site, Area1 and Area2

the model is tuned against measurement, the model definitely will give better results. More information about model tuning can be found in Appendix D.

Table 8.1 also shows that Ericsson implementation of the Okumura-Hata model gives better result in Area2 than results in Area1. Since Area2 is far from Area1, and Okumura-Hata based models gives better results in remote areas than close areas.

Ericsson implementation of the Walfisch-Ikegami model gives the best result in Beşiktaş. As stated in [21], Hata Model gives good result for medium and small cities while Cost 231 Walfisch-Ikegami Model gives better result in large cities and over rooftop propagation. Since İstanbul is a very large city and the antennas were deployed over rooftop, so the propagation of waves over rooftop, it is straightforward, Walfisch-Ikegami Model gives better result in İstanbul.

Figures 8.5, 8.6 and 8.7 show path loss maps for Taksim site, which were created by using Algorithm 9999, Ericsson implementation of the Okumura-Hata and Walfisch-

Table 8.1. Statistical analysis of the error in Beşiktaş with different models

Test Area	Okumura-Hata		Walfisch-Ikegami		Algorithm 9999	
	μ (dB)	σ (dB)	μ (dB)	σ (dB)	μ (dB)	σ (dB)
Beşiktaş Area 1	5.7144	7.97919	-0.2431	7.698	25.7378	9.70921
Beşiktaş Area 2	-9.94497	4.50152	-10.7216	3.96764	14.8249	5.3139

Ikegami path loss models respectively.

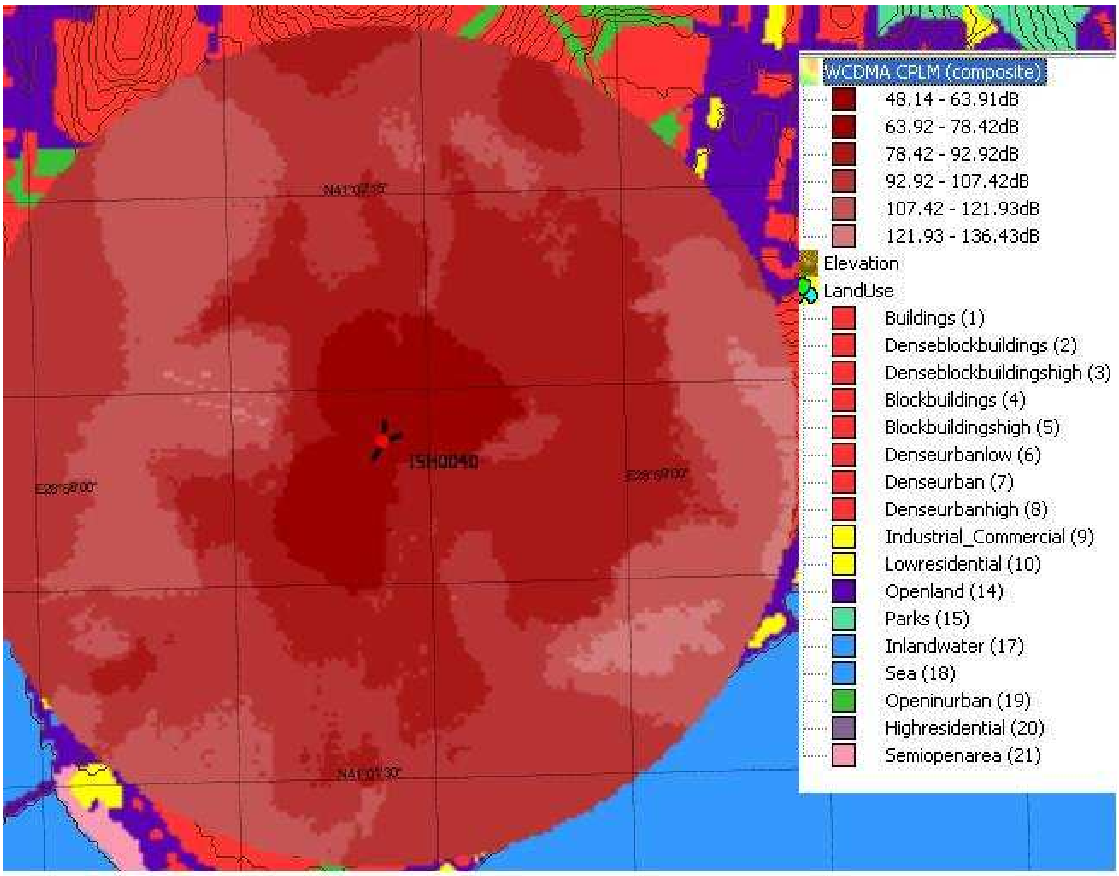

Figure 8.5. Path loss of map of Taksim UMTS NodeB by Algorithm 9999

According to Table 8.2, among all three path loss model, Ericsson implementation of the Walfisch-Ikegami model gives the best result in Taksim, too.

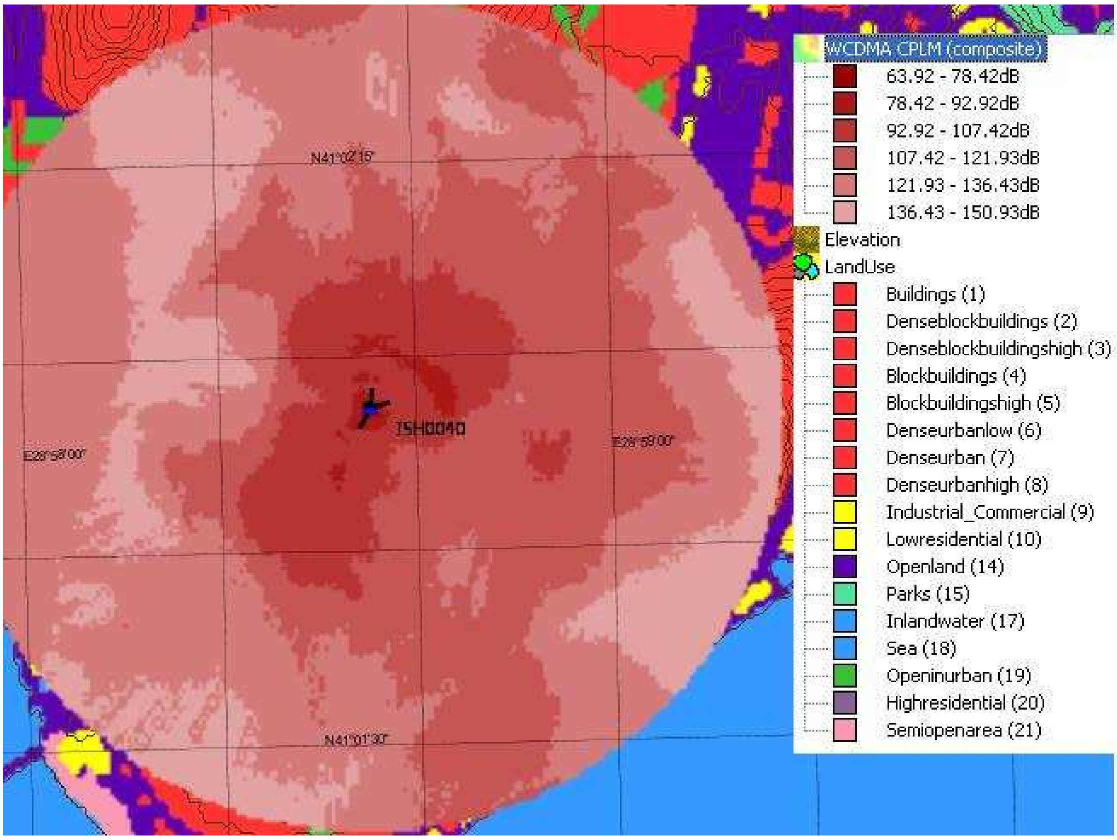

Figure 8.6. Path loss of map of Taksim UMTS NodeB by Okumura-Hata

Table 8.2. Statistical analysis of the error in Taksim with different models

Test Area	Okumura-Hata		Walfisch-Ikegami		Algorithm 9999	
	μ(dB)	σ(dB)	μ(dB)	σ(dB)	μ(dB)	σ(dB)
Taksim	2.88741	13.7049	2.33018	13.5482	29.2916	14.5018

When Table 8.1 and Table 8.2 are compared, all three path loss models give better result in Beşiktaş. Because standard deviation of error for each path loss model gives smallest value in Beşiktaş. The reason for better result in Beşiktaş may be the antenna deployment for Beşiktaş site. Since antenna heights of Beşiktaş are considerable higher than Taksim antennas, accuracy of path loss prediction is high in Beşiktaş.

In Beşiktaş, path loss models works better in Area2. The reason for this, like stated in [36], empirical models work better in remote areas than close areas.

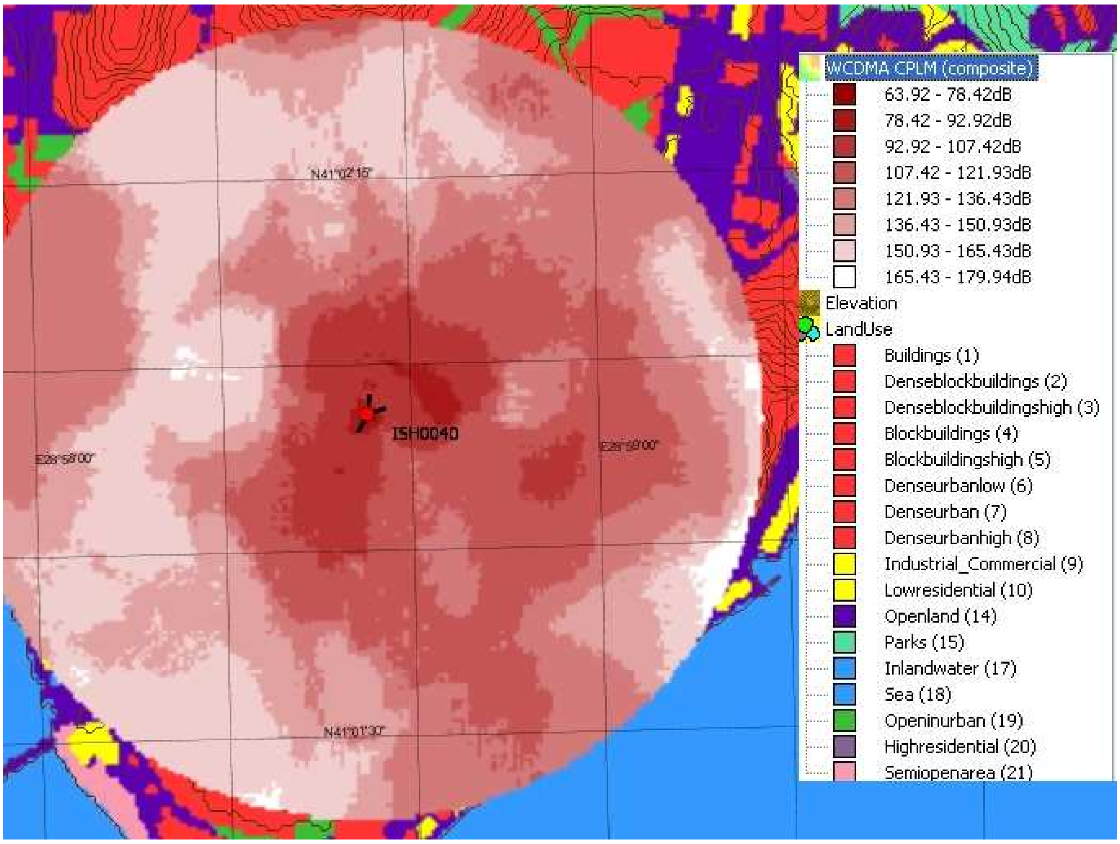

Figure 8.7. Path loss of map of Taksim UMTS NodeB by Walfisch-Ikegami

As a summary, it can be concluded that Walfisch-Ikegami model works best in both Beşiktaş and Taksim sites, and antenna position of sites is very important parameter in accuracy of a path loss prediction model.

8.2. LOS of Sites

In order make an easy comment about created path loss maps, LOS of Beşiktaş and Taksim sites are shown in Figure 8.8 and 8.9 respectively. In these figures, LOS of sites are stated as yellow color. Curves in Figure 8.8 and 8.9 show elevation map of Beşiktaş and Taksim.

When path loss maps and LOS of sites are compared, for instance, when Figure 8.1 and Figure 8.8 are compared, it can be seen that darkest tone of red in Figure 8.1 and yellow colored area in Figure 8.8 match each other. In Figure 8.1, the darkest tone shows the smallest path loss value, in Figure 8.8 yellow colored area shows LOS of Beşiktaş site. It is straightforward, in LOS, path loss will be smaller.

However, LOS area of Beşiktaş site in sea region has somewhat continuous counters. But in Figure 8.1, the darkest red tone does not have continuous counters. This mismatch is due to antenna pattern effect of Beşiktaş site.

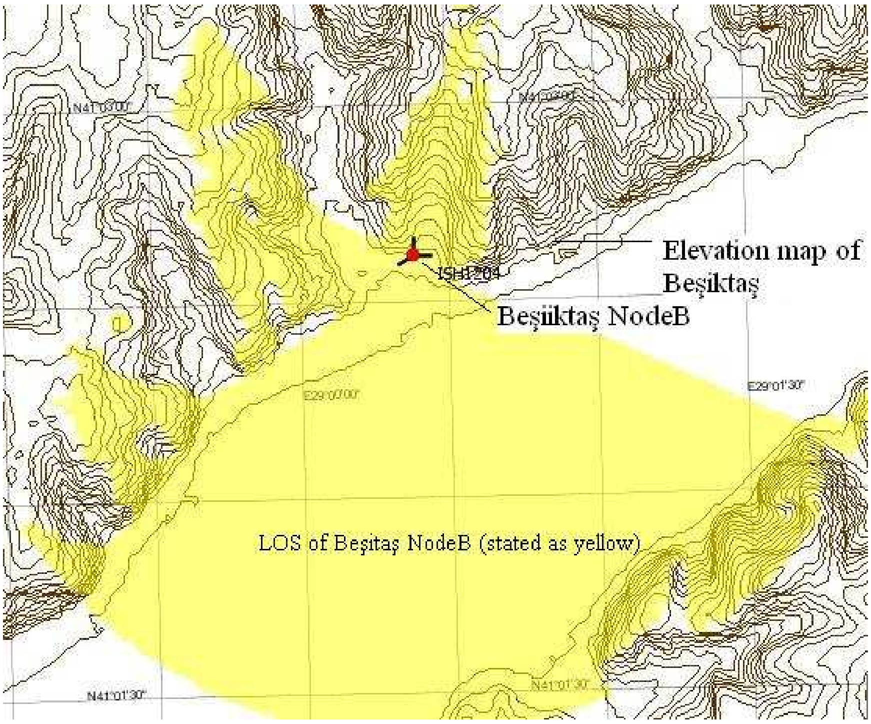

Figure 8.8. Line of sight of Beşiktaş Site

8.3. Description of the Measurement Environment

Measurements route carried out in Beşiktaş and Taksim site are shown Figure 8.10 and Figure 8.11 respectively.

In Figure 8.10, building information map data and measurement points are shown in Beşiktaş. Three triangle with red, blue and green colors show Beşiktaş antennas. Small green stars show measurement points in Beşiktaş. The point number is shown every 5 points in measurement points. Measurements start with the 1 and continue through the route. In Figure 8.11, clutter map and measurement points are shown in

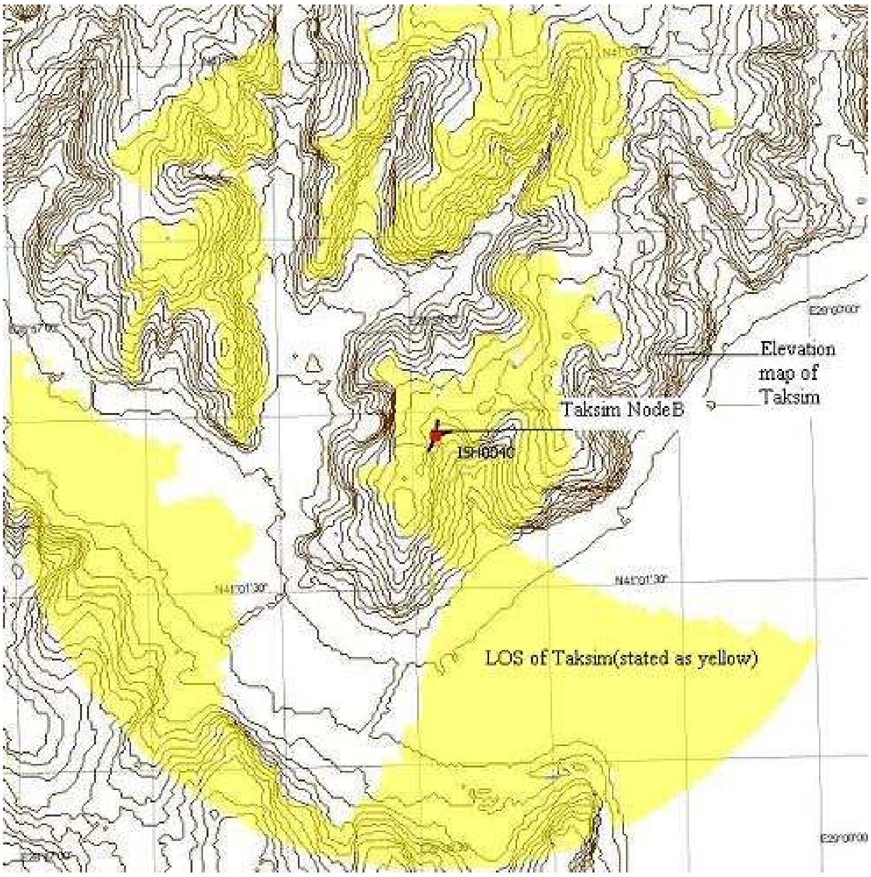

Figure 8.9. Line of sight of Taksim Site

Taksim. Three triangle with red, blue and green colors shown Taksim antennas.

Figures, from 8.12 to 8.17, show simulation versus measurements for Beşiktaş and Taksim respectively.

Figure 8.12 shows that Algorithm 9999 underestimates the path loss in Beşiktaş . Real path loss values are higher than values that Algorithm 9999 predict for this area. Figure 8.14 shows that Okumura-Hata Model gives better result than Algorithm 9999 Model. From Figure 8.13, it can be seen that generally simulation path loss values and real path loss values are parallel in Walfisch-Ikegami Model. There is small mean error between simulation and real values.

Table 8.1 and Figure 8.13 indicate that simulation values and real values are generally similar. When all the graphics are examined, it can be concluded that Walfisch-

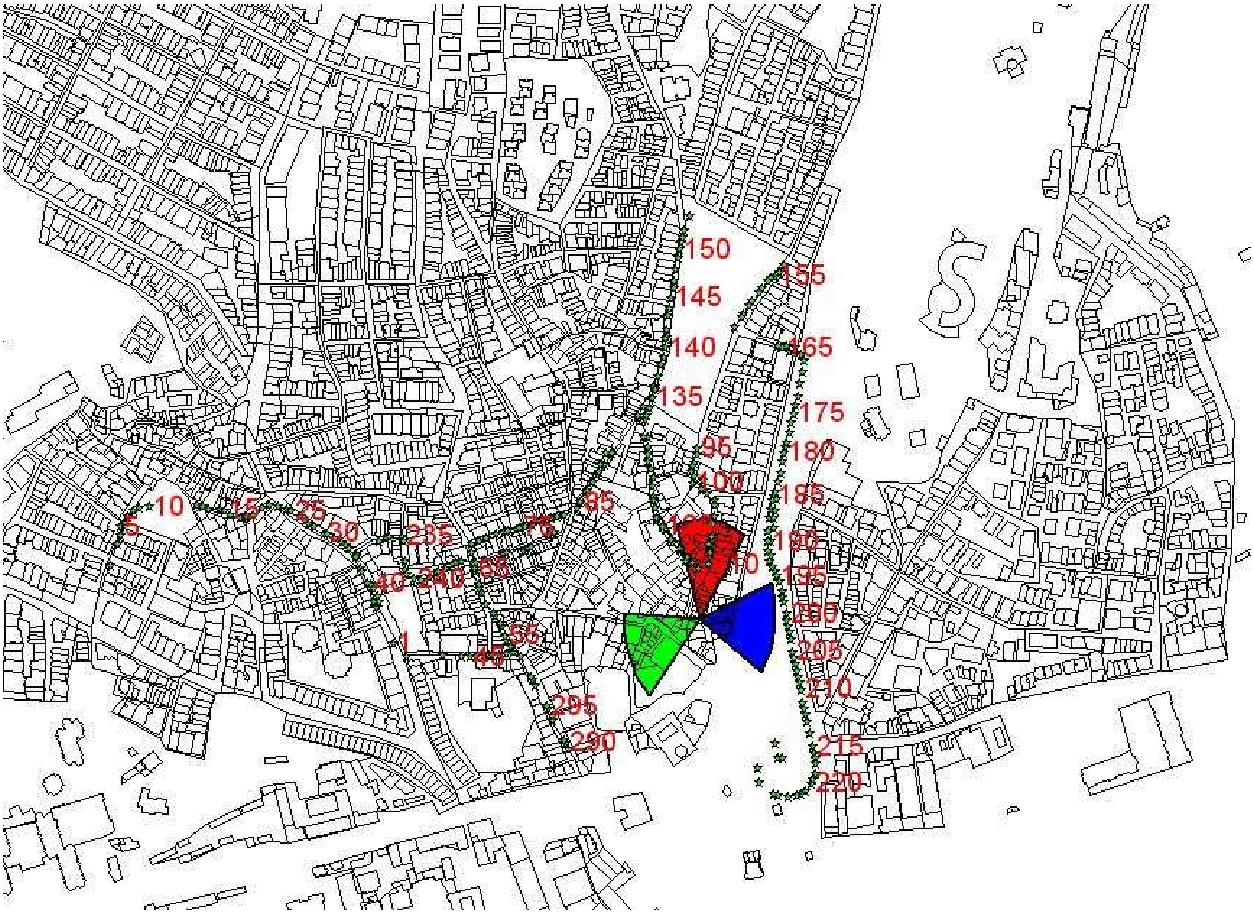

Figure 8.10. Measurement points in Beşiktaş site

Ikegami Model is the best for Beşiktaş.

Figures, from 8.15 to 8.17 show that both Algorithm 9999 and Walfisch-Ikegami underestimate path loss values in Taksim. Among there models, Walfisch-Ikegami gets the best result in Taksim, too.

8.4. Error in Clutters

Beşiktaş drive test data collected on openland, dense urban, openinurban, industrial commercial and parks clutters.

Taksim drive test data collected on Denseurbanlow, DenseUrban, Denseurbanhigh, Openinurban, Buildings clutters.

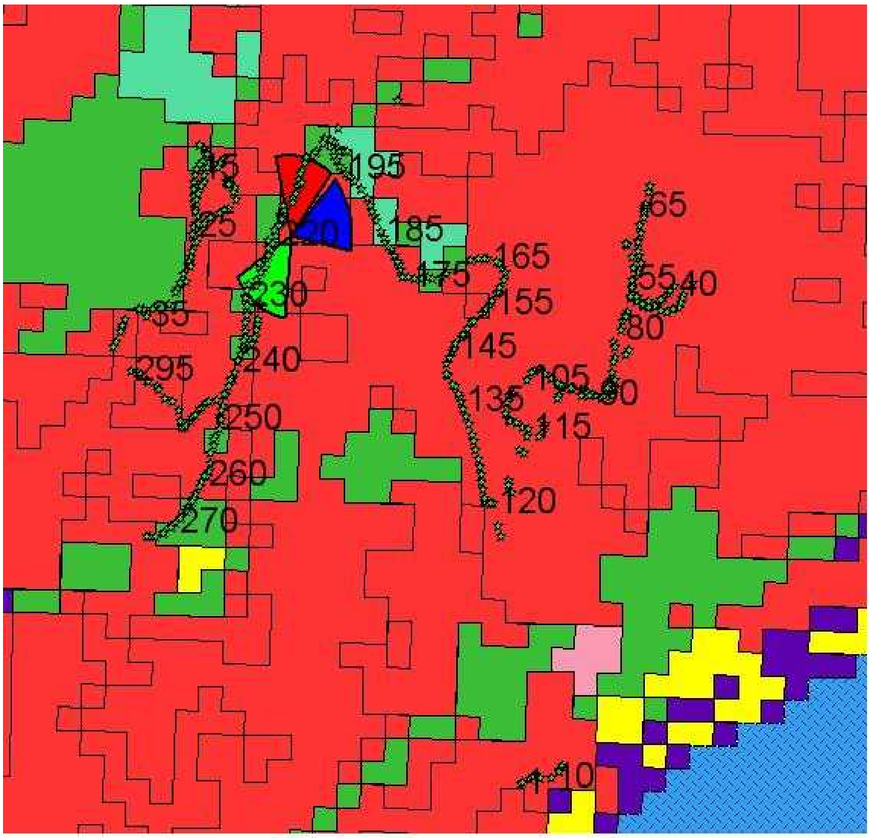

Figure 8.11. Measurement points in Taksim site

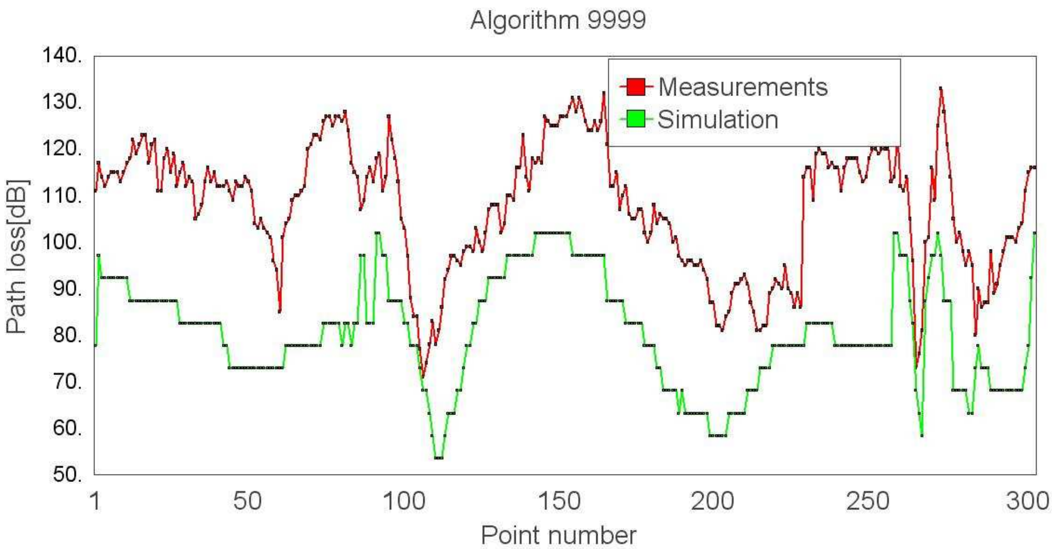

Figure 8.12. Comparisons in Beşiktaş Algorithm 9999 predictions results and measurements

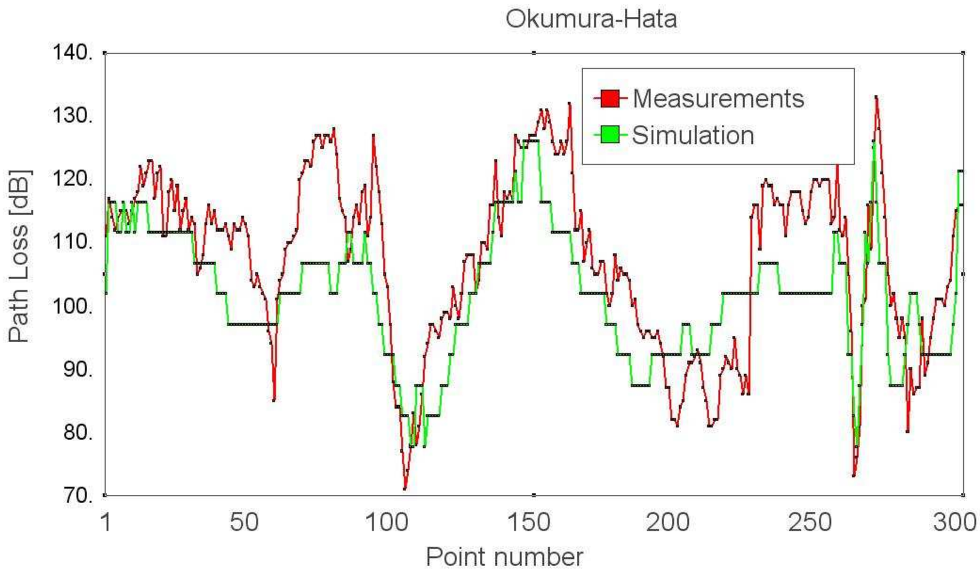

Figure 8.13. Comparisons in Beşiktaş Okumura-Hata model in TCPU predictions results and measurements

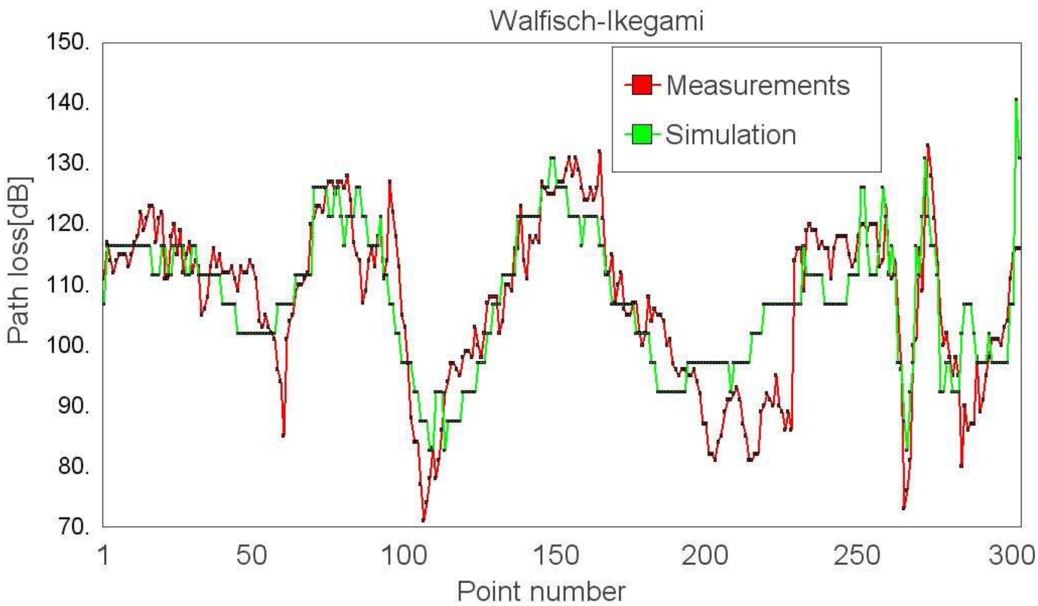

Figure 8.14. Comparisons in Beşiktaş Walfisch-Ikegami predictions results and measurements

Clutter error results are presented Table 8.3 and 8.4 for Beşiktaş and Taksim sites respectively.

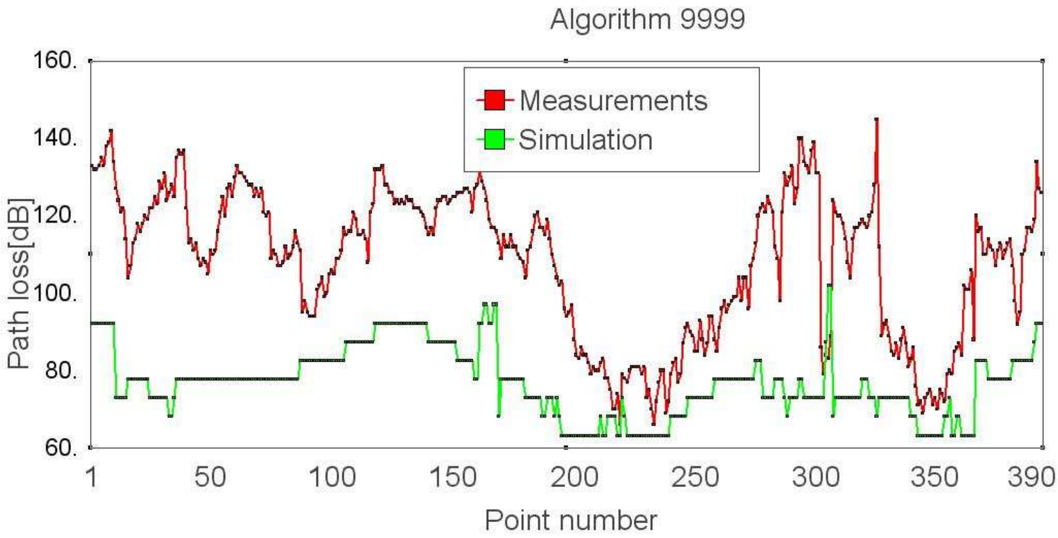

Figure 8.15. Comparisons in Taksim Algorithm 9999 predictions results and measurements

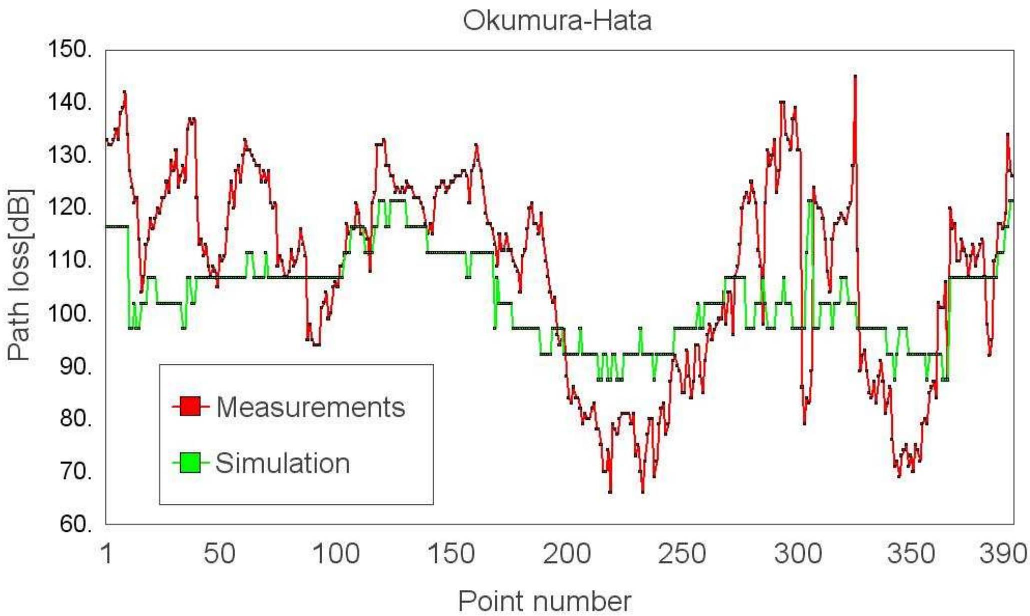

Figure 8.16. Comparisons in Taksim Okumura-Hata predictions results and measurements

When Tables 8.3 and 8.4 are investigated, it can be seen that models performs differently in different clutters.

When the results of this study and literature are compared, it can be seen that

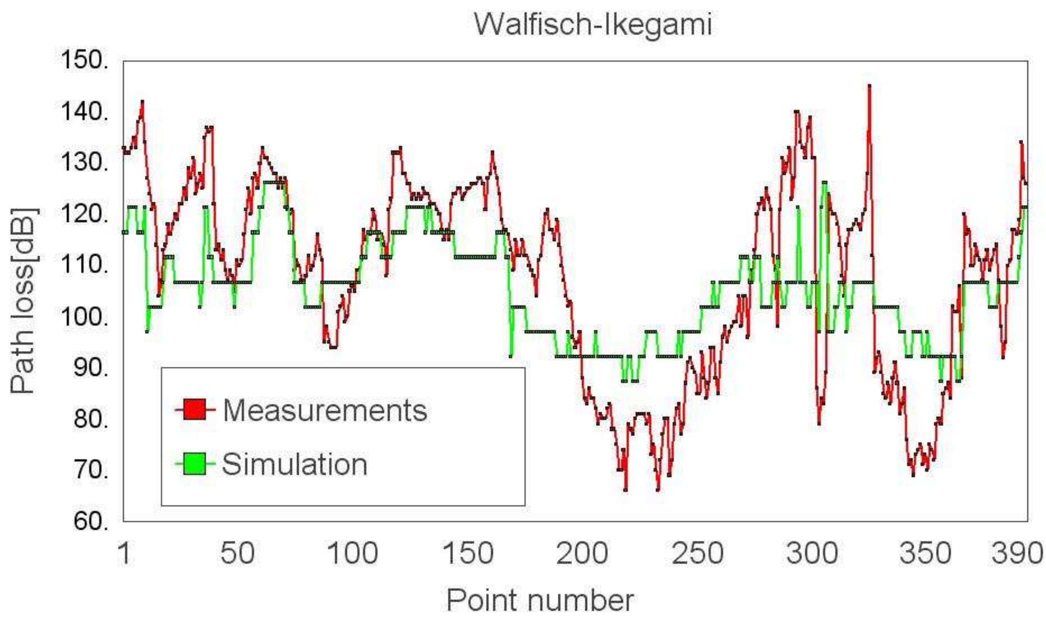

Figure 8.17. Comparisons in Taksim Walfisch-Ikegami predictions results and measurements

Table 8.3. Error in clutters in Beşiktaş site

	Algorithm 9999	**Okumura Hata**	**Walfisch Ikegami**
Openland	$\mu = 25.71$ $\sigma = 9.73$	$\mu = -0.59$ $\sigma = 11.90$	$\mu = -5.43$ $\sigma = 11.56$
DenseUrban	$\mu = 25.48$ $\sigma = 10.33$	$\mu = 7.46$ $\sigma = 7.61$	$\mu = 0.94$ $\sigma = 7.06$
Openinurban	$\mu = 22.80$ $\sigma = 8.48$	$\mu = 5.50$ $\sigma = 7.23$	$\mu = 1.28$ $\sigma = 7.27$
Industrial Commercial	$\mu = 28.69$ $\sigma = 2.74$	$\mu = -2.555$ $\sigma = 3.94$	$\mu = -5.58$ $\sigma = 4.99$
Parks	$\mu = 12.78$ $\sigma = 1.41$	$\mu = -5.26$ $\sigma = 0$	$\mu = -19.78$ $\sigma = 4.84$

results of this study are comparably worse than literature. Because in literature, models are tuned against measurement, however in this study, model tuning is not applied to models.

Table 8.4. Error in clutters in Taksim site

	Algorithm 9999	**Okumura Hata**	**Walfisch Ikegami**
Denseurbanlow	$\mu = 3228$ $\sigma = 1.5$	$\mu = 3.24$ $\sigma = 1.5$	$\mu = 3.24$ $\sigma = 1.5$
DenseUrban	$\mu = 31.75$ $\sigma = 10.59$	$\mu = 5.76$ $\sigma = 10.30$	$\mu = 4.88$ $\sigma = 10.18$
Denseurbanhigh	$\mu = 30.74$ $\sigma = 17.29$	$\mu = 4.08$ $\sigma = 16.84$	$\mu = 0.468$ $\sigma = 15.82$
Openinurban	$\mu = 33.18$ $\sigma = 18.44$	$\mu = 6.01$ $\sigma = 17.42$	$\mu = 3.81$ $\sigma = 16.68$
Buildings	$\mu = 25.25$ $\sigma = 19.52$	$\mu = -0.65$ $\sigma = 19.40$	$\mu = -2.93$ $\sigma = 15.83$

8.5. Literature survey

This study is one of the fewest studies performed in Turkey in terms of investigating path loss in UMTS. Here, there is a brief summary about studies all over the world investigating path loss.

8.5.1. The Impact of Radio Propagation Predictions on Urban UMTS Planning

This study was performed in 2002. Investigated area is 5.4 km^2 area of Paris (France). In order to create path loss maps, a simulation tool called Atoll is used. Used map in simulation program contains building data and terrain data. For path loss calculation, two model were used: Cost 231-Hata Model and Wavesight Ray Tracing model. First model, Cost 231-Hata Model, takes into account only terrain information in simulation, whereas, second model, namely Wavesight Ray Tracing model takes, takes into account both terrain information and building layout. After path loss calculation, models were tuned against measurements. As a quality measure of models mean error, standard deviation of error were used. The study is done for UMTS frequencies

[9].

Table 8.5. The statistical analysis of error in Paris with different models, [9]

	Wavesight Ray Tracing	**Cost 231-Hata Model**
Mean Error	3 dB	0 dB
Standard deviation	7 dB	10 dB

From Table 8.5, it is observed that deterministic Wavesight Ray Tracing model works better than empirical Cost 231-Hata Model in Paris, since standard deviation of error in Wavesight Ray Tracing model are considerable smaller. Also according to article [9], the canyon effect of streets and the impact of the buildings on the propagation are obvious in Wavesight Ray Tracing model.

8.5.2. Signal Level Interpolation for Coverage Area Prediction

Another study was performed in Helsinki, Finland. A tool for simulation is used but the name of the simulation tool was not mentioned. Apart from the simulation tool, Matlab was used. Used map in simulation contains building data and terrain data. For path loss calculation, four techniques were used, these models were tuned against measurements. Enhanced Cost 231 Hata model, Interpolation Technique, MLS (Mean Least Square) Technique and Triangulation Technique were used in order to calculate path loss values. As a quality measure of models mean error, standard deviation of error were used. The study is done for 1800 MHz [33]. Statistical analysis of prediction models is presented in Table 8.6.

In triangulation techniques, standard deviation of error equals to 3 dB in cases of closely spaced, evenly scattered points.

Table 8.6. The statistical analysis of error with different models, [33]

	Enhanced Cost 231-Hata	**Interpolation**	**Mean Least Square (MLS)**	**Triangulation**
μ**(dB)**	3.1	2.5	1.9	1.5
σ **(dB)**	5.9	3	3.1	3.5

8.5.3. Performance of Static WCDMA Simulator

This study was performed by in Tampere, Finland. For simulation, Nokia NetAct Planner tool is used. In simulation tool, used map has 5x5 meters resolution and building information was added to the map in vector format. Used model in simulation are Enhanced Cost 231 Hata model and Volcano ray tracing. As a quality measure of models, mean error, standard deviation of error were used. Study is performed for UMTS frequencies [35]. Statistical analysis of prediction models is presented in Table 8.7.

Table 8.7. The statistical analysis of error with different models, [35]

	Volcano ray tracing model	**Enhanced Cost 231 Hata model**
μ	0dB	0 dB
σ	6.5dB	6.85 dB

8.5.4. Microwave Propagation and Interference Prediction on Radio Coverage of GSM Cells for İstanbul

This study was performed by in İstanbul in 2005. Simulation program was written. Three models were used, namely Hata Model, Walfisch-Bertoni Model and Chan Model. As quality measure of used models average differences of predicted value from the measured value, standard deviation of the differences from averaged value, peak differences were used. The study was performed for GSM frequencies [40].

Table 8.8. The statistical analysis of error with different models, [40]

	Hata Model	**Walfisch-Bertoni model**	Chan Model
μ**(dB)**	4.2747	-1,2308	-1.8022
σ**(dB)**	8.7656	7.7461	6.8343
Peak Differences(dB)	23	19	17

As Table 8.8 indicates, according to applied quality measure, Chan Model works best result in İstanbul.

8.6. Comparison of the GSM and UMTS in Terms of Maximum Allowable Path Loss

Link budget evaluation is essential for system design and evaluation purposes, e.g., coverage and interference analysis. Basically, it consists of estimating the power at receiver [21].

In practice, initially, a mobile operator attempts to cover the service area as good as possible with only a limited number of base stations. The main concern is that the signal-to-noise ratio is sufficient at each location. Interference is not yet limiting the system performance [41].

In a later phase when more subscribers are using the system, the operator typically attempts to improve capacity by adding more base stations. The grid of base stations becomes denser and signal-to-noise ratio is no longer limiting the performance. Because of dense reuse, co-channel and adjacent channel interference become more of concern [41].

Equation 8.4 shows link budget calculation for radio systems [31].

$$P_{RX} = P_{TX} + G_{TX} - L_{TX} - L_{FS} - L_M + G_{RX} - L_{RX} \quad (8.4)$$

where:

- P_{RX} = received power (dBm)
- P_{TX} = transmitter output power (dBm)
- G_{TX} = transmitter antenna gain (dBi)
- L_{TX} = transmitter losses (coax, connectors...) (dB)
- L_{FS} = free space loss or path loss (dB)
- L_M = miscellaneous losses (fading margin, body loss, polarization mismatch, other losses...) (dB)
- G_{RX} = receiver antenna gain (dBi)
- L_{RX} = receiver losses (coax, connectors...) (dB)

Typical parameters for link budget analysis are presented in Table 8.9 for GSM and UMTS systems.

Base station and antenna line configurations can be designed for different aims in order to solve the path loss in the link budget. They can include both general and accessory elements and parameters. General power budget parameters are [22]:

- sensitivity
- transmitting power
- combiner loss
- receiving (RX) and transmitting (TX) antenna gains
- cable loss

Apart from general link budget parameters, there are some accessory elements that can be used in order to improve receiver or transmitter capabilities [22]:

Table 8.9. Typical Parameters for GSM and UMTS, [21]

	GSM		**UMTS**	
	Voice	Data	Voice	Data
Antenna Gain for MS[dBi]	[0,2]			
Body loss [dB]	3	0	3	0
Cable loss [dB]	2			
Antenna Gain for BS[dBi]	[0,13]			
Thermal noise density [dBm/Hz]	-174			
BS receiver noise figure[dB]	-		5	
Interference margin[dB]	-		3	
Required $E_b/N_0[dB]$	-		5	1.5 (144 kbps) 1.0 (384kbps)

- diversity reception
- low noise amplifier
- booster and power amplifier
- duplexfilter
- diplexfilter

In Figure 8.18, GSM 900 link budget calculation is depicted for downlink only without accessory equipment [42].

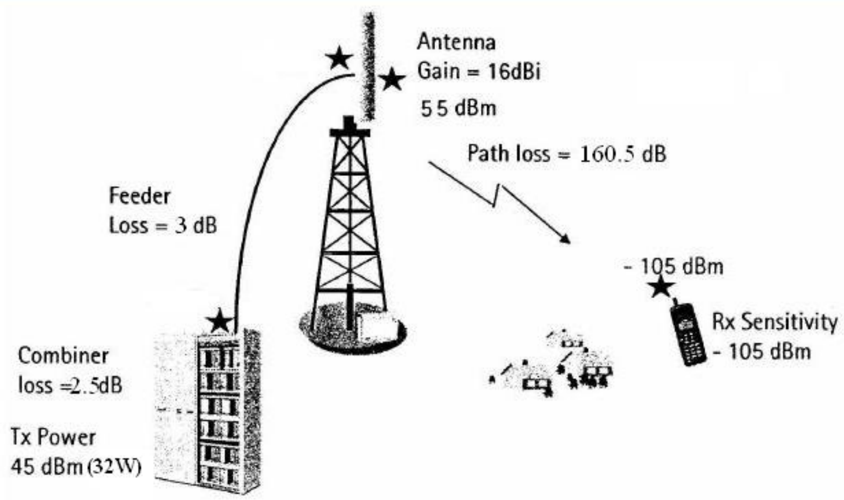

Figure 8.18. General power budget for the GSM900 system without accessory equipment (Downlink), [42]

It can be seen Table 8.10 and Table 8.11, allowed path loss in uplink direction is 160.5 dB-152 dB= 8.5 dB smaller than in the downlink when the base station transmitting power is 45 dBm. This 8.5 dB differences refers that downlink direction coverage area is greater than in the uplink direction coverage area. This imbalanced power budget can be balanced either by reducing the BTS transmit power (thus reducing downlink coverage) or by using accessory elements for the uplink [22].

Table 8.10. General power budget for the GSM900 system without accessory equipment, (Downlink), [22]

Base Station	**Unit**	**Value**	
RF Power	dBm	45	A
Combiner loss	dB	2.5	B
Cable loss	dB	3	C
TX antenna gain	dBi	16	D
Peak EIRP	dBm	55	$E = A - B - C + D$
Mobile Station	**Unit**	**Value**	
RX antenna gain	dBi	0	F
Cable loss	dB	0	G
MS Sensitivity	dBm	-105	H
Minimum reception level	dBm	-105	$I = -F + G + H$
Isotropic path loss	dB	160.5	J=E-I

Table 8.11. General power budget for the GSM900 system without accessory equipment (Uplink), [22]

Mobile Station	**Unit**	**Value**	
RF power	dBm	33	A
Cable loss	dB	0	B
TX antenna gain	dBi	0	C
Peak EIRP	dBm	33	D=A-B+C
Base Station	**Unit**	**Value**	
RX antenna gain	dBi	16	E
Cable loss	dB	3	F
BTS sensitivity	dBm	-106	G
Minimum reception level	dBm	-119	$H = -E + F + G$
Isotropic path loss	dB	152	$I = D - H$

In UMTS system, when coverage calculation is performed by using uplink link budget analysis, a complete UL coverage analysis should include dedicated channels (DCH) and common channels RACH [26].

This study will just focus on dedicated channels only. Table 8.12 shows a comparison between UL coverage existing GSM900/GSM1800 full rate speech services and WCDMA speech, 144 kbps, and 384 kbps data services [26].

When the results of Table 8.12 are investigated, following findings are observed [26]:

- Among three system, namely GSM 900, GSM 1800 and UMTS, the smallest MAPL value belongs to UMTS. That means smallest cell size also belongs to UMTS.
- In WCDMA, when the data rate of the system increases, maximum allowable path loss decreases, for example, while WCDMA speech services (12.2kbps) can be possible 156 dB path loss, WCDMA 384 kbps require 150 dB pathloss.
- If GSM 900 sites and GSM 1800 sites are deployed at the same place, coverage in GSM 1800 system will be 10 dB (164 dB-154 dB=10 dB) less than coverage in GSM 900.
- If GSM 1800 sites and WCDMA sites are deployed at the same place, 144 kbps WCDMA data services can be provided, with the same coverage probability as the GSM 1800 speech services.

Table 8.12. Uplink path loss derivation for existing GSM and WCDMA radio access, [26]

	Unit	**GSM900 /speech**	**GSM1800 /speech**	**WCDMA /speech**	**WCDMA /144 kbps**	**WCDMA /384 kbps**
Mobile Tx power	dBm	33	30	21	21	21
Receiver sensitivity [a]	dBm	-110	-110	-124	-117	-113
Interference margin [b]	dB	1	0	2	2	2
Fast fading margin [c]	dB	2	2	2	2	2
BS antenna gain [d]	dBi	16	18	18	18	18
Body loss [e]	dB	3	3	3	3	3
MS antenna gain [f]	dBi	0	0	0	2	2
Relative path loss gain with frequency [g]	dB	11	1			
MAPL [h]	dB	164	154	156	154	150

[a] GSM sensitivity includes receive antenna diversity. WCDMA sensitivity is calculated based on the equation $10 * 10\log(kTBF) - SF_{dB} + (EbN_0)_{dB}$, where bandwidth B=3.84 MHz, spreading gain $SF = B/(DataRate)$, and F=4dB is the WCDMA base station noise figure

[b] An interference margin of 1 dB was used for GSM because of the small amount of spectrum in GSM 900 that does not allow large reuse factor. For loading of $\chi = 37\%$, the noise raise is $10\log(1-\chi) = 2dB$

[c] The reduced fast fading margin comes from including the macro diversity gain

[d] Three sector confirmation are assumed for both GSM and WCDMA

[e] Data terminals have not to stay close to the user's had

[f] Antenna gain for data terminals is 2 dBi

[g] Represent variations in the path loss attenuation with frequency versus the UMTS Region 1 band

[h] MAPL stands for maximum allowable pathloss

9. CONCLUSIONS AND FUTURE WORK

UMTS network planning is far more complicated than GSM voice planning [9]. Each service requires a specific threshold values and network behavior changes with traffic, and also both quality of service and data throughput are directly related to the variations of radio propagations. So the need for an accurate propagation prediction is now more vital than before [9].

For radio propagation prediction, there are many propagation models. But each propagation model is valid in a specific scenario and specific frequency. If the model is not chosen correctly, the model will either overestimate or underestimate the path loss.

We can classify propagation models as empirical models and deterministic model. Empirical models are known to be accurate hundreds meters from base station and, therefore, empirical models generally are used in macrocells. Deterministic models have high computational demands and consequently, they are mostly used in microcells and picocells.

Since UMTS site density will be higher than GSM site density, the accuracy in the first hundreds of meters from the base station is more important [9]. So the usage of deterministic models may give better result.

In this thesis, three propagation path loss models are used in order to predict path loss in two UMTS sites. Two models from empirical class and one model from deterministic class. Prediction results are compared with real measurements obtained from a UMTS based wireless network for city İstanbul. According to comparison results, the model from deterministic class, namely Walfisch-Ikegami Model- gave the best result in UMTS network for İstanbul.

In literature, nowadays, ray tracing models are also used in order to predict path loss in UMTS system [9], [35]. The results are promising. However ray-tracing models needs accurate 3D topographic databases with building data, which are now very expensive maps in Turkey [37] and proper models for environment interaction i.e. reflection, diffraction and scattering required [33]. However, it is claimed that [9] model tuning is easier in ray tracing models. So next step of this thesis can be using ray tracing models in path loss prediction in UMTS systems.

Nowadays, GSM companies in Turkey are deploying new UMTS network over existing GSM networks. Whether UMTS can meet user expectation is the subject of many studies. Hovewer, while deployment in UMTS network in Turkey are continuing these days, organizations like 3GPP have started to work on 4G systems over existing 2G and 3G systems since 2004. The goal of 4G is the defining a next generation system evolved from the current supporting technologies, and primarily meeting the following goals [43].

- Use of OFDM and multi-antenna radio technologies
- "Flatter" architecture in the network
- Interoperability with 3G systems, including 3GPP2 systems
- High flexibility, versatility, mobility, performance
- Reduced complexity of systems, configuring process and specifications
- Provide a competitive answer to Wimax/802.16 and UMB/802.20

APPENDIX A: DECIBEL

The decibel(dB) is a logarithmic unit of measurement which is used in order to express the magnitude of a physical quantity which is generally power or intensity with respect to the specified or implied reference levels.

The decibel symbol is generally used with a suffix, which indicates which reference quantity or frequency weighting function has been used. For example, if we use "dBm" instead of "dB" that means the reference quantity is one milliwatt, instead of 1 watt.

When referring to measurements of power or intensity, a ratio can be expressed in decibels by evaluating ten times the base-10 logarithm of the ratio of the measured quantity to the reference level.Thus, if L represents the ratio of a power value P_1 to another power value P_0, then L_{dB}represents that ratio expressed in decibels and is calculated using the formula:

$$L_{dB} = 10log(\frac{P_1}{P_0})$$

dBm to dB: Following equation shows the relationship between dBm and dB.

$$X_{dBm} = X_{dB} + 30$$

Table A.1 shows dBm to watt conversion table.

Table A.1. dBm to watt conversion table

dBm	**Watts**	**dBm**	**Watts**	**dBm**	**Watts**
0	1.0 mW	16	40 mW	32	1.6 W
1	1.3 mW	17	50 mW	33	2.0 W
2	1.6 mW	18	63 mW	34	2.5 W
3	2.0 mW	19	79 mW	35	3.2 W
4	2.5 mW	20	100 mW	36	4.0 W
5	3.2 mW	21	126 mW	37	5.0 W
6	4 mW	22	158 mW	38	6.3 W
7	5 mW	23	200 mW	39	8.0 W
8	6 mW	24	250 mW	40	10 W
9	8 mW	25	316 mW	41	13 W
10	10 mW	26	398 mW	42	16 W
11	13 mW	27	500 mW	43	20 W
12	16 mW	28	630 mW	44	25 W
13	20 mW	29	800 mW	45	32 W
14	25 mW	30	1.0 W	46	40 W
15	32 mW	31	1.3 W	47	50 W

APPENDIX B: LAND USAGE CLASSES

Table B.1 shows land usage (clutter) definition of used map in TCPU software.

Table B.1. Land usage class description, [39]

No	Class name	Class description
1	Buildings	Isolated cluster of high towers and skyscrapers generally higher than 40 meters (>=14 floors)
2	Dense urban high	Generally financial, business or downtown shopping districts within the urban perimeter. This includes urban areas with dense development where built-up features do not appear distinct from each other.
3	Dense urban	Areas within the urban perimeter. This includes urban areas with dense development where built-up features do not appear distinct from each other. It also includes buildup features of downtown district with most heights in an average of 10-20 meters (4-6 floors).
4	Dense urban low	Areas within the urban perimeter. This includes urban areas with dense development where built-up features do not appear distinct from each other. It also includes buildup features of downtown district with most heights below an average of 10 meters (1-3 floors).
5	Tax-Area	Houses in or near urban environment. Tax (unfinished) buildings with most heights below an average of 10 meters (1-3 floors). Population of area is generally poor.
6	Dense block buildings high	Building blocks that are closely divided and often in regular pattern, without distinctive green spaces. Average height is generally more than 20 meters (7-13 floors).
7	Dense block buildings	Building blocks that are closely divided and often in regular pattern, without distinctive green spaces. Average height is generally up to 20 meters (4-6 floors).

Table B.2. Land usage class description, (Table B.1 continues)

No	**Class name**	**Class description**
8	Block buildings	Group of buildings, either parallel or not, that may be separated by large green spaces. Average height is generally up to 20 meters (4-6 floors).
9	Block buildings high	Group of buildings, either parallel or not, that may be separated by large green spaces. Average height is generally more than 20 meters (7-13 floors).
10	Mean urban	Developing areas within the urban perimeter. The mean urban should have mean street density with no pattern, the major streets are visible, the built-up features appear distinct from each other. Some small vegetation could be included. Average height is below approximately 20 meters. (4-6 floors)
11	High Residential	Houses in suburban environment. Suburban density typically involves laid out street patterns where streets are visible. Lots may be as small as 30 by 30 meters Individual houses are frequently visible mainly of apartment. Average height is typically above10 meters.
12	Low Residential	Houses in suburban environment. Suburban density typically involves laid out street patterns where streets are visible. Lots may be as small as 30 by 30 meters, but are generally larger and include vegetation cover. Individual houses are frequently visible. Average height is typically below 10 meters (1-3 floors). Population of area is generally rich.
13	Temporary	Residential areas prepared for earthquake victims. Temporary residential areas with 1 floor buildings.
14	Villages	Small built-up area in rural surroundings.

Table B.3. Example land usage(clutter) definition of a digital map

No	**Class name**	**Class description**
15	Industrial and commercial	Buildings generally with large footprints (greater or equal to 20 by 40 meters) or in well organized pattern with average height below 20 meters, separated by streets wider than 20 meters.
16	Parks	Any vegetation in urban environment. (Municipal parks, cemeteries, recreation lands, etc.)
17	Semi open area	Area with mixed low vegetation, bushes and a few trees
18	Sparse forest	Area with spread trees
19	Forest	Forested land with closed tree canopy. 20 Open wet area Marshes, swamp, rice coltures.
21	Inland water	Lake, river or canals.
22	Sea	Ocean and sea.
23	Open in urban	Small open land area with no vegetation surrounded by mean urban, dense urban, or residential.
24	Open land	Open areas with little or no buildings and vegetation.

APPENDIX C: ANTENNAS

Antenna typically refer an entire radiating element, connected with a line to the base station equipment as shown in Figure C.1.

The essential base station antenna parameters are:

- Gain (low/medium/high)
- Beamwidth (horizontal and vertical)
- Size
- Polarization
- Diversity technique
- Frequency band
- Tilting properties

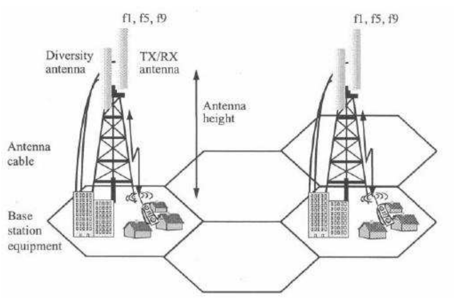

Figure C.1. Base station site configuration, [22].

APPENDIX D: MODEL TUNING

The propagation model-tuning is one of the most important issues in efficient network. Propagation model tuning means characterizing the RF signal propagation in a given propagation environment at a specific frequency for some specific Tx/Rx equipment.

Model tuning process starts with a measurements campaign to collect drive testing on the prediction areas. The second step is the comparison of measurements and predictions based on an existing propagation model. And finally that propagation model will be modified until best prediction performance is obtained [44].

Performance criteria here is propagation loss deviation between measurement and prediction. If propagation loss deviation is high, the tilt and the interception of the prediction propagation loss curve is so adjusted that a curve formed by plotting the measurement propagation loss in a path from a base station to the two or more points and the corresponding prediction propagation loss curve may approach to each other, and the propagation loss deviation is made smaller thereby [45].

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