ISTANBUL TECHNICAL UNIVERSITY ★ INFORMATICS INSTITUTE

ELECTROMAGNETIC SIGNAL STRENGTH INTENSITY MAPS OF GSM BASE STATIONS IN THE ISTANBUL TECHNICAL UNIVERSITY MAIN CAMPUS AREA

M.Sc. THESIS

Kubra BOZ

Informatics Institute

Geographic Information Technology Programme

Thesis Advisor: Prof. Dr. H. Hakan Denli

DECEMBER 2016

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ BİLİŞİM ENSTİTÜSÜ

İSTANBUL TEKNİK ÜNİVERSİTESİ ANA KAMPÜS ALANINDA GSM BAZ İSTASYONLARININ ELEKTROMANYETİK SİNYAL GÜÇ YOĞUNLUK HARİTALARI

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To my husband Utku Boz and my family,

FOREWORD

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December 2016 Kübra BOZ

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ABBREVIATIONS

ANSI	: American National Standards Institute
API	: Application Programming Interface
ARIB	: Alliance of Radio Industries and Business
DCS	: Digital Cellular System
db	: Decibel
EMF	: Electro-Magnetic Field
ETSI	: European Telecommunication Standard Institute
GIS	: Geographic Information Systems
GPRS	: General Packet Radio Service
GSM	: Global System for Mobile Communications
ICNIRP	: The International Commission on Non-Ionizing Radiation Protection
IEEE	: The Institute of Electrical and Electronics Engineers
IMT-2000	: International Mobile Telephone 2000
ITU	: Istanbul Technical University
KOSGEB	: Small And Medium Industry Development Organization
LA	: Location Area
LTE	: Long-Term Evolution
NMT	: Nordic Mobile Telephone
MHz	: Megahertz
MCS	: Mobile Switching Center
MSE	: Mean Square Error
PLMN	: Public Land Mobile Network
QR	: Quick Response
RF	: Radio frequency
RFID	: Radio-Frequency Identification
SAR	: Specific Absorption Rate
Wi-Fi	: Wireless Fidelity
2G, 3G, 4G, 4.5G	: 2nd Generation, 3rd Generation, 4th Generation, 4.5th Generation
3GPP	: Third Generation Partnership Project

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ELECTROMAGNETIC SIGNAL STRENGTH INTENSITIES MAP OF GSM BASE STATIONS IN THE ISTANBUL TECHNICAL UNIVERSITY

SUMMARY

Electromagnetic signals are described as waves with particular frequencies. The electromagnetic signals may be generated by natural causes as well as by man-made wireless communication systems. The level of the electromagnetic signal exposure increases as the technological developments require the higher usage of electronic devices as well as Wireless Fidelity (WiFi) and Global System for Mobile (GSM) services. Especially in recent years, the transition to 2^{nd} Genetration (2G), 3^{rd} Generation (3G) mobile technologies and the investments on the new generation 4^{th} Generation (4G) and 4.5^{th} Generation (4.5G) technologies cause rapid developments in Turkey in terms of GSM services.

The rapid development in the field of the GSM services and the consequent electromagnetic field (EMF) exposure to the human body generated the debate on the potential dangers of the services on the human health. A lot of research studies focused on the subject however there are no certain evidences about the consequences of the EMF exposure. On the other hand, there are still views suggesting such exposure might affect the human body in different ways. To reduce such effects to minimum, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) declared boundary values for the base stations, which are the main source of the electromagnetic fields, and those values are accepted by many European countries as well as some other countries all over the World in 1998.

In this study, within the boundaries of the Istanbul Technical University (ITU), using pre-specified 29 stations, the power densities of the electromagnetic signals having frequencies of 900 and 1800 MHz are measured in V/m unit by using the Spectra HF-6065 device. The results are geographically analyzed and the measurements taken for each frequency are shown on a heat map. Geographic Information Systems (GIS) and spatial interpolation techniques are used for performing electromagnetic field intensity maps. 3 different spatial interpolation methods are used for creating maps and results are compared with each other. Considering the minimum mean square error, Radial Basis and Empirical Bayesian Krigging methods are selected.

In addition to electromagnetic field intensity data, social media location data are used as a supportive data for analysing mobile and 3G technologies. Within the study area, location data from Twitter are collected during one month with using Twitter Application Programming Interface (API). After collecting the location data, a heatmap has been created for visualizing mobile density.

In the final step of the study, EMF intensity results are compared with mobile density map, which is created by using social media location data and the relation between the two data sets are composed. Based on the results, a methodology has been suggested for identifying spatial relation between mobile density and EMF intensity values. At the same time, it is introduced that the social media location data can be used for prediction of EMF intensity values.

Furthermore, the EMF intensity values are compared with the ICNIRP standards. Results showed that the exposure levels of the electromagnetic field intensities are within the limits of the ICNIRP. However, since the EMF intensity level for the human health is not known, it is not possible to confirm if the measured levels are safe for human health. The aim of this study is to create electromagnetic field intensity maps of ITU and find potential risky areas against threats in the future.

İSTANBUL TEKNİK ÜNİVERSİTESİ ANA KAMPÜS ALANINDA GSM BAZ İSTASYONLARININ ELEKTROMANYETİK SİNYAL GÜÇ YOĞUNLUK HARİTALARI

ÖZET

Kablosuz ağ ve mobil iletişim teknolojilerinin kullanımı gün geçtikçe artmaktadır. Bu teknolojilerin elektromanyetik alan yoğunluklarında artışa neden olup olmadığını belirlemek önemli bir araştırma konusudur. Elektromanyetik alanların insan sağlığı açısından zararlı olup olmadığı konusu henüz netleştirilememiştir. Bu nedenle, kablosuz ağ ve iletişim teknolojileri kaynaklı elektromanyetik alan yoğunluğu değerlerini ölçme ve ölçüm sonuçlarını analiz etme konusuna odaklanan bir çok bilimsel araştırma çalışması bulunmaktadır. 1989 yıllından başlayarak, araştırmacılar elektromanyetik alan yoğunluklarını ölçüp incelemiş ve sınır değerlerin tanımlanması açısından elektromanyetik alan yoğunluklarının etkilerini değerlendirmeye odaklanmışlardır.

Elektromanyetik sinyaller belirli bir frekans aralığındaki dalga salınımı olarak tanımlanır. Elektromanyetik sinyallerin bulunduğu alanlar, doğal olarak oluşabildiği gibi kablosuz ağ ve diğer iletişim teknolojileri gibi insan yapımı teknolojilerin kullanımı sonucunda da oluşmaktadır. Elektromanyetik alanların varlığı artan kablosuz ağ teknolojileri ve mobil iletişim teknolojilerinin kullanımı ile artmaktadır. Özellikle son yıllarda ülkemizde mobil iletişim alanında 2G, 3G, teknolojilerinden sonra yeni nesil olarak nitelendirilen 4G ve 4.5G teknolojilerine geçiş için altyapı yatırımlarının yapılması gibi hızlı gelişmeler yaşanmaktadır.

Mobil iletişim (GSM) alanında yaşanan hızlı gelişim ile birlikte artan elektromanyetik alanlar beraberinde insan sağlına etkileri konusunu da gündeme getirmiştir. Elektromanyetik alanlar ve insan sağlığına etkileri konusunda birçok bilimsel çalışma yapılmıştır. Etkileri konusunda kanıtlanmış, kesin sonuçlar olmasa da farklı etkileri olabileceği yönünde tezler geçerliliğini korumaktadır. Etkinin en aza indirilmesi konusunda Uluslararası alanda ICNIRP (International Commission on Non-Ionizing Radiation Protection – Uluslararası İyonlaştırıcı Olmayan Radyasyondan Korunma Komitesi) tarafından elektromanyetik alanlar ve bu alanları oluşturan etkenlerden biri olan baz istasyonları için sınır değerler belirlenmiş ve birçok Avrupa ülkesinde ve dünyanın farklı ülkelerinde yaygın kabul olarak kabul görmüştür. ICNIRP kılavuzundaki sınır değerleri, deney nesneleri üzerindeki kısa ve orta vadeli yanma, şok ve ısı etkileri ile ilgili araştırmaların sonuçları ile tanımlanmıştırç

Elektromanyetik alanlar ve insan sağlığı üzerindeki etkileri hakkında kesin sonuç bulunmamasına rağmen, duyarlı alanların elektromanyetik alan yoğunluk değerlerini analiz etmek önemlidir. Üniversite kampüsleri, yüksek öğrenci ve akademik personel nüfusu olması nedeni ile duyarlı bölgelerdir. Bu çalışmada, İstanbul Teknik Üniversitesi Ayazağa Kampüsü çalışma alanı olarak seçilmiş ve 900 MHz ve 1800

MHz frekanslarındaki elektromanyetik alan yoğunlukları ölçülmüştür. Çalışma kapsamında İstanbul Teknik Üniversitesi sınırları içerisinde belirlenen 29 nokta üzerinde 900, 1800 MHz frekanslarında elektromanyetik sinyal güç yoğunluk ölçümleri V/m cinsinden Spectra HF-6065 ölçüm aracı kullanılarak yapılmıştır. Ölçümün ilk aşamasında, baz istasyon konumları, baz istasyonları tarafından tedarik edilen elektromanyetik alan yoğunluklarının ölçülmesi için belirlenmiştir. Ardından, 50 m ve 300 m yarıçaplı dairesel bölgeler olacak şekilde baz istasyonlarının etki alanları, ArcGIS yazılımı kullanılarak oluşturulmuştur. 50 m yarıçaplı alan birincil etki alanı, 300 m yarıçaplı alan ikincil etki alanıdır. Bu etki alanları mobil baz istasyonu anteninin yakınında yaşamanın insan sağlığı üzerine etkilerini konu alan bir çalışma temel alınarak belirlenmiştir. Bir sonraki adım olarak, 300 m etki alanları içerisinde 29 farklı ölçüm noktası belirlenmiştir. Son adımda, elektromanyetik alan yoğunlukları, belirlenen her bir ölçüm noktasında, 15 dakika boyunca, bir hafta süresince farklı zamanlarda ölçüm çalışması yapılmıştır. Bir haftalık periyotta farklı zamanları içeren ölçüm çalışmasının tamamlanmasından sonra, analiz çalışmasında ölçümlenen maksimum değerler kullanılmıştır.

Ölçme sonucunda çıkan değerler mekansal olarak analiz edilmiş, her bir frekans aralığı için ısı haritası üretilmiştir. Isı haritalarının üretilmesi için Coğrafi Bilgi Sistemlerinden yararlanarak mekansal enterpolasyon yöntemleri kullanılmıştır. Çalışmada, 3 farklı enterpolasyon yöntem sonuçları karşılaştırılarak, minimum hatayı veren yöntemler seçilmiştir. Enterpolasyonun amacı gerçek değerlere en yakın tahmini elektromanyetik alan yoğunluk değerlerini bulmaktır.

Çalışmada, standart sapma ve ortalama minimum karesel hata değerleri, en uygun enterpolasyon yöntemini seçmek için kullanılmıştır. Sonuçlar 1800 MHz frekanslarında, “Radial Basis” enterpolasyon yönteminin minimum standart sapma ve ortalama karesel hata değerlerine sahip olduğunu göstermiştir. Öte yandan, 900 MHz frekanslarında, “Ampirik Bayesian Krigleme” enterpolasyon yöntemi minimum standart sapma ve ortalama karesel hata değerlerine sahip çıkmıştır. Üretilen sonuç ısı haritaları incelendiğinde çalışma alanın, 900 MHz haritasına göre, batı ve kuzeybatı bölgelerindeki elektromanyetik alan yoğunluğu değerleri diğer alanlardan daha yüksek ve 1800 MHz haritasına göre doğu ve kuzeydoğu bölgelerindeki elektromanyetik alan yoğunluğu değerleri diğer alanlardan daha yüksek olduğu tespit edilmiştir.

Çalışma alanındaki elektromanyetik alan yoğunluklarının ölçümlenen ve ısı haritaları değerleri, ICNIRP tarafından belirlenen ve Türkiye tarafından da kabul edilen sınır değerlerin altında çıkmıştır. Çalışma alanındaki en yüksek değer 5.5 V/m olarak ölçülmüştür. Elektromanyetik alan yoğunlukları için kabul edilen limit değerler ülkeden ülkeye farklılık göstermektedir. Bu noktada, İtalya'nın kabul ettiği sınır değer 6 V/m ve İsveç için 5 V/m'dir. Sonuç haritaları göz önüne aldığımızda, çalışma alanının kuzey-batı bölümü elektromanyetik alan yoğunluğu değerlerinin İsveç sınırlarının üstünde olduğu ve İtalya sınırlarının çok yakınında olduğu sonuçları gözlenmiştir.

Elektromanyetik alan yoğunluk verilerine ek olarak, cep telefonu ve 3G teknolojileri kullanımına yönelik analiz yapabilmek için destekleyici veri niteliğinde sosyal medya konum verilerinden yararlanılmıştır. Çalışma alanı içerisinde bir hafta süre ile atılan Twitter mesajlarının konum bilgileri Twitter API (Application Programming Interface) ile toplanarak mobil yoğunluk haritası oluşturulmuştur. Twitter coğrafi konum verileri, istatistiklere göre mobil kullanıcıların yaklaşık % 80'ini temsil ettiği varsayılarak çalışma alanındaki mobilite kullanıcı yoğunluğunu tanımlamak için kullanılmıştır. Twitter konum verileri, QGIS programının eklentisi olan 'Tweepy' aracı kullanılarak toplanmıştır. Twitter üzerinden veriler, elektromanyetik alan ölçümü yapılan aynı bir hafta boyunca toplanmıştır. Nihai sonuçlar, koordinat olarak toplanan günlük ortalama tweet sayılarını içermektedir. Çalışma içerisinde oluşturulan mobilite yoğunluk haritası sonuçlarına göre, mobilitenin merkezi kütüphane, merkez derslikler, stadyum ve yakın çevresinde yoğunlaştığı tespit edilmiştir. Diğer bir yoğunlaşma 2. ve 3. teknopark alanında gözlemlenmişdir.

Sosyal medya verileri dışında elektromanyetik alan yoğunluk değerlerini sınırlamak için tüm telekom operatörlerinin verilerini içeren kapsama haritları kullanılmıştır. Kapsama haritaları, kullanıcıların normal çalışma koşulları altında telekom operatörlerinden iyi bir hizmet almayı beklediği bir haritalardır. Mobil şebeke kapsama haritaları, iyi sinyalin elde edilebileceği alanları veya sinyalin değişken olabileceğini gösterir. Mobil şebeke kapsama alanlarındaki alıcıların varlığına dayanarak, çalışma içerisinde, bu alanlar içerinde kalacak şekilde elektromanyetik yoğunluk değerleri sınırlandırılmıştır. Çalışmada, mobil şebeke kapsama alanlarının sınırları içerisinde elektromanyetik yoğunluk değerlerinin analizi için, kalabalık kaynaklı hücresel kapsama haritaları olan Open Signal haritaları kullanılmıştır. Kapsama haritaları incelendiğinde, hemen hemen tüm çalışma alanı, lojman alanları ve yerleşim olmayan bölgeler hariç 2G, 3G ve 4G şebekeleri için tüm operatörler tarafından kapsandığı gözlenmiştir.

Çalışmanın son bölümünde, oluşturulan 1800 MHz, 900 MHz elektromanyetik alan yoğunlukları ve mobilite yoğunluklarını gösteren üç yoğunluk haritaları karşılaştırılmıştır. Haritaları karşılaştırmak için, her yoğunluk haritasının farklı ölçek değerleri bulunduğundan, veri sınıflandırma işlemi gerçekleştirilmiş ve ısı haritaları sınıflandırılmıştır. Sonuç olarak, elektromanyetik yoğunluk haritaları ile sosyal medya konum verileri kullanılarak oluşturulan mobilite yoğunluk haritaları karşılaştırılmış ve bu iki veri seti arasındaki ilişki incelenmiştir.

Sonuçlara dayanarak, mobil yoğunluk ve elektromanyetik alan yoğunluk değerleri arasındaki mekansal ilişkiyi tanımlamak için bir yöntem önerilmiştir. Aynı zamanda, sosyal medya konum verisinin elektromanyetik alan yoğunluk değerleri tahminlemesinde kullanılabilmesi konusu ortaya çıkarılmıştır. Elektromanyetik alan yoğunluk değerlerini ölçme süreci zaman alıcı ve zor olduğundan, sosyal medya ve kalabalık kaynaklı hücresel kapsama haritaları gibi destekleyici veriler arasındaki korelasyon kullanılarak farklı metolojiler geliştirilebileceği gündeme getirilmiştir. Bu çalışmanın sonuçlarına göre mobilite yoğunluk değerleri ile elektromanyetik alan yoğunluğu arasında mekansal bir ilişki vardır. Yüksek elektromanyetik alan yoğunluk değerlerine sahip çalışma alanının % 60'ının aynı zamanda yüksek mobilite yoğunluk değerlerine sahip olduğu tespit edilmiştir.

Büyük şehirler ve duyarlı alanlar için elektromanyetik alan yoğunluğunun ölçülmesi ve elektromanyetik alan haritalarının oluşturulması son derece önem taşımaktadır. Kentlerde, özellikle İstanbul'da, artan nüfus, artan cep telefonu ve sosyal medya kullanımına neden olmaktadır. Bu çalışmanın sonuçları, elektromanyetik alan yoğunluklarından etkilenme düzeylerinin ICNIRP limitleri içerisinde olduğunu göstermektedir. Ancak insan sağlığı açısından elektromanyetik alan yoğunluk değer limitleri kesin olarak bilinmemektedir. Bu çalışmanın amacı, İTÜ`nün EMF yoğunluk haritalarını oluşturmak ve gelecekteki tehlikelere karşı olası riskli alanlar bulmaktır.

1. INTRODUCTION

The usage of wireless network and mobile communication technologies are increasing day by day and it is an important research subject to determine if those technologies cause increase in electromagnetic field intensities. Furthermore, it is still not clear that if those technologies are harmful for human health. Therefore, there are a lot of scientific research studies focusing on the subject of measuring electromagnetic field intensity values that are sourced by wireless network and communication technologies, and analyzing the measurement results.

Electromagnetic signals are naturally waves with particular frequency and amplitudes. Those signals may emerge from natural causes or as a result of man-made technologies like GSM and Wi-Fi networks. There is a strong correlation between the usage of wireless and communication technologies and electromagnetic field areas [1]. As a result of this, in the daily life of the human, it is inevitable not to be exposed to the electromagnetic fields. While radio frequency waves that are emitted by mobile phones affect particularly the head, waves emitted by base stations have an impact on the entire body. These waves are called radiation and they vary in terms of severity [2].

Since the 1990s, the development of mobile communication technologies yielded significant increase on imposed electromagnetic field varieties and sources. Especially, recently in Turkey, new technologic infrastructures are established in mobile communication area. After 2G and 3G technologies in mobile communication area, 4.5G technology is recently introduced in Turkey [3]. As a result of the increase in electromagnetic fields due to the developments of GSM systems, the effects of such technologies on human health are currently debated extensively [4]. ICNIRP defined limit values for electromagnetic areas and base stations. Many of countries all over the world accept these limit values as standards .These limit values are basically defined to protect biological tissue from temperature increases (thermal effects) [5]. A lot of research studies were completed about the effects of electromagnetic field on human health but there are no certain results yet. Some of the reasearch studies indicate that EMF affects badly the health of the human while some of others claim that there is no effect. Koivisto et. al. [6] found out that electromagnetic fields emitted by GSM phones have a measurable effect on human cognitive performance and brain functions. The study conducted by Schüz J et. al. is about radio frequency (RF) fields and childhood leukaemia risk relation. They found that each participant provide little evidence for an association between RF fields and childhood leukaemia risk [7]. Agarwal et. al. have performed a study showing that the effects of electromagnetic waves on the human body. Results of the research prove that electromagnetic waves kill the neurons, absorb the proteins in the human body and cause stress in the human body [8]. On the other hand, there are a lot of research studies that prove no significant effects between electromagnetic exposure and human health. The study of Finnie et. al., have proven that there are no electromagnetic effects on cellular metabolism [9].

Despite that there are no certain results about electromagnetic fields and human health issue, it is important to analyze the electromagnetic field intensity values of sensitive areas. University campuses due to having high student and instructor population are sensitive areas. In this study, Istanbul Technical University Ayazaga Campus is selected as the study area, and electromagnetic field intensities on 900 MHz and 1800 MHz frequencies are measured.

In the following part of the study, electromagnetic fields, base stations, limit values of electromagnetic fields and mobile telecommunication technologies are explained. In the third part, study area details, measurement methodology, and analyses of measurement results with ArcGIS are expressed. In this study, electromagnetic field intensity maps emerge as a powerful analysis tool for defining the relationship between high population and over limit value areas. In the last part, results of the study are discussed.

2. OVERVIEW

In recent years, mobile communication systems and wireless network technology usage are increased rapidly and accompanied to increase in electromagnetic fields and electromagnetic field intensities. There are a lot of electromagnetic field intensity sources in our daily lifes such as base stations, power lines, cell phones, smart meters etc. With the development of the GSM technology, more and more applications are developed for daily usage of the community. Twitter e.g. is one of the most popular mobile applications. As of the second quarter of 2016, Twitter averaged at 313 million monthly active worldwide users [10]. Tweet locations can be collected if users enable location services from their phone and 10.3% of twitter users have geo-location enabled [11]. In this thesis, the main focus is to measure the electromagnetic field intensity values emerging from the base stations and create heatmaps for the monitoring received from the measurement stations to know see if the level of the signal is suitable for regulations. For this purpose, twitter usage density map has been created and the relation of the EMF intensity with the social media usage has been investigated. Istanbul Technical University Ayazaga Campus area has been selected for this study due to its high-density population composed of students and academic staff. Another purpose of this study is to create awareness about electromagnetic fields and human health issues. This study is a sample study for defining electromagnetic field intensities in a sensitive area, and it may be extended to another universities` campus areas.

Consequences of high EMF intensity values may have been lead to increase in health problems. To avoid this, large amount of studies have been concentrated on measuring the EMFs emerging from the base stations. Beginning from the 1989`s, researchers have measured and examined the EMF intensities, and focused on evaluating the effects of EMF in terms of defining the limit values. Among the first few pioneering studies that mentioned the biological effects of EMFs was published by Office of Technology Assesment (OTA). This research used human exposures of electromagnetic fields from power systems to humans and reviewed existing scientific evidence on the consequent biological effects [12]. The result of this study is inconclusive since there were many experiments, which caused harmful effects, yet those effects did not cause any change on the biological systems. However, there are positive experiments, which have clearly demonstrated that EMFs can produce substantial changes at the cellular level. Later, Environmental Protection Agency (EPA) [13] conducted studies about the concinogenicity of EMF and evaulated the likelihood that exposure to nonionizing electromagnetic radiation poses a risk for the development of cancer in humans. According to EPA`s studies, the frequency dependence of the radio frequency absorbed by an organism is dominated by the body size and final results of the study showed that there is a causal relationship between certain forms of cancer, namely leukemia, cancer of the nervous system, and, to a lesser extent, lymphoma. The Committee on the possible effects of electromagnetic fields on biologic systems of United States National Research Council [14] published a book addressing public concern regarding possible health risks of residential exposures to low-strength, low-frequency electric and magnetic fields. In that book, they presented the current body of evidence, which does not show that the exposure to these fields presents hazardous environment for human health. Specifically, no conclusive and consistent evidence shows that exposures to residential electric and magnetic fields produce cancer, adverse neurobehavioral effects, or reproductive and developmental effects. Kheifets et al. [15] published a paper adressing an assessment of the potential susceptibility of children to EMFs and concluded with a recommendation for additional research and the development of precautionary policies in the face of scientific uncertainty. In conclusion, study of Kheifets et al. claims that childhood exposure to EMF leads to the potentially susceptible maturation of the central nervous system.

In the mean time, the researchers who are working on EMF subject are also interested in measuring EMF intensity values for comparing limit values. Hamid et al. [16] made an experimental study on a pilot region in Turkey for measuring the electromagnetic radiations. They measured EMF intensity values as V/m units of GSM base stations by using directional antennas for 6 minutes average time interval and analyzed the results using standard deviation and Allan variance statistics. Allan variance is a method that is used for measuring frequency stability in amplifiers or ascillators and invented by David B. Allan. They found that all of the results of the measurements were below the ICNIRP limit values. Genc et al. [17] made a similar study in Ankara, Turkey. In this study, electromagnetic (EM) pollution in a transmitter region has been measured. Statistical analyses of the measurements were used to evaluate the contribution of the EMF sources causing pollution. They conducted random measurements in the transmitter region by using isotropic antennas for 6 minutes durations at each measurement location in V/m units. The results of this study indicated that the EMF pollution levels were below the limits for 900 MHz and 1800 MHz according to ICNIRP's recommendations. Durduran et al. [18] completed another similar study in Konya, Turkey by measuring the signal strenghts of base stations (900 MHz) in dBm units. In this study, the selected region is approximately 500,000 m^2 large with 4 base stations. Results of the measurments on the 53 predetermined stations representing the region shows that the measured values are within the boundaries of the national limits. In another recent study, Gulagiz et al. [19] measured EMF values at random stations in Umuttepe campus of Kocaeli University, which they choosed as pilot area. The measurements were done for all GSM 900, GSM 1800 frequencies and signal maps belonging to each measurement were obtained. At the end of the study, they concluded that, for GSM 900 and GSM 1800 frequencies, the level of the EMF intensity is below the level of the limits imposed by ICNIRP in the campus. Hasenfratz et al. [20] suggested a new approach about measuring the EMF intensity values. Since the epidemiological large-scale studies are rare and governmental compliance measurements can only cover a small number of locations of high interest, the spatially resolved EMF measurements are feasible with commodity sensor nodes. They showed the design, implementation and evaluation on mobile air quality sensor nodes, which traverse a large urban area on top of public transport vehicles in Zurich, Switzerland. At the end of the study, they collected a data set with over 4 million measurements and used it to develop the first exposure map of Zurich with a spatial resolution of 100 m. The results of this study showed that radiation emitted by mobile cellular base stations in Zurich had same exposure level with the radiation levels measured in other European cities 5 years prior to this study. Furhtermore, the measured values are below the ICNIRP limits.

In the following section, an overview of EMFs is presented and electromagnetic area sources are discussed.

3. ELECTROMAGNETIC FIELDS

Electromagnetic fields are all around us, like the flora cane lights of streets, which are a kind of electromagnetic field source. Electromagnetism is used in so many areas like remote sensing, telecommunication, defense industries etc. The electromagnetic fields are increasing in parallel with the development of technology [21]. In this chapter, definition of electromagnetic waves, spectrum and electromagnetic area sources are explained.

3.1 Electromagnetic Waves

Electricity can be static, and magnetism can also be static. A changing magnetic field will induce a changing electric field and the two is linked to each other. These changing fields compose electromagnetic waves. In the 1860's and 1870's, James Clerk Maxwell developed a scientific theory to explain electromagnetic waves. He noticed that electrical fields and magnetic fields can couple to form electromagnetic waves. He summarized this relationship between electricity and magnetism. It is referred to as "Maxwell's Equations". Heinrich Hertz applied Maxwell's theories to the production and reception of radio waves. The unit of frequency of a radio wave, which is one cycle per second, is named after him as Hertz [22].

For the detailed definition of electromagnetic wave, the electric, magnetic and wave terms must be analyzed separately. A wave is generated by the transmission of movement of flip and vibration. Waves have features like length, period, frequency, velocity and amplitude. Wavelength is the distance between the sequenced peeks. Wave height is the distance from start position to peek position of the wave. This distance changes in terms of the amount of energy. Wave height unit is decibel (db) [22].

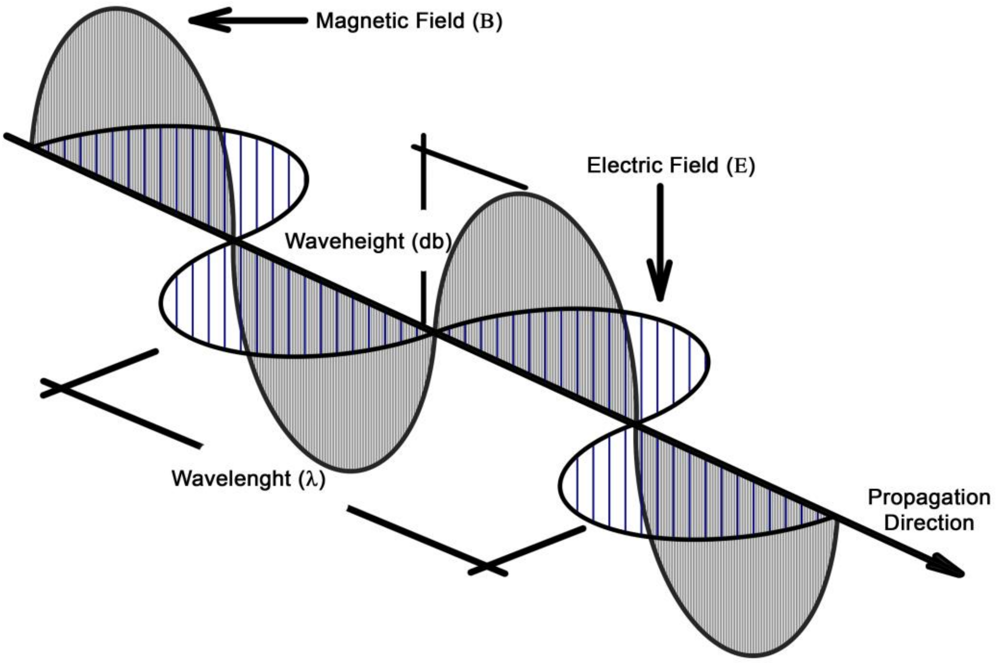


Figure 3.1 : Electromagnetic wave structure.

Frequency is the number of waves, which are passing from a constant point or can be described as amplitude intervals in a second and the unit to display this intervals is Hertz (Hz). An electric field is generated by the pull and push force on the electrical loads. A magnetic field is generated when electric charge carriers such as electrons move through space or within an electrical conductor [22].

As for that, an electromagnetic wave is kind of which are generated by orthogonal waves to forward movements of electric fields and magnetic fields [23].

3.2 Electromagnetic Spectrum

An electromagnetic spectrum is defined as combination of all the different wavelengths of electromagnetic radiation, including light, radio waves, and X-rays. [23]. Electromagnetic spectrum is formed by electromagnetic waves. The spectrum includes frequencies from 0 Hz to infinity. Electromagnetic sources such as power lines, FM radio, GSM operators and microwave ovens have different frequencies in the spectrum that is shown on the Figure 3.2 [24].

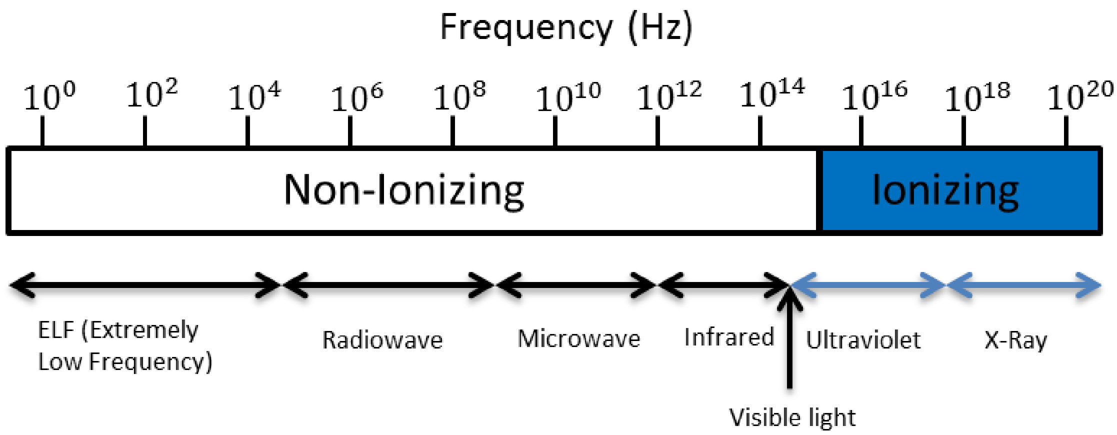


Figure 3.2 : The electromagnetic spectrum.

Power lines operate at 50 Hz, FM radio operates at around 100 MHz and GSM operate at 900 MHz and at 1800 MHz. In Figure 3.3 the measured electromagnetic spectrums for GSM 900 and GSM 1800 are shown [24].

X-rays have extremely high frequencies that are shown in Figure 3.2. In addition, these electromagnetic sources have sufficient energy to break chemical bonds. It is possible for X-rays to damage directly the human cells and these frequencies have ionizing radiation, which have energy to effect atoms or molecules. The lower frequencies have non-ionizing radiation, which have not enough energy to effect atoms or molecules [24].

There are seven types of waves in EM spectrum; those types and their feature are given in Table 3.1 [25].

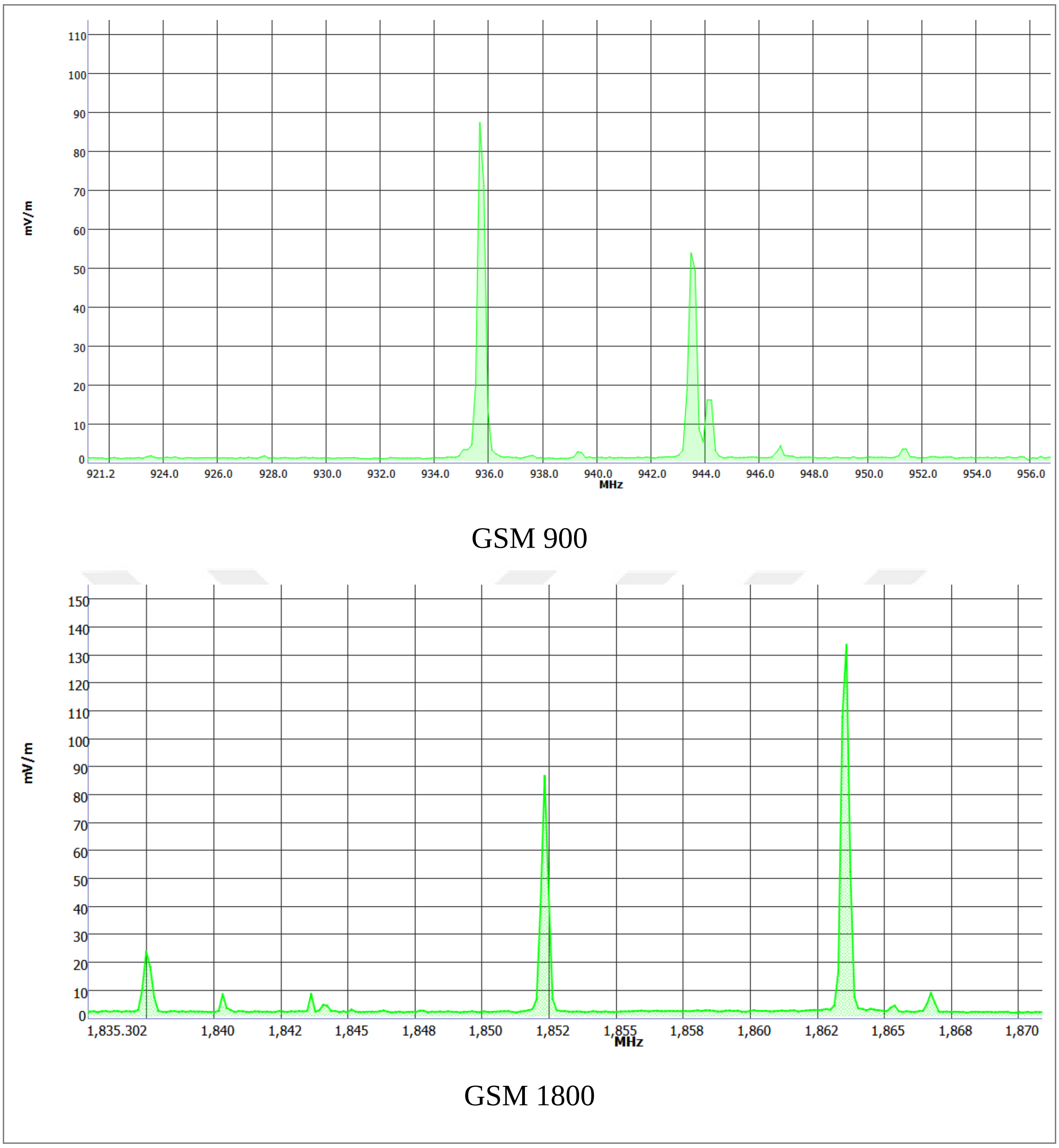


Figure 3.3 : Electromagnetic (EM) spectrum for GSM 900 and GSM 1800.

Table 3.1 : EM wave types.

Wave Type	**Frequencies**	**Wavelenghts**	**Usage Area**
Radio waves	<30 gigahertz (GHz)	>10 millimeters	Communications including voice, data and entertainment media
Microwaves	3 GHz – 30 trillion hertz (THz)	10 mm – 100 micrometers (μm)	High-bandwidth communications, radar and as a heat source for microwave ovens
Infrared	30 THz – 400 THz	100 μm – 740 nanometers (nm)	Astronomy, remote control systems and thermal imaging
Visible light	400 THz – 800 THz	740 nm – 380 nm	Seeing things, compact disc & DVD players, aircraft weapon aiming systems
Ultraviolet	8×10^{14} Hz – 3×10^{16} Hz	380 nm – 10 nm	Medical and industrial applications
X-rays	3×10^{16} Hz – $3 \text{ x } 10^{18}$ Hz	10 nm – 100 picometers (pm)	Medical and industrial applications
Gamma-rays	$>3 \text{ x } 10^{19}$ Hz	<100 pm	Medical applications (useful for killing cancer cells.)

** 1 THz=1x10^{3}GHz=1x10^{9} Hz*

*** 1 mm = 1x10^{3} μm=1x10^{6} nm=1x10^{9} pm*

3.3 Electromagnetic Area Sources

3.3.1 Natural sources

Electromagnetic fields are invisible to the human eye but they are everywhere in our environment. The local build-up of electric charges in the atmosphere produces electric fields [26].

Natural electromagnetic fields includes thunderstorms, solar and cosmic activity which are created by the earth`s background electromagnetic field. The strength of an electromagnetic field depends on the distance from the source and the power at the source [27].

3.3.2 Human-made sources

Electromagnetic fields are also generated by human-made sources. Electricity passes through a conductor creates electromagnetic fields. Two independent fields are created: an electric field and a magnetic field. The strength of the electric field depends on the transmitted voltage level, while the magnetic field strength depends on the amount of transmitted current level [27]. The electricity that comes out of every power socket has associated low frequency electromagnetic fields. In addition, various kinds of higher frequency radiowaves used for transmitting information whether via TV antennas, radio stations or mobile phone base stations [26].

Some of the human-made EMF sources are;

- Electrical Power Line: Power lines, in-home wiring, plumbing, and appliances create the electromagnetic fields. These include EMFs with a variety of frequencies and orientations [28].
- Broadcast Stations: They are used for transmission of Amplitude Modulation (AM), Frequency Modulation (FM) radio or television broadcasts. The vicinity of high-power broadcasting stations has considerably lower radiation levels than biologically hazardous fields [29].
- Cellular Telephones, Cordless Phones and Hand-Held Radios: They are used for communications purposes in our daily life. Cordless telephones and two-way hand-held radios have very low radio frequency (RF) power output. Cellular phone is close to the user's head and such devices create greater RF exposure [27].
- Base Stations: Cellular technology enables delivering voice, text, images and other data and it relies on base stations. RF levels produced by base stations are lower than the formed levels by usage of the cellular phones [30].
- Smart Meters: It is an important element of the smart grid and used for electricity that enables communication between the meter and the grid as well as between the meter and appliances in the building. Smart meters have several important sustainability benefits for example they offer potential benefits for resilience by shaving peak load, making it easier to pinpoint and managing power outages. However, wireless smart meters transmit frequent signals through microwave radiation and this brings concern about the health effects [31].

4. MOBILE COMMUNICATION SYSTEMS

4.1 Global System for Mobile Communications (GSM)

Mobile communication systems called as Global System Mobile (GSM) is a worldwide standard for mobile communication with an extensive coverage. It is a system, which includes cellular and numeric systems. Basically, GSM provides circuit switching power plant and data connection services. GSM has been used by over 2 billion people in 212 countries. All GSM standards have the moving ability of transmission between cellulars; so it can be possible to communicate in all over the world if the area is under the coverage of the base stations [32].

4.1.1 The GSM network structure

The organisational structure of GSM must be subdivided into different processing elements. These elements are:

- **GSM Service area:** All network elements are part of this area.
- **Public Land Mobile Network (PLMN) area:** PLMN is the one network operator`s service area. The area is defined by which an operator offers radio coverage and access to its network.
- **Mobile Switching Center (MSC) Service area:** MSC service area is a network operator`s subdivided area depending on the offered network capacity. The area covered by one MSC is called the MSC service area. The Mobile Switch (MS) is part of the switching network, responsible for connecting telephone calls.
- **Location area (LA):** The location is defined as a group of cells. Within the network, a subscriber's location is known by the LA. The identity of LA can be found in the current area of MS is located. When an MS crosses the boundary between two cells belonging to different LA's, it must report its new Location Area to the network. If it crosses a cell boundary within a LA, it does not report its new cell location to the network.

- **Cell area:** A cell is the basic unit of a cellular system and is defined as the area of radio coverage given by one base station (BS) antenna system. The lowest area in the geographical layers is formed by one radio cell. The radio cell is stretched out by the radio coverage of one BS, and has a range between a few hundred metres up to a maximum of 35 km. The Cell area forms the access point for the subscriber. One radio cell is identified by its Base Station Identity Code (BSIC). This code is broadcast in a periodic manner and quality to both serving cell and neighbour cells [33].

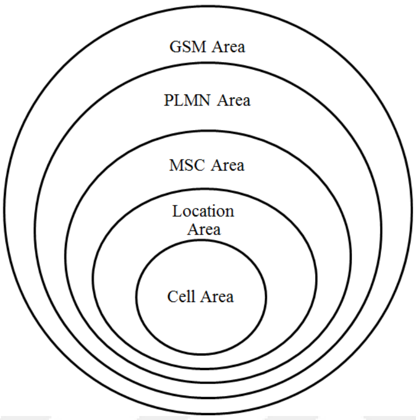


Figure 4.1 : Geographical structures of mobile networks.

GSM is the 25-35 MHz segregated cellular telephone systems for about 900 MHz frequency range. The coverage zones of base stations are divided into micro cells for serving much many subscribers. This means same frequencies of the waves can be used repeatedly. In the GSM systems there are 3 cell types; those are macro (25-35 km radius service area), mini (~2000 m radius service area), and micro (100-500 m radius service area) types. The cell types are planned by considering the settlement densities. The macro cells are enough for the rural areas; however, in the urban areas there is need to plan micro cells. For the micro cell generation, the frequency of base stations must be increased [34].

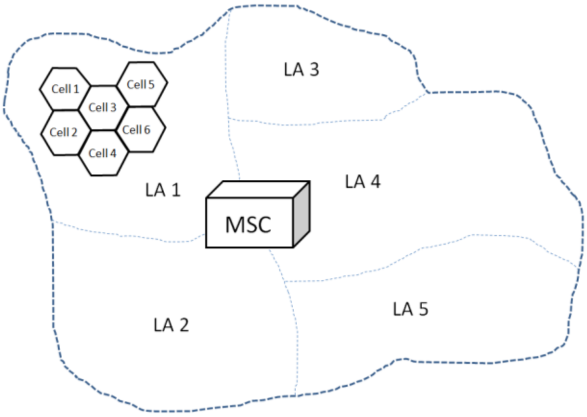


Figure 4.2 : The schema of a sample mobile network.

4.1.2 Evolution of mobile networks

Marconi, who is an inventor of the Marconi law, at the same time, is renowned for his works on distance radio communications and the radiotelegraph system, established the fundamentals of wireless technologies in communication systems in 1897. After Marconi, in 1972, concepts of cellular technologies for mobile communications were developed in Bell Laboratories [35]. Since then mobile communications have consequential changes and they evolved enormously. (Figure 4.3) shows the evolution of the mobile networks [36].

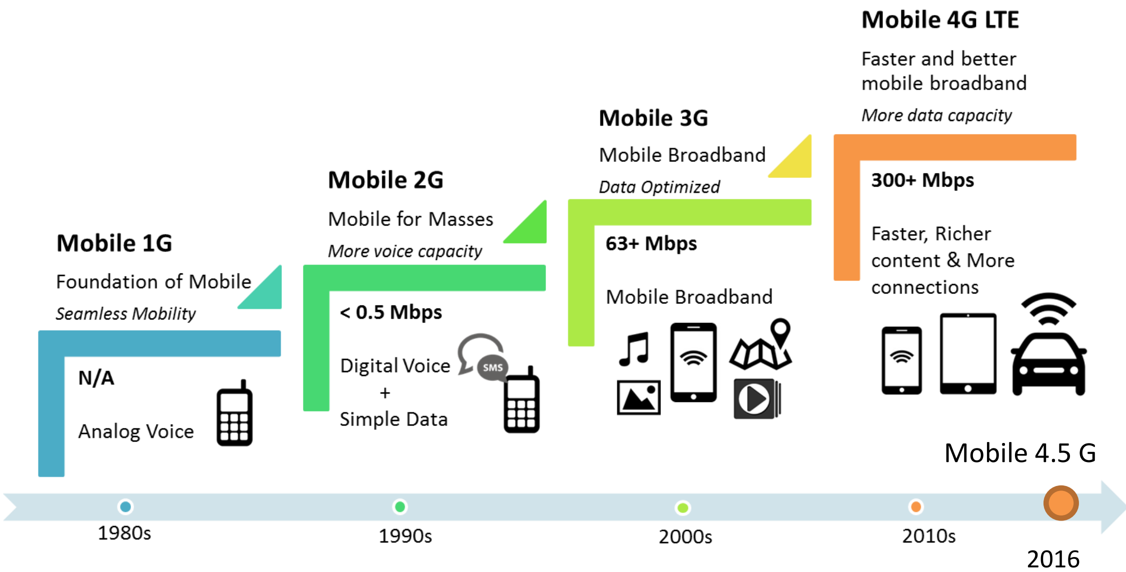


Figure 4.3 : Evolution of mobile networks.

Mobile networks have differences in terms of Generation (G). There is a big gap between generations. The first-generation mobile systems (1G) were analogue systems. They were released in the early 1980s. Another name of these technologies is Nordic Mobile Telephone (NMT). They were used for mainly speech related services. Their main limitations were the lack of services and incompatibility [37].

2G offers first digital systems by introducing services such as short messaging and low speed data. 2G technologies became available in the 1990s. Digital transmission rather than analogue transmission was used by these systems. Consequently, compared with first-generation systems, higher spectrum efficiency, better data services, and more advanced roaming were offered by 2G systems. In Europe, the GSM was deployed to provide a single unified standard. This enabled seamless services throughout Europe by means of international roaming. The earliest GSM system operated in the 900 MHz frequency band with a total bandwidth of 50 MHz.

During improvement process of GSM technology, new technologies were developed to offer better services in the market. 3G mobile communication system was one of the new technologies and released in 2000s [36]. International Telecommunication Union (ITU) specified the 3G requirements as part of the International Mobile Telephone 2000 (IMT-2000) project. The digital networks had to support 144 kbps of throughput at mobile speeds, 384 kbps at pedestrian speeds, and 2 Mbps in indoor environments [38]. 3G services gave the ability of wide-area wireless voice communications, video calls, and broadband wireless data in a mobile environment [39].

The rise of new technologies in the mobile communication systems and growing user demand caused to come up with an extensive revolution of the 4G mobile communication system [40]. The new 4G framework is established to achieve new levels of user experience. Also the system enables to integrate all the mobile technologies such as GSM, General Packet Radio Service (GPRS), IMT 2000 – International Mobile Communications, Wireless Fidelity (Wi-Fi) and Bluetooth [41]. 4G mobile communication services were released in 2010 but it became available to the market in 2014. 4G standards guide in a new era of mobile broadband communications. This technology provides faster data access, enhanced roaming capabilities, unified messaging and broadband multimedia [42].

4.1.3 GSM standards

The first-generation (1G) mobile systems` main limitations resulted in the necessity for the birth of the second-generation (2G) mobile systems. But these 2G network standards could not meet to have global standards for networks. The standards in Europe differed from Japan and America. The global standards are defined in the third-generation (3G) mobile systems. Also, 4G and 4.5G technologies has been developed to provide better performance than 3G systems. 4.5G mobile system can be consider as a step forward for deploying 5G mobile systems.

The major standards that play an important role in defining the specifications for the mobile technology are:

- **International Telecommunication Union (ITU):** It is an international organisation in the United Nations where government and the private sector coordinate global telecom networks and services. Its` headquarter is in Geneva, Switzerland. It produces the quality standards covering all the fields of telecommunications.
- **European Telecommunication Standard Institute (ETSI):** The primary responsiblity of ETSI is the development of specifications for the GSM. It also played an important role in the development of 3G mobile systems. It mainly develops the telecommunication standards for Europe and beyond.
- **Alliance of Radio Industries and Business (ARIB):** ARIB is dominant in the Australasian region. It is responsible for the development of 3G mobile systems. ARIB basically serves as a standard developing organisation for radio technology.
- **American National Standards Institute (ANSI):** ANSI provides a forum for over 270 ANSI-accredited standards for developers. It is representing approximately 200 distinct organisations in the private and public sectors. It is responsible for the standards development for the American networks.
- **Third Generation Partnership Project (3GPP):** 3GPP is created to maintain overall control of the specification design and process for 3G, 4G and 4.5G networks. The 3GPP work included a complete set of specifications that will maintain the global nature of the 3G networks [43].

- **Worldwide Interoperability for Microwave Acces (WiMAX):** It is intended for regional broadband internet. Wireless internet can be deployed at a speed of 75 megabit/second within a distance of 50 km. It is the standar of 802.16 series, which is developed by The Institute of Electrical and Electronics Engineers (IEEE). This technology also is used by 4G and 4.5G mobile systems.
- **Flash-Orthogonal Frequency Divisin Multiplexing (OFDM):** It is regarded as a technic which is used for both modulation type and multiplication. It allows the data stream to be transmitted in parallel channesl by dividing it into low-speed subcarriers. 4G and 4.5G mobile systems use this technology to increase speed of data transfer [64].

4.2 GSM Frequency Structures

Mobile frequencies are the sets of frequency ranges that assigned for cellular phone use. Most mobile networks use the radio frequency spectrum for the transmission and reception of their signals. The particular bands may also be shared with other radiocommunication services such as broadcasting service. Based on different standards, mobile networks may use the same frequency range. One network can find the same standards in use on the same frequency in the same area. This does not interfere with each other since they use different channels to carry data. The actual frequency used by a particular phone can differentiate between different places. It depends on the settings of the carrier's base station [44].

Basic technical properties that belong to different frequencies are given in Table 4.1 [33].

Table 4.1 : Basic technical properties of six frequency bands.

Sytem	NMT450	NMT 900	GSM 900	GSM 1800	CT1	DECT
Type	Analogue mobile telephony	Analogue mobile telephony	Digital mobile telephony	Digital mobile telephony	Analogue cordless telephony	Digital cordless telephony
Data structure	Frequency Division Multiple Access	Frequency Division Multiple Access	Time Division Multiple Access	Time Division Multiple Access	Frequency Division Multiple Access	Time Division Multiple Access
Time slot repetition rate	-	-	217 Hz	217 Hz	-	100 Hz
Frame duration	-	-	4.615 ms	4.615 ms	-	10 ms
Frequency uplink	453-457 MHz	890-914 MHz	890-914 MHz	1710-1785 MHz	914-915 MHz	1.88-1.9 GHz
Frequency downlink	463-457 MHz	935-959 MHz	935-959 MHz	1805-1880 MHz	959-960 MHz	1.88-1.9 GHz
Peak power mobile station (Power class)	15 W	1 W	2 W	1 W	10 mW	250 mW
Mean power mobile stations	1.5-15 W	0.1-1 W	0.4-250 mW	0.1-125 mW	10 mW	10 mW
Peak power base station	13 W	10 W	10 W	5 W	10 mW	250 mW
Cell radius	2-50 km	0.2-50 km	2-50 km	0.1-35 km	500 m	300 m

GSM 900 network frequency structure can be examined to understanding the details of mobile frequency structures. The frequency bands in GSM 900 network used are 890-915 MHz in the uplink direction and 935-960 MHz in the downlink direction, which means a bandwidth of 25 MHz in each direction. The whole or some fraction of this band is available to the network operator. The central frequencies start at 200 kHz from the 'edge' of the band. They are spread in it. There are 125 frequency slots in this band. The major interference problem is between the adjacent bands is overlapping at the borders of the individual channels [45].

4.3 Base Stations and Electromagnetic Fields

A base station is a kind of electromagnetic source in the telecommunication area. The antennas on the base stations transform electric signals to electromagnetic waves. The basic characteristics of antennas are being directional or omnidirectional Directional antennas receive signals in a specified direction. Omnidirectiona antennas receive signals over a large area in many directions [33].

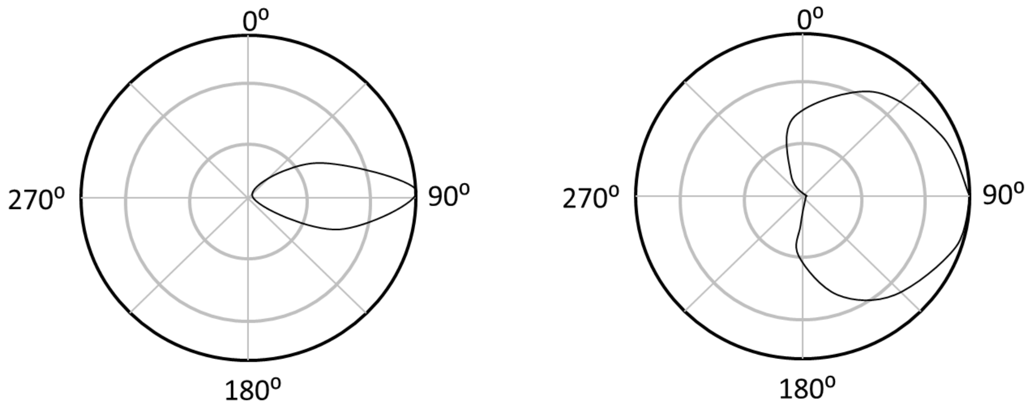


Figure 4.4 : Directional and omnidirectional antennas.

GSM operators are using base stations for communicating through the hand units. One of the most crucial parts of the system is the antenna on the base station. The location of the antenna is often in a high position; it can be mounted on tall buildings or towers. However, it may also be mounted on building walls or indoors and would then often have less output power. In order to gain output power density, the antenna is often directed both horizontal and vertical. Thus, it will radiate straight on a sector since there is no reason to transmit power straight up in the air or in directions where no receivers are [35].

The base stations are generally placed on 10-30 meters height towers. The antennas on the base stations have a 5-6^o beam angle. That beam touches the ground at a minimum of 50 meter away from the tower. The electromagnetic field intensity of a tower, which has a 60W origin power and 10 m height, is supposed to have a very low V/m outside of the 50 m radius. The wrong placement of base stations can cause to exceeding the limit values which are recognized in the standards of ICNIRP or other local institutions [33].

5. ELECTROMAGNETIC SIGNAL STRENGTH STANDARDS

5.1 International Standards

There are two types of standards in terms of human health, which are defined by ICNIRP. These are fundamental and derivative standards. If the absorption of the electromagnetic energy increases the body heat of a human by 1^{o}, it is assumed as harmful and this specifies the fundamental limits. The maximum power value of tissues absorption per kilogram is found as 4W in the results of studies conducted by ICNIRP. This value is defined as 10 times for business areas and 50 times for general and settlement areas in the fundamental limits. Here under the bulleted points show the standard values for business areas and the general and settlement areas [5];

- Business areas (Factories, plazas etc.) → 0.4 W/kg SAR
- General and settlement areas → 0.08 W/kg SAR

For finding the Specific Absorption Rate (SAR), the electric field intensity in the tissue must be measured. There are international scientific research committees, which are doing studies about SAR modelling like The Institute of Electrical and Electronics Engineers (IEEE) [46].

The fundamental limits given by ICNIRP are just about the intensity, which is absorbed by tissues. The electromagnetic power density limits is defined as the power per square of a meter and its unit is W/m^2. In opinion of ICNIRP, defining the limits in terms of thermal effect is enough. But in the case, the limits are the main source of dispute. Therefore, there may be differences about the limits between countries or international institutions. The accepted limit value for ICNIRP, in the frequency of 900 MHZ is 42 V/m (4.5 W/m^2), in the frequency of 1800 MHz is 59 V/m (9 W/m^2). V/m unit is used for measuring EMF intensity values and W/m^2 is used for measuring signal strength values of an area. The conversion V/m to W/m^2 is given below (5.1).

$$\frac{V}{m} = \left(377\frac{W}{m^2}\right)^{1/2} \quad (5.1)$$

5.2 National Standards

ICNIRP values are accepted by Turkey, United States of America and most countries of European Union except that Italy and Russia accepted the limit value as 6 V/m and Sweden accepted the limit value as 5 V/m for 900 MHz [47].

The limit values on ICNIRP guide are defined by the results of researches about short and medium term burning, shock and heat effects on experimental objects. The causes in long-term effects such as cancerogenic facts are not used for defining the limit values, based on lacking of scientific data about this subject. Therefore, long-term effects are ignored in the guide [34].

Table 5.1 : Limits for electric field intensities in Turkey, Italy, Lithuania, Poland, France and Sweden.

Country Name	Electric Field Intensity (900 MHz)	Electric Field Intensity (1800 MHz)
Italy	6 V/m	
Lithuania	6.1 V/m	
Poland	7 V/m	
Sweden	5 V/m	
France (Only in Paris)	5 V/m	7 V/m
TURKEY	41.25 V/m	58.34 V/m

The effects of electromagnetic areas on human health are still a research subject and there are no certain results yet but in these researches, inconclusive evaluations are more than conclusive evaluations on human health. There is lack of long-term and large-scale epidemiological studies quantifying these effects. Most of the effects of EMFs on the human body are not clear [61]. Some medical studies examine the EMF effects on human health such as the influence of EMFs on early childhood cancer [62].

6. STUDY AREA AND MEASUREMENT STUDY

6.1 StudyArea

Istanbul Technical University (ITU) Ayazaga Campus area is selected for the experiment. ITU is one of the largest universities in Istanbul, with about 32300 students, and 1450 academic staff [63]. The campus area is approximately 3 km^2. In this area, there are 4 techno parks, 1 KOSGEB (small and medium industry development organization) laboratory, 3 kindergartens, 1 elementary and 1 high school. Because of these facilities, ITU has high daytime population other than the students, administrative and academic personals as well. In addition to these, there are 10 base stations in the study area. With regard to these features, the study area is considered as the category of sensitive areas. For that reason, the measurements of electromagnetic field intensities, which are generated by base stations, are also compared with Italy and Sweden’s limit values in this study.

6.2 Measurement Methodology

In the study, Spectran HF-6065 branded spectrum analyzer is used for the measurements and is shown in Figure 6.1. Spectran HF-6065 has two antennas, which are logarithmic, and rod. The logarithmic antenna is used for directional sense measures. The rod antenna measures electromagnetic field intensity independent from directions. The direction term here is the orientation of the antenna to the measurement direction. The rod antenna does not need any orientation. In this study, the rod antenna is used for measurements.

Figure 6.1: Spectran HF-6065 branded spectrum analyzer.

The analyzer can measure frequency band between 10 MHz and 6GHz frequencies and has high sampling precision up to a level of 60 dB. The spectrum analyzer can show the measurement results as frequency-time charts on its screen and on computer screen with a USB connection. As a result of these features, it is possible to make detailed measurements and analyses [48].

In the first step of the measurement, base station locations are specified as the study area for measuring the electromagnetic field intensities sourced by base stations. Then, the effect areas of base stations, which are circular regions with 50 m and 300 m radius, are created by using ArcGIS software. The 50 m radius area is called the primary effect area while the 300 m radius stands for secondary effect area. These effect areas have been determined based on a study about health effects of living near mobile base station antenna. In this study, results show that people who are living 300 m distance far from base stations have minimum EMF exposure [65]. Then, 29 different survey locations are appointed in the 300 m effect areas. In the final step, electromagnetic field intensities are measured for 15 minutes at every appointed location for one-week period in different times. After completion of one-week period measurement, maximum values are used for further analysis. The measurements are made by establishing stationary setup at measurement locations by using Spectran® HF-6065, a computer and MCS Spectrum Analyzer software that is shown in Figure 6.2.

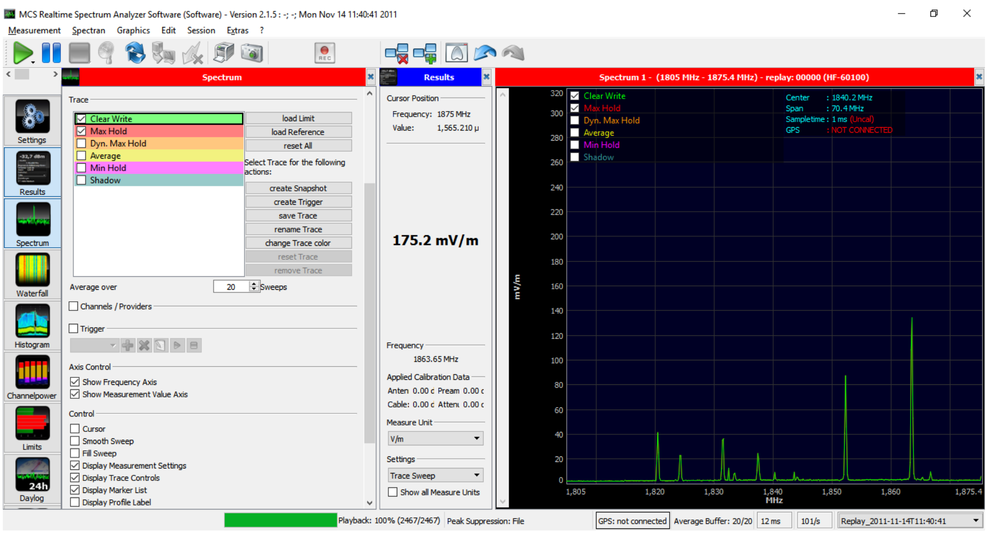


Figure 6.2: MCS spectrum analyzer software.

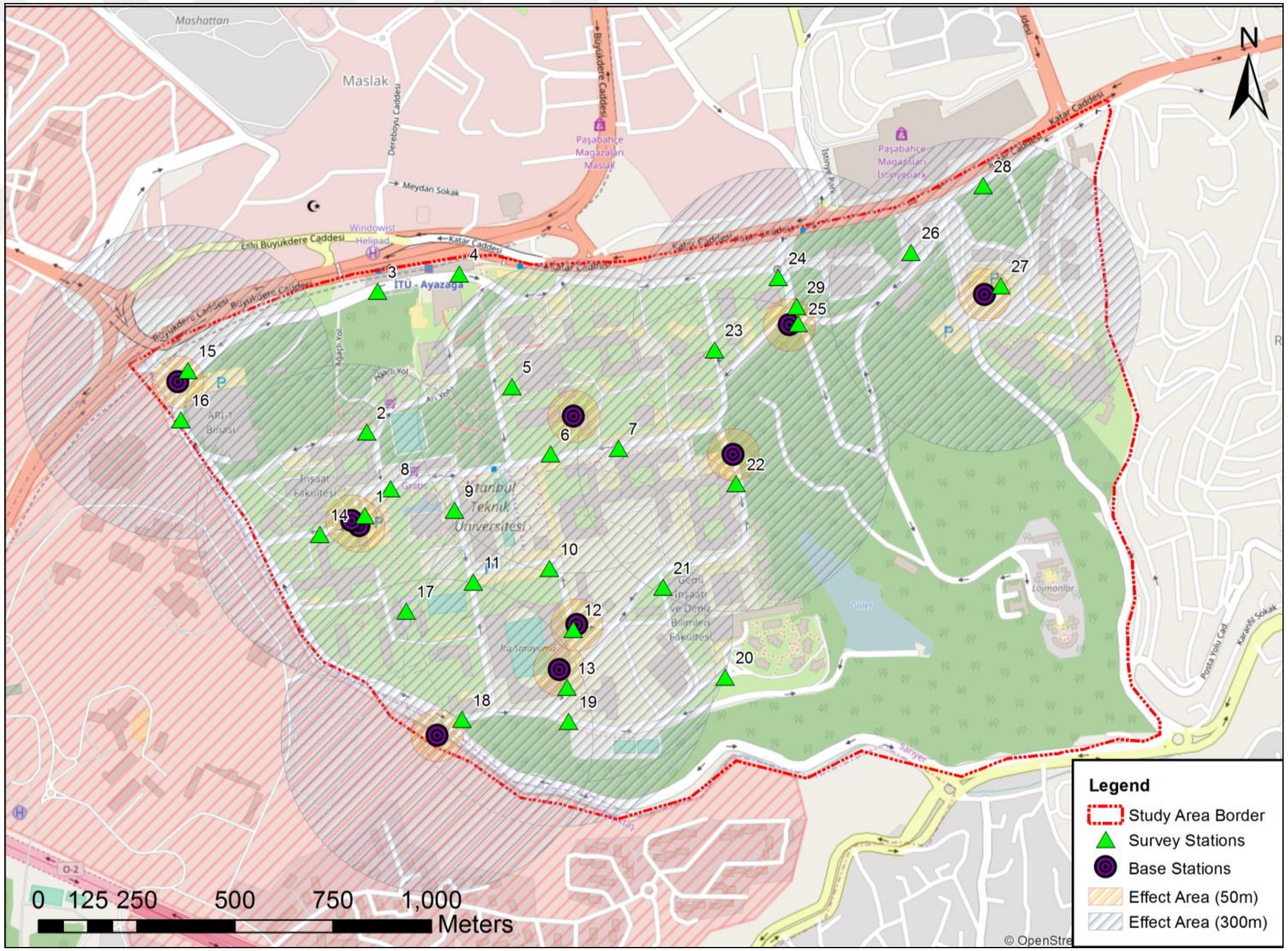


Figure 6.3: Study area, base stations and survey stations.

6.3 Measurement Results

The electromagnetic field intensities are measured between 900 MHz and 1800 MHz frequencies on each survey station. The results are shown in Table 6.1. Please note that the survey station codes stand for the same areas in both Table 6.1 and Figure 6.3.

Table 6.1 : Measurement results.

Survey Station Code	Max V/m	
	900 MHz	1800 MHz
1	1.015	0.792
2	0.063	0.061
3	0.235	0.17
4	0.186	0.148
5	0.165	0.406
6	0.299	0.325
7	0.166	0.408
8	0.303	0.326
9	0.043	0.133
10	0.23	0.283
11	0.372	0.173
12	1.543	0.731
13	0.231	1.323
14	2.723	0.484
15	1.665	0.406
16	0.924	2.895
17	0.192	0.151
18	0.409	0.057
19	0.314	1.396
20	0.041	0.111
21	0.256	1.856
22	1.622	1.324
23	0.437	0.102
24	0.035	2.045
25	0.03	1.845
26	0.044	0.099
27	0.198	0.069
28	0.95	0.5
29	0.095	5.5

For the 900 MHz frequency, the highest values has been measured on station 14 as 2.7 V/m and on station 15 as 1.7 V/m.

The survey station 14 is in front of the Civil Engineering Faculty Building. This station is close to 2 different base stations within the 300 m radius effect area. The location and spectrum graphics of station 14 are shown on Figure 6.4.

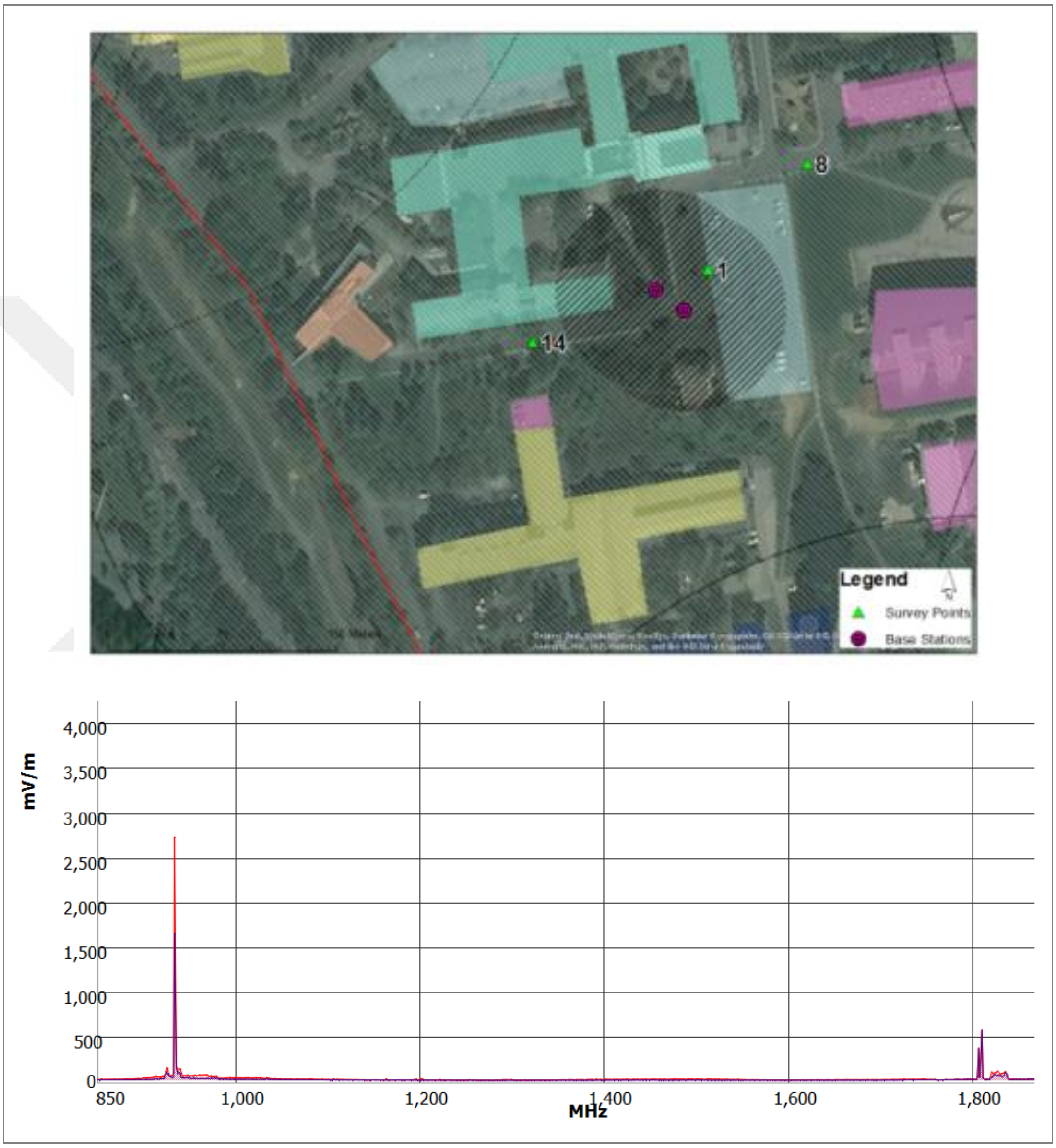


Figure 6.4: Survey Station (14) and its spectrum graphic.

The survey station 15 is in the area of a technopark and at the same time close to the campus boundaries. This station is in the 50 m radius effect area of the nearby base station. There are high-density business areas on the north side of the station. For this reason, this station can be under the effect of other base stations, which are outside the study area. The location and spectrum graphic of station 15 are shown on Figure 6.5.

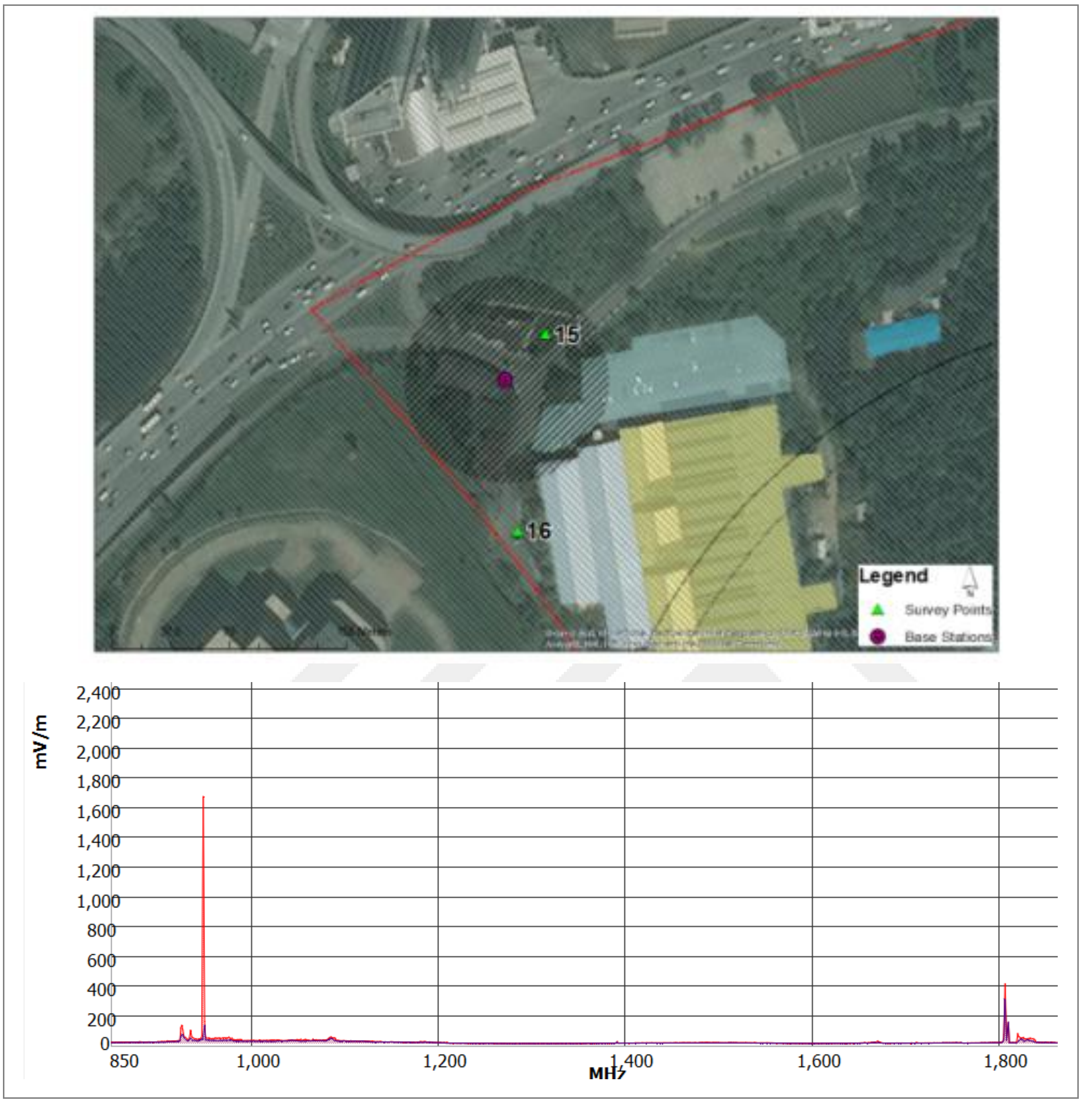


Figure 6.5: Survey Station (15) and its spectrum graphic.

For the 1800 MHz frequency, the highest values has been measured on station 29 as 5.5 V/m and on station 16 as 2.9 V/m.

The survey station 29 is located across the Istinye Park, which is one of the most popular shopping malls in Istanbul. The survey station is within the 50 m effect area of a nearby base station. The base station, survey station 29 and spectrum graphic of the station are shown on the Figure 6.6.

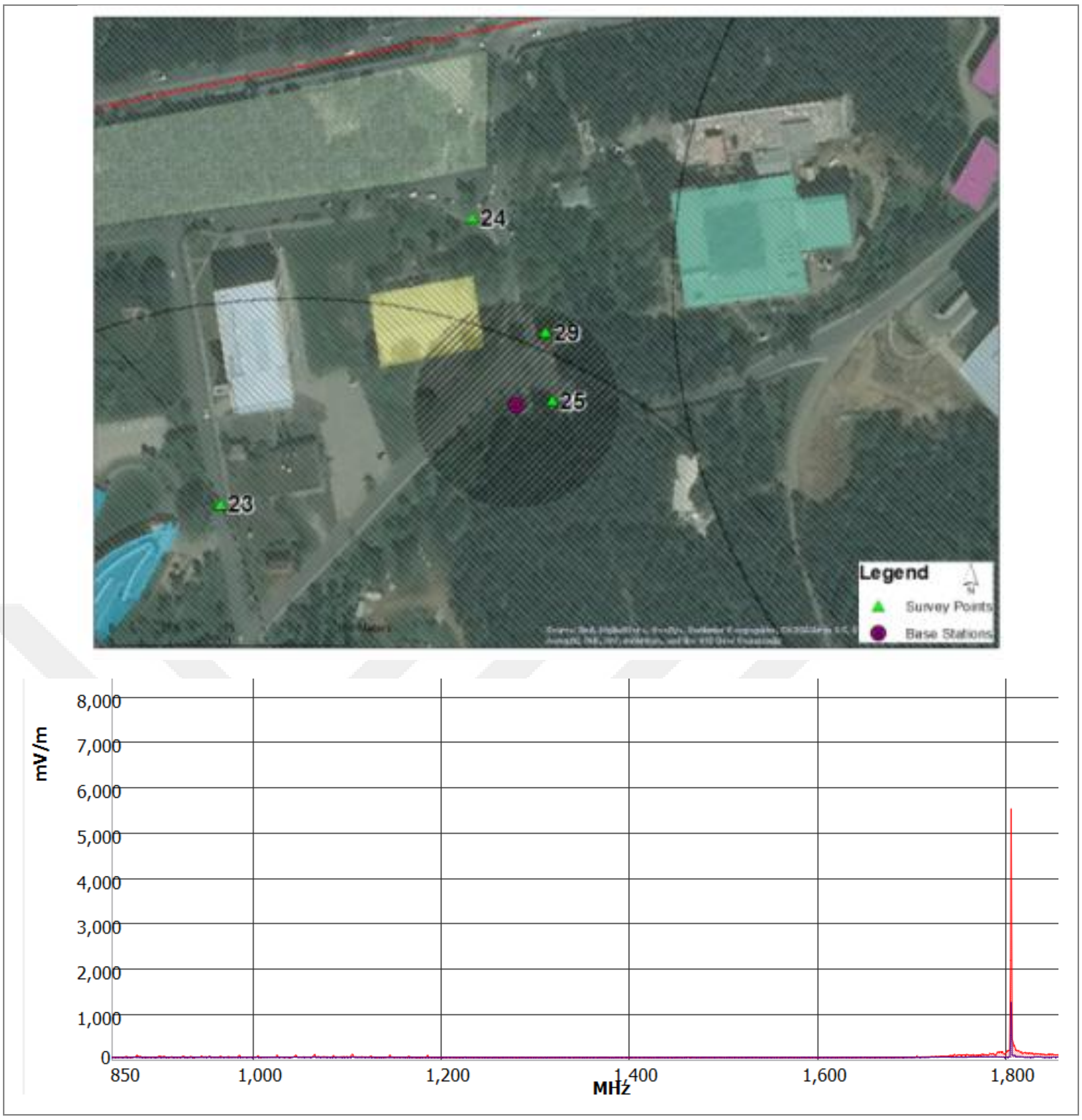


Figure 6.6: Survey Station (29) and its spectrum graphic.

The survey station 16 is inside the area of a technopark. The survey station is within 50 m effect area of a nearby base station. The base station, survey station 16 and spectrum graphic of the station are shown on the Figure 6.7.

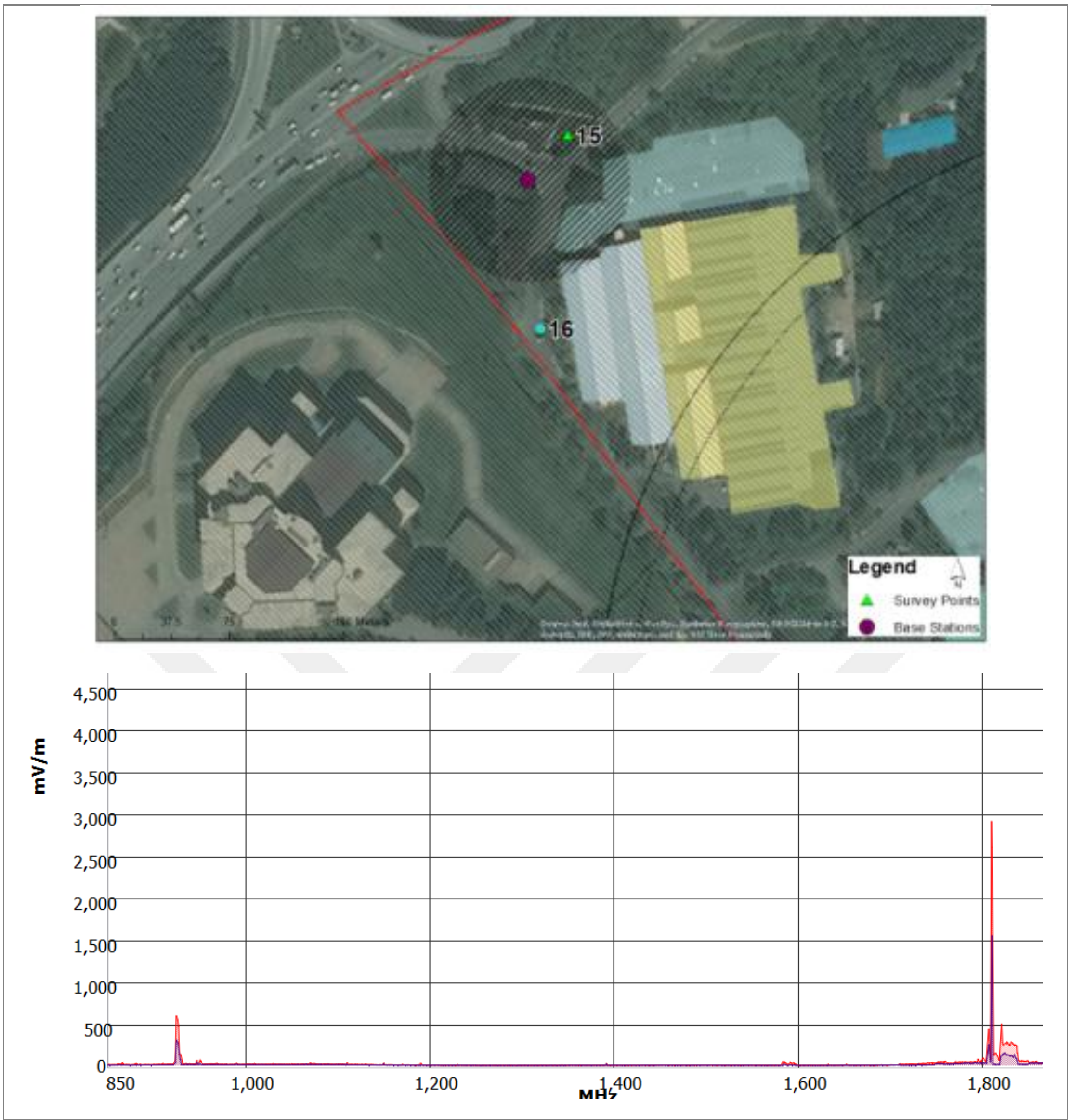


Figure 6.7: Survey Station (16) and its spectrum graphic.

6.4 EMF Intensity Distribution Maps

In this study, spatial interpolation methods are used for creating the maps. 29 different survey stations' electromagnetic field intensity values of 900 MHz and 1800 MHz frequencies are measured and used to create 2 signal maps for each frequency. Spatial interpolation is estimation of unmeasured values at locations on using measured locations values. Statistical technics are used to create interpolation methods. By using the spatial interpolation, a surface can be created. Different spatial interpolation methods can result in different surfaces since the prediction values are differed from a method to another [49]. This is intended to represent best empirical reality. Therefore, the selected interpolation method must be evaluated for its accuracy. There are two main types of interpolation methods; deterministic and stochastic. Stochastic interpolation provides assessment of prediction errors with estimated variances. Deterministic interpolation does not provide an estimation of errors associated with predicted values. Deterministic interpolation methods are basically radial basis, IDW and polynomial, while stochastic methods are e.g. regression and kriging [50]. The Radial Basis Regularized Spline and Empirical Bayesian Kriging spatial statistical interpolation methods are used via ArcGIS software for creating the maps.

The radial basis and spline functions can be determine as a weighted linear function of distance from grid point to data point without smoothing and a bias factor in simplest way. Simple formula of the form is given below (6.1).

$$\mathrm{Z_p} = \sum_{i=0}^{n} \mathrm{w_i}\varphi(r_i) + m \tag{6.1}$$

In this formula, *Zp* is the estimated value for the surface at grid point *p;* $\varphi(r_i)$ is the radial basis function selected, $\mathrm{w_i}$ is weight and bias value m are estimated from the data points [66].

In Empirical Bayesian Kriging model, empirical bayes based kriging techniques are used for spatial prediction. Kriging is a probablistic predictor. At the same time in this model, Bayes` theorem is used. The Bayes` formula is given below (6.2) [67].

$$p(\theta|y) = \frac{p(y|\theta)p(\theta)}{p(y)} = \frac{p(y|\theta)}{p(y)} \int p(\theta|n)\, p(n) dn \tag{6.2}$$

Point predictions are used for parameters *n*. The predictions for n are made from the first approximation to $p(\theta|y)$ without subsequent refinement.

In this study, 3 different spatial interpolation methods are used and results are compared with each other. The aim is to determine the method, which creates the best representation of reality for the measured EMF intensity values. The results are given in Table 6.2 below. According to the table, for 1800 MHz frequency Radial Basis method has minumum mean square error (MSE) value as 0.9 V/m and for 900 MHz frequency, Empirical Bayesian Kriging has minumum MSE value as 0.39 V/m. With reference to the results, Radial Basis Completely Regularized Spline method is used for creating heatmap on 1800 MHz frequencies and Empirical Bayesian Kriging method is used for creating heatmap on 900 MHz frequencies.

Table 6.2 : Results of spatial interpolation errors.

EMF Intensities Spatial Interpolation Errors	**1800 MHz**			**900 MHz**		
	IDW	Emprical Bayesian Krigging	Radial Basis (Completely Regularized Spline)	IDW	Empirical Bayesian Krigging	Radial Basis (Completely Regularized Spline)
Survey Station Count:	29	29	29	29	29	29
Standard Deviation:	1.08 V/m	1.02 V/m	0.94 V/m	0.66 V/m	0.62 V/m	0.64 V/m
Mean Error:	0.2 V/m	0.03 V/m	0.08 V/m	0.02 V/m	0.01 V/m	0.02 V/m
Mean Square Error :	1.24 V/m	1.05 V/m	0.9 V/m	0.43 V/m	0.39 V/m	0.42 V/m

In Table 6.2; standard deviation, mean error and mean square error of the predicted values for 29 survey stations are given. Electromagnetic field intensity values are calculated for each survey station by using 3 different interpolation methods and resultant values are presented in Table 6.2. Those results are calculated by comparing real electromagnetic field intensity values and predicted values.

The distribution of EMF intensity values of 900 MHz frequency map, which is created by using Empirical Bayesian Krigging interpolation method with ArcGIS software is shown in Figure 6.8.

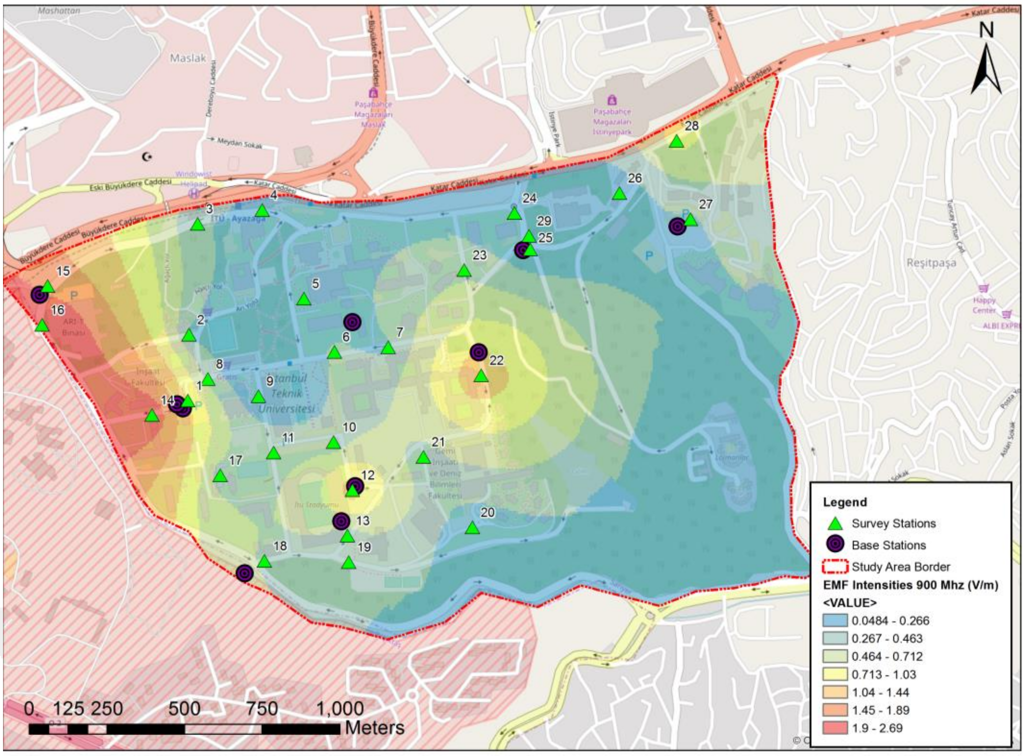


Figure 6.8: 900 MHz EMF intensity distribution map.

The distribution of EMF intensity values of 1800 MHz frequencies map, which is created by using Radial Basis (Completely Regularized Spline) interpolation method with ArcGIS software are shown in Figure 6.9.

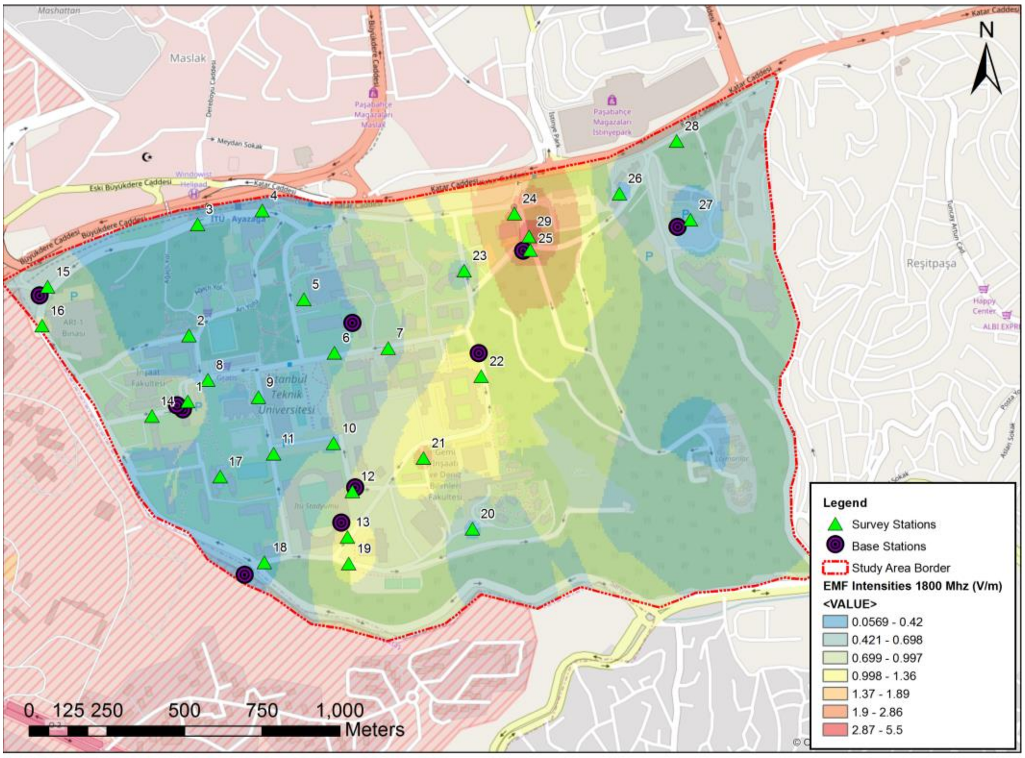


Figure 6.9: 1800 MHz EMF intensity distribution map.

These 2 maps show that there are no higher EMF intensity values than the limit values, which are defined by ICNIRP. However, the study area must be considered as a sensitive area, which should have special limits. In contrary, the values that have been measured on 900 MHz, are lower than the values that have been measured on 1800 MHz in the study area; because 3G, 4G, 4.5G technologies are using the 1700-1900 MHz frequency band and the usage of this technology increasing day by day.

6.5 Mobile Density Map

The relationship between GIS and social media comes from advanced other location aware technologies such as radio-frequency identification (RFID), quick response (QR) codes, WiFi and smart phones. Those technologies help us to know where everybody and everything are located on the places at any time. Now we have technologies that track a particular product for its entire life cycle as well as for monitoring individual movement in spatial and temporal detail [51]. We can collect data from social media sources such as Twitter, Facebook, and Foursquare. Especially Twitter has an open Application Programming Interface (API) for collecting data in this area.

Twitter has been grown exponentially since its founding in 2006. Today its active users count is averaged monthly 313 million and within this number, 82% of the users are on mobile [52]. Since August 2009, Twitter has allowed tweets to include geographic metadata indicating the location where the tweet is authored [53]. There are two types of tweet geolocation information available [54]:

- Place: It allows a user to manually specify a city or neighborhood using a software menu
- Exact Location: It is a set of coordinates usually provided via GPS or cellular triangulation.

In this study, Twitter geo-location data is used for defining mobile user density in the study area since it reprensets aproximately 80% of mobile users by the given statitistics as in the above paragraphs.

6.5.1 Technical details

The Representational State Transfer (REST) APIs provides programmatic access to read and write Twitter data. It allows to read author profile and follower data, and more. The REST API identifies Twitter applications and users using OAuth; responses are available in JSON (It is a javascript based data exchange format). OAuth is an open protocol and it allows a secure authorization in a simple and standard method from web, mobile and desktop applications to provide authorized access to its API [55].

REST web services are one way of providing interoperability between computer systems on the internet. REST-compliant web services allow requesting systems to access and manipulate textual representations of web resources using a uniform and predefined set of stateless operations. Simple Object Access Protocol (SOAP) is a protocol specification for exchanging structured information in the implementation of web services in computer networks [56]. When Web services use REST architecture, they are called RESTful APIs or REST APIs. An API is a code that allows two software programs to communicate with each other [57].

6.5.2 Data collection from Twitter and mapping the data

Twitter location data are collected by using ‘Tweepy’ in the study area. Tweets can have up to three different spatial references: “coordinates”, “geo” and “place”. Coordinates are used for determining spatial density of social media usage. The data have been collected over a period of one week. The final result includes daily average counts, collected as coordinates. The reason of daily average data usage is to compansate the peek values since some days in a week such as Friday and Monday have higher tweet densities than others.

The most reliable way to collect the coordinate data from Twitter is Twitter API from a python environment which is called Tweepy. The Twitter API needs some tokens and keys. Those are `access token`, `access token secret`, `consumer key` and `consumer key secret`. Tweet coordinates are collected by using these keys, python evironment Tweepy, python console QGIS [58].

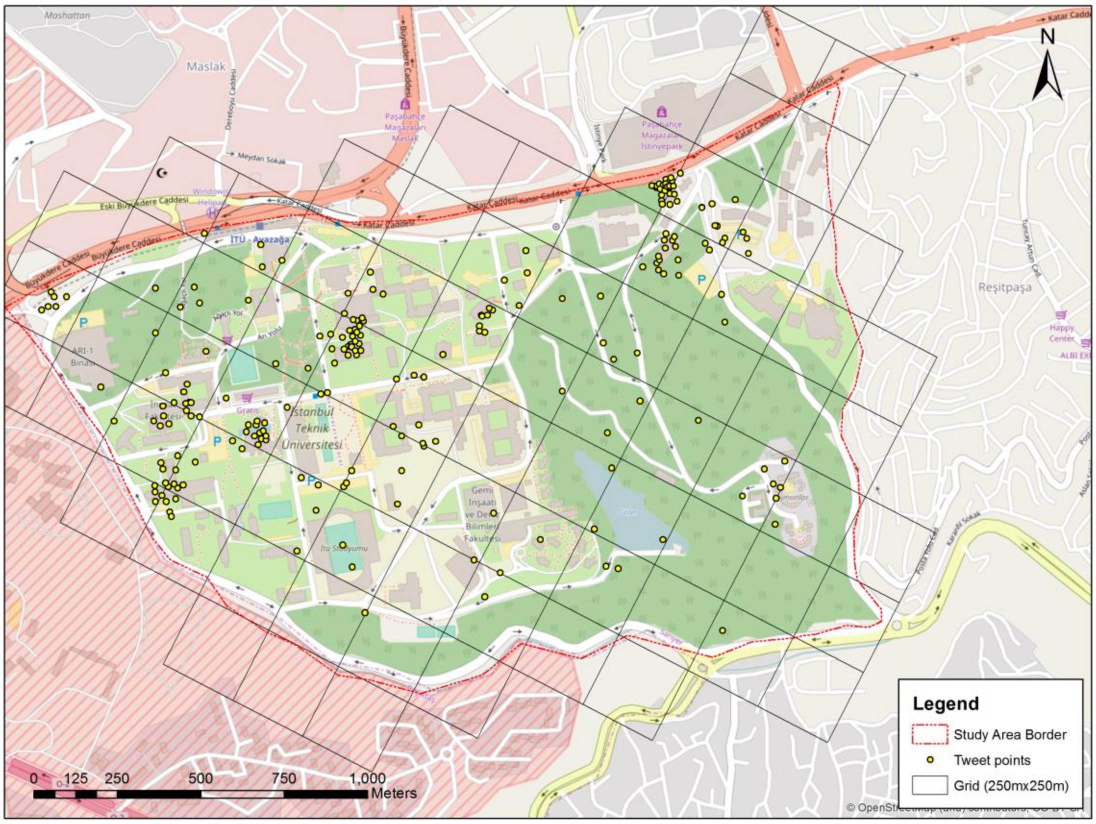


Figure 6.10: Tweet points and grid map.

Tweet points are shown in Figure 6.10 in order to create a mobile density map, in the study area, a grid network (250m x 250m) has been set up on the map, where Tweet points that have been counted for each grid. After the counting process, inverse distance weighted (IDW) spatial interpolation method has been used and final mobile density map has been created as shown in Figure 6.11.

The simplest IDW model involves dividing each of observations by the distance to a power of α and the formula is given below (6.3).

$$z_J = k_j \sum_{i=1}^{n} z_i / \, d_{ij}^{\propto} \tag{6.3}$$

The value k_j in the formula is an adjustment to ensure that the weights add up to 1. If parameter α=1 then the formula is given below (6.4) [65].

$$k_j = \sum_{i=1}^{n} 1 / \, d_{ij} \tag{6.4}$$

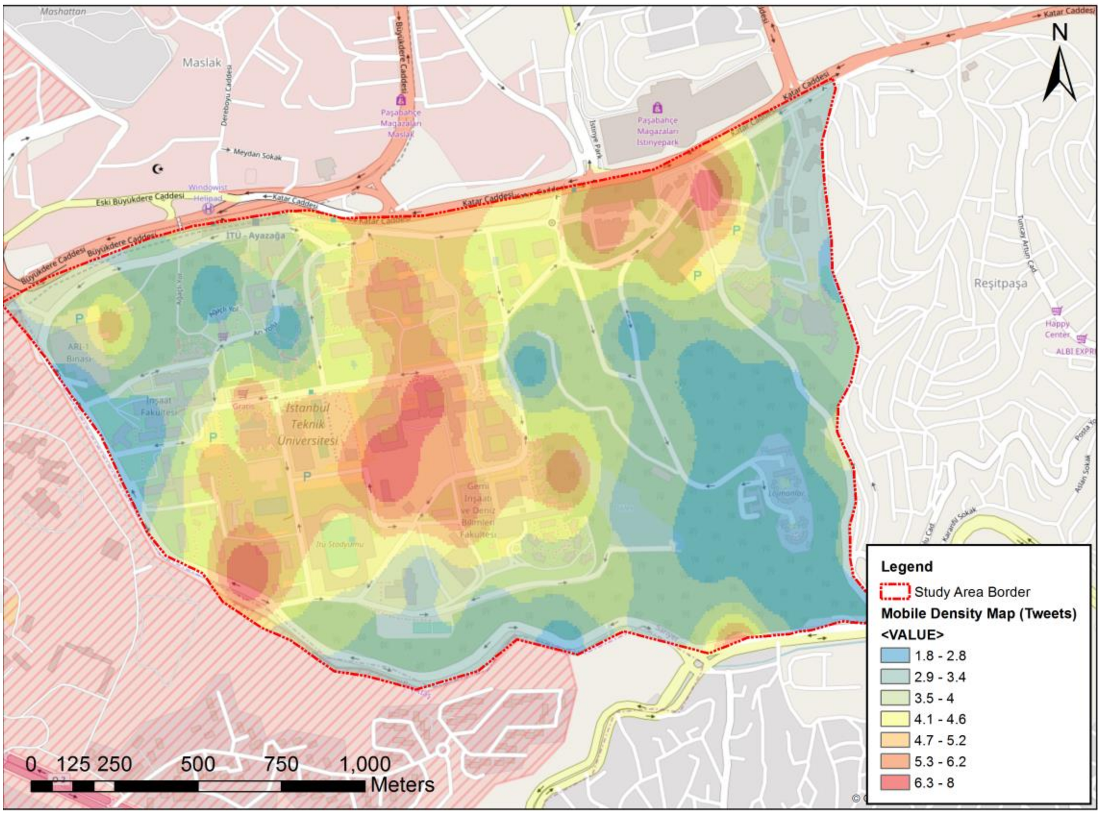


Figure 6.11: Mobile density map.

When the mobile density map is examined, it is seen that people are concentrated in the central library, the central classrooms, the stadium and the nearby area. Another concentration is observed in the technopark area. It is clearly seen that, no mobile density has been observed in and around the area that goes to the lodgings area, which is on south-west on the map. The reason for this is that, most of the area is forested and does not have settlements outside of the lodgings.

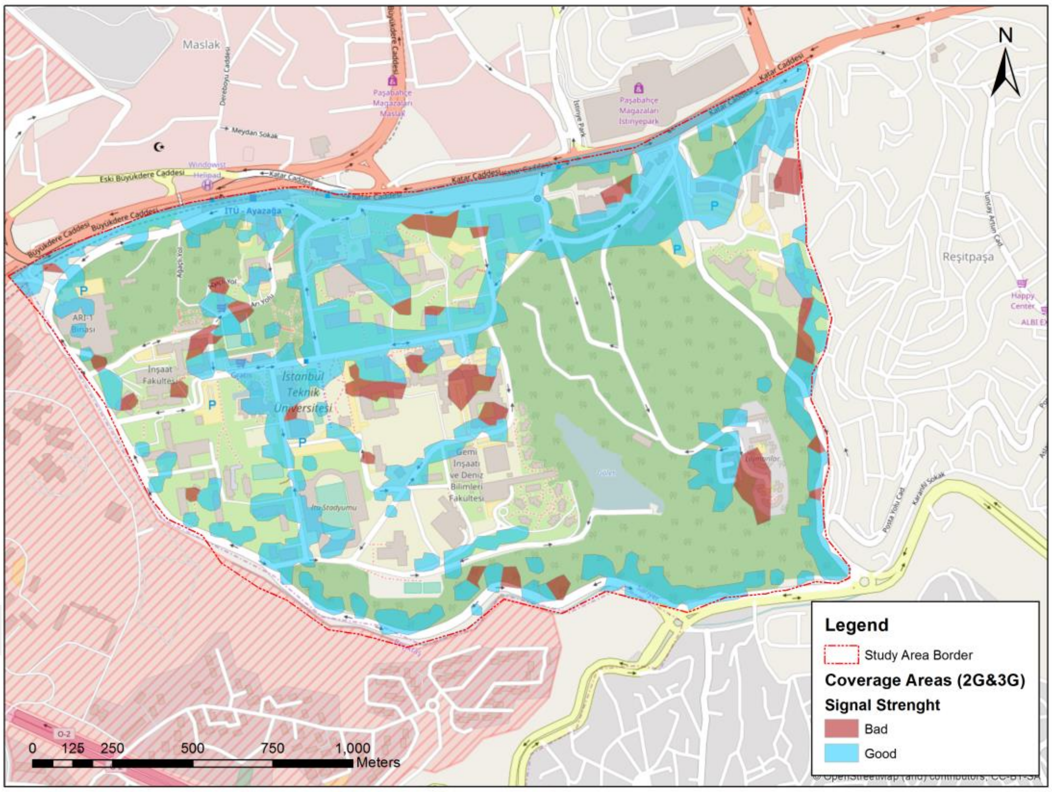
6.6 Crowd-sourced Cellular Coverage Maps

A coverage map is which the user expects to obtain good reception of the service of under normal operating conditions. The mobile network coverage maps represent the areas where good reception may be obtained or where reception may be variable. Based on the presence of receptions in mobile network coverage areas, it would be reasonable to limit EMF intensity values to these areas. In this study, for analysing EMF intensity values within limits of the mobile network coverage areas, crowd-sourced cellular coverage maps have been used.

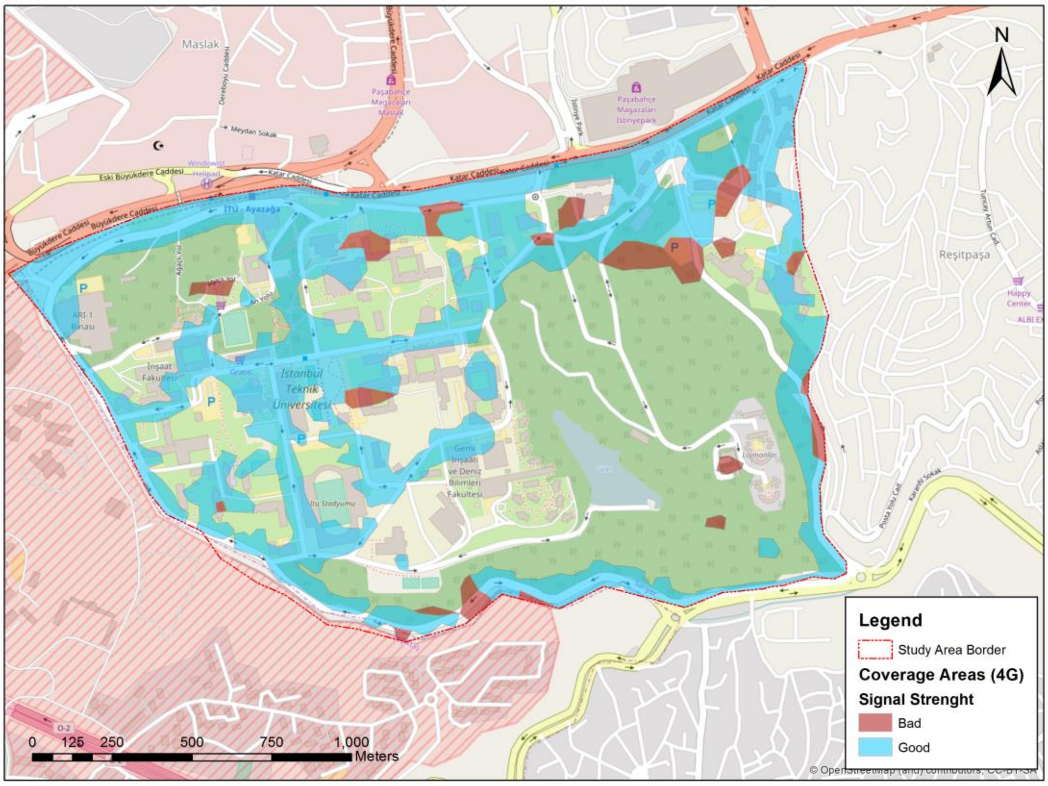
Crowd-sourced cellular coverage maps show mobile signal strength by using user data, which have the special application that is created for collecting mobile signal strength on their devices. One of the crowd-sourced cellular coverage maps providers is OpenSignal. OpenSignal data is collected from regular consumer smartphones and recorded under conditions of normal usage via their mobile application. These records collected in everyplace where users have been such as indoors, outdoors, in a city or in a countryside and represent mobile signal strength which the users experience it [59].

Mobile network covarage maps for all operators in the area of Istanbul Technical University main campus is created by using OpenSignal platform. The data is originally in raster format but in this study, it is converted into vector format by using ArcGIS software to limit EMF intensity values to mobile coverage areas. Coverages of operators Turkcell, Turk Telecom and Vodafone for 2G/3G and 4G are shown in Figure 6.12. Brown areas represent for bad signal, blue areas represent for good signal.

When the coverage maps are examined, almost all campus area are covered by all operators for 2G, 3G and 4G networks except the lodgings and non-residential areas. However, there are about 2000 faculty staff in the lodging area and it can be a problem for those who are not in the coverage area.



2G/3G Coverage Map (All operators)



4G Coverage Map (All operators)

Figure 6.12: 2G/3G/4G coverage maps (All operators).

6.7 Comparison of Density and Coverage Maps

In the sections 6.4 and 6.5 in Figure 6.8, 6.9 and 6.11, three density maps have been created demonstrating the EMF intensities on 1800 MHz, 900 MHz and mobile density. To compare the maps, a raster classification process has been performed as every density map has different scale values and to represent each raster relative to any different values on the raster, raster data are classified. Raster classification method helps to change from nominal values to interval or ratio values, so that the values can be used in relation to each another.

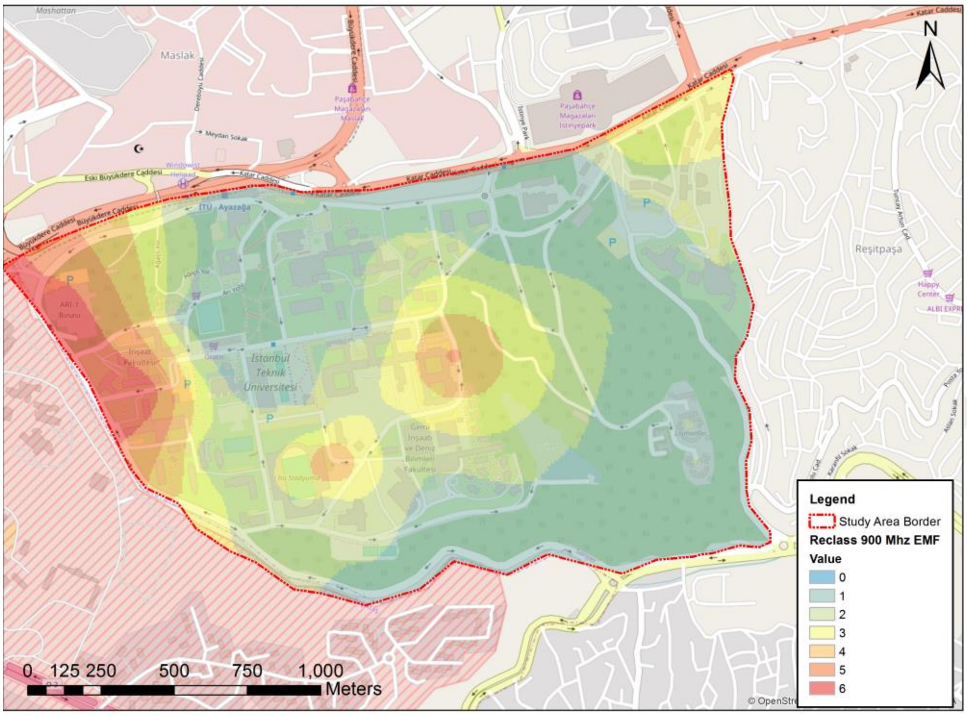


Figure 6.13: Reclassified EMF intensity map 900 MHz.

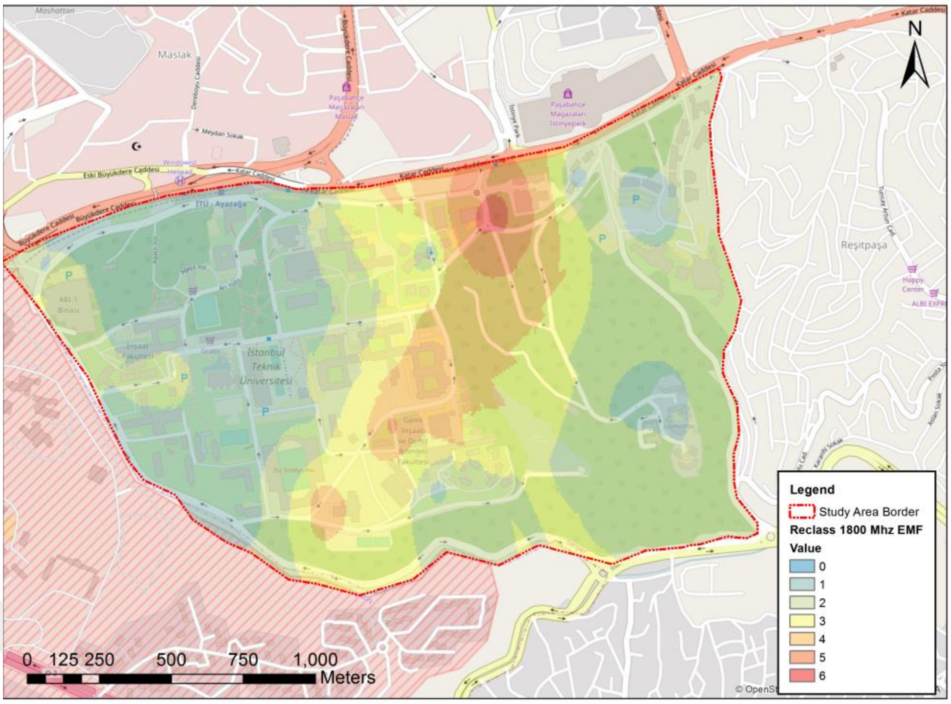


Figure 6.14: Reclassified EMF intensity map 1800 MHz.

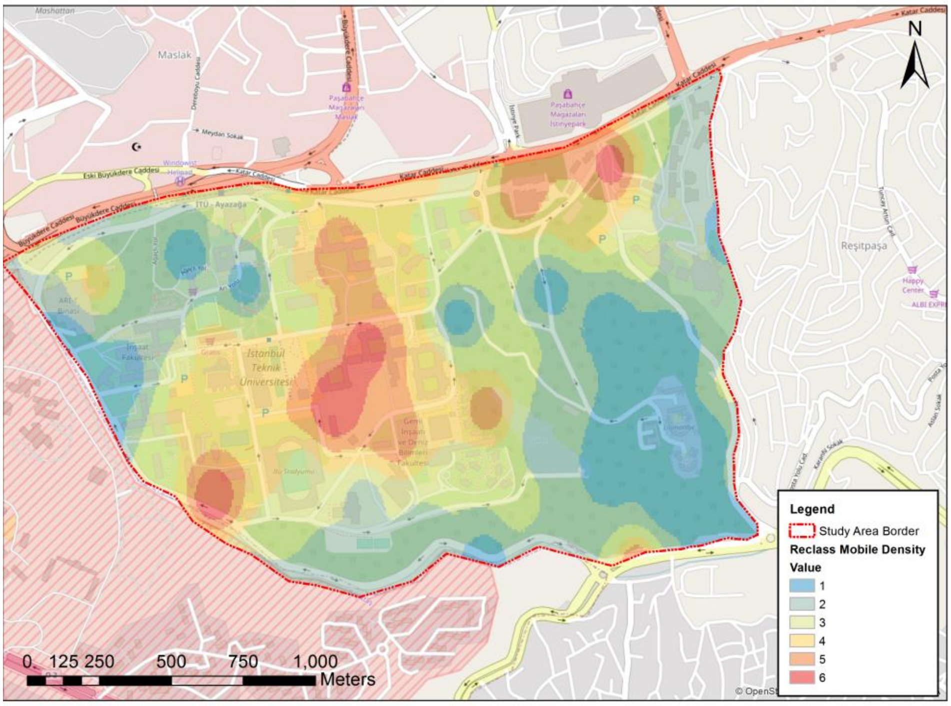


Figure 6.15: Reclassified mobile density map.

In the process of raster classification, there are different methodologies such as quantile, equal intervals, geometrical interval, standard deviation and natural breaks. In this study, natural breaks method is chosen since EMF intensity and mobile density values are uneven. It is used for classifying rasters into 6 classes. Natural Breaks (Jenks) is a data clustering method. The aim of this method is to minimize each class`s average deviation from class mean, while maximizing each class`s deviation from the means of the other groups. It seeks to reduce the variance within classes [60]. This method is widely used in Geographic Information Systems (GIS). Reclassified maps are given in Figure 6.13, 6.14, 6.15. When the maps are examined, it can be seen that all maps are in same scale and they can be used for the comparison. In addition to these maps, numerical results of the reclassification are given in Table 6.3 below. High-density areas can be considered as class 5 and 6 for EMF intensity and mobile density values. The total high-density area, for EMF intensity is approximately %4 of total study area and mobile density is %3 of total study area.

Table 6.3 : Reclassification area comparison table.

Class	EMF Density 900 Mhz			EMF Density 1800 Mhz			Mobile Density		
	V/m	Total Area (km2)	Perc. (%)	V/m	Total Area (km2)	Perc. (%)	Avg. check-in count	Total Area (km2)	Perc. (%)
1	0.05 - 0.28	1.46	48	0.06 - 0.44	0.85	27.9	1.8 - 2.8	0.48	15.6
2	0.29 - 0.52	0.78	25.6	0.44 - 0.72	1.17	38.4	2.8 - 3.6	0.87	28.7
3	0.52 - 0.83	0.42	13.9	0.72 - 1.02	0.59	19.5	3.6- 4.4	0.72	23.8
4	0.83 - 1.28	0.17	5.7	1.03 - 1.49	0.33	10.9	4.4 - 5.2	0.59	19.4
5	1.29 - 1.82	0.10	3.4	1.5 - 2.41	0.09	2.7	5.2 - 6.1	0.29	9.5
6	1.83 - 2.69	0.10	3.4	2.42 - 5.5	0.01	0.4	6.1 - 7.1	0.09	2.9

EMF intensity for 900 MHz and 1800 MHz maps has been overlayed with equal influence and the result map is shown on Figure 6.16. Also, reclassified mobile density map on Figure 6.17 are shown again for comparison. According to results, mobile density areas which have values greater than 4 are represented as red color range in Figure 6.17 and EMF intensity areas which have values greater than 4 are represented as red color range in Figure 6.16. When the maps are compared to each other, it can be seen that the high valued EMF intensity areas are related to high valued mobile density areas. In spatial manner, those two maps are similar and based on this result, it is concluded that EMF intensities and mobile densities are spatially related.

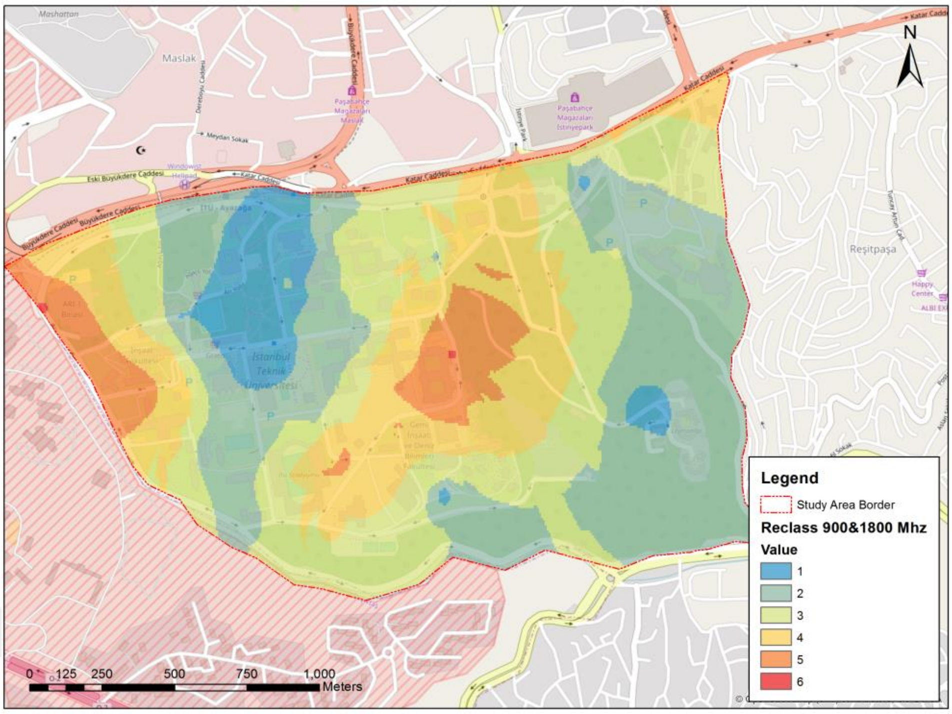


Figure 6.16: Reclassified EMF intensity map 900 and 1800 MHz.

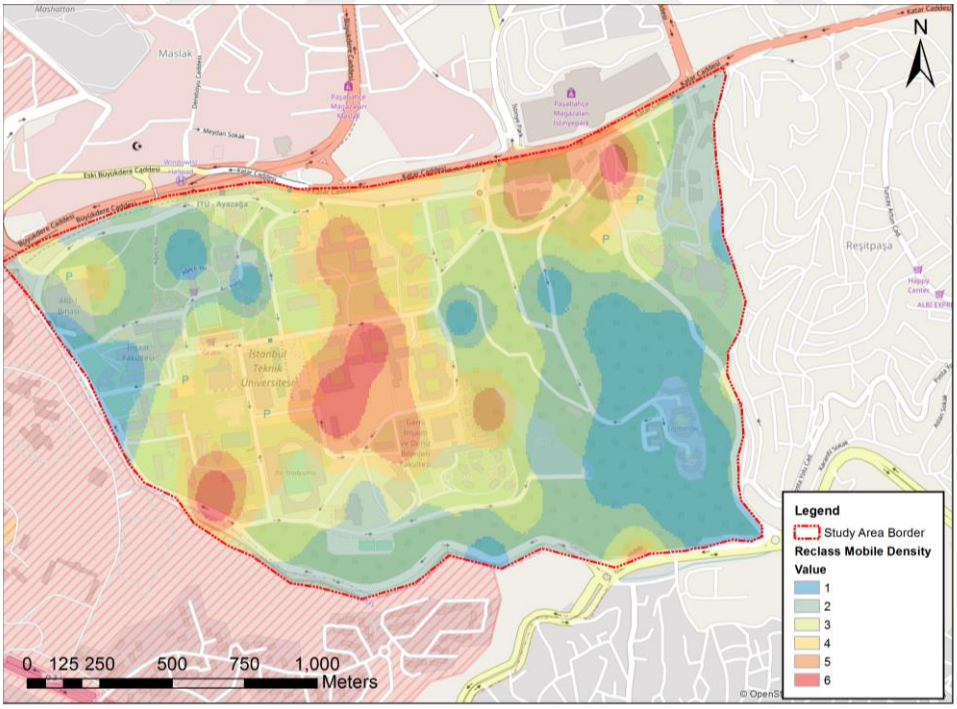


Figure 6.17: Reclassified mobile density map.

In order to determine spatial relationship between EMF intensities and mobile densities, further studies have been completed and a methodology is described below.

1. Reclassified maps are limited beyond the coverage areas.
2. 100 m x 100 m grid maps have been created.
3. The grids outside the coverage area are deleted.
4. EMF intensity and mobile density classes' values are calculated into the grids by using spatial join method which overlays different types of spatial data in one data. In this study, ArcGIS spatial join tool has been used.
5. To select EMF intensity values which are higher than '4' and mobile density values which are higher than '4', an atribute query is created.
6. Query results are determined and spatial relationship is defined.

The output of this process shows that 37 grids have mobile density values greater than 4 and 32 grids have EMF intensity values greater than 4. In common, 19 grids have both mobile density and EMF intensity values greater than 4. Result grids are given in Figure 6.18. Among 37 grids, approximately %60 of EMF intensity grids that have values higher than 4, have higher mobile densities, too and %51 of mobile density grids that have values higher than 4, have higher EMF intensities, too. This means, there is a positive spatial relation between mobile density and EMF intensity data and this relation can be used for prediction of EMF intensities.

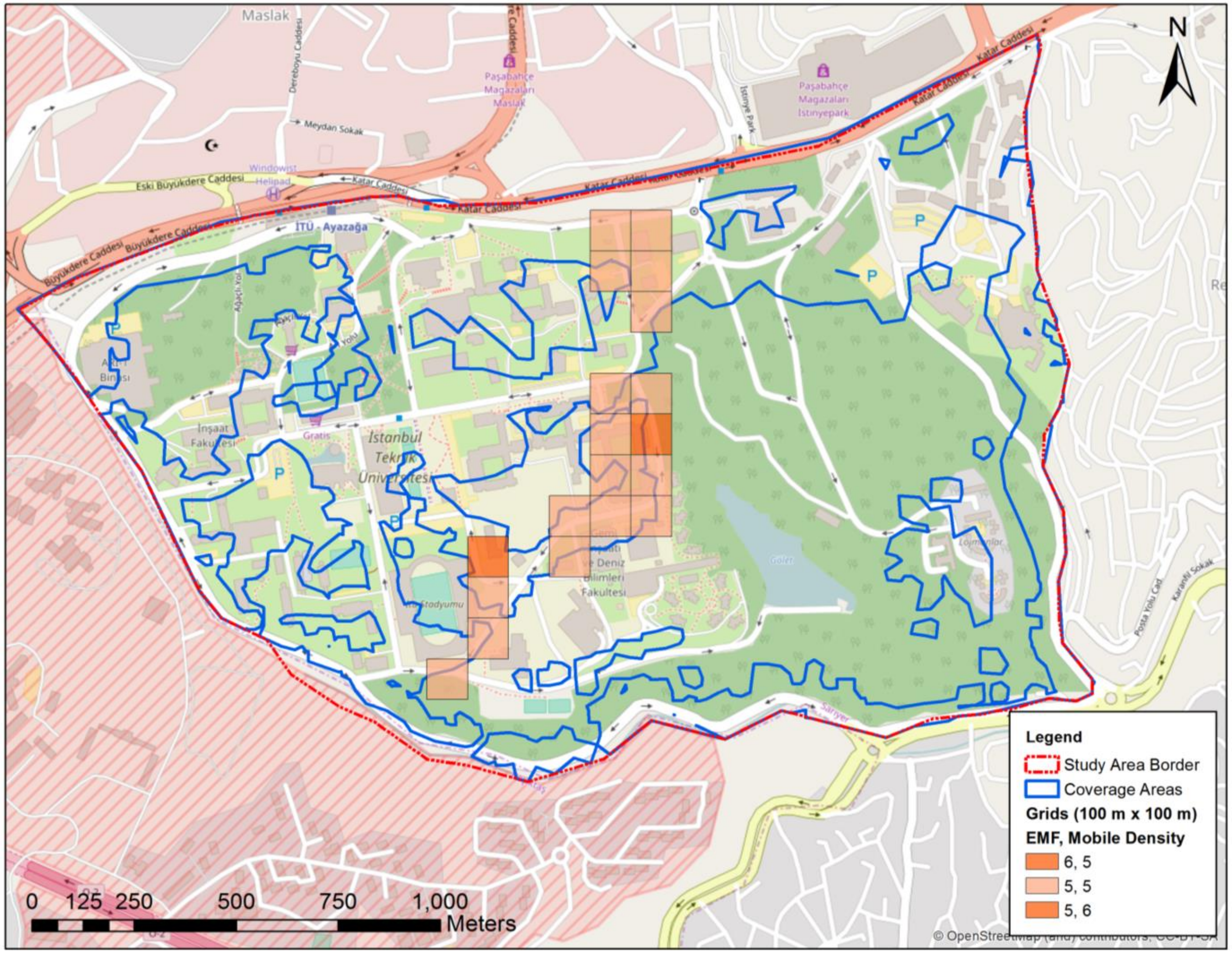


Figure 6.18: High class areas with regard to EMF and mobile density values.

7. CONCLUSIONS AND RECOMMENDATIONS

In this study, spatial interpolation methods are used for calculating EMF intensity values for all study area. The aim of the calculation is to find the nearest prediction values againist the real values. As for that, standard deviation and Mean Square Error (MSE) values have been considered for choosing the best fit interpolation method. The results show that the Radial Basis interpolation method has a minimum standard deviation and MSE values on 1800 MHz frequencies. On the other hand, on 900 MHz frequencies, Empirical Bayesian Krigging interpolation method has a minimum standard deviation and MSE values. According to the result map of 900 MHz frequency, electromagnetic field intensity values on west and north-west areas are higher than other areas and the result map of 1800 MHz frequency, EMF intensity values on east and northeast areas are higher than other areas.

The distribution maps of electromagnetic field intensities in the study area shows that the values are under the limits which are determinated by ICNIRP and are also accepted by Turkey. The highest value in the study area measures as 5.5 V/m. However, the accepted limit values differ from country to another country. In this point, the limit accepted for sensitive areas like universities by Italy is 6 V/m and Sweden is averagely 5 V/m. By considering the result maps, electromagnetic field intensity values of north-west area of ITU are above the Sweden limits and also very near to Italy limits.

Therefore, precautions must be taken for preventing from the undesired results. Especially in sensitive areas like schools, hospitals, the electromagnetic field intensity values must be measured periodically and be controlled with limit values. A standard geo-database can be created for storing electromagnetic intensity values and it may be updated periodically for tracking the values to check if the levels are within the limits or not. Also, accepted limit values must be reconsidered and updated based on more empirically derived results to protect human health.

In this study, there are two main outputs. By considering the possible harm of EMF energy, there are so much unknown issues about human health connected to electromagnetic areas. Furthermore, the accepted limit values in Turkey are high. ITU campus area has high electromagnetic field intensity values according to sensitive area limits of Italy and Sweden. As a precaution, the signal transmitters in electromagnetic areas should be located away from the sensitive areas as far as possible considering 300 m radius effect area.

The second output is the measuring of EMF intensity and creating EMF maps for cities and sensitive areas as it is important for being able to determine the levels periodically. The increasing population in the cities, especially in Istanbul, may lead to increasing cell and social media usage. Consequently, the EMF intensity values may exceed the limits in the near future. As the measurement process is time-consuming and hard, different methologies may be improved by using correlation between supportive data such as social media and crowd-sourced cellular coverage maps. There is a spatial relationship between the values of mobil density and EMF intensity according to the results of this study. %60 of the study area with high EMF intensity values also has high mobile density values at the same time. In this case, this study can be considered as a sample project.

This study is a model study for showing the electromagnetic field intensity distribution of ITU Ayazaga campus area and it can be applied to all university campus areas. As the second step of the study, EMF intensity values, which are not generated by the base stations, should also be measured, mapped and controlled with limit values on indoor and outdoor areas such as Wi-Fi networks.

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