DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

MEASUREMENT AND ANALYSIS OF GSM BASE STATION FOR HUMAN HEALTH FACTORS

by
Didem DEMİRKILINÇ

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İZMİR

MEASUREMENT AND ANALYSIS OF GSM BASE STATION FOR HUMAN HEALTH FACTORS

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **“MEASUREMENT AND ANALYSIS OF GSM BASE STATION FOR HUMAN HEALTH FACTORS”** completed by **DİDEM DEMİRKILINÇ** under supervision of **ASST. PROF. DR. AHMET ÖZKURT** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

Asst. Prof. Dr. Ahmet ÖZKURT

Supervisor

(Jury Member) (Jury Member)

Prof. Dr. Mustafa Sabuncu

Director

Graduate School of Natural and Applied Sciences

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ABSTRACT

Increasing use of cellular phones and associated base stations in people's daily life have been considered as perturbed electromagnetic field sources recently. These considerations cause remarkable concerns on public health. For eliminating these concerns, many electromagnetic field measurements have been realized by independent foundations in some countries ("Hermes", Greece; "monIT", Portugal; "National Radiation Laboratory", New Zealand etc.). There has been no similar wide range and long studies in Turkey, yet.

There are three basic base station installation types used by operators: Roof-top, tower and in-building solutions. Each type has different antenna gain and power usages which directly affect radiation of base station and Specific Absorption Rate (SAR). Radiation levels are limited at all around the world by researches by organizations and commissions like World Health Organization (WHO), International Commission on Non-Ionizing Radiation Protection (ICNIRP) etc.

In this study, the daily variation of electric field caused by several base station antennas according to national limitations in Turkey was investigated in several measurements. For this purpose, continuous electric field measurements with two seconds intervals were occurred at different days and long time periods and several measurement data was given as reference to other base station types.

According to measurement results and analyses, it is observed that, the measured signal from the base station may change about 4dB during the day and each station should be evaluated independently because of installation parameters can be different.

Keywords: GSM, GSM Base Station measurements, Electromagnetic fields, Health effects, Radio Frequency, Radiation.

İNSAN SAĞLIĞI FAKTÖRLERİ AÇISINDAN GSM BAZ İSTASYONLARI ÖLÇÜM VE ANALİZİ

ÖZ

Gündelik hayatta kullanımı gün geçtikçe artan cep telefonları ve bunlara bağlı baz istasyonları kaygı uyandıran elektromanyetik alan kaynakları olarak gösterilmektedir. Bu düşünceler halk sağlığı üzerinde kayda değer endişelere sebep olmaktadır. Bu endişeleri gidermek amacıyla bazı ülkelerde bağımsız kurumlar tarafından elektromanyetik alan ölçümleri yapılmaktadır. Türkiye'de henüz böyle geniş çaplı ve uzun süreli bir çalışma yapılmamıştır. (Yunanistan'da "Hermes", Portekiz'de "monIT", Yeni Zellanda'da "National Radiation Laboratory" v.b.)

Operatörler tarafından kullanılan üç temel baz istasyonu kurulum modeli vardır: Binaüstü, kule ve binaiçi kurulumları. Her kurulum modeline göre, elektromanyetik dalgalar ve SAR (özgül soğurma oranı) hesaplamalarına direkt olarak etkiyen anten kazancı ve güç kullanımı vardır. Elektromanyetik radyasyon seviyeleri tüm dünyada, WHO (Dünya Sağlık Örgütü), ICNIRP (Uluslararası İyonize Olmayan Radrasyon Koruma Komisyonu) v.b. organizasyonlar tarafından yapılan araştırmalar sonucu belirlenmektedir.

Bu çalışmada, baz istasyonu antenlerinin sebep olduğu elektrik alanın Türkiye ulusal elektromanyetik alan standartlarına göre değişimi çeşitli ölçümlerle incelenmiştir. Bu amaçla, iki saniye zaman aralığı kullanılarak farklı günlerde ve uzun sureli olarak elektrik alan ölçümü kesintisiz olarak yapılmış ve farklı kaynakların da baz istasyonu ölçümleri verilerek incelenmiştir.

Yapılan ölçüm sonuçlara ve analizlere göre, ölçülen baz istasyonu sinyalinin gün boyunca 4dB civarında bir değişim gösterdiği ve her baz istasyonunun farklı kurulum parametlerine sahip olduğundan dolayı birbirinden bağımsız olarak değerlendirilmesi gerektiği gözlemlenmiştir.

Anahtar Sözcükler: GSM, GSM Baz İstasyonu ölçümleri, Elektromanyetik alanlar, Sağlık etkileri, Radyo frekansı, Yayılım

CONTENTS

CHAPTER ONE
INTRODUCTION

Nowadays, GSM technology have been used more and more with capabilities of voice, image and data transfer, on personal, environmental and public health studies. At the same time, effects of the mobile phones and their technical specifications on the human health are interested more; because international organizations and regional authorities have different approaches and applications (Seyhan, 2003). In addition, also, there is no certain study about damages or harmful levels, time periods and dosages which are formed by such non ionizing radiation type Radiofrequency (RF) systems. Due to these uncertainties on the thermal and the non thermal effects, it is observed that doubts or against attitudes have been begun to occur on public. In the same way, between the related private and public organizations and scientists, there has been this similar argument (Sevgi, 2008).

The organizations like World Health Organization (WHO), National Council on Radiation Protection and Measurements (NCRP), International Commission on Non-Ionizing Radiation Protection (ICNIRP) have studied on this subject to build a criteria and certain standard values have been adopted (ICNIRP, 1998). These standards are generally adopted as the basis thermal effects based on SAR (Specific Absorption Rate) but implemented in some regions or countries slightly different.

Effects of mobile phones and base stations have been the main subject of many researches for last ten years. Although many questions have been answered, still lots of unknown stand on people's minds. All researches cannot go beyond the proposing a few new ideas because it's the human body with such a complicated systems what has been researched. Some long-term (5 to 20 years long) researches have begun to come to end recently but still they are not even clear solutions to electromagnetic radiation (EMR) subjects.

All the limitations have been set due to completed researches and all of them are questionable values. Like standing below the limitations does not mean that there will not be a problem, also, getting over the limitations does not mean that there certainly will be a problem. But, as being safe, it is suggested that, the radiated energy must be low as possible for clear transmission, instead of near the limit values.

According to their frequency and energy, electromagnetic waves can be classified as either 'ionizing radiations' or 'non-ionizing radiations'. Ionizing radiations are extremely high frequency electromagnetic waves (X-rays and gamma rays), which have enough photon energy to produce ionization (create positive and negative electrically charged atoms or parts of molecules) by breaking the atomic bonds that hold molecules in cells together. Non-ionizing radiation (NIR) is a general term for that part of the electromagnetic spectrum which has photon energies too weak to break atomic bonds. They include; ultraviolet (UV) radiation, visible light, infrared radiation, radio frequency and microwave fields, extremely low frequency (ELF) fields and as well as static electric and magnetic fields (Talal, 2000).

Radio frequencies which base stations and mobile phones use are in non-ionizing radiation region. Main effect of radio waves on human body is generating electric current and due to current getting higher heat of live organisms. There has still been no certain word about the subject although there have been many studies about relations between mobile phones/base stations and cancer. It can only be said that the car accidents due to mobile phones are only real consequences (TÜBİTAK, 2001). On the other hand, definition of health includes not only biological status but also as well as mental health and social well-being. For this reason, people, also by not having sufficient information about the system, have many concerns and have been afraid.

The radio wave exposure from 3G base stations is no higher; also even lower than from 2G base stations. 2G and 3G systems use same dual antennas only at difference bandwidths. When it is measured from the same point to calculate specific observation rate values of 900/1800/2100, it is seen that 3G systems has almost lowest values between others (Ismail, Din, Jamaludin & Balasubramaniam, 2010).

EMR measurements of increasing number of 2G and 3G base stations installations due to highly common usage of mobile phones are performed by related operators and authorized government staffs to approve legal compatibility of systems and to avoid future public health concerns. Of course, it is not appropriate to make a generalization for all systems before performing required measurements. As a result of implementation of measurements, it is required to reveal a level about application of each system and this level should rather be estimated under above standards and safe-band.

In this study, basically, by performing the long term and the short term power measurements for the Base Transceiver Station (BTS), seen in the block diagram below, components of Global Mobile System (GSM), it is aimed to comment about subjects:

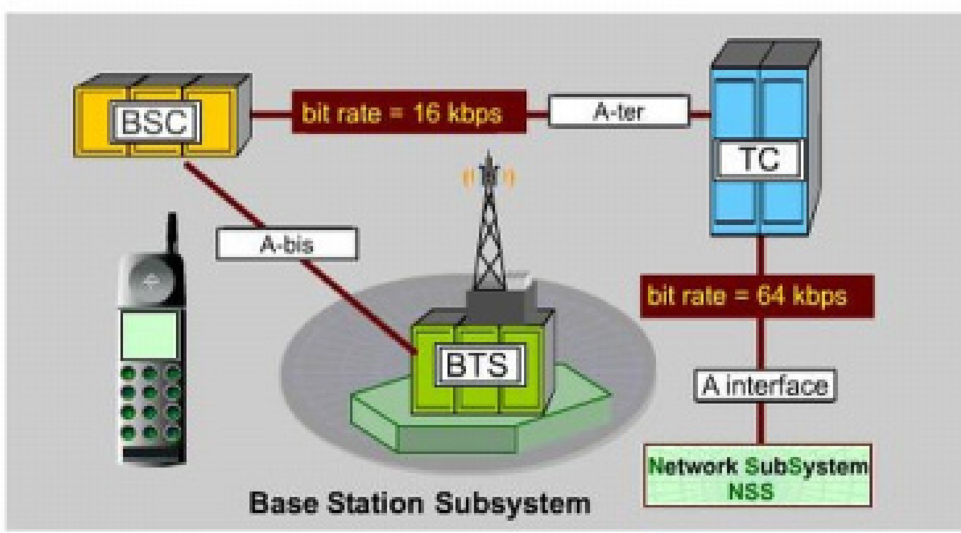

Figure 1.1 Technical block diagram of GSM communication architecture (Heine, 1999).

1. The max and the min power densities of BTS may approach,

2. Distribution of power density around BTS,
3. Power density variation of BTS during the day,
4. Comparison of power density of same BTS in different days,
5. Operating trend of BTS during the day,
6. Power density analysis due to BTS traffic.

These comments are based on long term and short term computer assisted measurements of tower, rooftop and in-building BTS equipments. Besides, some domestic and foreign measurement reports are given with the permission of independent authorized organizations and operators (Portugal, 2009).

In this thesis study, human health factors related with the GSM base stations are investigated. Those human health factors are, Electric Field Strength values, exposure time, Power level variations, Call volume effects on the signal level, station platform and design parameters. Although those factors are not directly related with health care, but in a technical view, those parameters effect signal levels which are the basic elements of calculation procedure used to determine limit value which is based on SAR.

The aim, the performance and the methodology of the study are given in chapter I. Theoretical explanations, limitations and spectrum of electromagnetic radiation and their relations to GSM are given in chapter II. Information and technical specifications of GSM world and its common components are given in chapter III. The results and related comments obtained from the study are given in chapter IV.

CHAPTER TWO
ELECTROMAGNETIC FIELD

2.1 What is Electromagnetic Field?

Both positive and negative electric charges generate electric field in a stable or moving situation. The current caused by moving charges is main source of magnetic field. Time varying electric and magnetic fields are accompanied to each other to produce an electromagnetic field. After that, electromagnetic waves which radiate from sources are produced by these time varying electromagnetic fields (Cheng, 1992).

Faraday thought that the electric and the magnetic fields had been coupled at the first time, but Maxwell proved that the hypothesis was correct. Also, Maxwell made a simple correction on Ampere's Law and conversation of charge. That simple correction caused big consequences which showed to the world the existence of electromagnetic waves which radiate with the speed of light. Due to this consequence, it was showed that the light had been an electromagnetic wave. For the reason Maxwell made the correction; electromagnetic field laws have been given the name of "Maxwell's Equations" (Zahn, 2003).

Gauss' law for electricity : $$\oint_{\substack{\text{Closed}\\ \text{surface}}} \vec{\mathrm{E}} * \mathrm{d}\vec{\mathrm{A}} = \frac{Q_{enc}}{\varepsilon_0}$$

Gauss' law for magnetism : $$\oint_{\substack{\text{Closed}\\ \text{surface}}} \vec{\mathrm{B}} * \mathrm{d}\vec{\mathrm{A}} = 0$$

Faraday's Law : $$\oint \vec{\mathrm{E}} * \mathrm{d}\vec{\mathrm{s}} = -\frac{d\phi_B}{\mathrm{dt}}$$

Ampere – Maxwell Law : $$\oint \vec{\mathrm{B}} * \mathrm{d}\vec{\mathrm{s}} = \mu_0 \varepsilon_0 \frac{d\phi_E}{d_t} + \mu_0 i_{enc}$$

Each electromagnetic wave has an amount of energy at the point of radiation source. For the time that the wave travels, energy level stands same as the beginning but wave strength decreases because total energy is distributed over larger areas. By the help of speed of light and the frequency (measured wave cycle per second) of wave, wavelength (lambda) is calculated.

$$\lambda = \left(C/F\right) \quad C = 300.000\, km/s \qquad \text{(F = frequency)}$$

2.1.1 Electric Field

Electric field is caused by any positive or negative electrical charges which apply forces on other charges within the field. The strength of the electric field is measured in volts per meter (V/m). Any charged electrical wire produces an electric field. This field exists even when there is no current on wire. At a certain distance from wire, electric field strength increases rationally by increase in voltage. But, the strength rapidly decreases by distance (Cheng, 1989).

2.1.2 Magnetic Field

Moving electric charges produce magnetic field. The strength of the magnetic field is measured in amperes per meter (A/m). Also the flux density in micro tesla (μT) is commonly used by scientists. Magnetic field is not like electric field and only produced when there is current flowing through a device. Magnetic field strength increases rationally by increase in current. But, on the other hand, it decreases rapidly by distance like electric field (Cheng, 1989).

2.2 Electromagnetic Spectrum

The electromagnetic spectrum consists of all electromagnetic waves arranged according to specific frequency bands and wavelengths. Electromagnetic waves are also called electromagnetic radiation because they radiate from the electrically charges. The electromagnetic spectrum extends from below frequencies used for modern radio to gamma radiation at the short-wavelength (Knaw B, 1998).

The electromagnetic spectrum is commonly placed in daily life. Beside the house appliances, also, the light that our eyes can see is also part of the electromagnetic spectrum. This visible part of the electromagnetic spectrum consists of the colors from reds and oranges, through blues and purples. The frequency spectrum includes ionizing and non-ionizing radiations (Knaw B, 1998).

2.2.1 Ionizing Radiation

Ionizing radiation has higher frequency than visible light. It has a smaller wavelength and carries high quantities of energy with cosmic radiations like X-rays and radioactive α-decay, β-decay and γ-rays. It causes matter to ionize. The photon of the radiation carries so much energy that it can remove an electron from an atom of matter. This radiation can cause serious harm to biological matter and DNA cell (ICNIRP, 1998).

2.2.2 Non-Ionizing Radiation

Non-ionizing electromagnetic radiation does not carry enough energy to ionize atoms or molecules for completely removing an electron from an atom or molecule. The electromagnetic radiation has sufficient energy only for the movement of an electron to a higher energy state. Nevertheless, different biological effects are also observed for different types of non-ionizing radiation (ICNIRP, 1998).

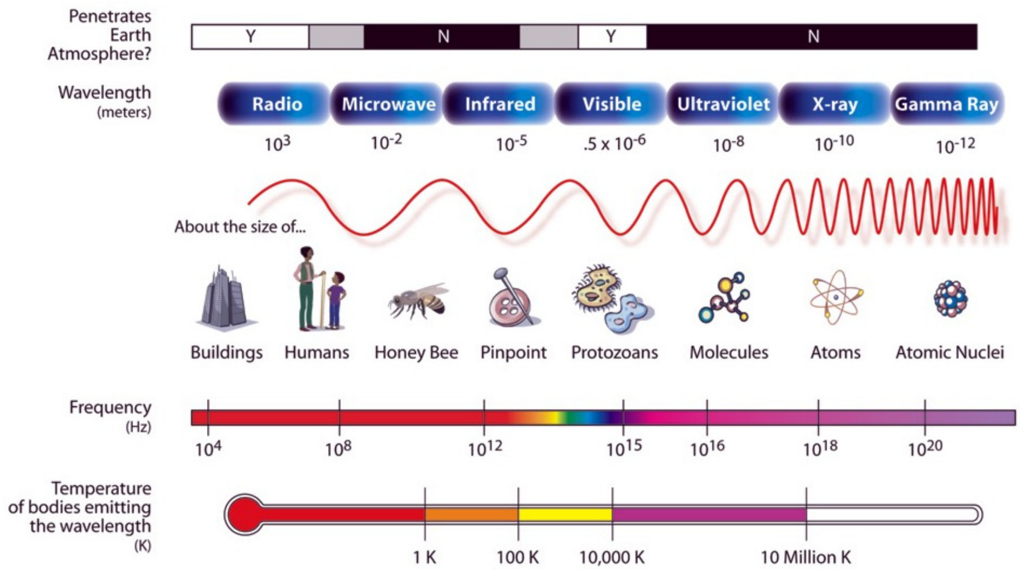

Figure 2.1 Electromagnetic spectrum (http://mc2.gulf-pixels.com/?p=281)

2.3 Sources of Electromagnetic Fields at House & Environment

Besides the natural sources, the electromagnetic spectrum also includes human made electromagnetic sources. These are the devices which have been commonly used by people in daily life. Depending on increasing usage of electric devices, electromagnetic field has become a new class of pollution.

Magnetic fields are caused by electricity running through wirings and general house appliances using electricity are main ELF field sources. All the radio, television, telephones, radars, satellite receivers and transmitters, power lines and transformers and cellular phones and associated base station systems are also RF field sources

Table 2.1 Federal Office for Radiation Safety, Germany 1999

Electric appliance	**Electric field strength (V/m)**	**30 cm distance (µT)**	**1 m distance (µT)**
Iron	120	0.12 – 0.3	0.01 – 0.15
Refrigerator	120	0.01 – 0.25	< 0.1
Hair dryer	80	0.01 – 7	0.01 – 0.03
Colour TV	60	0.04 – 2	0.01 – 0.15
Vacuum cleaner	50	2 – 20	0.13 – 2
Electric oven	8	0.15 – 0.5	0.01 – 0.04

All of the appliances at the table operate on electricity at a frequency level of 50 Hz. It also clearly seems that magnetic strength around appliances decreases the further it was measured. The electric field strength may be considered higher than the GSM limitations but it should be remembered that electric field limitations depend on frequency which the device work at and as it will be discussed further the general public reference level is 5 kV/m for 50 Hz and 4.2 kV/m for 60 Hz (ICNIRP, 1998).

2.4 Standards & Limits

Standards are generally used for foods or concentrations of chemicals in water or air and set to protect our health. Similarly, electric and magnetic field standards exist to limit overexposure to electromagnetic field levels present in our environment.

Countries set their own national standards for exposure to electromagnetic fields according to the guidelines set by the ICNIRP. This non-governmental organization, formally recognized by WHO, evaluates scientific results from all over the world. After that, ICNIRP produces guidelines recommending limits on exposure for all over the world. These guidelines have been reviewed periodically and updated if there are new experimental results.

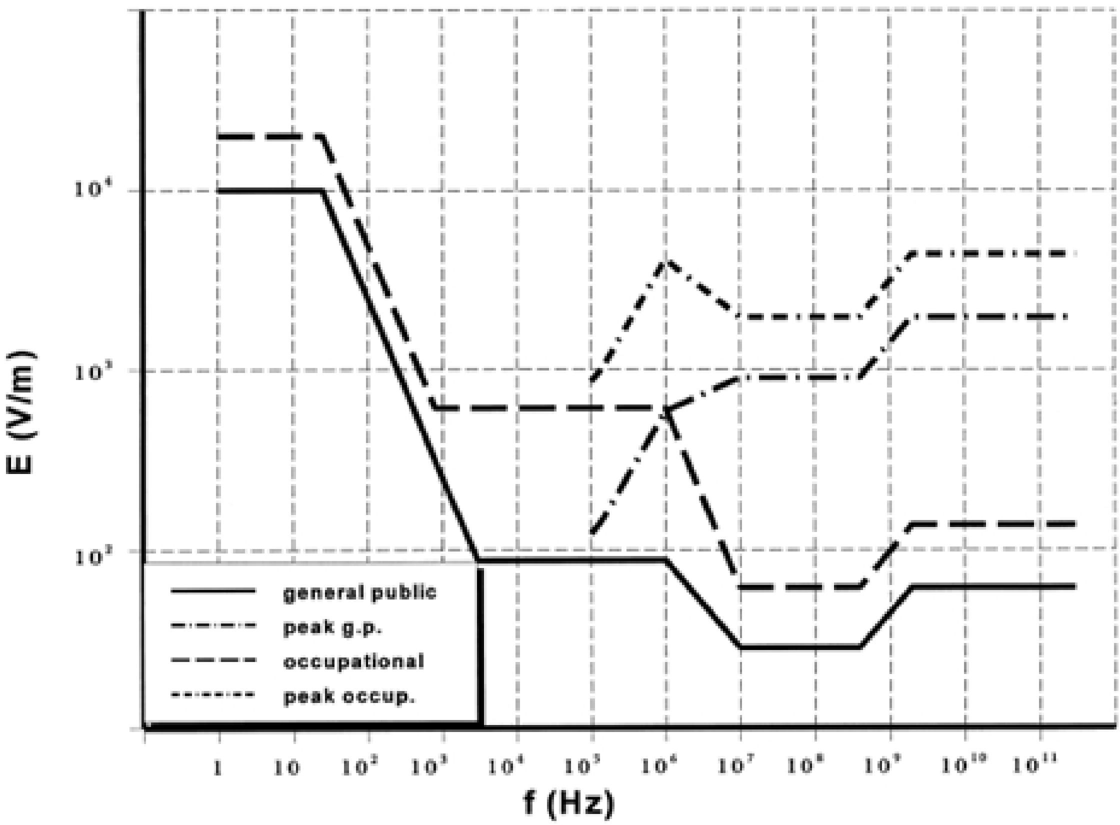

Figure 2.2 Reference levels for exposure to time varying electric fields (ICNIRP Guidelines, 1998)

It should be noticed that these guideline limits are not the exact lines between safety and hazard. There is no certain (proved) limit which exposures become hazardous to health. But, it may be said that, the potential risk to human health gradually increases with higher exposure levels. Guidelines indicate that, below a given threshold, electromagnetic field exposure is safe according to scientific and experimental knowledge. Still, it shouldn't be said that, above the given limits, exposure is harmful. In the Figure 2.2, general public means electromagnetic field usage in daily life and occupational means the field that people run across at work.

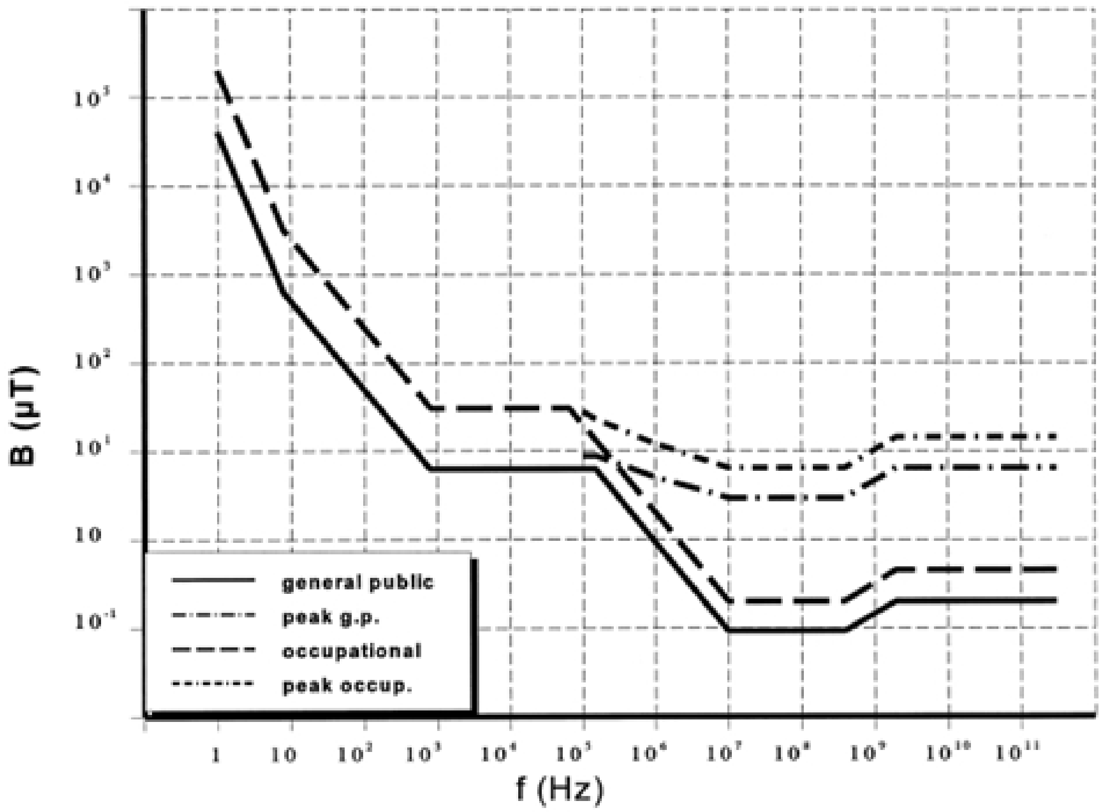

Figure 2.3 Reference levels for exposure to time varying magnetic fields (ICNRIP Guidelines, 1998)

To be able to set limits on exposure, scientific studies need to identify the threshold levels at that first health effects become apparent. ICNIRP applies a safety factor of 10 to derive occupational exposure limits, and a factor of 50 to obtain the guideline value for the general public. For example, in the radiofrequency and microwave frequency ranges, the maximum levels which might be experienced in the environment or in our home are at least 50 times lower than the threshold for experimental results in animals' apparent.

Table 2.2 Exposure limits of electromagnetic waves (ICNIRP, 1998)

	European power frequency		Mobile phone base station frequency		Microwave oven frequency
Frequency	**50 Hz**	**50 Hz**	**900 MHz**	**1.8 GHz**	**2.45 GHz**
	Electric field (V/m)	**Magnetic field (μT)**	**Power density (W/m^2)**	**Power density (W/m^2)**	**Power density (W/m^2)**
Public exposure limits	5 000	100	4.5	9	10
Occupational exposure limits	10 000	500	22.5	45	-

In everyday situations, most people do not consider that electromagnetic fields exceed the guideline limits. Anyway, general exposures are far below these values. But, there may be some special situations which a person's exposure may just for a short period approach or even exceed the guidelines. According to ICNIRP, radiofrequency and microwave exposures should be averaged over time to have cumulative effects. The guidelines specify a time-averaging period of six minutes and short-term exposures above the limits are acceptable.

On the other side, exposure of low frequency electric and magnetic fields are not time-averaged in the guidelines. On this subject, another factor called coupling stands for limitations. Coupling refers to the interaction between the electric and magnetic fields exposed by the body. This depends on the size and shape of the body. ICNIRP always assumes maximum coupling of the field. The guideline limits provide maximum protection. For example, even though the magnetic field values for hairdryers and electric shavers seem to exceed the recommended values, extremely weak coupling between the field and the head prevents the induction of electrical currents that could exceed guideline limits.

International guidelines and national safety standards for electromagnetic fields are developed on the basis of the current scientific knowledge to ensure that the fields are not harmful to health. Large safety factors are corporated into the exposure limits to compensate uncertainties. The type of the cautionary policy has been chosen critically depending on the strength of evidence for a health risk and the scale and nature of the potential consequences. Guidelines are set for the general public and cannot directly provide the requirements of small part of more sensitive people. Electromagnetic field guideline does not cover the protection people from interference with biological implementations like medical electronics such as heart pacemakers.

2.5 Health Effects

Potential health effects of electric fields have become to be researched more and more in recent years. Cancer risk on children caused by power lines was the first research performed by Wertheimer & Leeper in 1979. From the first days of investigations till today, it has still not been proved that, there is a direct effect of electromagnetic waves on human body about causing tumors or cancer.

Due to the evolution of technology in everyday life, as it was discussed in above sections, people have been more exposed by electromagnetic waves recently. A complicated electrical network covers inside of a human body. Every single molecule and atom communicates with each other through this network. Magnetic waves cause corruptions on electrical network of body and these corruptions have negative effects on systems like cardiovascular system, immune system and nervous system mostly (Walleczek, 1992). They also cause corruptions on chemical structure of the cell surface.

Human body stands like an antenna against the magnetic waves and absorbs the energy inside them. Absorbed energy level increases by higher frequencies and electric field quantities. The energy is transported to the cell tissues when absorption occurs in human body. This transportation drives heating level of the tissues up by vibrating the molecules. Increase in the heat may only be balanced again by the help of fast blood circulation of body (D'Andrea, 2003).

Several researches observed that heat effect of magnetic fields make little bit changes on blood – brain barrier. But, also any other low level heat interaction may cause these kinds of changes on brain, so, they are still not certain approaches. Heat increase inside the body by magnetic waves also cause, blood – brain barrier to become to be more permeable (D'Andrea, 2003). Also, high level magnetic field absorption effect structure and actions of neurons. They start to have fewer activities because of absorption. Heat factor, through the sensitive genital organs, causes contraction on blood vessels or it directly affects the genital system. Human volunteer experiments have been realized by organizations about absorbed magnetic field effects on brain activities but there have been no remarkable changes on memory situations etc. (D'andrea, 2003).

2.6 Electromagnetic Field Protection in Turkey

2.6.1 Information & Communication Technologies Authority

Law No.4502 is the most important structural transformation in Turkey's telecommunication sector for regulation. By this law, Telecommunications Authority (Information and Communication Technologies Authority, since 2009) has been established and has become the first sector regulation institution of Turkey. Policy and strategy establishment task was left to Ministry of Transportation. Regulation functions were left to Telecommunications Authority (Information and Communication Technologies Authority [ICTA]). This law not only established a full competition and a transparent licensing policy but also enabled the commercial independence of Turkish Telecom.

The main purpose of the ICTA is to ensure a complete equality in the sector. The establishment of the authority has an important factor for ensuring continuance, order, reliability and transparency in the sector. The authority implements independently the responsibilities under an administrative and financial autonomy. The authority's concerned ministry is the Ministry of Transportation. There are seven Regional Directorates for all Turkey, which are placed in Ankara, Istanbul, Samsun, Mersin, Diyarbakır, Erzurum and İzmir (http://www.tk.gov.tr/eng/abo_boa/establishment.html).

2.6.2 National Limits

ICNIRP Guidelines on 900 MHz and 1800 MHz were accepted and declared as regulations of Ministry of Transportation and Ministry of Environment in 2000. In 2001 Telecommunication Authority was declared as responsible for putting the regulations on RF radiation between 10 kHz – 60 GHz. ICNIRP Limits are used only if number of RF sources is greater than four.

Table 2.3 Turkish Standards for 10 kHz - 60 GHz (ICTA, 2009)

Frequency (MHz)	E Field (V/m) one instrument	E Field (V/m) Σ instrument	Power Density (W/m^2) one instrument	Power Density (W/m^2) Σ instrument
1 - 10	$22 / f^2$	$87 / f^2$	-	-
10 - 400	7	28	0.125	2
400 - 2000	$0.341 f^2$	$1.375 f^2$	f / 3200	f / 200
2000 - 60000	15	61	0.625	10

Table 2.4 EMF limits in Turkey (for one instrument) (ICTA, 2009)

Frequency (MHz)	E - Field (V/m)	H - Field (A/m)	B - Field (mT)	Power Density (W/m^2)
900	10.23	0.027	0.03	0.28
1800	14.47	0.038	0.042	0.56

Table 2.5 EMF limits in Turkey (for total environment) (ICTA, 2009)

Frequency (MHz)	E - Field (V/m)	H - Field (A/m)	B - Field (mT)	Power Density (W/m^2)
900	41.25	0.111	0.138	4.5
1800	58.33	0.156	0.195	9

CHAPTER THREE
GLOBAL SYSTEMS FOR MOBILE COMMUNICATIONS

3.1 History of GSM

The acronym GSM was used for the first time in 1982 in the meaning of Group Special Mobile by decision of the European Conference of and Telecommunication (CEPT) which was the European standardization organization. The task of GSM had been to define a new standard for mobile communications in the 900 MHz range. It was decided to use digital technology. In the course of time, CEPT evolved into a new organization, the European Telecommunications Standard Institute (ETSI). But, that did not change the task of GSM. The goal of GSM had still been to apply international standards (Heine, 1999).

In 1991, the first GSM systems were ready to be brought into friendly user operation. The meaning of the acronym GSM was changed to Global System for Mobile Communications same year. In 1992, the first derivative of GSM, the Digital Cellular System 1800 MHz (DCS 1800) was introduced to communication world. GSM operates originally in the 900 MHz (ETSI/TC, 1993) and also in 1800 MHz bands in Europe and in the 850 MHz and 1900 MHz bands in the USA. Besides, in Australia, Canada and South American countries 850 MHz band is used for GSM.

3.2 The System Architecture of GSM

3.2.1 Base Station System (BSS)

The GSM cellular structure provides almost complete radio coverage. The system serves along 35 kilometers distance between the mobile station and the base station. Therefore, the geographical area where GSM is used must be divided into smaller areas, which are known as cells with frequency re-using (Tolstrup, 2008).

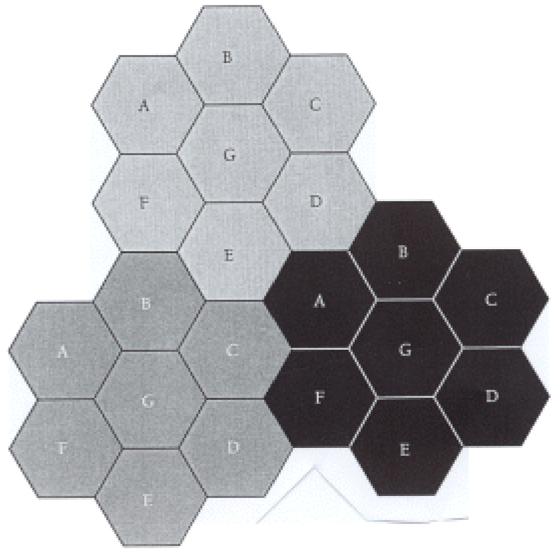

Figure 3.1 GSM cell structure (Tolstrup, 2008)

The basic idea of a cellular network is to partition the available frequency range. It assigns the parts of frequency spectrum to any base transceiver station. This process reduces the range of base stations to be able to reuse the scarce frequencies as often as possible. Generally, for mobile stations with low power emission, only small distances (less than 5 km) to a base station are feasible. The second and third items require extensive communication between the mobile station and the network. That communication is referred to as signaling. The extension of communications requires a cellular network which has modular or hierarchical structure (Heine, 1999).

A GSM network comprises several elements: the mobile station (MS), the subscriber identity module (SIM), the base transceiver station (BTS), the base station controller (BSC), the transcoder and rate adaptation unit (TRAU), the mobile services switching center (MSC), the home location register (HLR), the visitor location register (VLR), and the equipment identity register (EIR). Together, they form a public land mobile network (PLMN) (Heine, 1999).

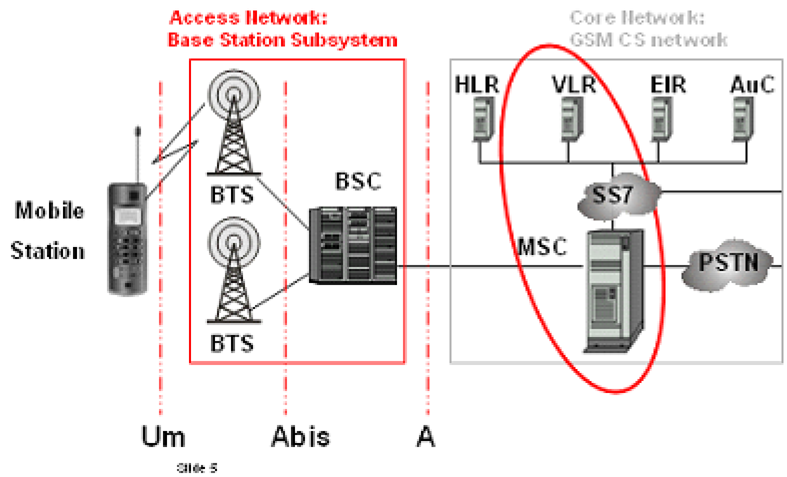

Figure 3.2 System equipment connections (Tolstrup, 2008)

3.2.2 Network Switching Subsystem (NSS)

GSM – PLMN contains as many MSs as possible, available in various styles and power classes. In particular, the portable stations need to be distinguished. GSM distinguishes between the identity of the subscriber and his mobile equipment. The SIM determines the directory number and the calls billed to a subscriber. The SIM is a database on the user side. Physically, it consists of a chip, which the user must insert into the GSM telephone before it can be used. The SIM communicates directly with the VLR and indirectly with the HLR

The MSC is only one sub center of a GSM network. Another sub center is the HLR, a storage that saves the data of a large number of subscribers. An HLR can be regarded as a large database that administers the data of literally hundreds of thousands of subscribers. Every PLMN requires at least one HLR. The VLR was developed for the HLR would not be overloaded with errors about its subscribers. Like the HLR, a VLR contains subscriber data, but only part of the data in the HLR and only while the particular subscriber roams in the area for which the VLR is responsible. When the subscriber moves out of the VLR area, the HLR requests removal of the data related to a subscriber from the VLR. The geographic area of the VLR consists of the total area covered by those BTSs that are related to the MSCs for which the VLR provides its services (Heine, 1999).

3.2.3 Base Transceiver Station

3.2.3.1 System Structure

The BTS provides the physical connection of an MS to the network in form of air – interface. On the other side, toward the NSS, the BTS is connected to the BSC via the abis – interface.

The manufacturers of BTS equipment have been quite able to reduce its size. The typical size in 1991 was like a wardrobe but today the size is nearly comparable to a mailbox. However, the basic structure of the BTS has not changed. In the field, the majority of the BTSs host between one and four transceivers (TRX).

The TRX module is, due to signal processing, the most important part of a BTS. The TRX consists of a low – frequency part for digital signal processing and a high – frequency part for GMSK modulation and demodulation. Both parts are connected via a separate or an integrated frequency hopping unit. All other parts of the BTS are more or less associated with the TRXs and perform auxiliary or administrative tasks.

The operations and maintenance (O&M) module consists of at least one central unit, which administers all other parts of the BTS. For those purposes, it is connected directly to the BSC by means of a specifically assigned O&M channel. That allows the O&M module to process the commands from the BSC or the MSC directly into the BTS and to report the results. Typically, the central unit also contains the system and operations software of the TRXs. That allows it to be reloaded when necessary, without the need to “consult” the BSC. Furthermore, the O&M module provides a human – machine interface (HMI), which allows for local control of the BTS.

3.2.3.2 Different System Configurations

Different BTS configurations, depending on load and subscriber behavior have to be considered to provide optimum radio coverage of an area. While using standard configuration, all BTSs are assigned different cell identities (CIs). A number of BTSs (in some cases, a single BTS) form a location area. The systems are usually not fine – synchronized, which prevents synchronized handover between them. That method of implementing BTSs is the one most frequently used. That may change soon for urban areas with growing traffic density.

The umbrella cell configuration consists of one BTS with high transmission power and an antenna installed high above the ground that serves as an “umbrella” for a number of BTSs with low transmission power and small diameters. Such a configuration appears to make no sense at first, because the frequency of the umbrella cell cannot be reused in all the cells of that area due to interference. Interference even over a large distance was one of the reasons why the high radio and television towers were abandoned as sites for antennas shortly after they were brought into service at the initial network startup.

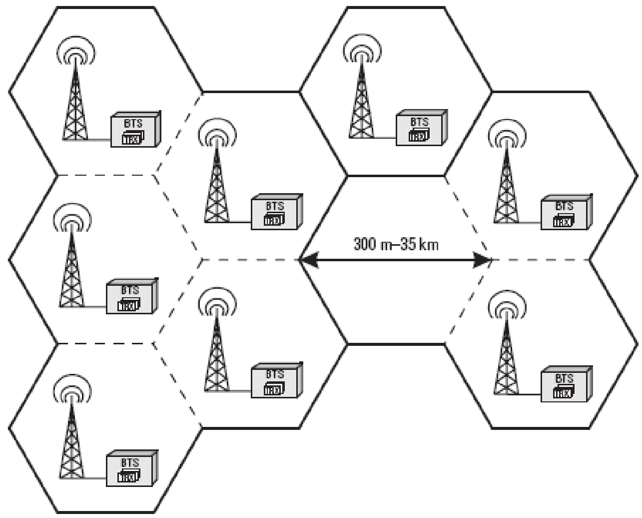

Figure 3.3 BTS distribution in GSM network (Tolstrup, 2008)

The term sectorized or collocated BTSs refer to a configuration in which several BTSs are collocated at one site but their antennas cover only an area of 120 or 180 degrees. Typically, it is implemented with BTSs with few TRXs and low transmission power. Like the umbrella cell configuration, this configuration is used mostly in highly populated areas. A peculiarity is that it is fairly easy to fine-synchronize the cells with each other, which allows for synchronized handover between them. Even though in a collocated configuration, one channel per BTS has to be used for the generation of the BCCH (Broadcast Control Channel), such a configuration has the advantages that from the radio perspective, using cells with a 120 degree angle is that it allows reuse of frequencies in one sector (one direction), which otherwise would cause interference with neighbor cells if an omni – directional cell were used. Also, sectorization eases the demand for frequencies, particularly in an urban environment (Heine, 1999).

3.3 Antenna Systems

Antennas transform wire propagated waves into space propagated waves. They both receive and transmit the electromagnetic waves. Due to voltage potential through the antenna, electric field and magnetic field are produced which correspond to the voltage and the current distribution on the antenna dipoles.

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Figure 3.4 Sample wall-mounted RF antennas

Radio signals are a form of electromagnetic wave, and as they are the way in which radio signals travel, they have a major bearing on RF antennas themselves and RF antenna design. The free propagation of the wave from the dipole is achieved by the permanent transformation from electrical into magnetic energy and vice versa.

The dipole antennas are one of the most important and commonly used types of RF antenna. They are widely used on their own, and they are also incorporated into many other RF antenna designs where they form the radiating or driven element for the antenna.

3.3.1 Antenna Polarization

Polarization is an important factor for RF antennas and radio communications in general. It can be defined as the direction of oscillation of the electric field vector. Both

RF antennas and electromagnetic waves are said to have a polarization. For the electromagnetic wave the polarization is effectively the plane in which the electric wave vibrates.

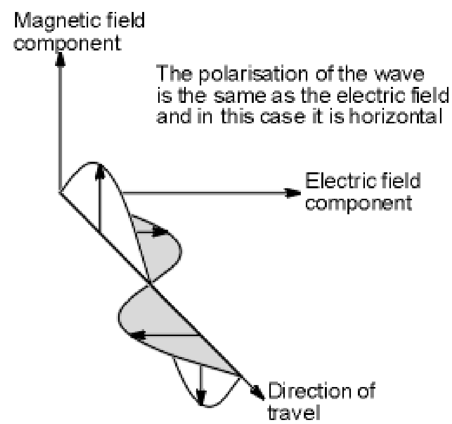

Figure 3.5 Polarization of a wave

In some applications there are performance differences between horizontal and vertical polarization. For example medium wave broadcast stations generally use vertical polarization because ground wave propagation over the earth is considerably better using vertical polarization, where horizontal polarization shows a marginal improvement for long distance communications using the ionosphere.

3.3.2 Antenna Feed Impedance

When a signal source is applied to an RF antenna at its feed point, it is found that it presents load impedance to the source. This is known as the antenna "feed impedance" and it is complex impedance made up from resistance, capacitance and inductance. The feed impedance of the antenna is formed by a number of factors including the size and shape of the RF antenna, the frequency of operation and its environment.

3.3.3 Antenna Bandwidth

Most RF antenna designs are operated around the resonant point. This means that there is only a limited bandwidth over which an RF antenna design can operate efficiently. Outside this the levels of reactance rise to levels that may be too high for satisfactory operation. Other characteristics of the antenna may also be impaired away from the centre operating frequency. The antenna bandwidth is particularly important where radio transmitters are concerned as damage may occur to the transmitter if the antenna is operated outside its operating range and the radio transmitter is not protected. In addition to this the signal radiated by the RF antenna may be less for a number of reasons. For receiving purposes the performance of the antenna is less critical in some respects. It can be operated outside its normal bandwidth without any fear of damage to the set. Even a random length of wire will pick up signals, and it may be possible to receive several distant stations. However for the best reception it is necessary to ensure that the performance of the RF antenna design is optimum.

3.3.4 Antenna Directivity

RF antennas do not radiate equally in all directions. It is found that any realizable RF antenna design will radiate more in some directions than others. The actual pattern is dependent upon the type of antenna design, its size, the environment and a variety of other factors. This directional pattern can be used to ensure that the power radiated is focused in the desired directions (Cheng, 1989).

It is normal to refer to the directional patterns and gain in terms of the transmitted signal. It is often easier to visualize the RF antenna is terms of its radiated power; however the antenna performs in an exactly equivalent manner for reception, having identical figures and specifications.

Directivity of the Antenna : $D = \frac{4\pi U_{\max}}{P_r} = \frac{4\pi |E_{\max}|^2}{\int_0^{2\pi}\int_0^{\pi} |E(\theta,\phi)|^2 \sin\theta d\theta d\phi}$

Where:

U = Radiation intensity

P_r = Total time – average power radiated

In order to visualize the way in which an antenna radiates a diagram known as a polar diagram is used. This is normally a two dimensional plot around an antenna showing the intensity of the radiation at each point for a particular plane. Normally the scale that is used is logarithmic so that the differences can be conveniently seen on the plot. Although the radiation pattern of the antenna varies in three dimensions, it is normal to make a plot in a particular plane, normally either horizontal or vertical as these are the two that are most used, and it simplifies the measurements and presentation.

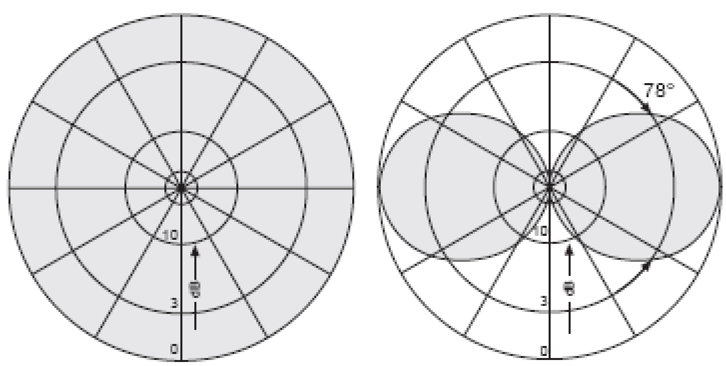

Figure 3.6 Horizontal & vertical signal distribution diagram of RF antenna (Kathrein, 2010).

An RF antenna radiates a given amount of power. This is the power dissipated in the radiation resistance of the RF antenna. An isotropic radiator will distribute this equally in all directions. For an antenna with a directional pattern, less power will be radiated in some directions and more in others. The fact that more power is radiated in given directions implies that it can be considered to have a gain (Kathrein, 2010).

3.3.5 Antenna Gain

The gain can be defined as a ratio of the signal transmitted in the maximum direction to a standard or reference antenna. This may sometimes be called the "forward gain". The figure that is obtained is then normally expressed in decibels (dB). In theory the standard antenna could be almost anything but two types are generally used. The most common type is a simple dipole as it is easily available and it is the basis of many other types of antenna. In this case the gain is often expressed as dBd i.e. gain expressed in decibels over a dipole. For the reason a dipole does not radiated equally in all directions in all planes and so an isotropic source is sometimes used. In this case the gain may be specified in dBi i.e. gain in decibels over an isotropic source. It is possible to relate the two gains as a dipole has a gain of 2.1 dB over an isotropic source i.e.

$$\text{Directive Gain: } G_D(\theta,\phi) = \frac{U(\theta,\phi)}{P_r/4\pi} = \frac{4\pi U(\theta,\phi)}{\oint U d\Omega}$$

Apart from the forward gain of an antenna another parameter which is important is the front to back ratio. This is expressed in decibels and as the name implies it is the ratio of the maximum signal in the forward direction to the signal in the opposite direction. This figure is normally expressed in decibels. It is found that the design of an antenna can be adjusted to give either maximum forward gain of the optimum front to back ratio as the two do not normally coincide exactly.

It may appear that maximizing the gain of an antenna will optimize its performance in a system. This may not always be the case. By the nature of gain and beam width, increasing the gain will result in a reduction in the beam width. This will make setting the direction of the antenna more critical. This may be quite acceptable in many applications, but not in others. This balance should be considered when designing and setting up a radio link.

3.4 Power Control

As the distance between mobile station and the associated base station is increased, mobile station uses more power to achieve good quality. Power control decreases both mobile and base stations' power consumption. Utilizing power control means defining maximum (upper) and minimum (lower) signal receiving limits for mobile stations.

Signal level lower than -106dBm cannot be reached by mobile stations which defines approximate cell coverage. After this level, signal is fading out by radiating and this very low level signal causes interference between base station coverage areas. Power control has an important effect on blocking interferences by limiting signal service level for mobile stations. Power control cannot be used only on BCCH in the downlink direction because on this channel there is continuous data transmission (Lempiainen & Manninen, 2001).

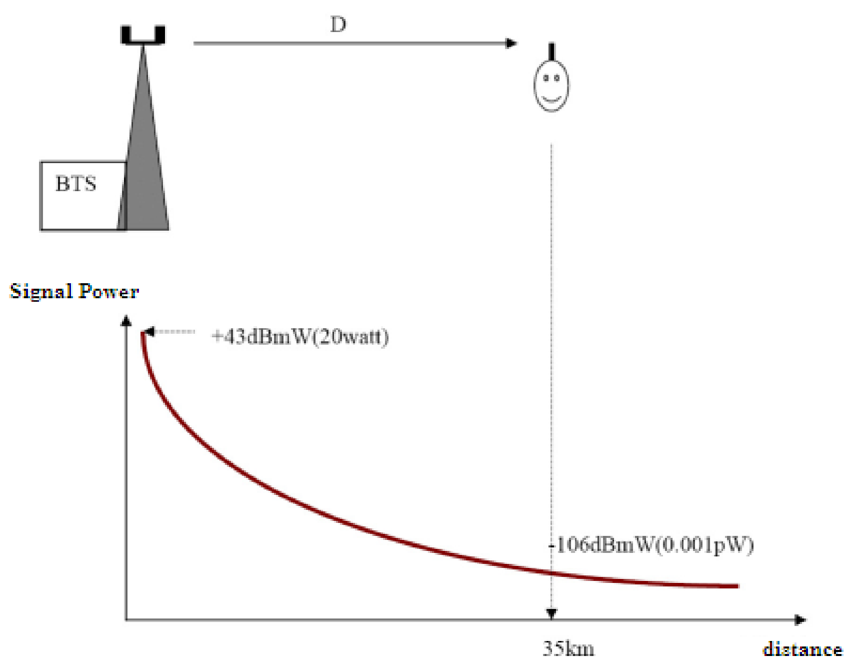

Figure 3.7 Relation between power and distance for GSM (Can, 2006)

At the beginning of the conversation, mobile station uses 2W power. As the distance to the base station decreases, power used by mobile station also decreases even to 0.012W level. According to ETSI standards, there are 15 periods of time for decreasing from 33 dBm to 5dBm by approximately 2dB power steps (ETSI, 1996).

3.5 Power Density

Power density is power per area normal to the direction of propagation and is expressed in units of watts per square meter ("W/m^2" or "mW/cm^2") in general. An isotropic antenna radiates uniformly in all directions. The power of a transmitter that is radiated from an isotropic antenna will have a uniform power density (power per unit area) in all directions. The power density at any distance from an isotropic antenna is simply the transmitter power divided by the surface area of a sphere ($4\pi R^2$) at that distance. The surface area of the sphere increases by the square of the radius, therefore the power density, S, decreases by the square of the radius.

$$S = \frac{P_t G_t}{4\pi R^2} \left(W/m^2 \right)$$

$$S = \frac{E}{120\pi} \left(W/m^2 \right)$$

Where:

S = Power density

P_T & P_R = Transmitter and receiver power (watt)

G_T & G_R = Antenna gain of transmitter and receiver antenna

R = Distance between transmitter and receiver

CHAPTER FOUR
MEASUREMENT RESULTS

The number of mobile phone users increases and in order to support the growing number of users, the base stations can be seen in almost everywhere. Increase in the quantity of the base station numbers make people concern about the potential negative effects on public health. For this reason, by many researches from all around the world, the effects of base stations have been investigated recently.

The most reliable way to prevent public concern is to perform randomly selected field measurements like in countries Portugal, Greece, New Zealand, uniformly. By the help of the measurements, it is possible to observe magnetic field values of base stations and to compare them with the national and world-wide limitations. Only after the measurement and comparison, it might be said that the system is a dangerous to public health or not. As it is explained in GSM and EMF chapters, there are different kinds of base stations around. Every base station has its own peculiar technical specification. We should rather not to compare effects of different base stations like one is a rooftop or in-building installation in city-center and one is a 20 meters to 50 meters tower.

Figure 4.1 Sample base station installations (tower & rooftop)

In many European countries, there has been independent field monitoring programs to measure and monitor the total electromagnetic radio-frequency (RF) field strength in the environment, from all sources (TV, radio, mobile telephony base stations etc), near mobile base stations. The aim of the programs is to provide the public with independent, reliable and direct information on the total electromagnetic RF levels in the environment.

In Turkey, there has been no measurement program such as those monitoring systems from the view of health care yet. ICTA is measuring the spectrum and the Base stations periodically, but it is not interested in such concerns. It is aimed to perform on this study was to simulate a long-term measurement through a randomly selected site (which is suitable to perform and research) and to compare electrical values with daily usage of the base station which may vary by the behavior of the operator's customers even by minutes or hours. Also, measurements from other European countries like Portugal, Albania and New Zealand will be subjects to be examined.

4.1 Base Station Installation Models

Three main installation types which are in-building, roof-top and green field solutions can be observed around people's daily life according to technical requirements and customers expectations.

4.1.1 Indoor (In-Building) Solutions

Buildings, specially the concrete walls, are the biggest barriers against the RF signals. For example, -80dBm signal level can be measured just in front of a building but behind the walls only -90dBm to -105dBm signal level can be achieved. So, when, an hotel or a shopping-mall is considered to be covered inside completely , it is not that easy to feed the every points by couples of base stations from outside. For this reason, a complete indoor design project is realized to cover all around the walls like an electrical network.

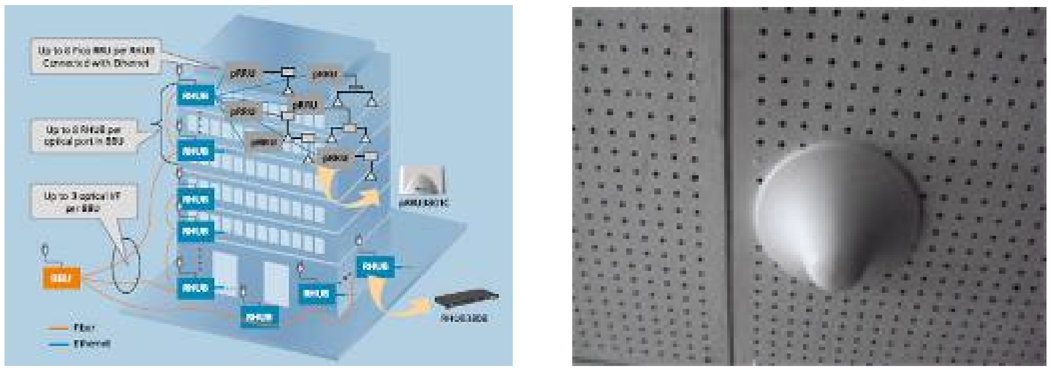

Figure 4.2 Sample In-building design and systems

In this system, antenna gain changes 2dBi to 7dBi according to construction of the building with very low power working levels between 0.5W – 1W. SAR values caused by these antennas, then, get quite low and innocent levels. Also, safety distance is just about 30cm, because, people always walk just below the RF network.

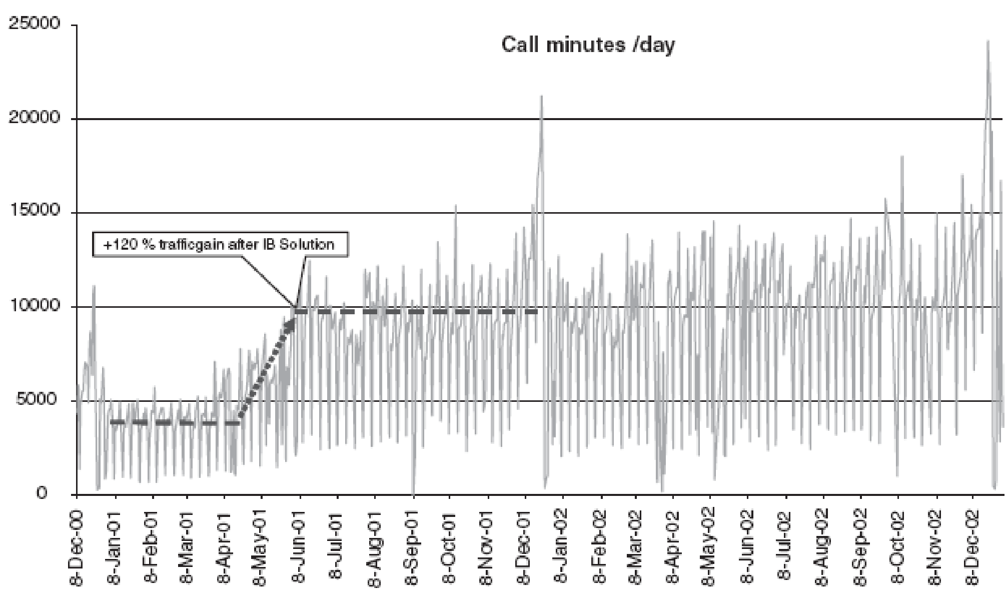

Figure 4.3 The traffic after implementing in-building system in the area covered by macro sites at first (Tolstrup, 2008) .

4.1.2 Rooftop Solutions

Operators have millions of customers and thousands of them talk simultaneously. But, the service supplied by a base station is limited for technically specified number of them. For the reason to provide a continuous communication there are many base stations installed top of the buildings in cities. It is the most common installation type that can be run across. Under normal circumstances, in every 1.5km to 2km radius area, there is a base station of an operator's GSM network.

Figure 4.4 Sample roof-top base station installations

In this system, common usage of antenna gain is about 15dBi with 5W to 7W power level which generates about six meters to eight meters of safety distances. Antennas generally are installed by the edges of the roofs with a sight of space at least which is specified as safety distance. The roof which is selected by the operator should rather be highest building among the others for the goodness of RF signal and health concerns of the public.

4.1.3 Greenfield Solutions

Customers don't only stand in big city centers but also they live in villages or even behind the big mountains. Operators are also all responsible for these customers as much as they are for metropolitans. Because of the geographical structure of those areas, high tower and antenna gain solutions are chosen for radiating the signal. Generally, fifty to sixty meter towers are installed with 18dBi antenna gain and 15W to 20W power level. Safety distance is not the main subject to concern about because it is not possible an individual person to reach near antenna systems. The bottom of the tower is just an individual area where we can meet SAR values less than even 1V/m.

Figure 4.5 Sample green-field (tower) base station installations

4.2 Measurement Systems

Public safety around radio sites remains a highly emotive issue. While site design criteria exclude the possibility of public exposure reference levels being exceeded, on-site measurements can help to reassure the public, giving them real information rather than anecdotal or issue-driven evidence on which to base their decisions.

The power absorbed by biological tissues results in a rise in temperature of these tissues, the power from which it exceeded the capacity of the thermo-regulatory body sets a limit value of SAR. The SAR limit value is converted to quantities that can be measured externally the human body, for example the electric field, E (V/m), which is provided directly by the measuring equipment used.

4.2.1 Broadband Meters

The EMR-300 Meter features a lightweight design with an integral shock resistant cover. It is utilized for high sensitivity and high dynamic range surveys. Electric, magnetic and shaped probes are available to satisfy virtually every survey need. Every probe available has approximately 60dB of dynamic range, without changing measurement ranges. Unique to this series are H-field probes available from 3 kHz to 1 GHz.

Figure 4.6 EMR – 300 broadband meter tool set

The EMR-300 has the ability to store readings and also has time and spatial averaging capabilities. Spatially averaged limits are the basis for almost all international standards or guidance’s. For readings of averaged fields such as vertical scans over the height of the body, or time averaged readings in front of rotating radar, averaging is almost always required to properly assess the whole body limits. Data logging is an additional feature of the EMR-300. Being able to store readings can be a time saving, important method of documenting your survey. Data is stored with time-of-day information so that you can tie readings directly to the date and time of your survey.

4.2.2 Narrowband Meters

The Selective Radiation Meter (SRM) is a hand-held selective measuring device for safety analysis of RF and microwave electromagnetic fields. The SRM can be used by broadcasters, radio network operators, measurement service providers and public authorities to selectively measure the field exposure produced by individual telecom services and assess the results in accordance with the applicable standards. Most measurements required in the mobile radio sector can be performed directly using the hand-held device. The SRM immediately evaluates the results on site.

The SRM is capable of taking long-term measurements showing how the field strength of a selected frequency varies over time. The peak values can be saved to provide valuable information for service providers and local authorities alike.

Figure 4.7 SRM – 3000 meter

In multi-frequency environments, the Spectrum Analysis provides an overview of all frequency components with their field strengths. Even in a very complex field environment, and in the vicinity of powerful broadcast signals, the spectrum analyzer can be used to measure individual transmit channels or frequencies. The device is capable of integrating over its frequency range and displaying the total value (an absolute value). For example, for GSM measurements, the spectrum analyzer can use a 200 kHz resolution bandwidth (RBW) to measure the field strength of an individual control channel (BCCH) which always transmits at full power and estimates the field emissions which all of the traffic channels (TCH) would produce under full load. For UMTS measurements, the spectrum analyzer can use a 5 MHz resolution bandwidth to measure an entire frequency block.

Figure 4.8 Sample spectrum analyzer

4.3 Measurement Technique & Results

In this study, daily magnetic radiation of a base station was observed for different two days which are Saturday, representing weekend, and Tuesday, representing weekdays. For the in-building and tower solutions, technical measurement from Turkey and other countries will be examined.

Two EMR-300 broadband meters with a pc connection is placed as the measurement equipments against the related antennas at the safety distance points. One device was used to observe average electric field values of medium and the other to collect continuous data.

Figure 4.9 EMR-300 connected to PC

The equipment used for the measurement in the study is the Wandel & Golterman EMR-300 probe 8.3. Date of calibration is the 14.07.2009. Calibration was performed by TUBITAK. The calibrated field strength measuring system Wandel & Golterman type EMR-300 consists of the following specifications:

- Field probes (Type 8.3) to measure the electrical field strength.
- Readout unit (EMR-300) in a separate case and connected through a fiber optical link with the optical to serial interface.
- Frequency range is between 100KHz…3GHz
- Field strength display range is between 1…600V/m

The instrument can record and store instantaneous, maximum and mean values of electric and magnetic field values. According to all European and International standards, the measured values in the frequency range 100 kHz – 10 GHz should be expressed in at least any six minute time period. In the measuring set up used, acquisition, storage and processing of the measurements data is controlled with a portable pc which controls the instrument with a special software (ETS-1) via a double optical fiber interface to an RS 232 input and special software. The duration of measurements was continuous for the quantity of electric field strength.

Different type of base station installations have different effects and results to be examined:

1. Rooftop Installations: Daily variation of magnetic radiation caused by a base station is observed.
2. In-Building (Indoor) Installations: Power distribution of magnetic radiation in complex mediums is observed.
3. Greenfield (Tower) Installations: Azimuth and distance dependent power distribution of magnetic radiation is observed.

4.3.1 Rooftop Base Station Installation Measurements

The building which has been meant to be observed is placed in a casual neighborhood. It is not an industrial area or near to the business centers where the building is placed. Measurements were performed from 9:00/10:00 o'clock in the morning till 20:00 o'clock in the evening for two days: 16.01.2010 – Saturday & 19.01.2010 – Tuesday. All the similarities and the differences between two days data will be examined and pointed by the graphs below:

Figure 4.10.aThe building where the measurement was performed

Figure 4.10.bThe building where the measurement was performed through city view

I. All day continuous measurement results of two days with data examined by the time period of 30 minutes in separated & same graphs.
II. Curve fit application of continuous measurement results of two days with data examined by the time period of 30 minutes in separated & same graphs.
III. Smooth application of continuous measurement results of two days with data examined by the time period all day in separated & same graphs.
IV. All day continuous measurement results against the traffic values of two days with data examined by the time period of 30 minutes in separated & same graphs.
V. Comparison of max values observed in two hour time period of two days
VI. Curve fit application of comparison of max values observed in two hour time period of two days
VII. Comparison of min values observed in two hour time period of two days
VIII. Curve fit application of comparison of min values observed in two hour time period of two days

Figure 4.11 The roof where the measurement was performed

4.3.1.1 16.01.2010 & 19.012010 Daily EMR Results

I. Second sector of the base station that operates at dual band for 2G&3G:

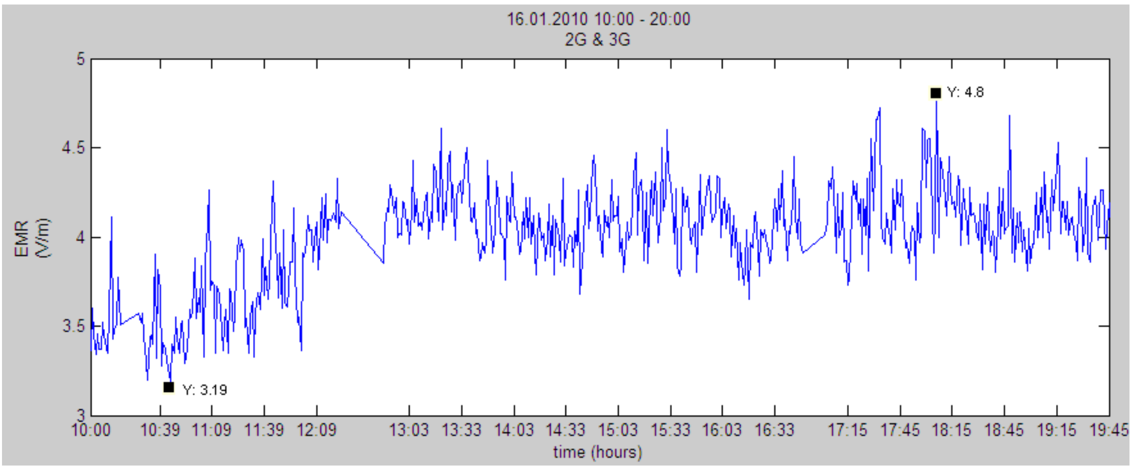

Figure 4.12 Variation of electric field values between the hours 10:00 & 20:00 at 16.01.2010 Saturday

Electric field variation from ten o'clock in the morning till eight o'clock in the evening at the date 16.01.2010 (Saturday) of base station was observed. Till nearly eleven o'clock, electric field seems to be lower than other hours and lowest value was measured is 3.19 V/m. In the afternoon, electric field begins to rise and keeps its form for remaining hours. Highest value was measured is 4.8 V/m which has been taken about six p.m.

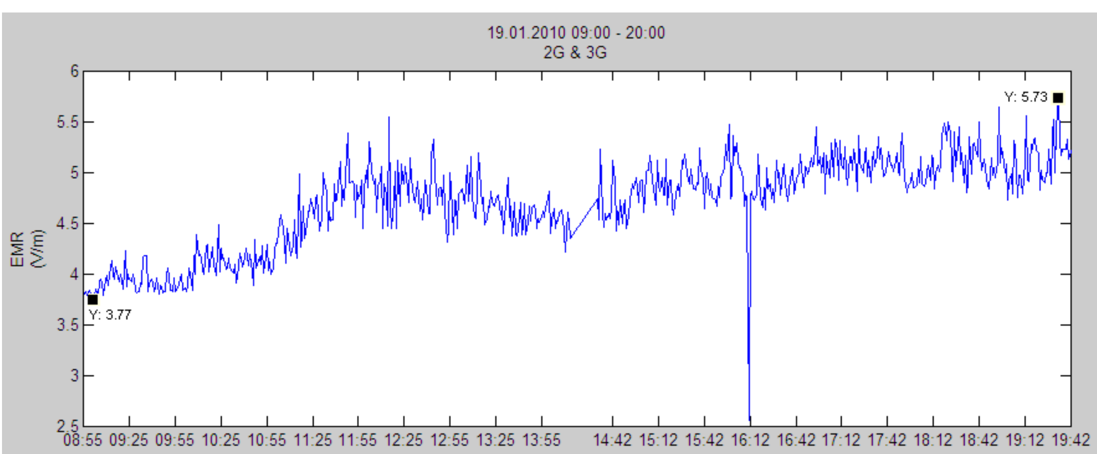

Figure 4.13 Variation of electric field values between the hours 09:00 & 20:00 at 19.01.2010 Tuesday

Electric field variation from nine o'clock in the morning till eight o'clock in the evening at the date 19.01.2010 (Tuesday) of base station was observed. From nine to eleven o'clock, electric field clearly seems to be lower than other hours and lowest value was measured is 3.77V/m. By about the eleven o'clock, electric field begins to rise and keeps its form for remaining hours with small variations. After six p.m. electric field values get higher and higher where they approach the max measurement which is 5.73V/m.

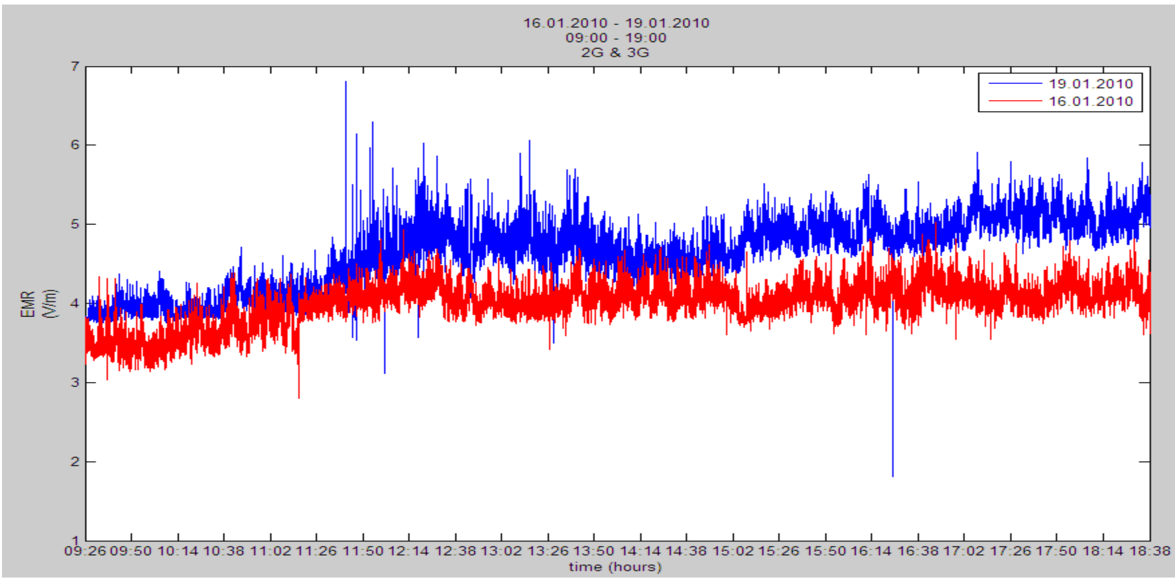

Figure 4.14 Comparison of electric field values recorded at two days

Electric field variation from early hours in the morning to busy evening hours in the evening for both two days seems to be similar to each other after measurement. Electric field values have been lower in the morning. In the afternoon, electric field seems to be increasing for remaining hours. Highest values for both two days were observed in the evening time. Although, start and finish points are different in two days, measurement results have same trend which it will be analyzed better with curve-fitting in future sections.

II. Third sector of the base station that operates only for 2G:

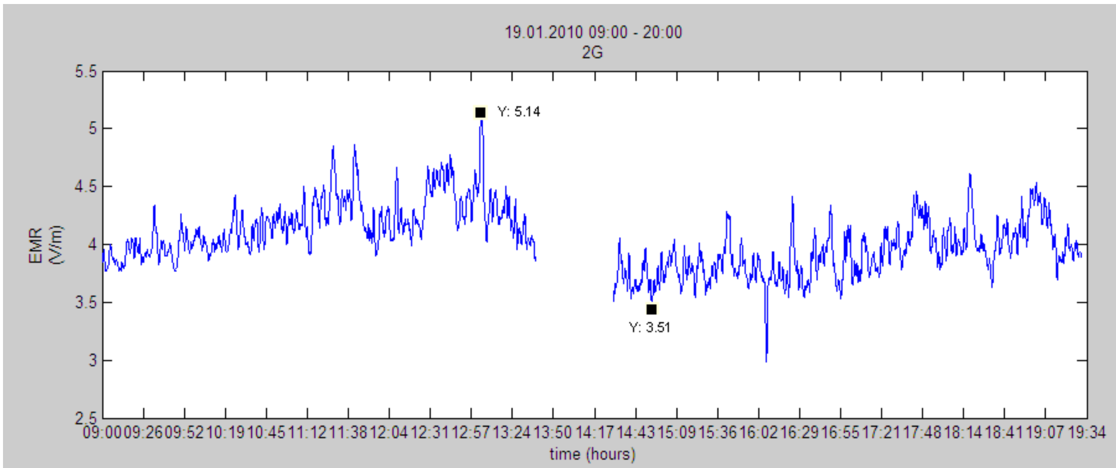

Figure 4.15 Variation of average electric field values between the hours 09:00 & 20:00 at 19.01.2010 Tuesday

Mean electric field of 2G medium was observed for the day 19.01.2010 (Tuesday) from nine o'clock in the morning to eight o'clock in the evening by twelve second time period and for the reason the antenna measured has been serving for only 2G, as expected, lower electric field values were measured. As it is analyzed in above sections, daily continuous data (2sc between two measurements) vary between seconds but average measurement of medium seems to be more regular by having more time between two measurements. Electric field begins with lower values in the morning and then gets higher in the afternoon with max 5.14 V/m. After two p.m. to six p.m. values seems regular with min 3.51 V/m and then again begins to uniformly rise till eight p.m.

4.3.1.2 Curve Fitting Calculation Results of Daily EMR Data

Curve fitting is the process of constructing a curve, or mathematical function that has the best fit to a series of data points, possibly subject to constraints.

I. Second sector of the base station that operates at dual band for 2G&3G:

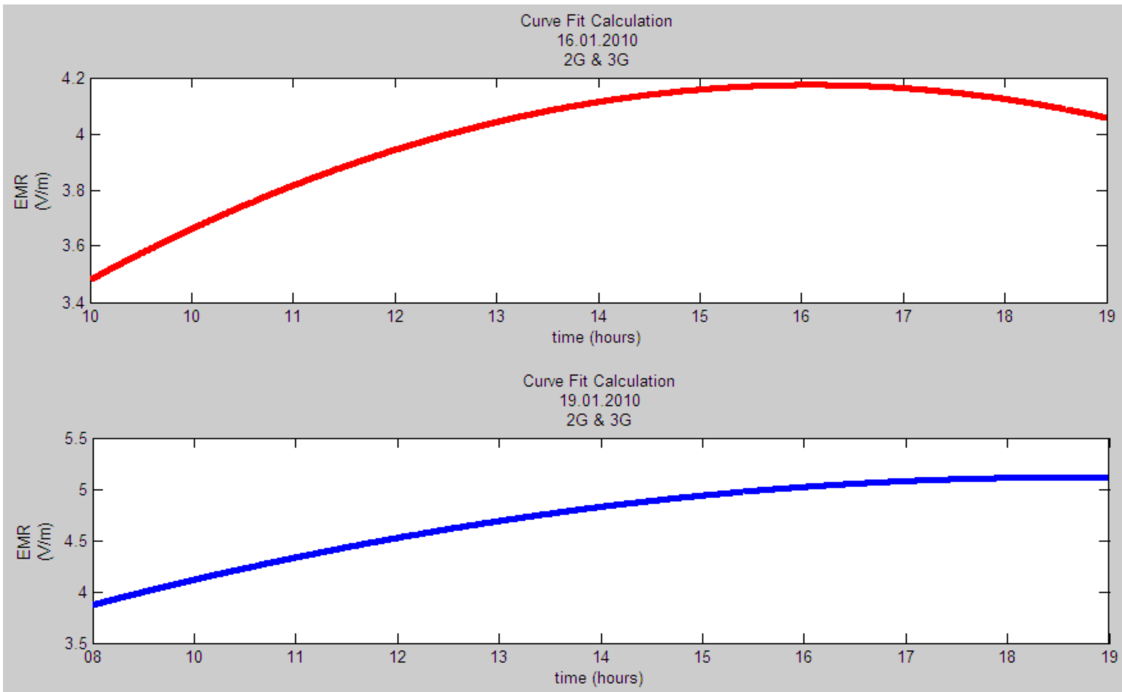

Figure 4.16 Curfe-Fit calculation on values between the hours 09:00 & 20:00 at 19.01.2010 Tuesday

Daily raw electric field measurements are given by graphics before. After applying curve fitting method, it is clearer to see daily trend of electric field variation. It seems that data get the lowest position in the morning than higher and higher for remaining hours. Electric field increase stands between hours two p.m. and six p.m. at Saturday and after about three p.m. at Tuesday for antenna serving both for 2G &3G.

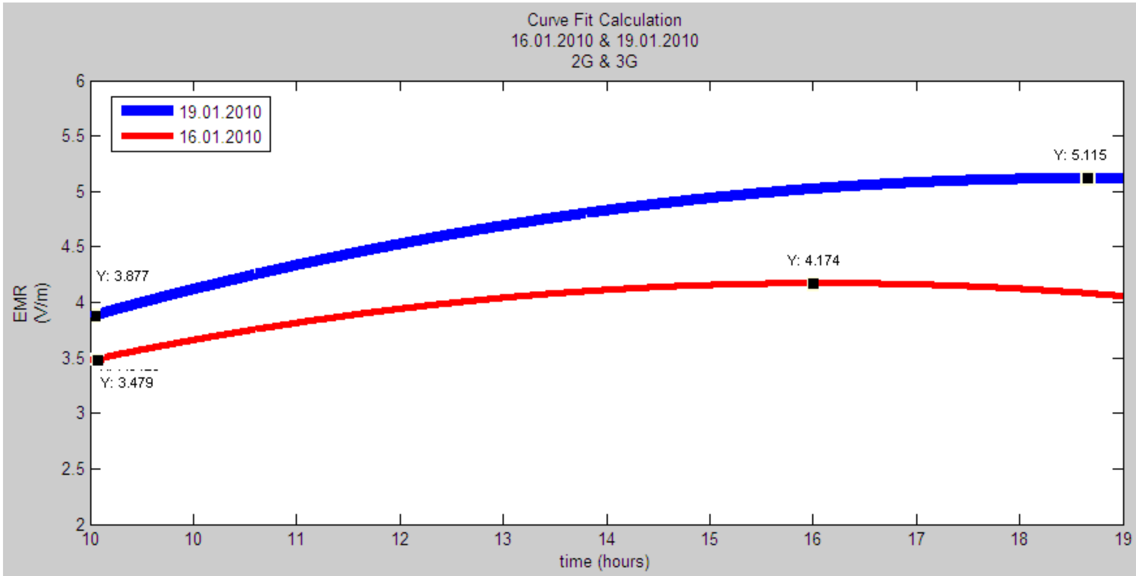

Figure 4.17 Comparison of curve-fit calculation on values between two days

Although, electric field values measured at two days start and end at different levels, variation also seems similar to each other through daily trend. Minor differences were observed between min and max levels of days which 0.398V/m has been difference of min values (3.479V/m as min of Saturday morning and 3.877V/m as min of Tuesday morning) and 0.941V/m has been difference of max values (4.174V/m as max of Saturday morning and 5.115V/m as max of Tuesday morning)

II. Third sector of the base station that operates only for 2G:

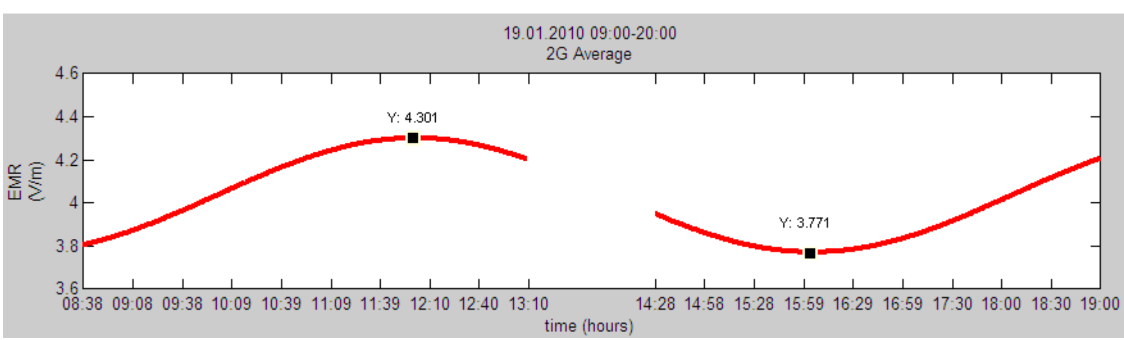

Figure 4.18 Curve-Fit calculation on values between the hours 09:00 – 19:00 at 19.01.2010(Tuesday)

Variation of mean electric field of 2G antenna medium was observed for the day 19.01.2010 Tuesday seems clearer after curve-fit calculation. As it seems on graphic, data vary between close electric field values which are 3.771V/m as min and 4.301V/m as max for all day. The difference of max and min measurements of day is only 0.53V/m.

4.3.1.3 Smooth Calculation Results of Daily Data

In mathematical analysis, a differentiability class is a classification of functions according to the properties of their derivatives. Higher order differentiability classes correspond to the existence of more derivatives. Functions that have derivatives of all orders are called smooth. Smooth calculation clarifies instant increases and decreases on values.

I. Second sector of the base station that operates at dual band for 2G&3G:

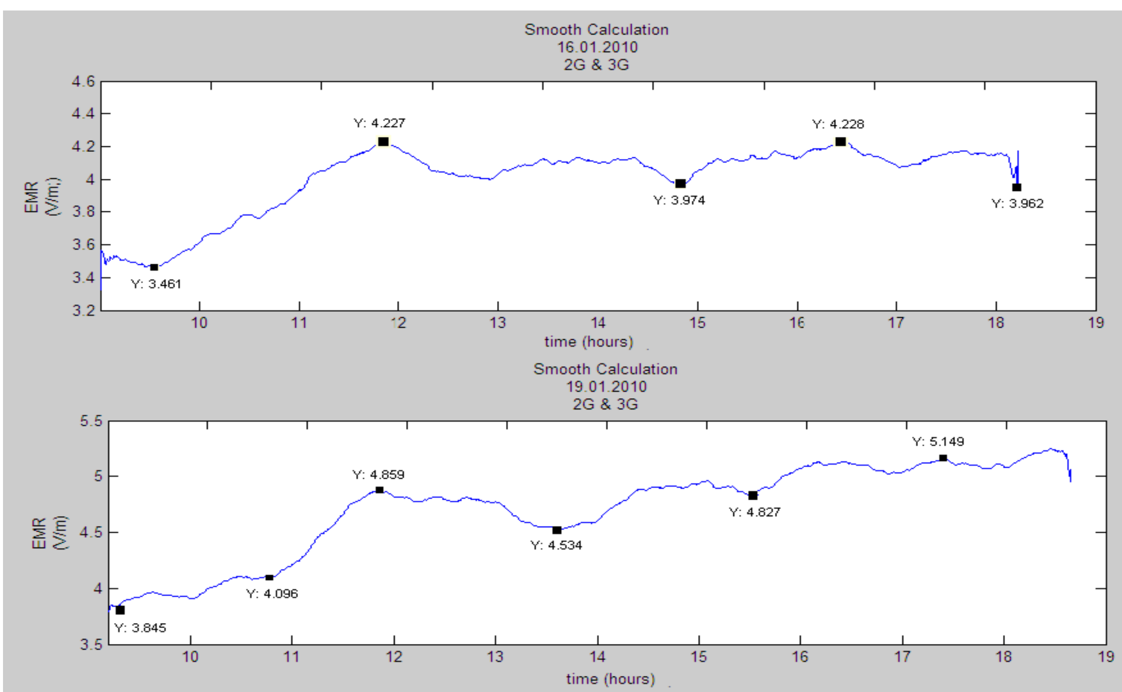

Figure 4.19 Smooth calculations of daily data (16.01.2010 – Saturday & 19.01.2010 – Tuesday)

As it is seen on daily trend, there are minor variation levels which may be observed after smoothing. Even the max and min points of two days are different; the time sequence seems nearly similar to each other. After two hours low segment measurements in the morning, meanly by two hours there has been a little increase for remaining hours.

II. Third sector of the base station that operates only for 2G:

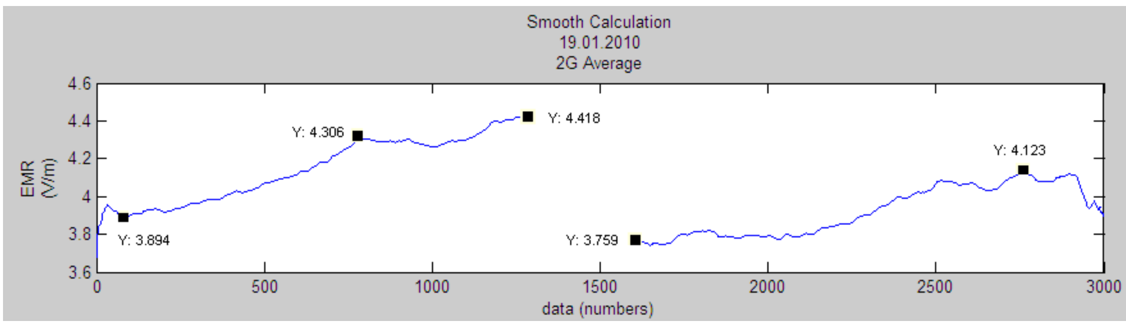

Figure 4.20 Smooth calculation of daily average data (19.01.2010 – Tuesday)

After applying smooth calculation, min and max of average measurements are reorganized and shifted a little to optimize points. Electric field level stands between close values for all day.

4.3.1.4 EMR Data vs Daily Usage of Base Station

I. Second sector of the base station that operates at dual band for 2G&3G:

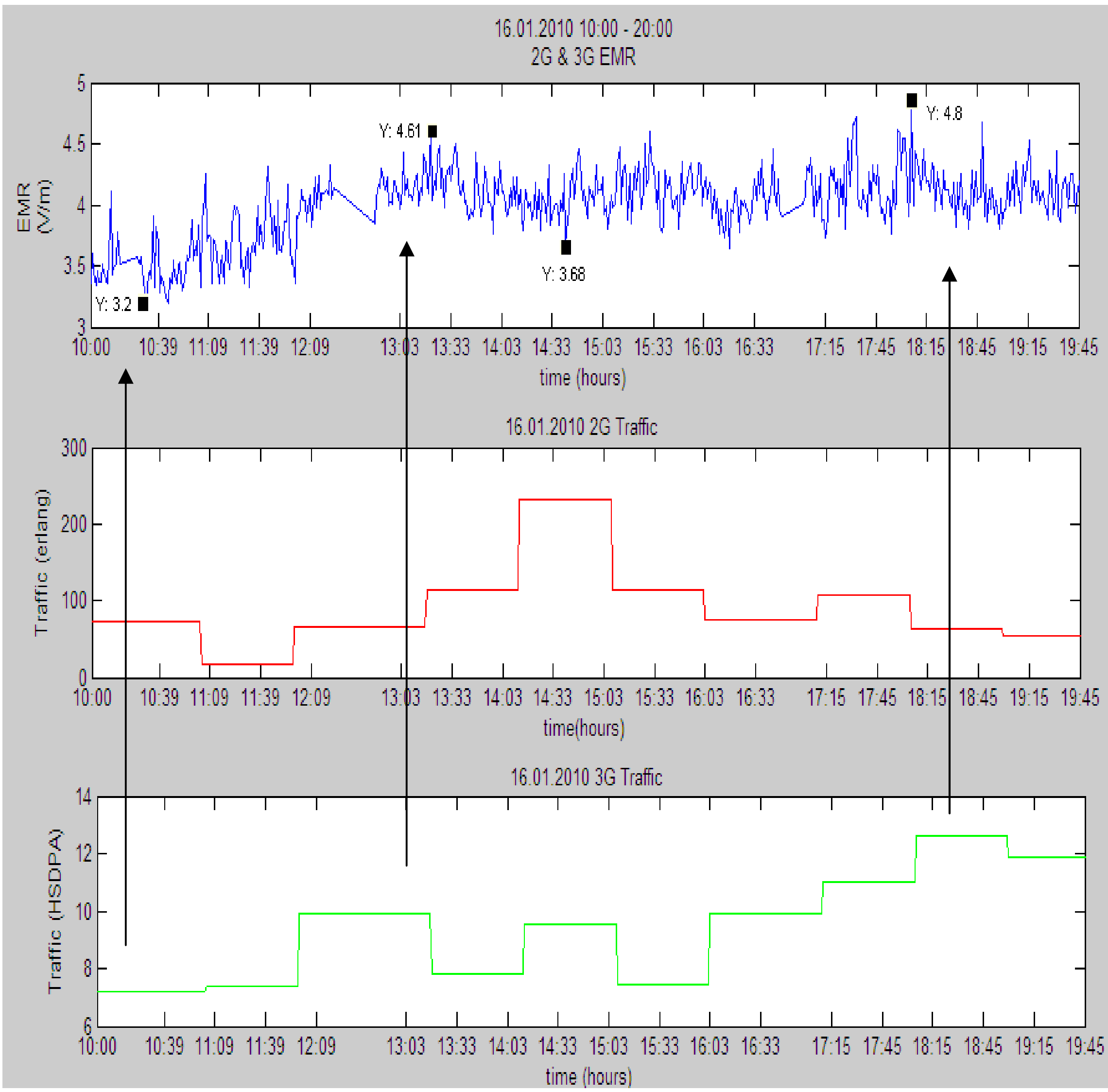

Figure 4.21 Electric field values vs daily usage of 2G & 3G data (16.01.2010 – Saturday)

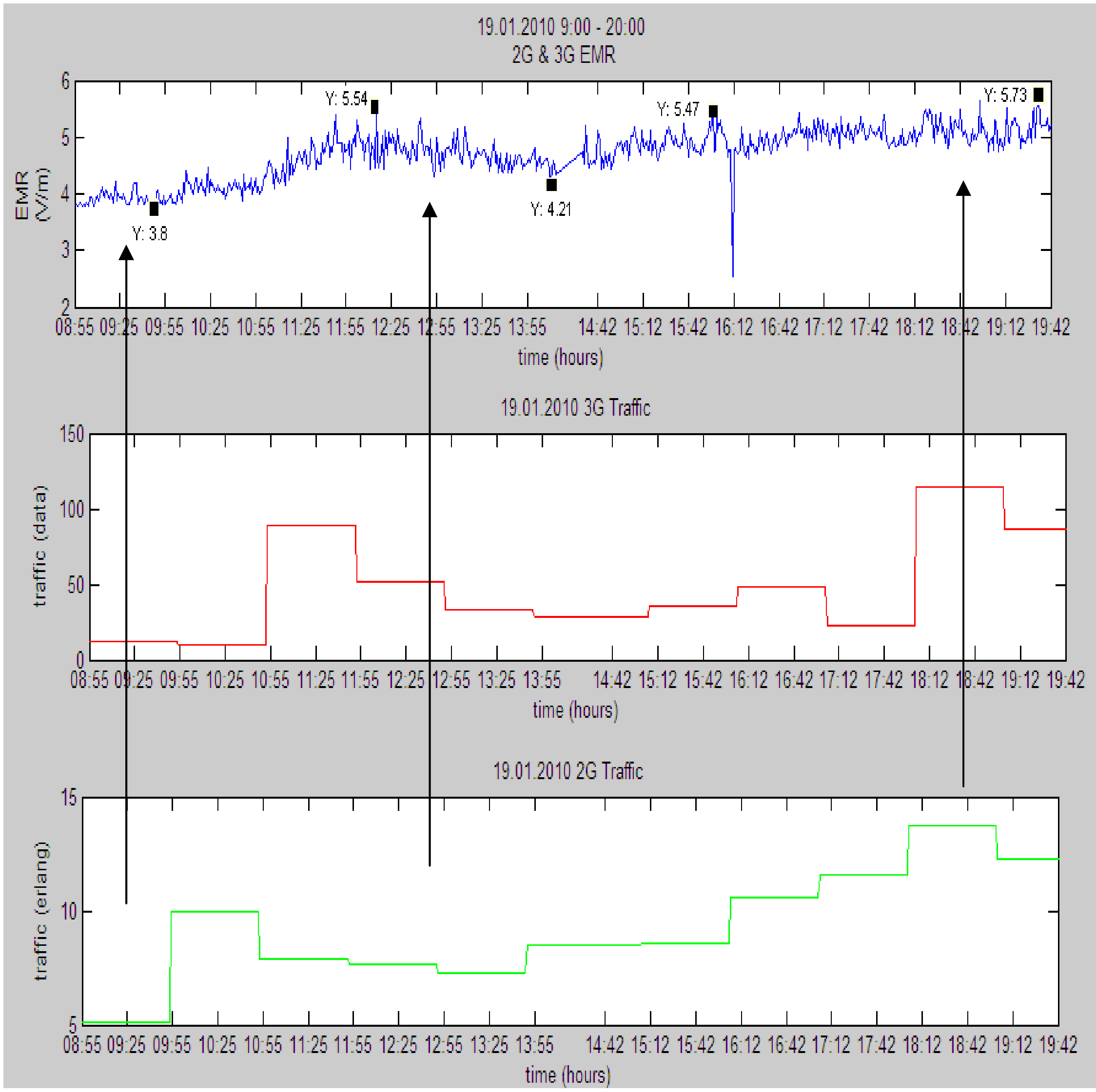

Figure 4.22 Electric field values vs daily usage of 2G & 3G data (19.01.2010 – Tuesday)

It is aimed to observe the variation of electric field versus daily usage of base station on this graphics. Sector – 2 supplies services for both 2G and 3G. Daily variation of 2G&3G total traffic is just similar to variation of electric field, but not directly proportional. Such as; at 16.01.2010 Saturday; when 2G traffic data doubles from 7 erlang to 14 erlang or downloads from 80Mbytes to 250Mbytes; electric field only varies from about 3.2V/m to 4.8V/m. In the same way, at 19.01.2010 Tuesday in the morning traffic was 5 erl and total download was 20Mbytes; 3.8V/m was measured. After that in the evening traffic was about 15 erlang and total download was 140Mbytes; 5.73V/m was measured. Late traffic value was three times of morning but there has been an increase for only about 1.83V/m electric field.

II. Third sector of the base station that operates only for 2G:

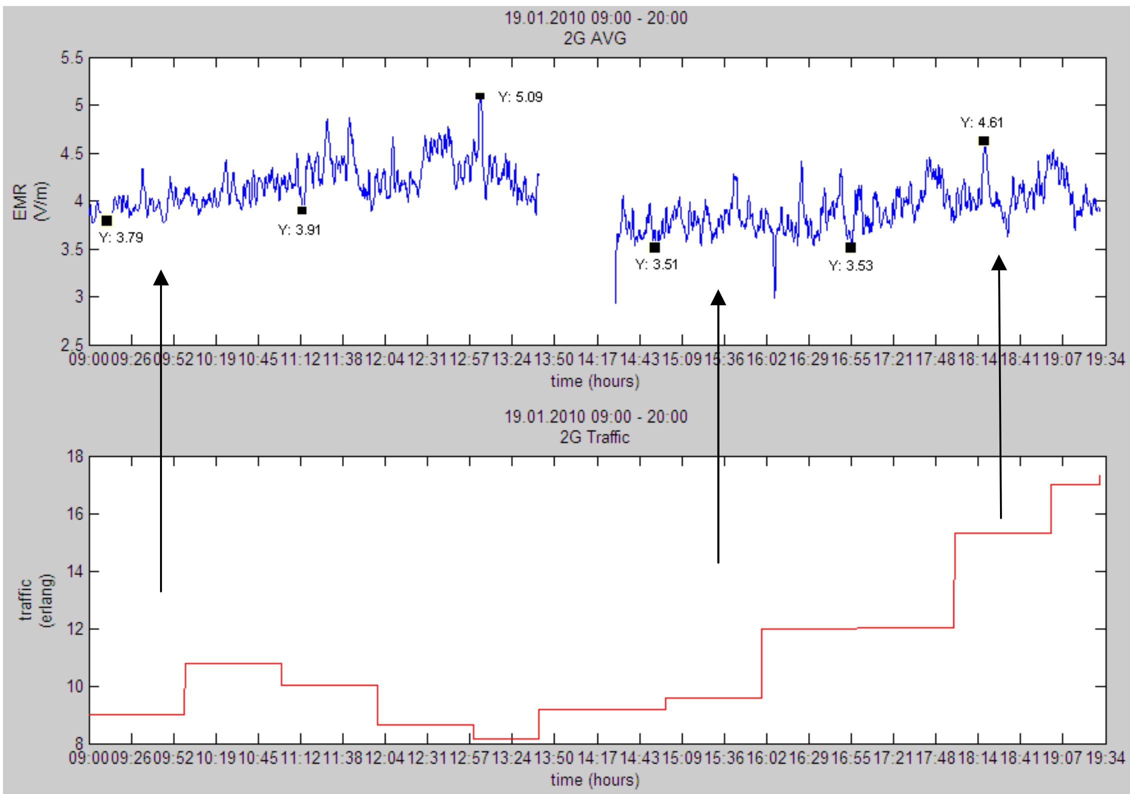

Figure 4.23 Electric field values vs daily usage of 2G data (19.01.2010 – Tuesday)

Sector – 3 supplies only 2G service. As it been mentioned, increases and decreases on traffic values make electric field values get higher and lower proportionally. Although there has been a change twice as traffic values like from 9 erlang to 18 erlang; electric field varies even less than 1V/m from 3.79V/m to 4.61V/m.

4.3.1.5 MAX Valued Data Taken at 2- Hour Time Periods

I. Second sector of the base station that operates at dual band for 2G&3G:

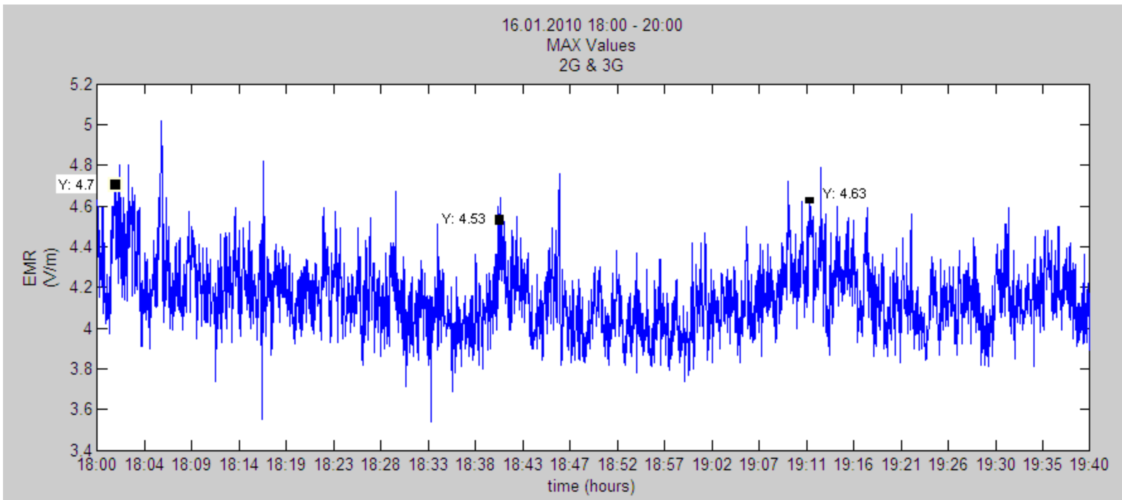

Figure 4.24 MAX electric field for 2-hour time period at 18:00 – 20:00 / 16.01.2010 – Saturday

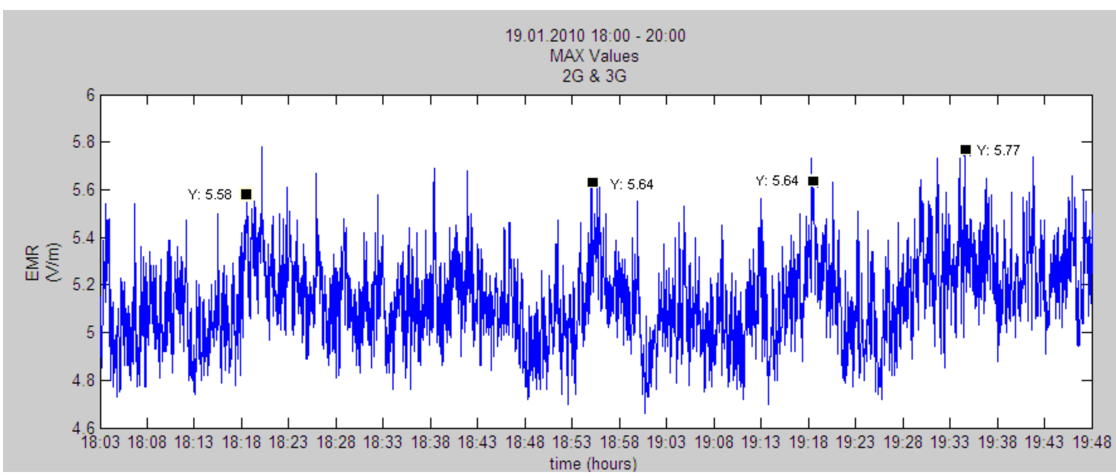

Figure 4.25 MAX electric field gor 2-hour time period at 18:00 – 20:00 / 19.01.2010 – Tuesday

People usually talk more in the evenings and this makes base stations work harder. As it is seen on graphics, both on Saturday and Tuesday there has been a 2-hour time period which had been the time that highest electric field values has been observed. Electric field is not still constant even in 2-hour period but, it has similar values to each other which are highest of the days.

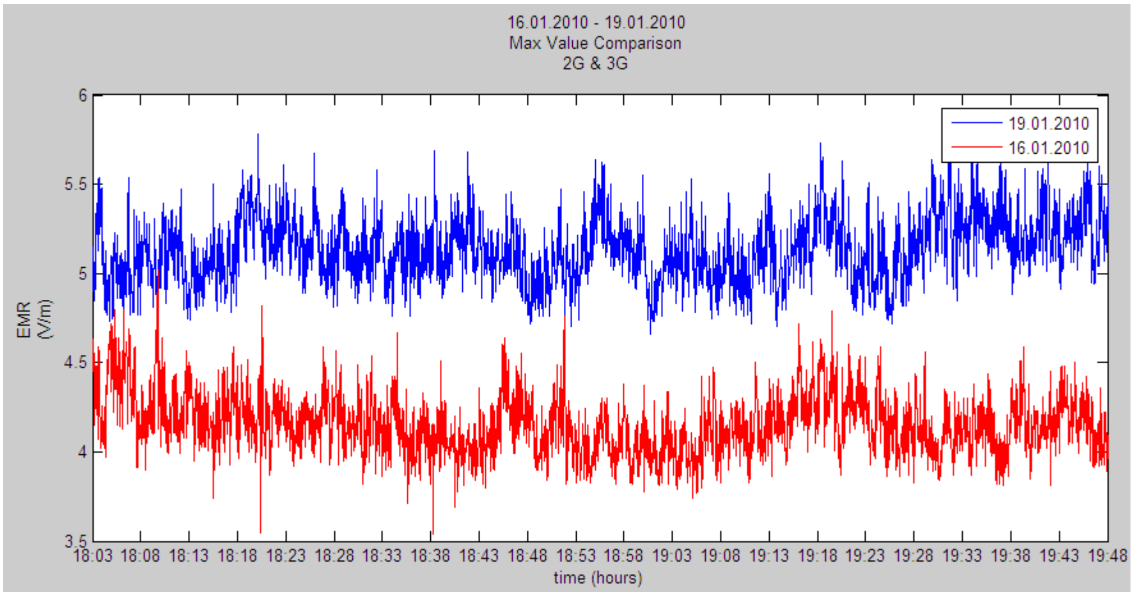

Figure 4.26 MAX electric field comparison between two days 16.01.2010 (Saturday) – 19.01.2010 (Tuesday) in 2-hour time period (18:00 – 20:00)

For both Saturday and Tuesday, max electric field measurement was observed between six p.m. and eight p.m. Variation trends are similar but with different max data levels which are 4.6V/m for Saturday and 5.6V/m for Tuesday averagely.

II. Third sector of the base station that operates only for 2G:

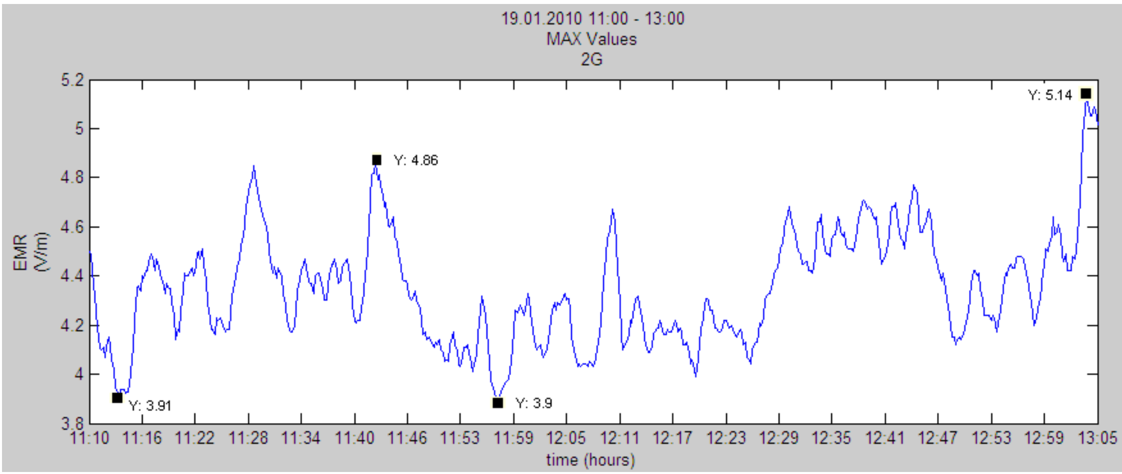

Figure 4.27 MAX average electric field for 2-hour time period at 11:00 – 12:00 / 19.01.2010 – Tuesday

For average medium measurement on Tuesday, max electric field values were observed between eleven a.m. and one p.m. Variation occurs between data levels 3.9V/m and 4.8V/m averagely.

4.3.1.6 MIN Valued Data Taken at 2- Hour Time Periods

I. Second sector of the base station that operates at dual band for 2G&3G:

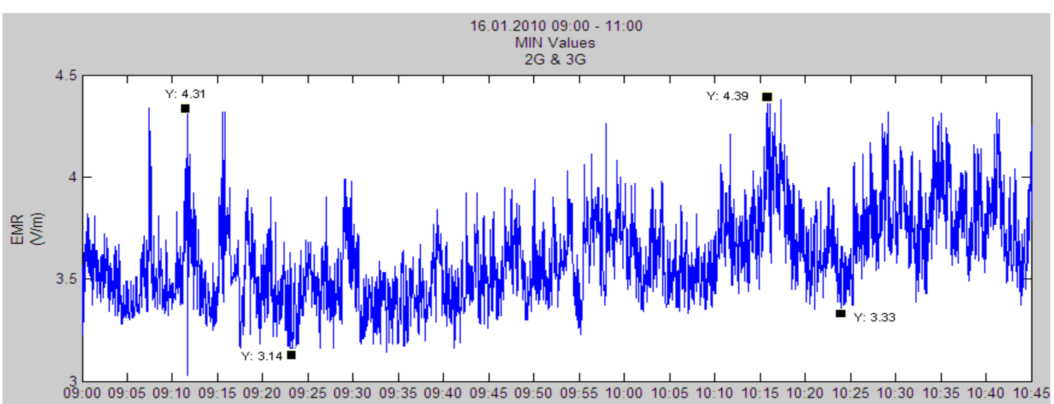

Figure 4.27 MIN electric field for 2-hour time period at 9:00 – 11:00 / 16.01.2010 – Saturday

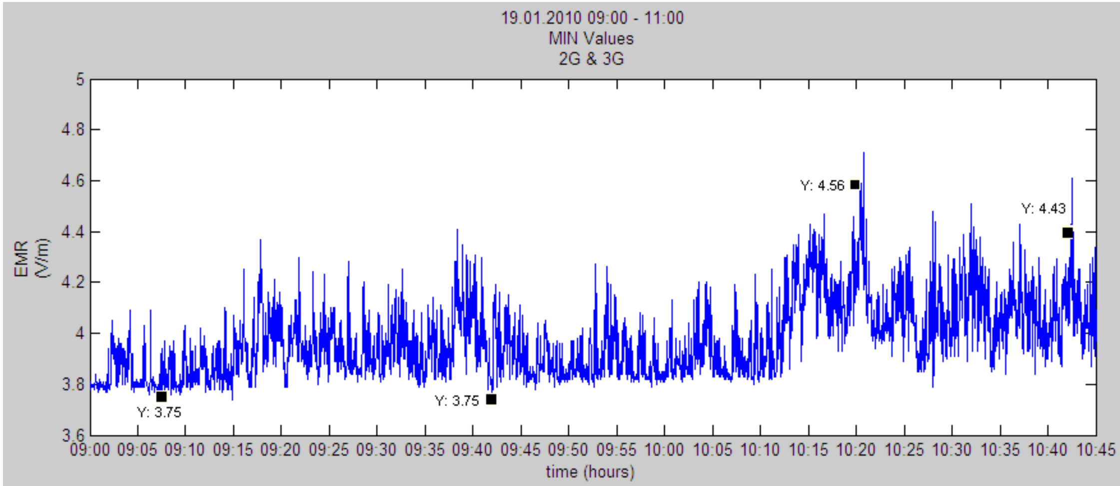

Figure 4.28 MIN electric field for 2-hour time period at 9:00 – 11:00 / 19.01.2010 – Tuesday

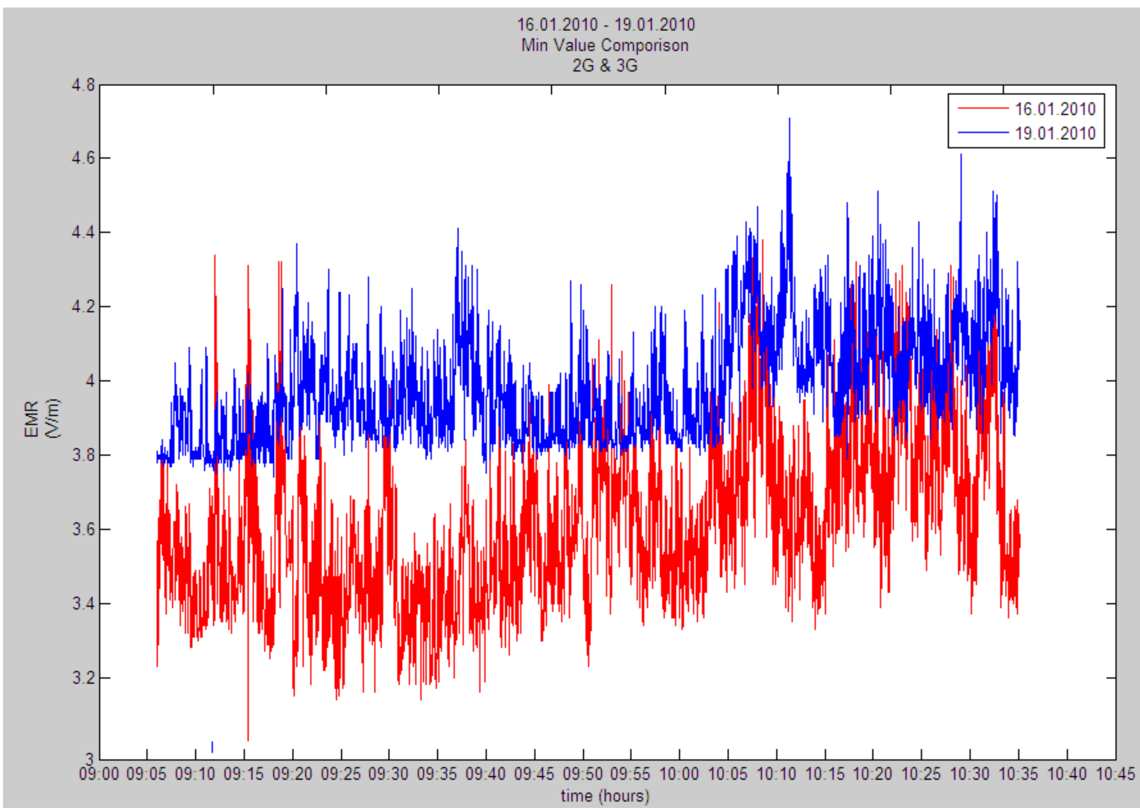

Figure 4.29 MIN electric field comparison between two days 16.01.2010 (Saturday) – 19.01.2010 (Tuesday) in 2-hour time period (9:00 – 11:00)

For both Saturday and Tuesday, min electric field measurements were observed between nine a.m. and eleven a.m. Variation trends are similar but with different min data levels which are 3.2V/m for Saturday and 3.7V/m for Tuesday averagely.

I. Third sector of the base station that operates only for 2G:

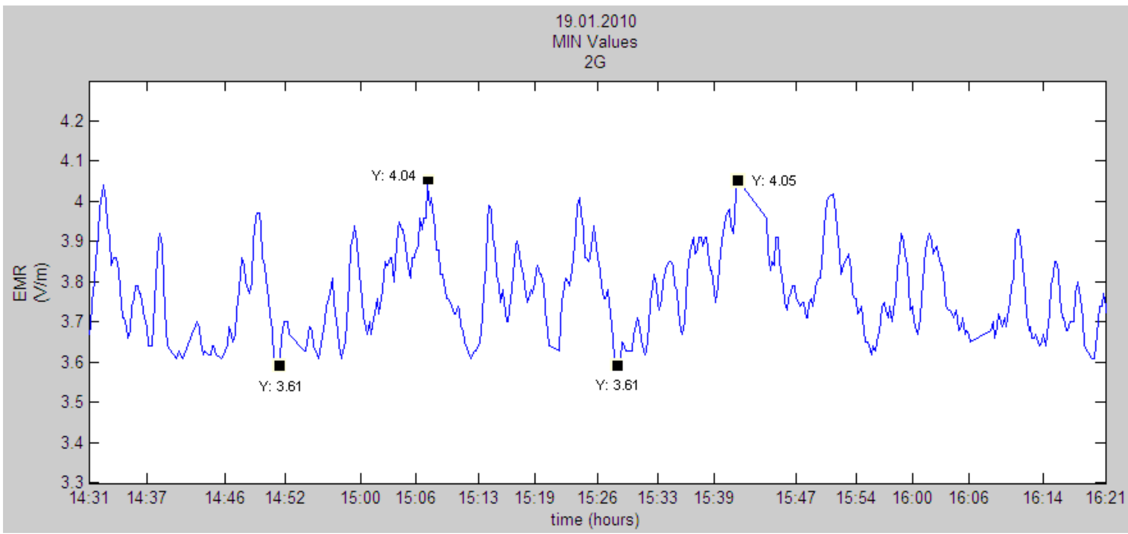

Figure 4.30 MIN average electric field for 2-hour time period at 14:30 – 16:30 / 19.01.2010 – Tuesday

For average medium measurement on Tuesday, min electric field values were observed between two and a half p.m. and four and a half p.m. Variation occurs between data levels 3.6V/m and 4.04V/m averagely. Difference is very small just because these data include mean values of medium.

4.3.1.7 MAX Valued Data Taken at Short-Time Periods

I. Second sector of the base station that operates at dual band for 2G&3G:

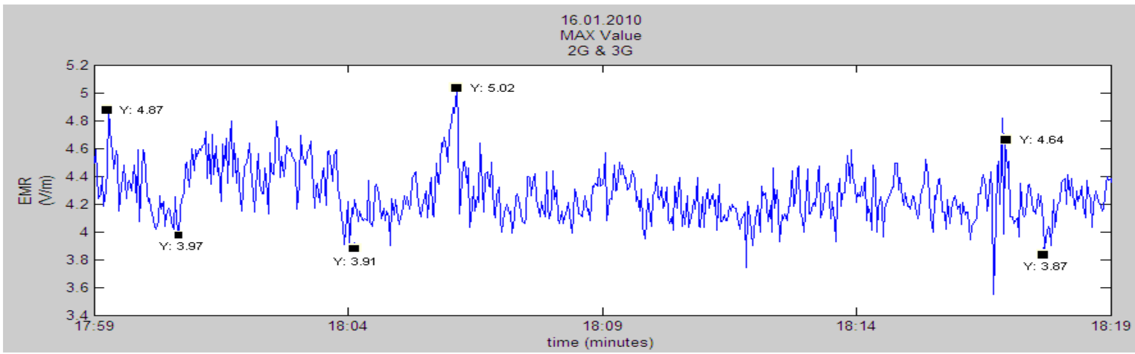

Figure 4.31 MAX electric field for 20-minute time period at 18:00 – 18:20 / 16.01.2010 – Saturday

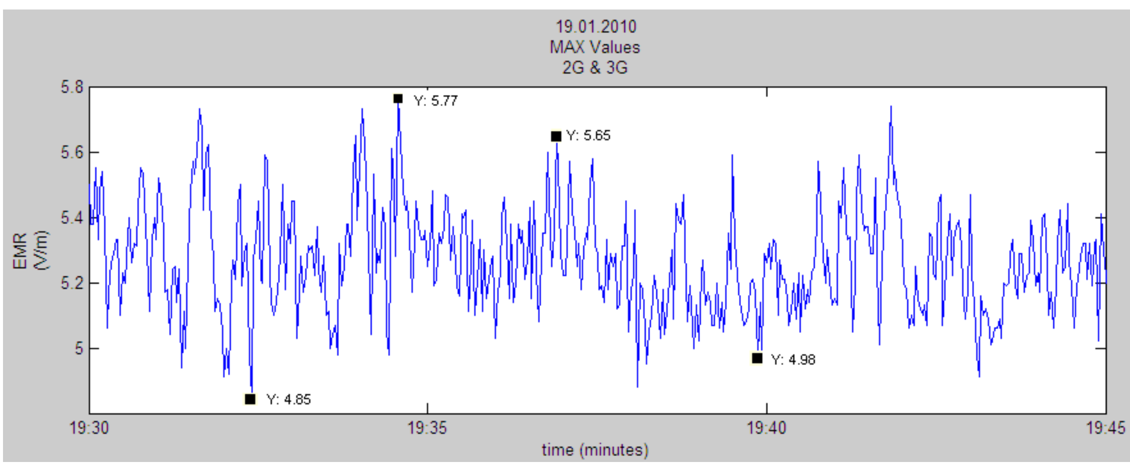

Figure 4.32 MAX electric field for 20-minute time period at 19:30 – 19:50 / 19.01.2010 – Tuesday

It is aimed to be observed max twenty minute period of 2-hours max electric field measurement to be able to see little variations between time sequences. Even, in this short time period there are instant increases and decreases by minutes where data vary between about from 3.9V/m to 5.02V/m at Saturday and from 4.85V/m to 5.77V/m at Tuesday.

II. Third sector of the base station that operates only for 2G:

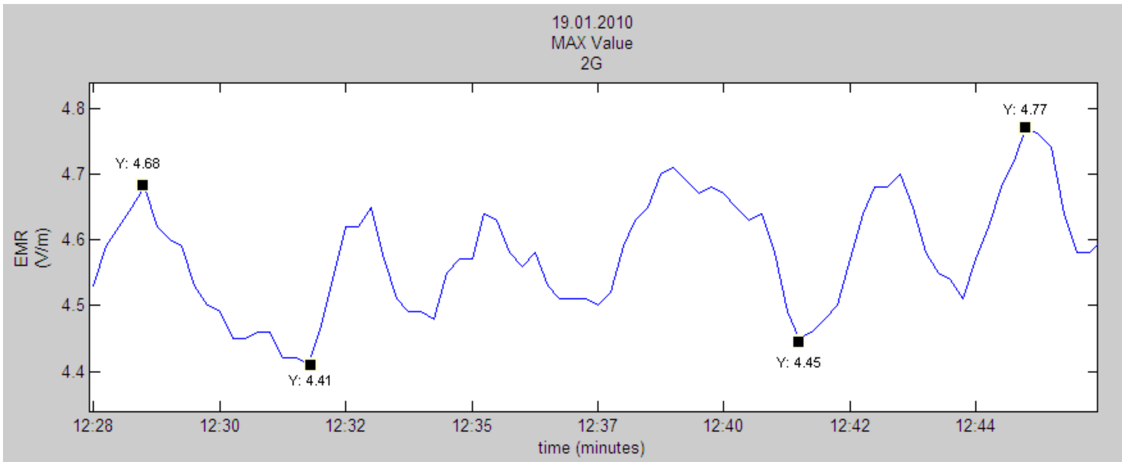

Figure 4.33 MAX average electric field for 20-minute time period at 12:28 – 12:48 / 19.01.2010 – Tuesday

Max twenty minutes of max 2-hours average measurement at Tuesday were observed to catch the variation details. Difference here is very small again for the reasons these data include mean values of medium. Data vary from about 4.4V/m to 4.7V/m averagely. It is more clearly seen on this graphs that data level is min for a minute and then max for next one minute.

4.3.1.8 MIN Valued Data Taken at Short-Time Periods

I. Second sector of the base station that operates at dual band for 2G&3G:

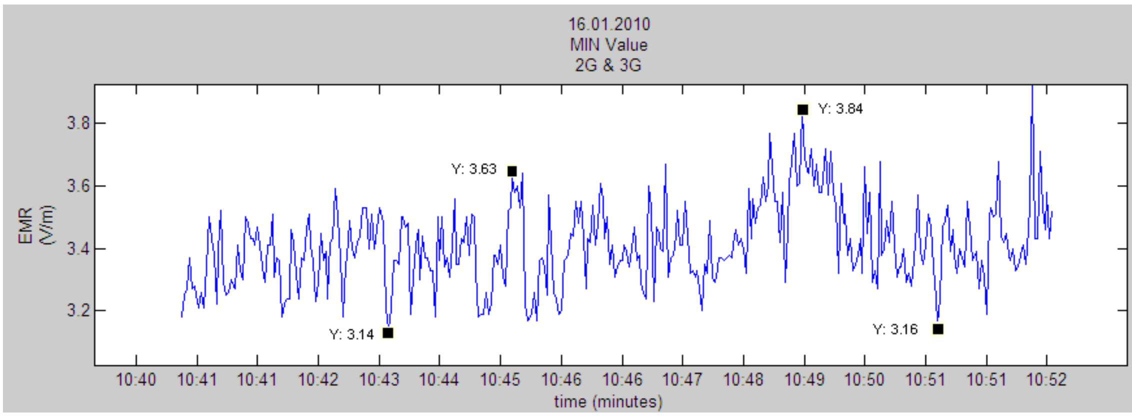

Figure 4.34 MIN electric field for 10-minute time period at 10:40 – 10:50 / 16.01.2010 – Saturday

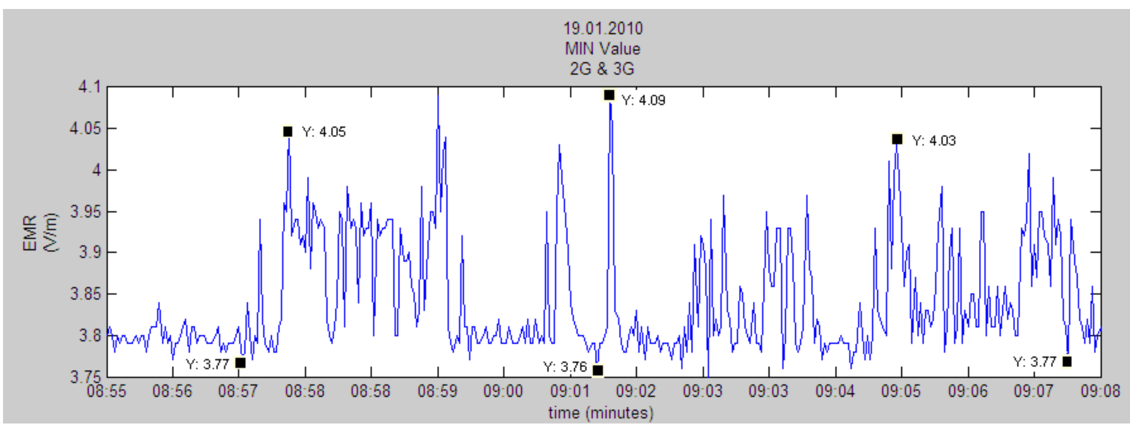

Figure 4.35 MIN electric field for 10-minute time period at 8:55 – 9:05 / 19.01.2010 – Tuesday

It is aimed to be observed min ten minute period of 2-hours min electric field measurement to be able to see little variations between time sequences. Also, in this short time periods, like they were at max periods, there are very quick instant increases and decreases by minutes where data vary between about from 3.15V/m to 3.8V/m at Saturday and from 3.76V/m to 4.05V/m at Tuesday.

II. Third sector of the base station that operates only for 2G:

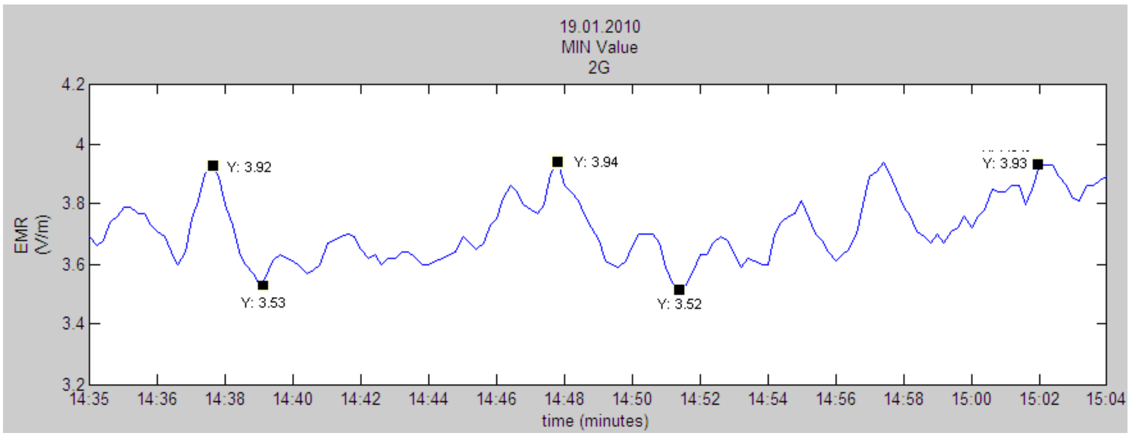

Figure 4.36 MIN average electric field for 30-minute time period at 14:35 – 15:05 / 19.01.2010 – Tuesday

Min thirty minutes of max 2-hours average measurement at Tuesday was observed to catch the variation details. Difference also here is very small again for the reasons these data include mean values of medium. Data vary from about 3.5V/m to 3.9V/m averagely. It may be observed that data level variation is close to a straight line.

4.3.2 In-Building (Indoor) Base Station Installation Measurements

It is a fact that the bulk of the traffic originates inside the buildings. Therefore, special attention to the in-building coverage is needed in order to fulfill the user's expectations. Below, what it is analyzed is an in-building design installation and its eighteen minute measurement results per antenna by Narda EMR-300 measurement tool.

As it was mentioned before, indoor antennas are placed near to living areas for small coverage solutions with low gains (2dBi-7dBi). It is observed that except several measurement points, electric field caused by indoor antennas get low values. The higher results are also still under limitations.

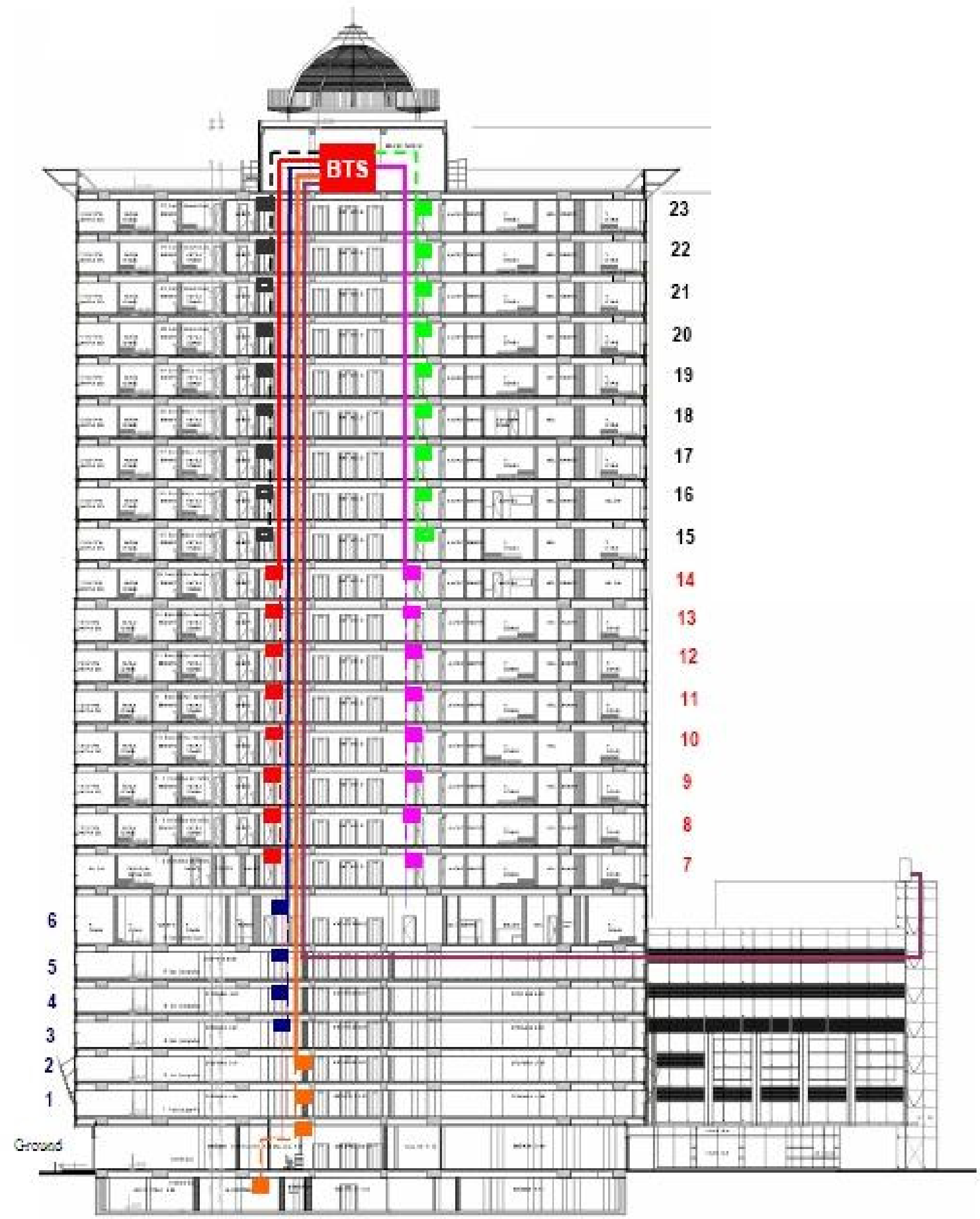

Figure 4.37 In-Building system design of a 23 floored plaza

Table 4.1 Measurement results of in-building antenna design of the plaza

Installation Position	Antenna Type	Direction	Gain (dBi)	Distance (m)	Duration (minutes)	Electric Field (V/m)
B_1	Cellmax-O-25	Omni	2	5	18	0.66
B_2	Cellmax-O-25	Omni	2	5	18	0.95
OTP_Z_1	Cellmax-O-25	Omni	2	5	18	1.51
OTP_Z_2	Cellmax-O-25	Omni	2	5	18	2.01
Z_1	Cellmax-O-25	Omni	2	5	18	1.49
Z_2	Cellmax-O-25	Omni	2	5	18	1.45
K_1	Cellmax-O-25	Omni	2	5	18	5.75
K_1_OTP_1_1	Cellmax-D-25	Panel	7	5	18	2.07
K_1_OTP_1_2	Cellmax-O-25	Omni	2	5	18	3.24
K_2	Cellmax-O-25	Omni	2	5	18	0.68
K_2_OTP_2_1	Cellmax-D-25	Panel	7	5	18	0.75
K_2_OTP_2_2	Cellmax-O-25	Omni	2	5	18	0.85
K_3	Cellmax-O-25	Omni	2	5	18	0.91
K_3_OTP_3_1	Cellmax-D-25	Panel	7	5	18	2.30
K_3_OTP_3_2	Cellmax-O-25	Omni	2	5	18	1.30
K_4	Cellmax-O-25	Omni	2	5	18	1.51
K_4_OTP_4_1	Cellmax-D-25	Panel	7	5	18	1.37
K_4_OTP_4_2	Cellmax-O-25	Omni	2	5	18	1.31
K_5	Cellmax-O-25	Omni	2	5	18	2.60
K_5_OTP_5_1	Cellmax-D-25	Panel	7	5	18	8.58
K_5_OTP_5_2	Cellmax-O-25	Omni	2	5	18	0.71
K_6_1	Cellmax-O-25	Omni	2	5	18	2.92
K_6_2	Cellmax-O-25	Omni	2	5	18	3.35
K_6_3	Cellmax-O-25	Omni	2	5	18	3.52
K_7_1	Cellmax-D-25	Panel	7	5	18	4.16
K_7_2	Cellmax-D-25	Panel	7	5	18	2.34
K_8_1	Cellmax-D-25	Panel	7	5	18	1.22
K_8_2	Cellmax-D-25	Panel	7	5	18	0.86
K_9_1	Cellmax-D-25	Panel	7	5	18	0.74
K_9_2	Cellmax-D-25	Panel	7	5	18	0.62
K_10_1	Cellmax-D-25	Panel	7	5	18	0.82
K_10_2	Cellmax-D-25	Panel	7	5	18	1.40
K_11_1	Cellmax-D-25	Panel	7	5	18	1.25
K_11_2	Cellmax-D-25	Panel	7	5	18	0.84
K_12_1	Cellmax-D-25	Panel	7	5	18	0.75
K_12_2	Cellmax-D-25	Panel	7	5	18	0.84

K_13_1	Cellmax-D-25	Panel	7	5	18	0.85
K_13_2	Cellmax-D-25	Panel	7	5	18	1.19
K_14_1	Cellmax-D-25	Panel	7	5	18	5.43
K_14_2	Cellmax-D-25	Panel	7	5	18	9.34
K_15_1	Cellmax-D-25	Panel	7	5	18	1.90
K_15_2	Cellmax-D-25	Panel	7	5	18	5.66
K_16_1	Cellmax-D-25	Panel	7	5	18	1.02
K_16_2	Cellmax-D-25	Panel	7	5	18	2.63
K_17_1	Cellmax-D-25	Panel	7	5	18	1.34
K_17_2	Cellmax-D-25	Panel	7	5	18	1.66
K_18_1	Cellmax-D-25	Panel	7	5	18	2.44
K_18_2	Cellmax-D-25	Panel	7	5	18	2.66
K_19_1	Cellmax-D-25	Panel	7	5	18	2.09
K_19_2	Cellmax-D-25	Panel	7	5	18	3.80
K_20_1	Cellmax-D-25	Panel	7	5	18	2.25
K_20_2	Cellmax-D-25	Panel	7	5	18	6.56
K_21_1	Cellmax-D-25	Panel	7	5	18	1.15
K_21_2	Cellmax-D-25	Panel	7	5	18	1.18
K_22_1	Cellmax-D-25	Panel	7	5	18	4.21
K_22_2	Cellmax-D-25	Panel	7	5	18	3.62
K_23_1	Cellmax-D-25	Panel	7	5	18	3.12
K_23_2	Cellmax-D-25	Panel	7	5	18	4.95

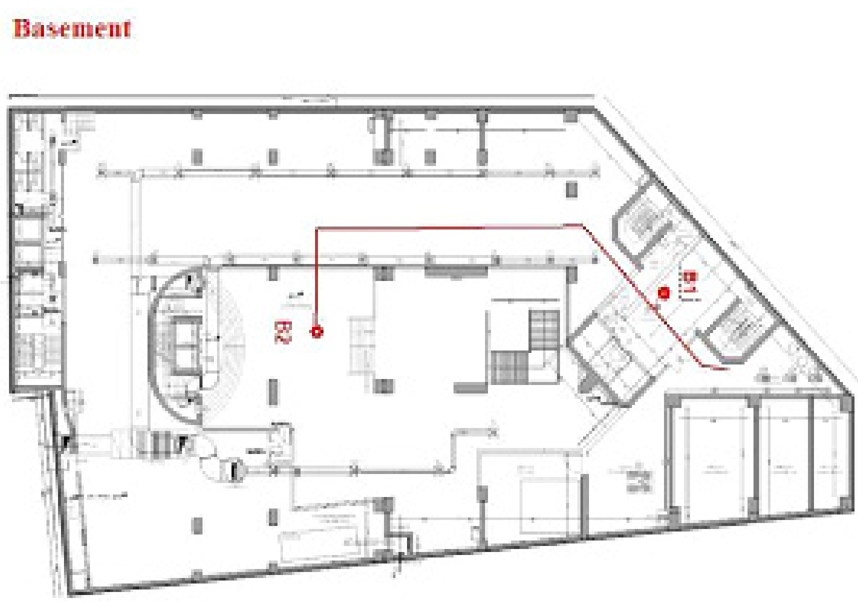

Figure 4.38.a Antenna installation positions: Basement (B1 and B2)

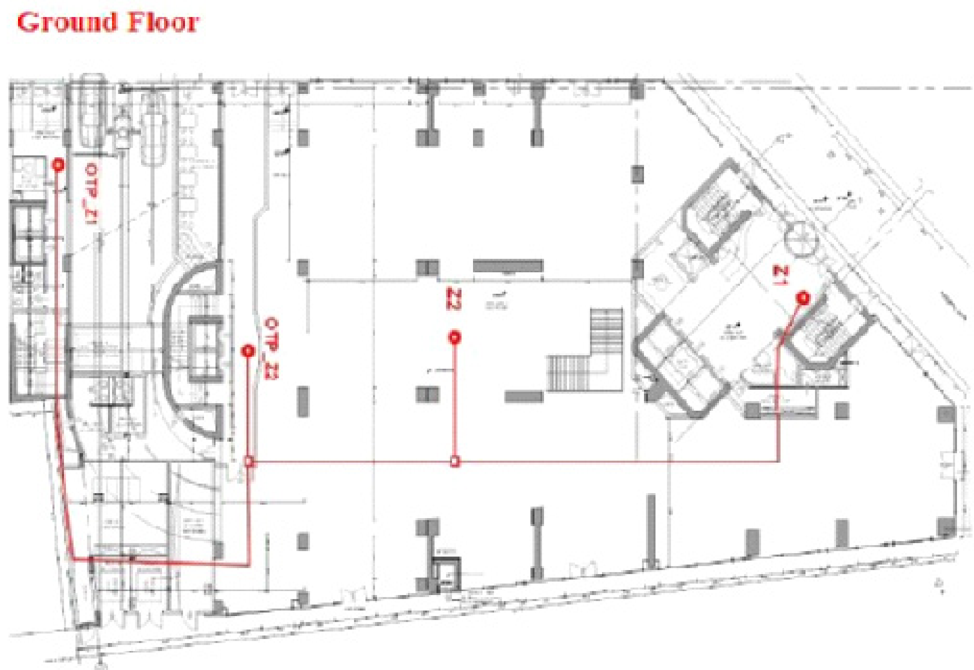

Figure 4.38.b Antenna installation positions: Ground floor (Z1, Z2, OTP_Z1 and OTP_Z2)

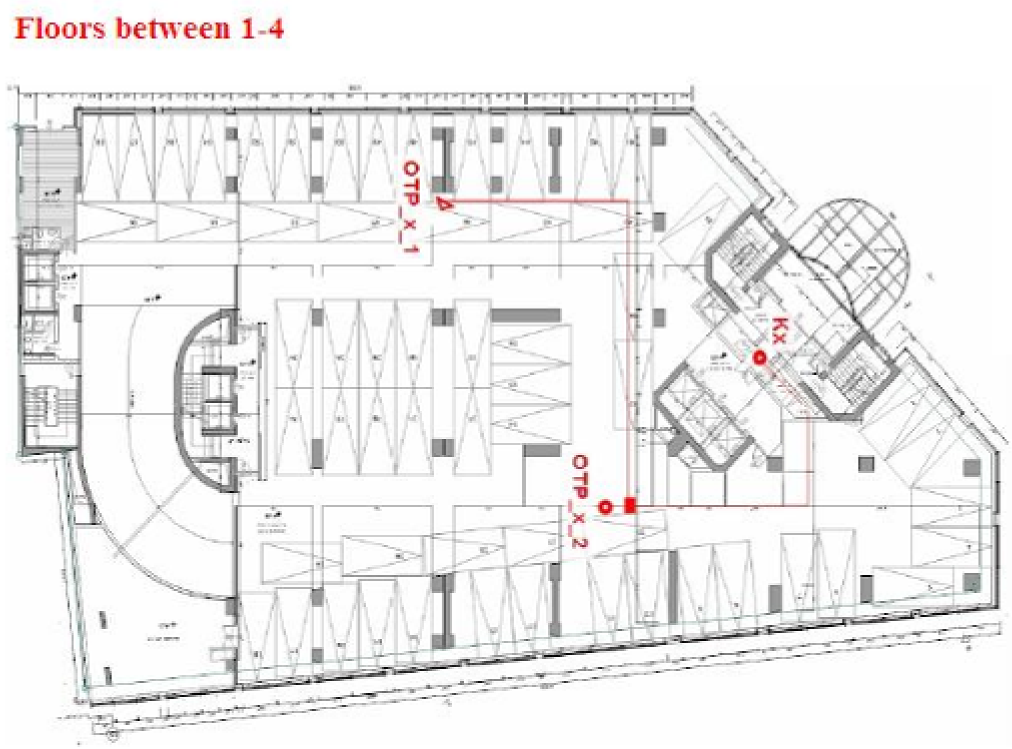

Figure 4.38.c Antenna installation positions: Floors between 1-4 (Kx, OTP_x_1, and OTP_x_2; x=1 to 4)

Floor 5

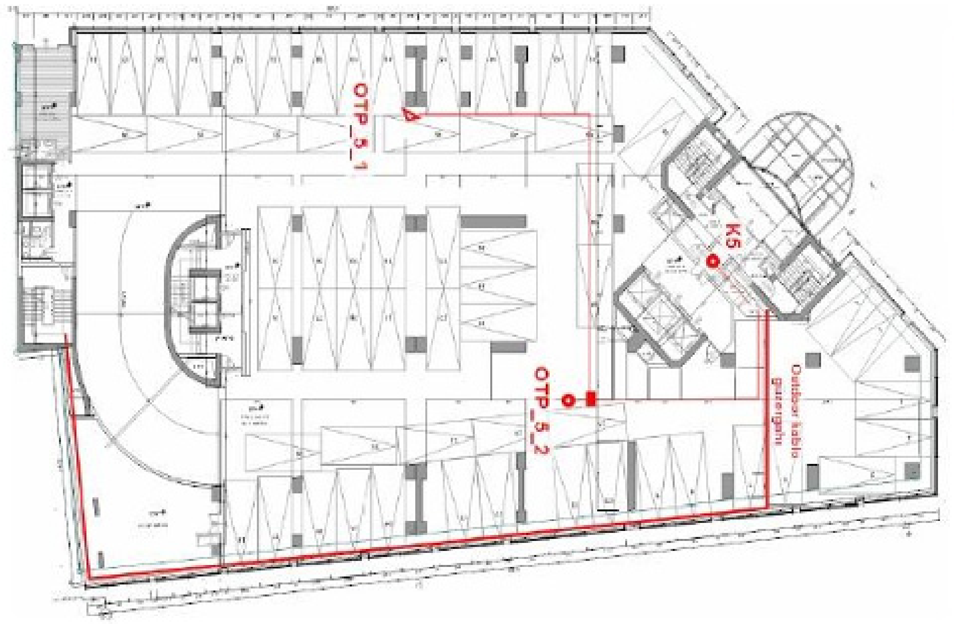

Figure 4.38.d Antenna installation positions: Floor 5 (K5, OTP_5_1, and OTP_5_2)

Floor 6 - Restaurant

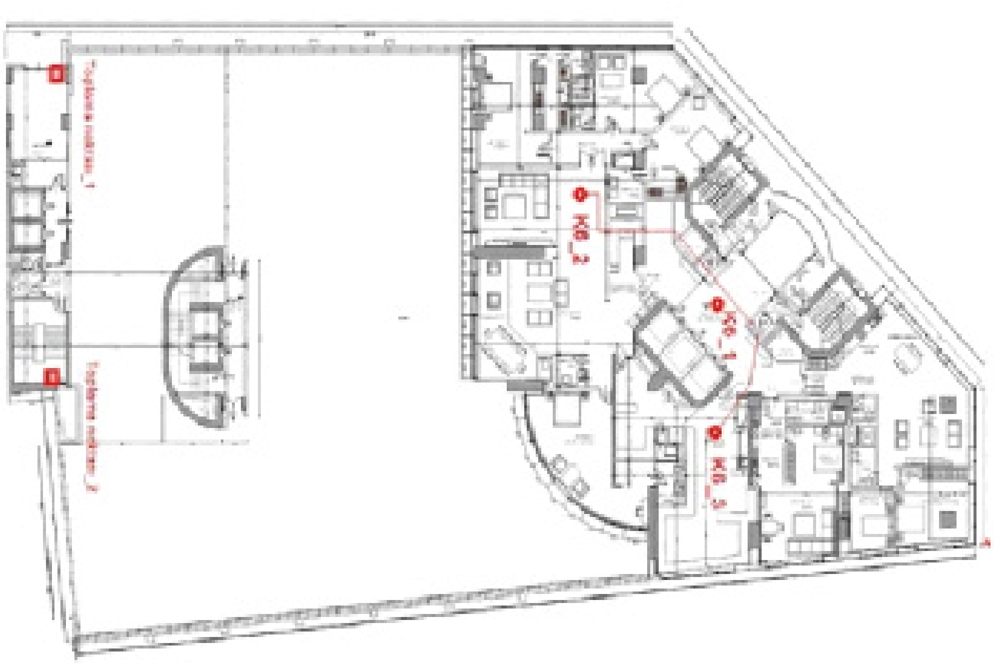

Figure 4.38.e Antenna installation positions: Floor 6 (K6_1, K6_2 and K6_3)

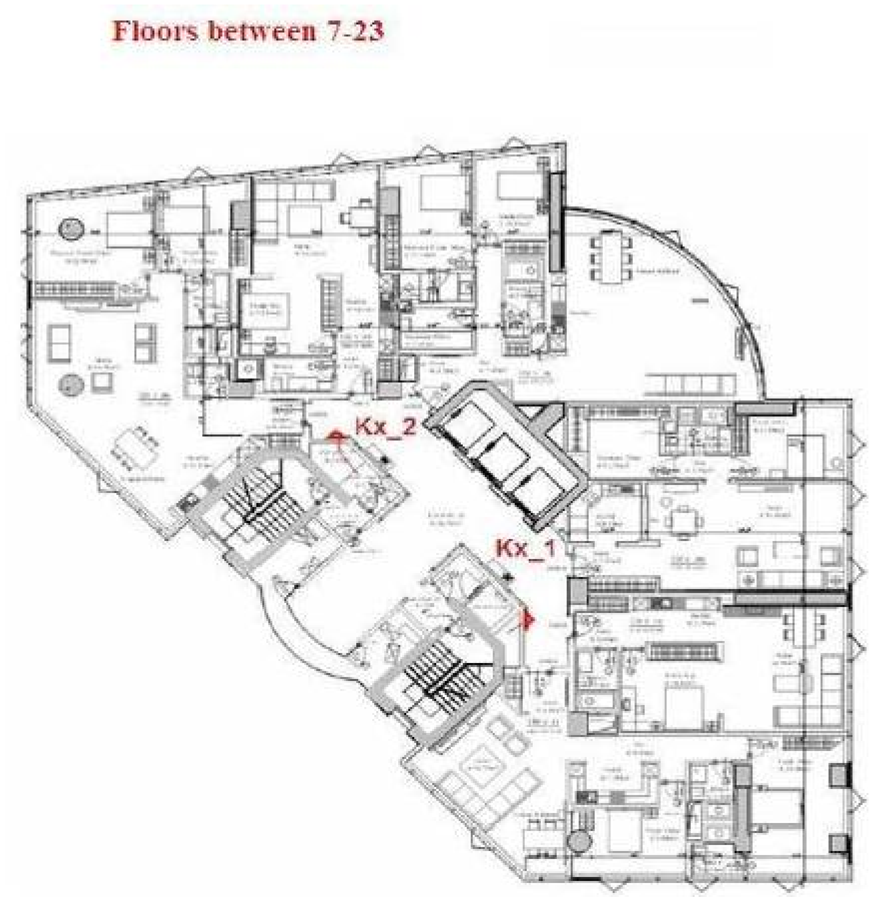

Figure 4.38.f Antenna installation positions: Floors between 7-23 (Kx_1, Kx_2; x=7 to 23)

4.3.3 Greenfield (Tower) Base Station Installation Measurements

Tower (Greenfield) solutions are generally used for the villages behind the mountains. But also, in cities, when a big gap is needed to be covered if there is no big building around (also, sometimes, big complexes do not give permission to base station installations around because of public concerns) to utilize a rooftop solution then operators prefer to use towers. Tower heights are generally between 24m and 50m. Electric field caused by a tower installation is given below to observe the effects from different distances (Foreign measurements are given by the permission of associated organizations).

Even high gained antennas with high powers are used through the towers; average safety distance is about nine meters to thirteen meters which means a fifty meter tower cannot be harmful for public concerns. As it is observed by the measurement results electric field values taken from surface ground are extremely low. Small variations are caused by not only antenna direction but also external sources.

Figure 4.39 Satellite view of the area where tower installation is occurred

The equipment used for the measurement in the study is PMM 8053 with Electric Field Probe EP-330. Calibration date is 11.01.2002 for PMM 8053 and 08.02.2002 for EP-330. Measurement tool consists of the following specifications:

Figure 4.40 PMM 8053 & EP-330

- Field probes (Type Ep-330) to measure the electrical field strength.
- Readout unit (PMM - 8053)
- Frequency range is between 100KHz…3GHz
- Field strength display range is between 0,3…300V/m

Figure 4.41 Measurement points (satellite view)

Table 4.2 Measurement results of chosen tower from different distances

Point	Distance (m)	Electric Field (V/m)	Power Density (mW/m2)	Duration (minutes)
1	45	3.86 V/m	39.52 mW/m^2	6
2	30	3.18 V/m	26.82 mW/m^2	6
3	10	2.13 V/m	12.03 mW/m^2	6
4	30	1.83 V/m	8.88 mW/m^2	6
5	45	1.50 V/m	5.97 mW/m^2	6
6	48	1.90 V/m	9.58 mW/m^2	6
7	98	2.32 V/m	14.28 mW/m^2	6
8	95	2.43 V/m	15.66 mW/m^2	6

Figure 4.42 Measurement points (photograph)

CHAPTER FIVE
CONCLUSION

The aim of this thesis is to measure and compare variations of electromagnetic field density of a base station against time. During the study of the thesis, the comparison of field strength in different days is figured out. At same time, mobile traffic effects on measured values are evaluated in the scope. The measurements are performed by several automated broadband power meters. In this study, basically roof-top designs have been subjects to be analyzed. But, investigations of different base station installations like in-building cells, tower structures, and dense urban micro stations are also given.

Our study has not been a statistic investigation because only few samples have been analyzed and given. This study has been performed to show attention to results given above. In the future, more independent measurements like in other countries with operators support should be realized on many base stations. This kind of studies with more base stations and more measurements will be helpful for public concern and human health.

The main effort in this study is roof-top station studies. Measurements on that area have been performed in front of four transmitter loaded antenna system with five watt input power and fifteen dBi antenna gain at the distance of 8 meter which is safety distance for related station

In those measurements, it is observed that:

1. Electric field has been measured from min 3.2 V/m to max 4.8 V/m at 16.01.2010 (Saturday) and from min 3.7V/m to max 5.7V/m at 19.01.2010 (Tuesday) as peak values in 6 minutes averaging.
2. In the week days, depending on the positions of the stations, the measured signal level can be higher than weekend. So, each station should be evaluated in its environmental conditions.

3. The instantaneous signal varies about 0.6V/m as Electric Field Strength or approximately 1.1 dB as power from time-averaged value.
4. While electric field has been varied about 1.6V/m – 2V/m by the day at Saturday and Tuesday, traffic of base station has turned from 7 erlang to 14 erlang or 5 erlang to 15 erlang.
5. Also highest traffic and highest electric field values have been measured between six p.m. and eight p.m. which it's called busy hour. (about 4.8V/m-5.2 V/m at Saturday and 5.65 V/m-5.77V/m at Tuesday)
6. In a normal traffic day, measured power values may be changed approximately 4dB between minimum and maximum power time points.
7. Due to these results, it may be said that there is a certain relation between usage of base station and measured electric field values but they are not directly proportional to each other.
8. Electric field has not risen to double or triple of itself as the traffic of base station has been doubled or tripled.

Measurements of tower solutions are performed from long distances because tower heights change 20meters-60meters generally. On the tower solutions, antennas with high gain and high power are used to cover big areas.

1. Although tower antennas use high powers, electric field density approaches to legal limitations after averagely 15meters away from the tower.
2. On ground (at human height) 1.5V/m-3V/m (depending on environmental conditions) field values are measured.
3. Electric field values vary for little changes after long distances like 1.83 V/m at 30^{th} meter and 1.5V/m at 45^{th} meters

In-building solutions use antenna systems with very low gain (generally 2dBi to 7dBi due to distance) and power (between 0.3W to 1W) because they are placed in close areas in public life.

1. Measurements of these systems are performed from 2m-5m distances.
2. Normally, under 4V/m electric field density is measured.
3. Rarely, due to system design, higher than 4V/m electric field density may be measured.

In city centers, not only roof-top solutions are installed by operators. Nowadays, in some areas, electricity poles are preferred to install base station systems.

1. Electric field density from poles which are placed away from buildings is observed like roof-top or low heighted tower solutions.
2. When electric pole installations are placed very close to the buildings, electric fields near to the limitations are estimated to be measured.

Today, base stations are main subject for public to concern but also mobile phones should be considered for human health with studies realized like Interphones Study by WHO at 2005. In our study, only base stations are analyzed and measured. No mobile phone related research is occurred and given. But, with the increase of GSM cell phone usage rates, the traffic and usage time averages are getting higher. The increase of usage brings more electromagnetic field intensity near the ear and head, so, more health effects may be occurred because of cell phones.

To overcome those problems coming from cell phones, it is suggested that; the limit values applied may be decreased to a level in which less power rates and more base stations are seen.

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