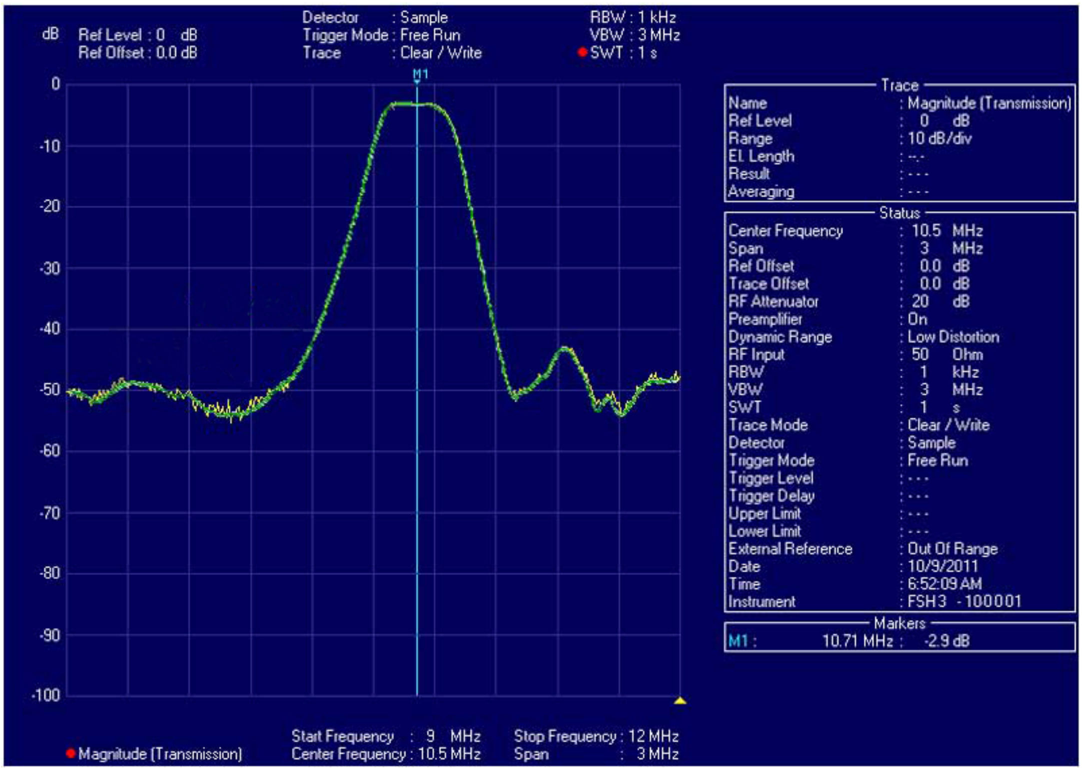

Electromagnetic exposure from wireless communicational systems

Master of Science Thesis in Biomedical Engineering

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Abstract

The purpose of this thesis was to measure the electromagnetic fields from radio and television broadcasting and from mobile phone base stations such as GSM 900, UMTS, and LTE and from WLAN networks. This report consists of measurement methods and result but also the basic information of the wireless communication systems.

The measurements were performed at 48 locations, which include indoors and outdoors sites in Gothenburg city during September 2011. Comparisons between the measurement results and references values, which are provided by ICNIRP, have been performed. These measurement results have also been compared with the measurement results from 2004 [Nilsson and Rydh, 2004] and 1999 [Uddmar, 1999].

The overall mean value of the measured power density was 505 $\mu W/m^2$ and the median value was 228 $\mu W/m^2$. Compared to the reference levels of ICNIRP, the mean value was 139 ppm of the reference level and the median values was 69 ppm of the reference level. The highest total value was measured at Vasagatan Street crossing Avenyn Street with a value of 3005 $\mu W/m^2$ (748 ppm) and the lowest power densities were found at Marklandsgatan 71 and Kaponjärgatan 4C, with the same value of 23 $\mu W/m^2$ (10 ppm). The mean value of power density from indoor sites was 537 $\mu W/m^2$ and the median value was 151 $\mu W/m^2$ and the mean value of power density from outdoors sites was 491 $\mu W/m^2$ and the median value was 251 $\mu W/m^2$. In general, the largest contribution to the total exposure consisted of UMTS and GSM-900 systems for both indoor and outdoor sites.

A comparison with the results from 2004 and 1999 shows that there were higher FM-Radio and analog TV values than the results from 2011, since analog TV system is terminated. The results from 2011 show a small increase in exposure from radio frequency sources. In general, the power densities are in the same order for the three investigations but there are some differences.

Acknowledgments

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February 2012, Gothenburg
Ali Akbari

Content

1 Introduction

A master thesis assessing the electromagnetic fields exposure from radio frequency sources was performed in Gothenburg city and some country sites in 1999 [Uddmar, 1999], there were 26 measurement site in that thesis. In that thesis, the power densities from different radio frequency sources were measured and in each measurement site, the obtained value was compared with standard level of exposure. Another master thesis was done in 2004, in which the exposure from radio frequency sources were measured in 48 measurement sites in Gothenburg [Nilsson and Rydh, 2004]. The exposure power densities from different radio frequency sources were compared with the exposure recommendation and finally they were compared with some of the measurement values from 1999.

The aim of this thesis is to perform measurements, as the previous measurements were done in 1999 and 2004, and in addition measuring the exposure from new sources such as LTE (4G), digital audio broadcasting (DAB), UMTS-450 and WLAN sources, in 48 measurement sites. The results will be compared with the previous measurement values. The aim of this thesis is to provide a range of typical exposure values compare and check the obtained values with the guidelines from the International Commission on Non-Ionizing Radiation Protection (ICNRIP) [ICNIRP, 1998].

The purpose of performing measurements at the same sites is to have a survey of exposure of electromagnetic radiation in Gothenburg, during the measurement years and comparing these exposures. In each measurement site, I tried to perform the measurement at the same place where the previous measurement was done. I have to mention that in 2004, many of the measurement sites were indoor sites, in 2011 I did not have access to the several of these indoor sites so in these sites, I performed outdoor measurements at the some addresses.

Since NMT-450 and analog TV sources are discontinued, we do not have any exposure from these sources. There were exposure from analog TV, NMT-450 and other frequencies in the previous theses, to show and compare the values I use the word ‘Other’ for these sources. In this thesis, all frequency sources from 80 MHz to 2700 MHz are included. In this range of the spectrum, we have radio broadcasting, digital audio broadcasting, digital television broadcasting, mobile phone signals and wireless system such as WLAN.

2 The electromagnetic spectrum

The radio frequency spectrum is a small part of the electromagnetic spectrum, including the frequency range from 3 kHz to 300 GHz as it is shown in figure (2-1). The radio waves are electromagnetic waves; transmitted from antennas. The radio spectrum is divided into frequency bands and sub-bands allotted for various usage.

The electromagnetic spectrum is arranged according to frequency or wavelength. Each frequency has different characteristics. The spectrum can be divided into two categories, an ionizing radiation and a non-ionizing radiation. The non-ionizing radiation does not have enough energy to eject an electron from the atom. Ionizing radiation has enough energy to eject the electron from the atom. For example x-ray and gamma ray are ionizing and radio frequencies are non-ionizing. The low frequency 50 Hz or 60 Hz which are used in power lines and the microwave section from the electromagnetic spectrum which is used in satellite communication.

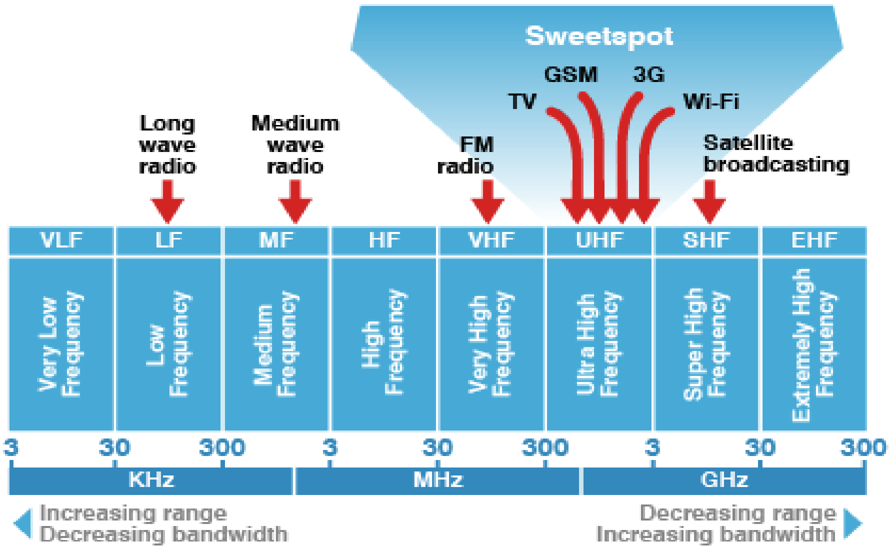

Figure (2-1): A schematic figure of the electromagnetic spectrum [copy right from http://rfdesignuk.com].

In this thesis we focus on radio, mobile phone systems, television system and WLAN system. The frequency spectrum is divided into the various sections. For mobile phone systems, each operator has a special frequency band within the band allocated to mobile phone systems. The first generation of mobile phone systems was NMT (Nordic Mobile Telephony), which used the frequency range 450 MHz, but it was terminated in December 2007 by PTS's (Post och Telestyrelsen) decision. In 2011, a company with the name Net1 was allowed to use this frequency range for UMTS. The second generation of mobile phones which is GSM (Global System for Mobile Communication) works at the frequency bands around 900 MHz and around 1800 MHz. The GSM mobile phone system is divided into the two categories, GSM 900 and GSM 1800.

The third generation of mobile phone system is UMTS (Universal Mobile Telecommunications System) that is marketed as '3G', this generation of mobile phone systems uses a frequency band of 2 GHz. The fourth generation of mobile phone system is LTE (Long Term Evolution), which is marketed as '4G'. The 4G system uses a frequency band of 2.6 GHz. There are also DVB (Digital Video Broadcasting), FM-Radio system, DAB system (Digital Audio Broadcasting) which is a digital radio uses the frequency range 87~200 MHz, DECT system (Digital Enhanced Cordless Telecommunications) which it is a wireless phone system for indoor uses and its frequency range is 1900 MHz, WLAN (Wireless Local Area Network), it is generally producing a connection through an access point to the broad internet and its frequency range is 2400~2500 MHz.

2.1 Electromagnetic fields (EMF)

The magnetic fields are produced when an electric current flows, by increasing the electric current we will have a greater magnetic field. There are important parameters in EMF; amplitude, frequency, phase, wavelength. Frequency 'f' is the number of changes that wave changes direction per second and its unit is [Hz]. Amplitude is the magnitude of change in displacement from the beginning of the EMF wave. The wavelength is the length of the EMF wave 'λ' which is from one peak to the next peak and its unit is [m] and it is equal to the speed of light 'c' divided by its frequency as it is shown in the equation (2-1). The electromagnetic fields are used in wireless communication system for transferring the signals. The communicational signals such as mobile telephones, television, radio transmitter and radar can be transferred over long distances by using radio waves.

$$\lambda = \frac{c}{f} \qquad \text{Equation (2-1)}$$

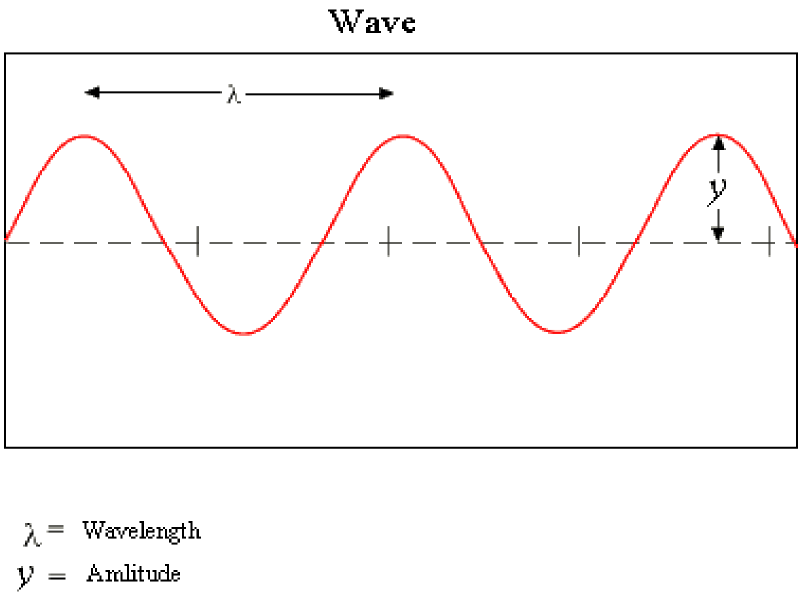

Figure (2-2): A principal sketch of an electromagnetic wave.

The electric field is expressed by E and its unit is [V/m]. H expresses the magnetic field strength, and its unit is [A/m], it shows the measured amperes per meter. The relation between electric and magnetic fields in the far field is shown in the equation (2-2).

$$\boldsymbol{H} = \frac{\boldsymbol{E}}{\boldsymbol{Z}} \qquad \text{Equation (2-2)}$$

Where Z is the impedance in the free space and vacuum and its value is 377 Ω [Cheng, 1994].

The power density which is propagated trough a surface as it is shown in the equation (2-3) represents the intensity of radio frequency fields. The power density unit is watt per square meters [W/m^2]. S expresses the power density.

$$\mathbf{S = E \times H = E^2 / 377 = 377 \times H^2} \qquad \text{Equation (2-3)}$$

The exposure from the far field where the wave fronts considered have a planar geometry, decrease with the second power of the distance, see equation (2-4).

$$S = \frac{P.G}{4.\pi.r^2}$$ Equation (2-4)

Where S is the power density with the unit of [W/m^2] and G is the gain from antenna and r is the distance from the antenna and P is the transmitted power with the unit [W].

This exposure from base station antenna can be shown in vertical and horizontal pattern. The vertical radiation is narrower than horizontal exposure in the base station antenna. In figure (2-3) these exposures are shown. Sector is the coverage zone by the antenna. Base station antennas use 120 degrees of sectors. The radiation in front of the antenna is usually 300 times bigger than the radiation behind the antenna and the radiation in the ground level is smaller than the radiation from the upper level [Mohammad, 2007].

The radiation increases inside of the main lobs and at the same time the radiation decreases with the second power of the distance from the source. This means that the highest level of radiation at ground level can be seen around 50~300 meter from an elevated antenna, [Hamnerius, 2005, page 44].

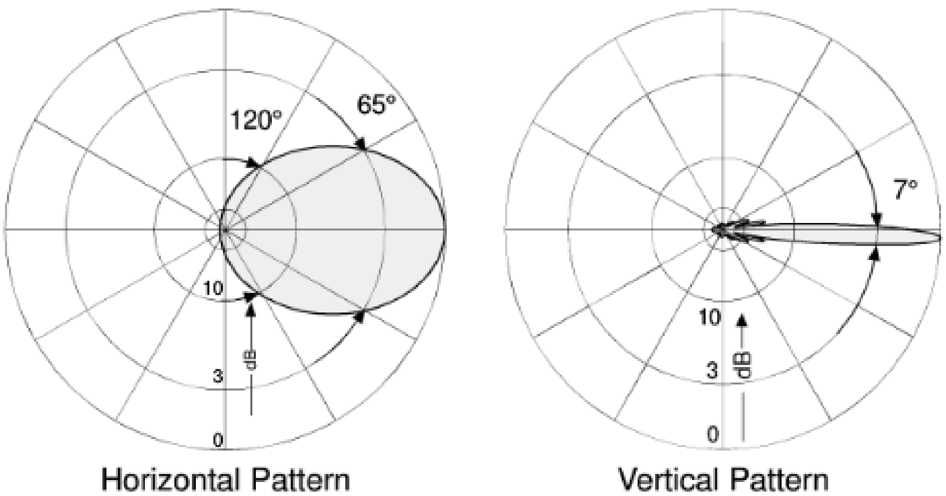

Figure (2-3): Radiations from horizontal and vertical directions from the antenna.

2.2 Fading

Wireless channels are very unpredictable with challenging propagation conditions. In an ideal wireless channel, the received signal is a reconstruction of the transmitted signal. However, in real radio systems, the signal would be modified during its transmission along the channel [Arbat, 2008].

Wireless channel is characterized by:

- Path loss
- Fading
    - Fast fading
    - Slow fading

2.2.1 Path loss

Path loss describes the attenuation, in power density, when the signal propagates into space. This expression is usually used in wireless systems and it is one of the parameters in analysis and designs the telecommunication systems. It depends on many parameters such as refraction, the distance between transmitted and received antennas, propagating in the humid or dry air, coupling loss, diffraction and absorption [Arbat, 2008].

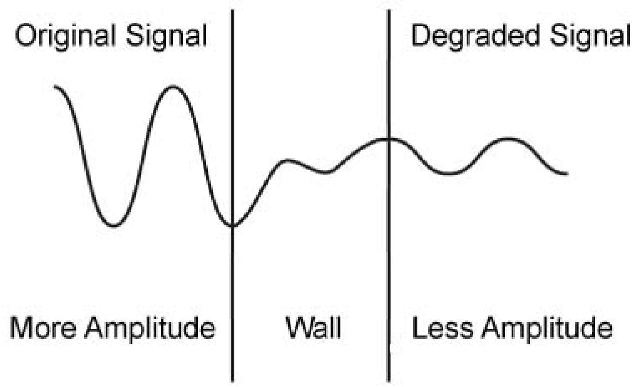

Figure (2-3): The example of how path loss affects on the signal by an absorption object.

2.2.2 Fading

Fading is an expression in wireless communications. Fading is a deviation of attenuation that a carrier-modulated telecommunication signal experiences over specific spreading area. The fading might be various with time and physical position (geographical position) and it is usually modeled as a random process [Arbat, 2008].

2.2.2.1 Fast fading

The amplitude and phase would be changed by the channel changes significantly over the period of use. This effect also is known as multipath fading. In other word, because of the reflections in the surroundings, the signal can carry away several different routes to arrive a certain point. Since the signals that come from various routs, they would be super-positioned so that the amplitude and phase of the signal will be changed (attenuated or amplified).

As a result, in the small space between two points, the amplitude and phase of the signal from the second point might have a different value from the first point. This phenomenon affects on the power densities from mobile phone systems. There is solution to overcome this losing that is known ‘frequency hopping’, we will discuss about it in the next page [Arbat, 2008].

2.2.2.2 Slow fading

Shadowing causes slow fading. This fading can modify the covering area. If there is an obstacle between the mobile station and base station, it causes the signal’s energy can be changed so that the power density in the receiver will be varied. In this type of fading due to the low rate of its changing, the amplitude and phase can be considered as constant during a cycle of the time. By varying the time, it is not possible to correct it. As we mentioned, in fast fading, by changing the distance, the signal can change extremely but slow fading is more constant [Arbat, 2008].

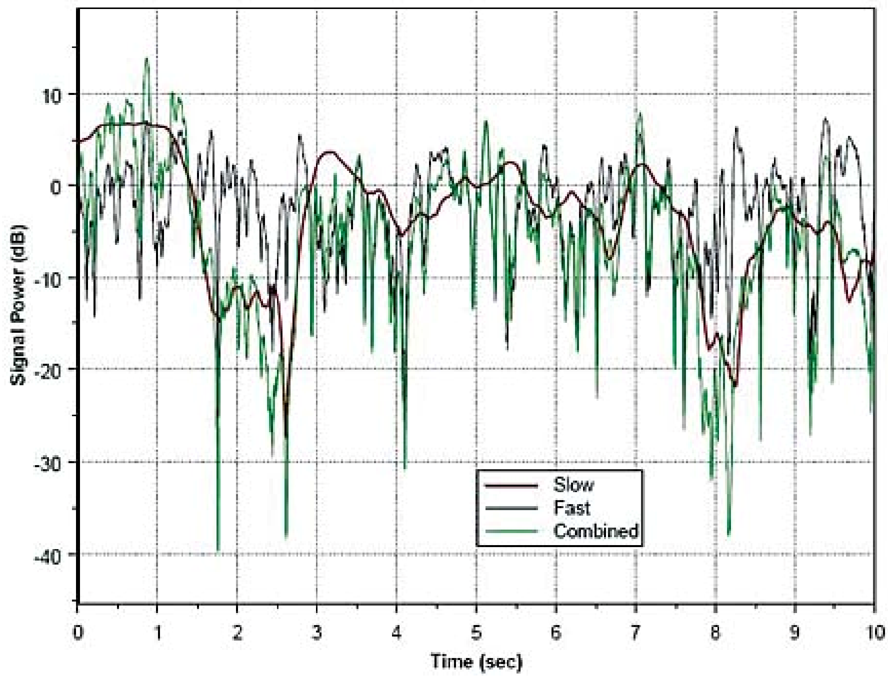

Figure (2-4): Fast and slow fading.

2.3 Frequency hopping

Frequency hopping (FH) is a modulation method that is used in GSM systems. Frequency Hopping means that the calls jump between different frequencies channels according to a scheme. The main purpose of FH is to change the frequency constantly and thereby reduce the loss of signal power due to multipath fading. Some of the frequency channels, however, do not hop. These channels are called BCCH (Broadcast Control Channel), and do not contain audio. Instead they are used for such things as controlling which BS the MS shall communicate with. This technique can minimize the fast fading phenomenon [Nilsson and Rydh, 2004].

3 Data transmission techniques

3.1 Frequency Division Multiple Access (FDMA)

The radio frequency spectrum is a limited source. In order to use it by many mobile phone users, there is a procedure, which is called multiplex. The multiplex is a method for separating the data in the time domain or frequency domain. NMT cellular system used a multiplex method for carrying the data, which is known Frequency Division Multiple Access (FDMA). The data channel uses different frequencies for transmitting the data. So that one channel is assigned for data from mobile station to base station which is called uplink and another channel for data from base station to mobile station which is known downlink. These two separate channels are like a pair of channels. This technique for connection is known duplex. Duplex was used in NMT cellular system with frequency separation, which is called Frequency Division Duplex (FDD), see figure (3-1) [ENKI-Training, 2009].

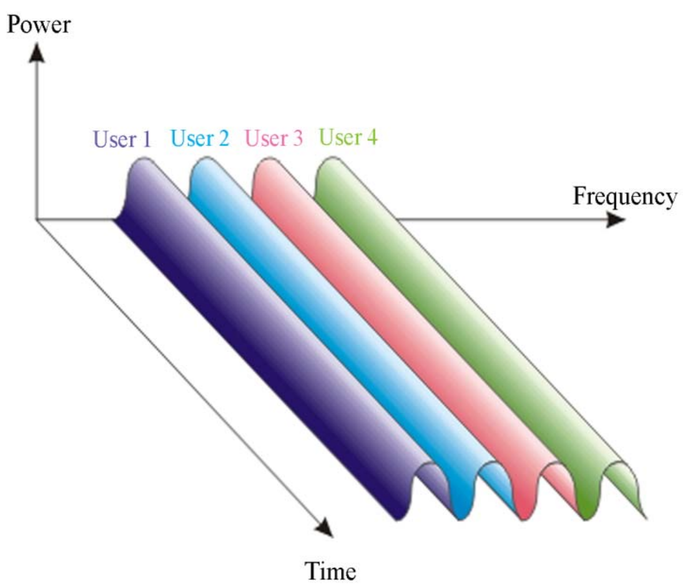

Figure (3-1): FDMA with FDD is usually used in analogue cellular system.

3.2 Time Division Multiple Access (TDMA)

Other digital cellular mobile systems, like GSM-900 and GSM-1800, use a system to separate the data in time and transmit the time slots of data at a certain time on a certain frequency; one timeslot at a certain frequency channel is called a slot. This technique is called Time Division Multiple Access (TDMA) so, by using the various time slots, different data can be transmitted at the same time. In GSM cellular systems the duplex separation is created by FDD. In figure (3-2) TDMA is shown. Time Division Duplex is another duplex technique, which uses a single frequency channel for transmitting and receiving data at the same time. By dividing time on frequency into two packets (time slot), this technique is obtained [ENKI-Training, 2009].

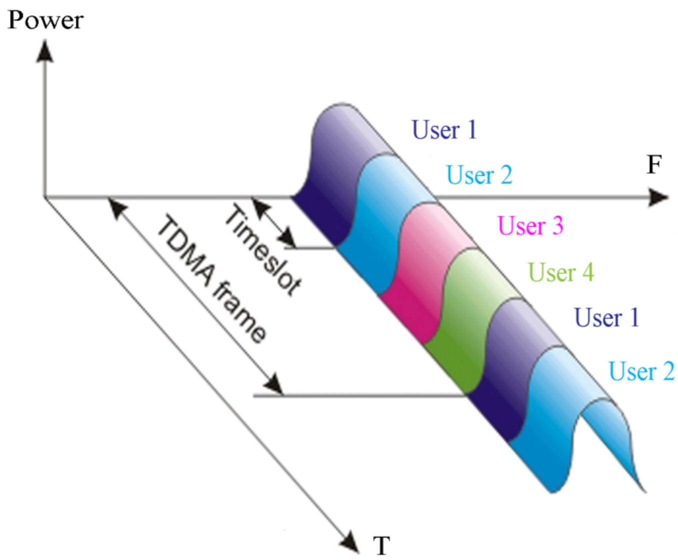

Figure (3-2): TDMA technique in GSM cellular systems.

3.3 Code Division Multiple Access (CDMA)

The third generation mobile phone system uses Code Division Multiple Access (CDMA). This technique lets the simultaneous transmission of multiple mobile phone users in the same frequency band. By means of different codes, this separation is obtained. These codes have to be independent of each other. UMTS uses the Wideband Code Division Multiple Access (WCDMA) technique, which uses the wide frequency bandwidth range, 5 MHz. This wide frequency bandwidth allows lowering in the power density, therefore the mobile phone signal might be weaker than the thermal noise rate. In figure (3-3) CDMA technique is shown [ENKI-Training, 2009].

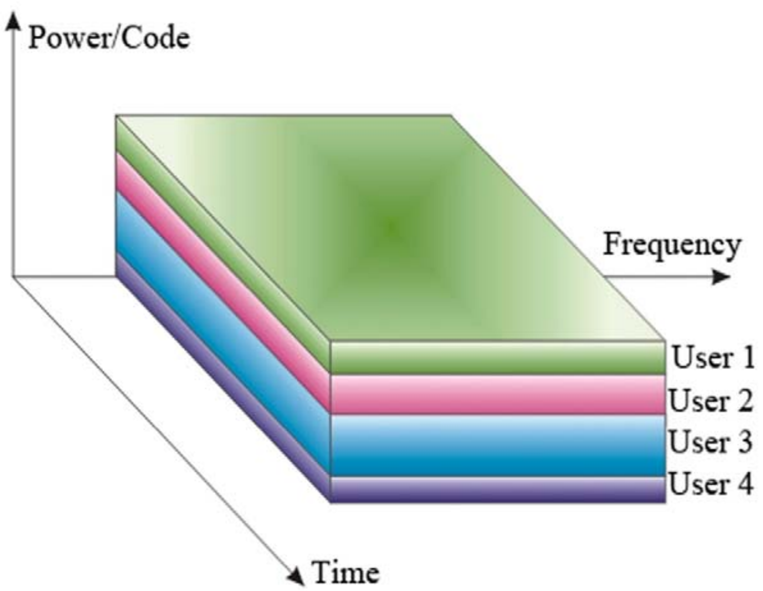

Figure (3-3): CDMA technique in wireless commutation.

3.4 Orthogonal Frequency Division Multiple Access (OFDMA)

The fourth generation of mobile phone systems and digital broadcasting use OFDMA (Orthogonal Frequency Division Multiple Access). Long Term Evolution (LTE) and Worldwide Interoperability for Microwave Access (WiMAX) use this technique for transmitting the signals. This method was introduced in 1960 but because of the high expenses and lack of the appropriate technology for employing it, that was just theoretical technique for a long time. By development in technology, this technique now is widely used in Wireless Local Access Network (WLAN) and digital broadcasting and digital television broadcasting and LTE and WiMAX. The OFDMA technique is a special kind of Frequency Division Multiple Access (FDMA), which allows for transmitting the message simultaneously, by using multiple narrow ranges of frequencies, which are known subcarriers. The idea of this technique is simple but when you want to implement it, it is not. Multiplexing and de-multiplexing of OFDMA symbols, which are representing user data bits rate, into subcarriers is performed by using computations which are called Inverse Discrete Fourier Transform (IDFT) and Discrete Fourier Transform (DFT). These methods can transform signal from the frequency domain into the time domain and it can be done reversely by using IFFT (Inverse Fast Fourier Transform) and FFT (Fast Fourier Transform) algorithms. These algorithms use complex numbers. In figure (3-4) OFDMA is shown [ENKI-Training, 2009].

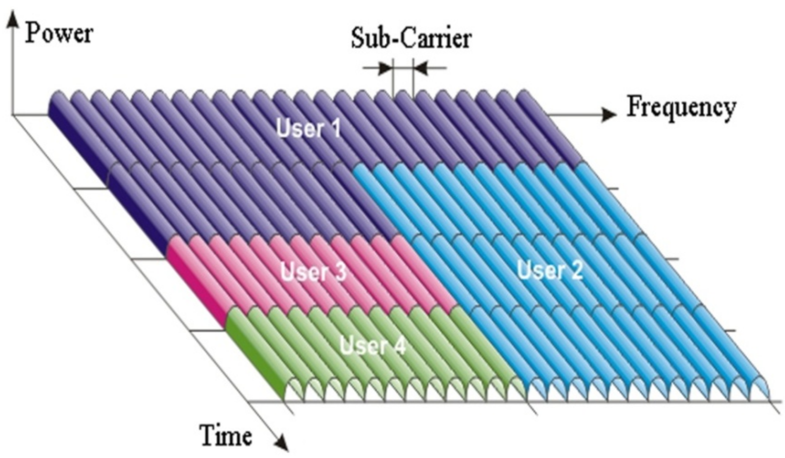

Figure (3-4): OFDMA technique in digital transmitting.

4 Cellular mobile phone systems and WLAN

A cellular service in an area consists of many cells and in each cell there is a transmitter and receiver, which is called Base Station (BS), these base stations are not moveable and usually fixed in a high position such as roofs and towers and on walls. A mobile phone system also includes of mobile stations (MS), which are moveable. The mobile stations can move freely in the coverage zone and make a connection to the other mobile stations in the coverage zone by using the coverage from other base stations.

Therefore a mobile station can connect either with another nearby the mobile station via the base station, if the mobile station moves away and outs of the coverage zone, another base station can cover and support the mobile station. The signal transmission from the base station is called downlink and the signal transmission from the mobile station is called uplink. Another parameter in mobile phone system is switching. The switching sub system is linked to the Public Switched Telephone Network (PSTN). It creates a connection between mobile stations and conventional telephones [Mohammad, 2007].

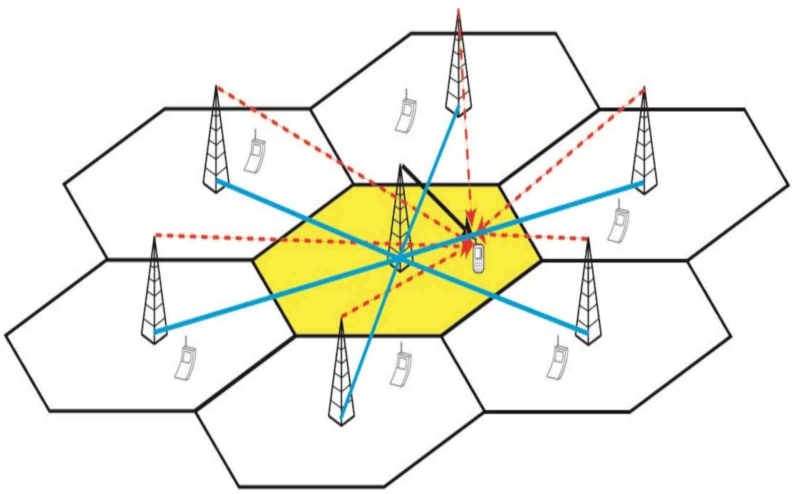

Figure (4-1): A cellular system of seven base stations, corresponding to seven different cells.

Important characteristics are frequencies, which are reusable by distant transmitter. The cellular service in each zone contains cells and each cell has a base station and certain frequencies that are reused in other cells that are far from the base station. These cells use all frequencies, which are known ‘cluster’, they are repeated periodically. An important basic principal in cellular system is a hand-over, which is performed between two near cells. By using this mechanism, it ensures continuity in the communication during a movement of mobile station between two cells. By increased user's demands, there is need to increase the network capacity. This can be achieved by dividing a cell into a numbers of smaller cells. The numbers of antennas (transmitter-receiver) are increased thus more mobile phone users can be supported, using of the corresponding frequencies.

4.1 Nordic Mobile Telephony System (NMT)

There are different types of mobile communication system with different techniques in transmission; at the first part we describe NMT 450. Nordic Mobile Telephony was the first type of cellular mobile phone systems. This system was based on analogue technique; it was the first generation of mobile phone systems (marketing name, 1G). There were two types of this system, NMT-450 and NMT-900. The numbers after NMT were indicated the frequency band which are used in the radio frequency communication. The downlink frequency band for NMT-450 was 463~468 MHz and the uplink frequency band was 453~458 MHz. The channel separation was 25 kHz. In NMT-900, the downlink frequency band was 945~960 MHz and the uplink frequency band was 890~915 MHz. NMT-450 had 180 pairs of channels and NMT-900 had more channels, it contained 1999 pairs of channels. Nowadays there is no more use of NMT-450 and NMT-900; instead the frequencies are used for other systems such as UMTS-450 and UMTS-900. NMT system had an advantage in coverage. The data technique transmission, which was used for NMT system, is known Frequency Division Duplex (FDD). If the base station has to support many users in the same time, then automatically the other users will be diverted to the different frequency duplex. In this technique the separation is called Frequency Division Multiple Access (FDMA). Figure (4-4) shows an example of FDMA in NMT system.

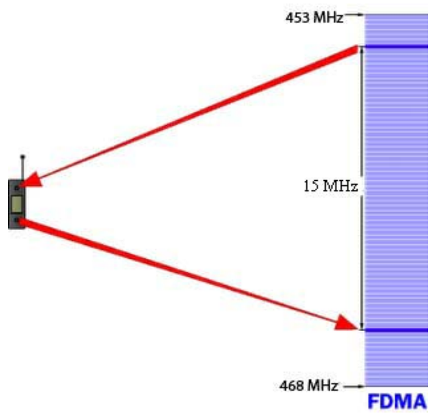

Figure (4-4): FDMA in NMT system with 25 kHz separation bandwidth.

4.2 Global System for Mobile Communications (GSM)

The second generation of mobile phone system is one of the most used systems. GSM is a digital system unlike the NMT system, but GSM also uses FDD technique for separating the uplink and downlink channels. A method for separating data in the GSM system is little more complicated than in the NMT system. The data, which is transferred between, base station and mobile station, is discontinuously in downlink and uplink. The time is divided into the packets and each packet contains of eight time-slots. The base station and mobile station transmit just one eighth of the time. This means that up to eight calls can share the same frequency channel. The TDMA technique is for separating the time into the different time-slots for different calls as we mentioned in the previous pages [Uddmar, 1999].

The GSM cellular system uses a combination of FDMA and TDMA techniques, with channel separation 200 kHz, to separate downlink and uplink. There are two types of GSM cellular systems, GSM-900 and GSM-1800. In a GSM system, a call corresponded to the same slot in each packet. To reduce interference, the GSM cellular systems use frequency-hopping method (section 2-3) [Nilsson and Rydh, 2004].

The downlink frequency channels for GSM-900 are between 921~960 MHz and it uses 124 pairs of channels. The uplink frequency channels for GSM-900 are 876~915 MHz. In the GSM-1800 cellular system, the uplink frequency channels are 1710~1785 MHz and the downlink frequency channels are 1805~1880 MHz. The GSM-1800 uses 374 pairs of channels, so it has more capacities than GSM-900. The wavelength in GSM-900 is twice as long as that in GSM-1800. Both of them have good covering in the areas, for example behind a building and a wall. Fewer base stations are needed which means that the fewer channels are needed at GSM-900 than GSM-1800 for reaching the same coverage [The Stewart Report, 2000].

The maximum output power is 2 W for GSM-900 and 1 W for GSM-1800. This power is the peak power. The average maximum value from GSM cellular system is 0.25~0.125 W, due to using TDMA method [SSM, 2001]. The total power from a call is commonly reduced by a considerable amount, because of using these two techniques, adaptive power control (APC) and discontinuous transmission (DTX). APC means that the phone continuously adapts the power density, which it transmits, to the minimum power density, which is needed for the base station to receive the signal. This can be less than the maximum power by a parameter of up to a thousand, if the phone is adjacent a base station [The Stewart Report, 2000]. This also means the reducing of the disturbing signals to neighboring zones.

When the user starts a call, the maximum power density is first used, but then APC is used to obtain a level decided by the base station. In DTX, the power density is switched off when the mobile phone user halts the conversation or listening. By using of DTX, it results in reducing the average of power density with approximately 50 % and decreases the use of the mobile phone's battery. These controls are used in both up- and downlinks transmission. DTX is used in GSM and UMTS, [Hamnerius, 2005]. The maximum output from a mobile phone happens, if it is in a far distance from base station or call is made inside the building.

4.3 Universal Mobile Telecommunications System (UMTS)

The UMTS system is also known as the third generation of mobile telecommunication systems. UMTS is more complicated technique than GMS system. This system uses the frequency channels 2110~2170 MHz for downlink and the frequency channels 1920~1980 MHz for uplink. This type of digital cellular mobile phones in addition transferring audio data is also used for transferring high bit rate of multimedia communications.

The typical maximum output power is around 0.25 W, but the output power is generally one thousand of this value due to APC. UMTS uses WCDMA (see the section 3-3) technique for transferring the data with the maximum speed of originally 2 Mbps that lets advanced multimedia communications, but it is developed now and the maximum speed of download is 16 Mbps [Hamnerius, 2005]. The various mobile stations can use of the same frequency channel at the same time likes GSM system, the frequency channels separation is 5 MHz between downlink and uplink frequency channels. Since the transmission happens at the same time the changes in the amplitude in the carrier signal are random.

There are two kinds of CDMA (FDD and TDD). FDD separates the downlink and uplink with 5 MHz and TDD uses the same channel for downlink and uplink but in the different time-slots. These two techniques come to pulse modulation, due to the need of sending the usual commands from the base station to change the power level. In Sweden, FDD is used for separating the channel frequencies. Each channel is divided into packets of 10 ms period. Each packet contains of 15 time-slots. These time-slots include two physical channels, one of them is for the data and another one is for pilot [Trulsson, 2003].

The pilot is transmitted continuously from the base station to produce the power density, which is needed for synchronization to the code sequence. In DSSS, the signal is multiplied to a certain code which this code is -1~1 which spreads the signal over a larger frequency interval. UMTS base stations usually have three different antennas, which correspond to three sectors. These three antennas can be operated independently of each other with different power densities [Trulsson, 2003]. All cells use the same frequency channel for one carrier. When a mobile station is inside a certain base station sector, the mobile station will be connected to this base station. During the movement of mobile station, it will go out of the coverage from the base station, and then the mobile station will be transferred to another base station.

4.4 Long-Term Evolution system (LTE)

LTE (Long-Term Evolution) system is a fourth generation of the cellular mobile phones, which in the marketing is known as 4G. This system was introduced in 2009 in Stockholm, Sweden. The downlink frequency channel is 2620~2690 MHz and the frequency channel for the uplink is 2500~2570 MHz. The maximum speed rate of download is 100 Mbps and it can be increased up to 300 Mbps [Wout, 2011].

4.4.1 LTE Requirements and Performance Targets

During the 3rd Generation Partnership Project (3GPP) it was understood in 2005 that the High Speed Packet Access (HSPA) could support the mobile broadband solution for many years, the potential threats from other technologies produced a desire to make sure competitiveness in the long time. It was the justification for beginning the LTE research in 3GPP. The important points for the LTE system in 3GPP are the data rates, which it can handle many users, and improving the capacities on the coverage zone and decreasing the expenses for the cellular mobile phone companies [Clerckx, 2009].

The LTE system supports a flexible carrier channel bandwidths from 5 MHz to 20 MHz. It also supports Frequency Division Duplex (FDD) and Time Division Duplex (TDD). So far, there are 10 paired frequency bands and 4 unpaired frequency bands, which have been identified by 3GPP for LTE. An operator might describe the LTE system in the new bandwidth where it is simple to spread the carrier from 10 MHz ~ 20 MHz and in result, spreading the LTE system in all of the bandwidths. The LTE system can have many features which simplifies the management of the next cellular network system. The self-configuration and self-optimization can decrease the expenses of implementation of the cellular network [Weber, 2011].

There are many electronic devices like computer, laptop, mobile phones that can use the LTE system. All of these devices can use the LTE system, that can provide the hand over and roaming feature to create the mobile network.

4.4.2 Performance and capacity

One of the requirements in the LTE system is to support the maximum rate of 100 Mbps. The LTE system lets the speed increases up to 200 Mbps. Ericsson Company has presented 150 Mbps. The Radio Access Network (RAN) round-trip times will be less than 10 ms, this means that the LTE system has more requirements of 4G system than the other systems. The comparing both UMTS and LTE systems is shown in table (4-1).

	UMTS	LTE
The maximum downlink speed [bps]	16 M	100 M
The maximum uplink speed [bps]	5.76 M	50 M
Latency round trip time approx [ms]	150	~10
Approx years of initial roll out	2003~2004	2009~2010
Access methodology	CDMA	SC-OFDMA / OFDMA

Table (4-1): Comparing the basics of UMTS and LTE systems.

4.4.5 MIMO in the LTE system

Multiple Input Multiple Output (MIMO) is another major topic, which is used to improve the LTE system. By using the OFDMA technology, it can provide the LTE system with the ability of improving the data rate. In spite of the fact that MIMO technology adds intricacy to the system regarding of processing and the number of the base station antennas which are needed, it provides a high rate of the data to be obtained along with the improved efficiency, therefore MIMO consists an integral section of the LTE system. The basic concept of MIMO is that this technology uses the multipath signal scattering that is represented in all types of communications [Weber, 2011].

There are two restrictions in the communication channels; multipath interference and the restriction on the information throughput described by Shannon's Law. The MIMO technology supports a way of using the multipath signal routs, which is between a receiver and transmitter, to meaningfully improving the information throughput available, on a certain channel, with the described bandwidth. By using the multiple of the base stations along with the some complicated digital signal processing, the MIMO technology makes it possible for the system to set up multiple information on the same channel, as a result increasing the size of the information of the channel bandwidth. The MIMO technology performs multiple base stations antennas on the receiver and transmitter to use the multipath influences that are to transfer the extra information rather than causing interference [Weber, 2011].

The plans performed in the LTE system are very different between the downlink and the uplink. The reason for this is to maintain the terminal expenses in low range. For the uplink channels, from the mobile station to the base station, there is a scheme that is known Multi User MIMO (MU-MIMO). By using the MU-MIMO even though the base station needs the multiple antennas, the mobile stations just have one transmitting antenna because of this, the price of the mobile phone will be lower. For the downlink channels, there are two transmitting antennas in the terminal station and there are two receiving antenna in the mobile station; So that, we have four configurations for the antennas [Weber, 2011].

4.4.6 System Architecture Evolution (SAE)

There is a high data rate for the LTE system; therefore it is essential to develop the structure of the system to have an optimized performance of the system. A number of functions were handled by the core network, which has transferred out to the periphery. This provides a lot flatter form of the network structure, so the latency times will be decreased and the information will be routed to its destination. It is expected that the operators will commence defining hardware conforming to the new SAE; therefore the expected information ratio will be controlled [Weber, 2011].

A new SAE has been released, which is compatible with the Long-Term Evolution Advanced (LTE-Advanced), which is the next technology in the cellular mobile phone systems. So that when the new generation of LTE (LTE-Advanced) is released, the cellular network can handle the increased information with a small change in the network. The SAE has many advantages compared to the previous technologies that are used in the different cellular systems. The main advantage is the improved capacity of the network while using this technology. The information downlink speed level is 100 Mbps and it is completely focused on the mobile broadband system. So the network can support high data rate transfer of information [Weber, 2011].

The SAE system scheme has adopted the entire IP network configuration. The third advantage of the SAE system is that it can act faster to responses, so the SAE system is evolved to make sure that the rate of the latency is decreased to around 10 ms. This means that it is suitable response for the LTE system. The last benefit of using the SAE system, which is the main parameter for every operator, is to decrease the expenses of the network.

Hence, it is possible while using SAE system to decrease costs, the expenses of the network should be decreased, these expenses which are called the Capital Expenditure (CAPEX) and the Operational Expenditure (OPEX).

4.4.7 The LTE frame and sub-frame structures

The LTE system can keep synchronization; also the network can handle different kinds of the data which are required to be carried between the BS and eNodeB (E-UTRAN solely contains the evolved base stations, called eNodeB or eNB), so the LTE system has introduced frame and sub-frame structures for the Evolved UMTS Terrestrial Radio Access (E-UTRA), for example the air interface for the LTE system. The frame structures for the LTE system use different technique modes (FDD and TDD). There are various requirements in the transferring of information.

The overall time in this structure is 10 ms. This length of the time is divided into 20 time-slots. Therefore the LTE frame consists of 10 sub-frames. The length of time 10 ms comprises two half frames (5 ms) and each half frame is divided into five sub-frames (1 ms). These two types of LTE frame structures are shown in figure (4-5).

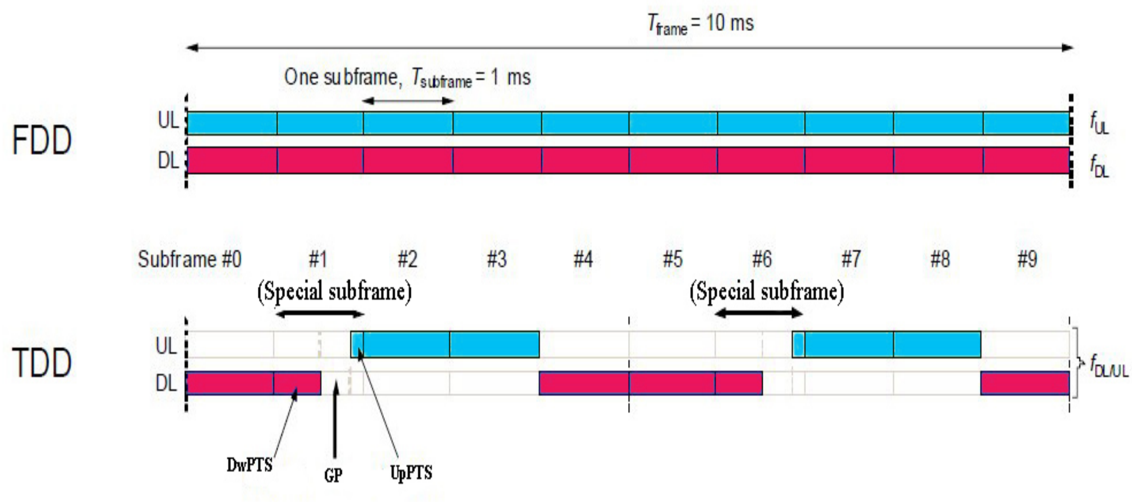

Figure (4-5): The LTE frame structure.

The sub-frames are divided into the standard sub-frames of the special sub-frames. There are three types of special sub-frames:

- Downlink Pilot Time-Slot (DwPTS)
- Uplink Pilot Time-Slot (UpPTS)
- Guard Period (GP)

4.4.8 Transmission techniques for LTE system

The LTE system uses OFDMA for downlink, which is a multi carrier OFDMA transmission procedure. There were three techniques for uplink, Single Carrier Frequency Division Multiple Access (SC-FDMA) and OFDMA and Multi Carrier CDMA (MC-CDMA) but majority of the operators preferred to use SC-FDMA, because of its more desirable Peak to Average Power density Ratio (PAPR), PAPR is a very important parameter in the uplink, because efficient power control is needed in the cell phone, therefore LTE system uses SC-FDMA technique for the uplink [Weber, 2011].

SC-FDMA has a great PAPR, but in the other hand, this technique suffers from inter symbol interference, when the channel is frequency selective within the allocated bandwidth, it is comparable bigger than the coherence frequency bandwidth of the channel, but OFDMA has not this problem so that there should be optimization for SC-FDMA technique. SC-FDMA technique uses a period prefix like OFDMA technique for downlink [Weber, 2011].

The computational mathematics in both downlink and uplink is the same. The downlink and uplink share the same source block size of 180 kHz that are 12 subcarriers. The maximum bandwidth for downlink and uplink is the same; the SC-FDMA symbol time for downlink is like OFDMA symbol time. For implementing the SC-FDMA is just simply need to take DFT from the modulation symbols prior to mapping the IFFT in a conventional OFDMA. There is a limitation here, in order to obtain the single carrier property; the subcarriers that are used for a special mobile phone user have to be contiguous [Weber, 2011].

The single carrier property can be reached by using a distributed allocation with uniformly spaced sub-carriers. The uplink's orthogonality of the LTE system is held in two ways; the first way is by synchronizing the time of users inside a small fraction of the CP through the use of Timing Advance (TA). The second way is by using schedulers in the base stations that will make sure that the different mobile phone users are allocated to the different sub-carriers.

Orthogonal technique in the LTE system means that the mobile phone users do not have the same cell interference as in the case of CDMA technique. Another factor in the LTE uplink is the availability of a channel Sounding Reference Signal (SRS). The SRS is a sequence that is transmitted from the mobile phone user mobile device in order to let the scheduler of the base station to reach the channel state data [Weber, 2011].

4.4.9 Security in the LTE system

The security is one of the important parameters in the LTE system. However with growing the rate of security attacks, it is important to make sure that the LTE system lets users to operate freely and without any fear of the security attack. The LTE system also has to be organized in a way that this is secure against of hackers. By development in the security of the LTE system, there are several parameters that should be concerned; the first one is, the LTE system must support at least the same level of the security parameters, which was supported by UMTS system.

The second parameter is that the security of the LTE system must not affect on the convenience of user. The security of the LTE system has to support the users from security attacks. The third parameter is that the security functions of the LTE system must not affect on the transferring from the UMTS system to the LTE system and finally the fourth parameter is that the security method, which is called Universal Subscriber Identity Module (USIM) and is used in the UMTS system, has to also be used in the LTE system.

4.5 Digital Enhanced Cordless Telecommunications (DECT)

DECT is a cordless phones system which is used indoors and it operates at the frequency channels 1880~1900 MHz. The DECT standard uses ten carriers (frequencies) in the 1880-1900 MHz band, in a TDD transmission mode [Uddmar, 1999]. In 1992 European Telecommunications Standards Institute (ETSI) introduced this technique. The DECT system is also used as a wireless PABX (Private Automatic Branch Exchange). DECT system uses TDD for transferring the data [Uddmar, 1999]. A single packet contains 24 TDMA time-slots and occupies 10 ms. The first 12 time-slots describe 12 logical channels for transferring the data from the base station to the mobile station and the remain of 12 time-slots describe 12 logical channels for transferring the data from mobile station to the base station.

A mobile station has access to all possible combinations of frequency and time-slot and when a call is connected to the base station, the base station can allocate the combination of frequency and time-slot, with the least interference. Therefore a single carrier supports 12 full-duplex logical channels [William Stallings, 2001]. The maximum output power from the base station and mobile station is around 250 mW but depending on how many calls are made, and how many of them the base station can support, the average of power density from the base station to the mobile station can be around 10~125 mW. The maximum output power from the mobile phone are changing between 125~250 mW and the mean values are around 5~10 mW [SSM, 2001] which means that the mean power can be around 4% of the maximum value.

In some of the PABX systems a beacon signal is transmitted from the base station in order to synchronize the mobile station. This signal is just one-fifth time-slot and its average of power is 2 mW [Uddmar, 1999]. The coverage of base station inside building is 50~100 meters and in the outdoor, without any obstacle, is around 300 meters.

4.6 Wireless Local Area Network (WLAN)

WLAN system is a wireless local area network, which connects two or more computers without any wires. This system uses a spread-spectrum technology based on high frequency radio waves enabling communication between devices in the limited zone. There is a standard for using this system that is defined from IEEE LAN/MAN standard committee and is called IEE 802.11x. In the 802.11x family are included several modulation in the air technique and all of these techniques use the same protocol. There is a standard for 802.11 which was introduced in 1997 and it can provide 1~2 Mbps transmission rate in the frequency channel 2400 MHz [Mohammad, 2007].

The transmission technique, which is used in this system, is Frequency Hopping Spread Spectrum (FHSS) or Direct Sequence Spread Spectrum (DSSS). There three types standards of 802.11n, 802.11b and 802.11g. 802.11b and 802.11g use the frequency channel 2400 MHz and they can provide 11~54 Mbps transmissions. The Bluetooth technology and DECT system also operate at 2400 MHz so that there is interference between WLAN and these systems. The 802.11b standard uses the Complementary Code Keying technique (CCK) for transferring data and the 802.11g standard uses the OFDMA method to transfer data. The 802.11n can operate in both 2400 MHz and 5100 MHz bands. Only the 2400 MHz band was measured in this study because of the range of spectrum analyzer. The parameters of WLAN system, which link to a wireless network, are called stations and equipped with Wireless Network Interference Cards (WNICs) [Mohammad, 2007].

There are two types of stations, Access Points (AP) which are the base stations for the wireless network and they are for transmitting and receiving the high rate of radio frequency signals enabled devices to communicate with, another types of station are Wireless Clients (WC) which are generally the mobile stations for example computer, laptop and etc. but these kind of stations can be fixed some mobile stations for example workstations which are equipped with WNICs. There are two types of wireless systems, the Basic Service Set (BBS) that contains several stations that can connect to the AP, and the Extended Service Set (ESS) that consists of several BSS interconnected into one logical network. The AP in the ESS is linked together by a distribution system [Mohammad, 2007].

4.7 Overview of seven wireless systems

System	UMTS 450	GSM 900	GSM 1800	DECT	UMTS	WLAN	LTE
Type	Digital	Digital	Digital	Digital	Digital	Digital	Digital
Transmission Technique	FDMA	TDMA	TDMA	TDMA	WCDMA	--------	OFDMA
Frequency downlink [MHz]	463~468	921~960	1805~1880	1880~1900	2110~2170	2400~2500	2620~2690
Frequency uplink [MHz]	453~458	876~915	1710~1785	1880~1900	1920~1980	2400~2500	2500~2570
Duplex method (APC)	FDD	FDD	FDD	TDD	FDD	TDD	FDD
Discontinues transmission (DTX)	NO	YES	YES	NO	YES	---------	YES
Channel separation [MHz]	0.025	0.2	0.2	1.728	5	22	5

Table (4-2): Basic technical properties of seven wireless systems.

5 The broadcasting communications

The most common system for radio broadcasting in Sweden is FM-Radio. FM refers to frequency modulation and happens on VHF airwaves in the frequency range 88~108 MHz. The FM-Radio stations are assigned center frequencies with 100 kHz channel separation. In FM-Radio, the carrier signal is moved in the frequency domain because of the modulation of the signal. The benefit of using FM-Radio is that the signal is independent of the variation from amplitude because of the fading phenomenon. During movement of the user, FM-Radio is still covered [Nordqvist, 2002].

Another radio broadcasting system is Digital Audio Broadcasting (DAB), which is digital radio, broadcasting. In this system, all of the programmes are changed and coded, so they can be used in the same frequency channel bandwidth. The frequency channel for this signal is around 2 MHz. The total frequency assignation is small, compared to the sum of the all frequencies channels for the FM-Radio programmes.

Since there is no more analogue television system in Sweden so we focused on the new version of the video broadcasting, Digital Video Broadcasting (DVB). The DVB system has been adopted for digital television broadcasting by many countries. Many countries mainly use VHF 7 MHz and UHF 8 MHz frequency channel; in Sweden the channel band that is used for this system is 8 MHz. In the DVB system the video and audio data are spread over the whole bandwidth. The DVB system uses OFDMA modulation system for transmitting the data. The DVB system as a digital transmission delivers information in a series of discrete blocks at the symbol rate.

6 Standards and guidelines

Many people are concerned about the exposure from radio frequency fields and how to protect themselves against of these radiations. The authorities have issued standards and guidelines. In Sweden, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines are used; the main aim of these guidelines is to restrict the electromagnetic field exposure, providing protection against known adverse health effects.

ICNIRP guideline for limiting exposure to time-varying electric, magnetic and electromagnetic fields, up to 300 GHz is used in this study. The European Union uses this guideline as a recommendation to the member countries. The guideline has been adopted and proceeds by the Swedish radiation authority that in Swedish is Strålsäkerhetsmyndighetens (SSM) [SSM, 2002]. The basic restrictions and references levels are based on studies in laboratories and on epidemiological studies.

There are two types of limits that are given by ICNIRP, Basic restriction and Reference levels. The basic restrictions are taken from established health effects divided by a safety factor, they are depending on the frequency of the field, this value is presented as SAR (Specific Absorption Rate). In the frequency range 1~10 MHz, the basic restrictions are based upon current densities in the body. Too high current densities affect the nervous system. In the frequency range 100 kHz ~ 10 GHz the basic restrictions are represented as SAR values for limiting how much power which is absorbed in the specific part of the body. Too high values will give a thermal effect on the body's tissues. The restriction of the SAR values are dependent on where is given into the body the electromagnetic signals are absorbed and is given as a mean value over a time period of 6 minutes. The ICNIRP guidelines are based on acute health risks such as heating but not upon eventual long-term effects like cancer.

Another type of restriction level as we mentioned above, is the Reference levels (Table 6-1). Reference levels are provided for practical radiation assessment to determine whether the basic restrictions are likely to be exceeded. There are reference levels on the electric field (E), magnetic field (H) and the power density (S). The reference levels on power density are used in this thesis. If the measured values, or the calculated values, exceed the reference restrictions, it does not follow that the basic restrictions are exceeded. In this case, it is important to do more analyze and calculation to assess compliance with the basic restriction [ICNIRP, 1998].

In this thesis the measurement values are compared with the reference restrictions from the ICNIRP guideline for the general public. For occupational radiation the power density ratio is increased by a factor of 5. The motivation is that should be aware of the potential risks and be able to take precaution.

Frequency Range	**E-Field Strength [V/m]**	**H-Field Strength [A/m]**	**Equivalent plane wave power density S_{eq} [W/m^2]**
10~400 MHz	28	0.073	2
400~2000 MHz	$1.375 * f^{0.5}$	$0.0037 * f^{0.5}$	f/200
2~300 GHz	61	0.16	10

Table (6-1): Reference levels for general public exposure to time-varying electric and magnetic fields, f as indicated in the frequency range column. For frequencies between 100 kHz and 10 GHz, S, E^2,H^2 and B^2 are averaged over any 6 minute period.

If there are simultaneous radiations to the fields of the different frequencies, it is essential to determine whether these radiations are compliant with the guideline. The summation in the equations (6-1) and (6-2) assume the worst case conditions among the fields from multiple resources for thermal considerations [ICNIRP, 1998].

$$\sum_{i=100\ kHz}^{1\ MHz} \left(\frac{E_i}{c}\right)^2 + \sum_{i>1\ MHz}^{300\ GHz} \left(\frac{E_i}{E_{L,i}}\right)^2 \leq 1 \qquad \text{Equation } (6-1)$$

$$\sum_{j=100\ kHz}^{1\ MHz} \left(\frac{H_j}{d}\right)^2 + \sum_{j>1\ MHz}^{300\ GHz} \left(\frac{H_j}{H_{L,j}}\right)^2 \leq 1 \qquad \text{Equation } (6-2)$$

Where in these formulas:

E_i = the electric field strength at frequency

$E_{L,i}$ = the electric field reference level

H_j = the magnetic field strength at frequency

$H_{L,i}$ = the magnetic field reference level

c = $610/f$ Vm^{-1} (f in MHz) for occupational exposure and $87/\sqrt{f}$ Vm^{-1} for general public exposure

d = $1.6/f$ Am^{-1} (f in MHz) for occupational exposure and $0.73/f$ for general public exposure

In this thesis we look at the frequencies from 80 ~ 2700 MHz. The E-field and the H-field can be written as the power density (S), equation (6-3) shall be satisfied.

$$\sum_{i>80\ MHz}^{2.7GHz} \frac{S_i}{S_L} < 1 \qquad \text{Equation } (6-3)$$

Where in this formula:

S_i = the power density at frequency 'i'.

S_L = the power density limit given in table (6-1)

7 Measurement Techniques

In this chapter, we are going to describe the equipments, settings, measuring methods and calculation.

7.1 Spectrum Analyzer

The electrical field strength is measured in this thesis. Knowing the field strength, the power density can be calculated and expressed into $\mu W/m^2$. A spectrum analyzer is a device for measuring and displaying the frequency representation of the signal. It shows a spectrum with the frequencies on the x-axis and the field strength for each frequency on the y-axis. The channel of frequencies to be measured is chosen by defining the start and stop frequency. The analyzer is then scanning though the spectrum from the start frequency to the stop frequency measuring the field strength in one small frequency interval, which is called window at the time. The length of this window is called Resolution Bandwidth (RBW). This parameter is the most important setting of the analyzer and the selection the RBW's value completely depends on the frequency width of the signal that is measured. There are more details about this parameter in the next pages.

A spectrum analyzer and one calibrated electromagnetic field antenna were used in these measurements. The spectrum analyzer was FSH3 from Rohde & Schwarz with the serial number 100842. The FSH3 spectrum analyzer is small and the weight is less than other spectrum analyzers, this spectrum analyzer is shown in figure (7-1). It has an internal battery and does not need continuous electricity power. The FSH is the ideal spectrum analyzer for rapid, high-precision, cost-effective signal investigations. It provides a large number of measurement functions and so can handle anything from the installation or maintenance of a mobile radio base station up to on-site fault location in RF cables as well as development and service – an extensive range of applications. In the table (7-1), we can see the brief data of FSH3 spectrum analyzer.

Data	R&S ® FSH3 Spectrum analyzer
Frequency range	100 kHz to 3 GHz
Resolution Bandwidths	100 Hz to 1 MHz
Video Bandwidths	10 Hz to 1 MHz
Displayed average noise level	typ. –135 dBm (100 Hz)
TOI	typ. 13 dBm
SSB phase noise	<–100 dBc (1 Hz) at 100 kHz from carrier
Detectors	sample, max/min peak, auto peak, RMS
Level measurement uncertainty	<1.5 dB, typ. 0.5 dB
Reference level	–80 dBm to +20 dBm
Dimensions	170 mm × 120 mm × 270 mm
Weight	2.5 kg

Table (7-1): The breif data of FSH3 spectrum anayzer from Rohde & Schwarz.

7.2 Antenna

A TS-EMF from Rohde & Schwarz was used in this thesis, a serial number 100001 (see figure 7-2). The TS-EMF probes consist of three separate antennas arranged perpendicularly to each other, one antenna for each polarization of the electric field (X, Y, and Z). A round ball of a protective material covers these three antennas. Because the TS-EMF probes have a different type of fastening, we cannot use the non-conducting tripod to reduce the EMF reflections, instead of the non-conducting tripod, we used a camera tripod of aluminum. In all of the measurement sites, I used the tripod that was made of aluminum. A metal tripod and a non-metallic tripod was compared for this probe by Nilsson and Rydh (2004), they found no significant differences in the measurement results for these two tripods.

Figure (7-1): The spectrum analyzer FSH3 from Rohde & Schwarz.

Figure (7-2): The TS-EMF antenna from Rohde & Schwarz.

7.3 The RFEX software

The Rohde & Schwarz company has developed a software for manage the spectrum analyzer and the TS-EMF antenna which is called RFEX. This program sends the setting to the spectrum analyzer and receives the results from antenna and spectrum analyzer. Several measurement packets with different setting can be loaded and run after each other, with the results saved on the laptop. The laptop is connected to the measurement probe, controlling software RFEX changes the polarization of the antenna separately by switching and also RFEX allows the spectrum analyzer measure the electric field in each polarization at a time and then adding the field strengths into the total electric field by using the equation (7-1). This software also gets the antenna gain factor for the three antennas directions into itself for calculating the electric field.

$$E = \sqrt{E_x^2 + E_y^2 + E_z^2} \qquad \text{Equation (7-1)}$$

The antenna converts the electric field that is represented by V/m to the voltage that presented by V. Then this measured voltage over 50-Ω impedance is converted into power by the spectrum analyzer. Unit of dBm gives this power. P_{dBm} expresses the field strength from the measured power, and $A_{dB/m}$ expresses the antenna factor and finally a conversion factor is added. This equation is shown in the equation (7-2). The antenna factors are received from a calibration of the antenna and the conversion factor of 107 (≈ 90 + 10 * log 50) comes from the 50-Ω system and changed between different orders of the magnitudes.

$$E_{dB\mu V/m} = P_{dBm} + A_{dB/m} + 107 \qquad \text{Equation (7-2)}$$

This equation gives the electric field in dBμV/m. The equation (7-2) is converted into V/m by equation (7-3).

$$E_{V/m} = 10^{\frac{-E\frac{\mathrm{dB\mu V}}{m} - 120}{20}} \qquad \text{Equation (7-3)}$$

The total power density S needs to be in W/m^2, so it can be reached by using the equations (2-3) and (7-1).

For narrow band signals the RFEX software generates a list of channels for each frequency band, and then the RFEX can give a value for each of these channels. I selected the RBW and choose channel width = half distance to adjacent channel instead of channel width = RBW. For the chosen case the largest peak in the interval until the adjacent channel is taken. In the other cases the peak at exactly the given frequency in the channel is given. When measuring wide band signals using the channel power function also a list of center frequencies for the channels was generated before the measurements. Instead of measuring the whole frequency channel band for DVB, I select a list of the channels, which is broadcasting from transmitters in the Gothenburg city area. When running the RFEX program integration is performed over the requested channels and one value for each channel is obtained [Nilsson and Rydh, 2004].

The exact frequency intervals that are measured are shown in the table (7-2). I just focused on downlink frequency band which is emitted from the base station to mobile station. For the narrow bandwidth signals and wide band signals the average mode in the spectrum analyzer was selected. The time over that the average measuring is performed is called dwell time.

Frequency Band	**Channel Separation [MHz]**	**RBW [kHz]**	**Dwell Time [MS]**	**VBW [MHz]**	**Channel Power**
FM-Radio	0.1	30	2000	0.3	No
DAB	2	100	2000	1	Yes
UMTS 450	0.25	10	2000	0.1	Yes
DVB	8	100	2000	1	Yes
GSM 900	0.2	30	2000	0.3	No
GSM 1800	0.2	30	2000	0.3	No
DECT	1.728	30	2000	0.3	No
UMTS	5	100	1000	1	Yes
WLAN	22	100	1000	1	Yes
LTE	5	100	1000	1	Yes

Table (7-2): Spectrum analyzer settings for the different frequency bands used in the field measurements.

7.4 Setting of the measuring instrument

Selecting of the instrument setting completely affects the measurement result values, so it affects the estimation of the human exposure to the radio frequency signals. The most important settings are described in the below.

7.4.1 Resolution Bandwidth (RBW)

The RBW can be described as a frequency-sweeping window, which measures the rate of the signal. The appropriate RBW of the measurement system varies depending on the modulation type and the frequency bandwidth but it should not be greater than the channel bandwidth of the transmitter being measured [Tektronix, 1993].

The RBW in the narrow band wave measurements presents the smallest distance in the frequency domain between two adjacent peaks. These peaks should be distinguishable if the two peaks have the same strength. The smaller RBW than the length of signal leads to an underestimation of the real signal power and increase the sweep time. The RBW must to be at least as the signals bandwidth to prevent underestimating the real values. For wide band signals there is a possibility of using the channel power function to get around the problem of having RBW much smaller than the signal bandwidth. If the RBW is set too large the peaks become wider and float into each other. For channel power measurements, the RBW should be between 1% ~ 3% of the channel bandwidth [Trulsson, 2003].

7.4.2 Video Bandwidth (VBW)

The VBW is used to filter the noise of the signal, which leads to smooth the curve on the display of the analyzer. A small value of VBW is desirable but it can increase the measurement time. Choosing the automatic assessments in the spectrum analyzer, then the VBW adapt after the chosen RBW. The VBW must be set as a function of RBW. The VBW value, which is used in this thesis, was set to *couple* mode. The detector, which is used, also must to be taken into account in the VBW setting [Rauscher, 2001].

When the sample detector is used it is important to select the VBW at least three times larger than the RBW to prevent underestimation of the signals. The VBW for pulsed signals should be ten times larger than the RBW [Myhr, 2004].

7.4.3 Max peak detector

The max peak detector finds the maximum values in the selected frequency channel. Therefore this type of detection is useful for EMC measurements. The detector finds the maximum value within the pixel in a frame of the time which is set by the user.

7.4.4 Average detector

With the average detector mode the spectrum analyzer calculate the average from the samples assigned to a pixel using the linear level scale.

7.4.5 Max hold mode

The max hold mode is a display mode which is used for the trace measured and it can show the maximum value at the fixed amount of sweeps time for each frequency point [Rauscher, 2001]. This mode is useful for measuring the discontinuous signals [Uddmar, 1999].

7.5 GSM measurements

In both GSM-900 and GSM-1800, frequency hopping is used. Hence, we are not sure whether the spectrum analyzer can detect the signals or not. Furthermore one call just uses one eighth of the time due to the TDMA transmitting technique. The GSM systems did not use the frequency hopping technique in 1999 so the values were measured by using the max hold detection them [Uddmar, 1999].

It is difficult to measure the actual values of the power density at a frequency because of GSM signals is emitting fields in time-slots at the same frequency the power is fluctuating a lot at each frequency so the max mode detector is good to be used, but there is a disadvantage here [Nilsson and Rydh, 2004], by using max hold mode for measuring the signals, the maximum value at each frequency channel can be detected (as we mentioned above) and it gives somewhat overestimated values, just because of it is not been able to detect how many of the time-slots which are used. In my measurement, I did not use max hold mode due to the overestimated values. Instead of the max hold mode, I used the average mode with the dwell time 2000 ms to have a better estimation of the power density.

7.6 Channel power measurement

Channel power is used in the measurement of wideband systems. The possible regulated size of the RBW is smaller than the bandwidth of the broadband signal, which makes it impossible to directly measure the value of the signal [Rauscher, 2001].

Channel power can be calculated by integrating the measured power levels within the frequency channel and then dividing by n factor [Trulsson, 2003], see equation (7-4).

$$\mathfrak{n} = \frac{RBW * num}{\mathcal{F}} \qquad \text{Equation (7-4)}$$

Where '*num*'is number of trace points and *f* is the frequency span.

The FSH3 spectrum analyzer has this ability to calculate the channel power instantaneously by just defining the frequency channel.

7.7 The antenna factor

The Antenna Factor is defined as the level of the incident electromagnetic field to the output voltage from the antenna, when terminated in 50 Ω load. The AF is the factor by which one would multiply the output voltage of a receiving antenna to reach the incident electric or magnetic field. The antenna factor has a unit of dB/m. The electric field AF is often represented in dBm^{-1} that means referenced to an antenna factor of m^{-1}, [Ishigami, Takashi, Iwasaki, 1996].

7.8 Measurement points

To reach a better estimate of the exposure at a site, several points with small distances within the area of a body can be measured. However this is taking too much time, I had to perform a compromise between the accuracy and the time, which spent at each measurement place. My compromise is to measure at three points at every site, so this took around one hour and the differences between the value at one height and the mean value of all three heights were up to about two times.

The three chosen points were at the different heights 1.1, 1.5, 1.7 meters but above the same point in the vertical plane as it is shown in the following figure (7-2). My choice height was done considering a proposal to a new EU standard [CENELEC, 2006]. By having several measurement points, the effect of fast fading can be averaged.

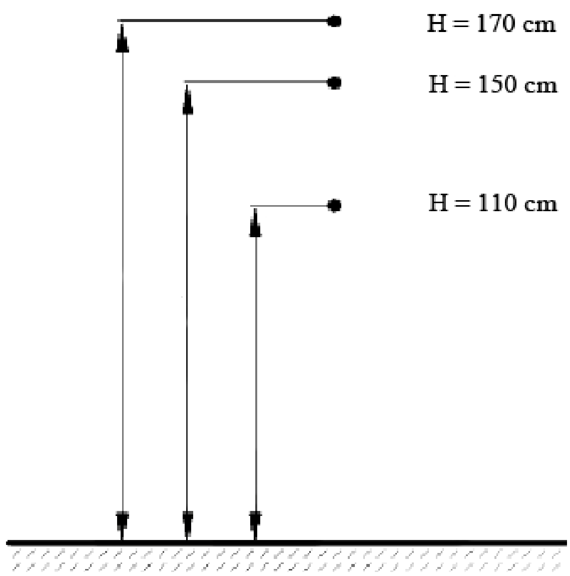

Figure (7-2): Three measurement points at different heights.

7.9 Measurement uncertainty

In metrology, measurement uncertainty is a non-negative parameter characterizing the dispersion of the values attributed to a measured quantity. The uncertainty has a probabilistic basis and reflects incomplete knowledge of the quantity. All measurements are subject to uncertainty and a measured value is only complete if it is accompanied by a statement of the associated uncertainty. Fractional uncertainty is the measurement uncertainty divided by the measured value [Miller, 2010].

The expanded measurement uncertainty R&S® TS-EMF with R&S® FSH3 is ≤ ± 3.1 dB, ±2.3 dB at 0.9 GHz and ±2.8 dB at 1.8 GHz [Rohde & Schwarz, 2007].

8 Measurement sites

I performed the measurements at 48 different sites in Gothenburg city. In these measurements, 14 measurement sites were indoors and 34 measurement sites were outdoors which are shown in tables (8-1) and (8-2). These measurement sites were spread in a big part of Gothenburg from Angered in north of Gothenburg to Frölunda area in the south west of Gothenburg. Most of the measurement sites were same as in previous measurements, Nilsson and Rydh in 2004 and Uddmar in 1999 used. There is a column in tables (8-1) and (8-2) which shows, if the measurement place is same with the previous measurements or not. The measurement date and time are given for each measurement.

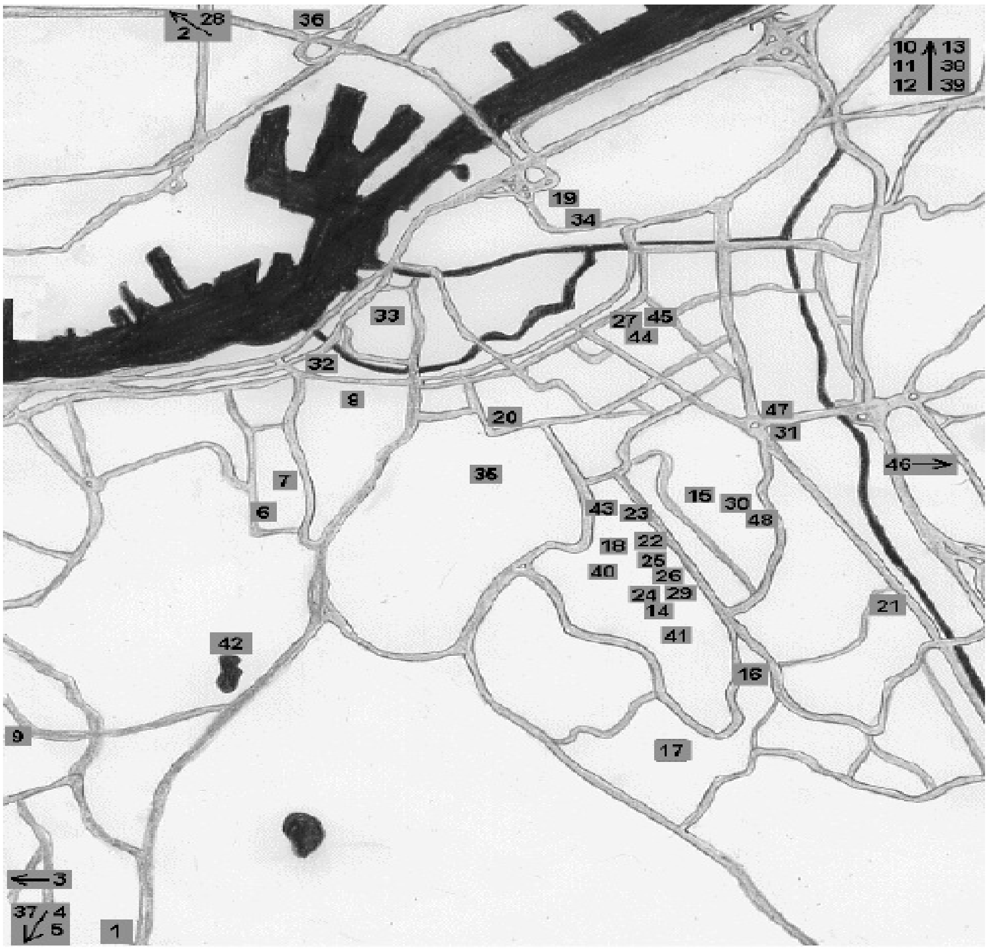

Figure (8-1): Locations of the measurements sites [Nilsson and Rydh, 2004].

Site	Address	Floor 2011	Floor 2004	Date	Time	Indoor/ Outdoor	2004	1999
1	Chemistry building at Chalmers	Gr*	Gr	13-9-2011	10:00	Indoor	Yes	No
2	Drottningtorget			13-9-2011	12:30	Outdoor	Yes	Yes
3	Signal and System Building at Chalmers	7		13-9-2011	16:30	Indoor	No	No
4	Civil Engineering at Chalmers	Gr	Gr	14-9-2011	09:00	Indoor	Yes	No
5	Technology Management and Economics at Chalmers	Gr	Gr	14-9-2011	12:30	Indoor	Yes	No
6	Architecture building at Chalmers	5	5	14-9-2011	15:30	Indoor	Yes	No
7	Chalmers Science Park			15-9-2011	11:00	Indoor	Yes	No
8	E and D&IT building at Chalmers	6	6	15-9-2011	14:45	Indoor	Yes	Yes
9	Physics building at Chalmers	7	7	16-9-2011	09:00	Indoor	Yes	No
10	Mechanical Engineering at Chalmers, North	5	5	16-9-2011	12:15	Indoor	Yes	No
11	Mechanical Engineering at Chalmers, South	5	5	16-9-2011	15:30	Indoor	Yes	No
12	Teknologgården			17-9-2011	11:30	Outdoor	Yes	No
13	Central Station	Gr	Gr	17-9-2011	14:30	Outdoor	Yes	Yes
14	Trollspisgatan			18-9-2011	09:00	Outdoor	Yes	No
15	KortedalaTorg			18-9-2011	12.30	Outdoor	Yes	No
16	Korsvägen -Liseberg			18-9-2011	15.45	Outdoor	Yes	No
17	Korsvägen-Svenska Mässan			19-9-2011	09:00	Outdoor	Yes	Yes
18	Järntorget			19-9-2011	12:30	Outdoor	Yes	Yes
19	Slottskogen			19-9-2011	15:30	Outdoor	Yes	No
20	Föreningsgatan			20-9-2011	11:15	Outdoor	Yes	Yes
21	Frölunda Torg			20-9-2011	14:30	Outdoor	Yes	No
22	Richertsgatan 2D		2	21-9-2011	9:30	Outdoor	Yes	No
23	DoktorForseliusBacke42		6	21-9-2011	12:30	Outdoor	Yes	No
24	Brudaremossen			21-9-2011	15:45	Outdoor	Yes	No

Table (8-1): Measurement locations. (Gr*: Ground).

Site	Address	Floor 2011	Floor 2004	Date	Time	Indoor/ Outdoor	2004	1999
25	Lindholmen Science park			22-9-2011	09:00	Outdoor	Yes	No
26	Gamlestadstorget			22-9-2011	12:50	Outdoor	Yes	No
27	Vasagatan 48	4	4	24-9-2011	14:15	Indoor	Yes	Yes
28	Vasagatan 48-Balcony	4	4	24-9-2011	15:00	Indoor	Yes	Yes
29	Vasagatan -Avenyn			24-9-2011	16:00	Outdoor	Yes	Yes
30	Viktoriagatan 36		5	24-9-2011	17:15	Outdoor	Yes	No
31	Framnäsgatan 6		2	24-9-2011	19:00	Outdoor	Yes	No
32	Otterhällan			25-9-2011	09:00	Outdoor	Yes	Yes
33	Stackmolnsgatan 3		3	25-9-2011	12:45	Outdoor	Yes	Yes
34	Brunnsparken, Gustav Adolfs torg			25-9-2011	16:00	Outdoor	No	No
35	Backaplan			26-9-2011	09:00	Outdoor	Yes	No
36	Gibraltargatan 82		1	26-9-2011	12:15	Outdoor	Yes	No
37	Årstidsgatan 30		1	26-9-2011	15:30	Outdoor	Yes	No
38	Marklandsgatan 71		5	27-9-2011	08:00	Outdoor	Yes	No
39	Mejerigatan 2B	8		27-9-2011	10:45	Indoor	No	No
40	Trollspisgatan-VolratThamsgatan			27-9-2011	12:30	Outdoor	Yes	Yes
41	Uppstigen 110	2		27-9-2011	14:40	Indoor	No	No
42	Kaponjärgatan 4C		4	27-9-2011	16:00	Outdoor	Yes	No
43	Mandolingatan 19		6	27-9-2011	18:15	Outdoor	Yes	No
44	Mandolingatan 41		5	27-9-2011	20:00	Outdoor	Yes	No
45	Nordhemsgatan 66		4	27-9-2011	22:30	Outdoor	Yes	No
46	Nordostpassagen 69		2	28-9-2011	06:00	Outdoor	Yes	No
47	Studiegången 4	2		28-9-2011	08:15	Indoor	No	No
48	Holländareplatsen 5A		2	28-9-2011	11:30	Outdoor	Yes	No

Table (8-2): Measurement locations. (Gr: Ground)

9 Measurement results

There is an overview of all measurements in table (9-1). All of the results are sorted with the total power densities and the average value of the results. The greatest value was found in the measurement site 29, Vasagatan St. crossing Avenyn St. with the total value of 3005 µW/m^2. The dominant source in this site was UMTS system. The smallest values in these measurements were found in sites 38 and 42, Marklandsgatan 71 and Kaponjärgatan 4C, with the value of 23 µW/m^2.

	2011	**2004**	**1999**	**2011**	**2004**	**1999**
System	**Mean power density [µW/m^2]**	**Mean power density [µW/m^2]**	**Mean power density [µW/m^2]**	**Maximal power density [µW/m^2]**	**Maximal power density [µW/m^2]**	**Maximal power density [µW/m^2]**
FM Radio	50	280	31	901	1600	319
Analog TV		59	121		2300	2035
DAB	2			3		
DVB	15	16		116	180	
NMT 450		0.45	3		7.7	48
UMTS 450	1			3		
GSM 900	121	140	120	1108	1300	731
GSM 1800	41	42	180	358	650	2470
DECT	0.02			0.5		
UMTS	174	35		1702	710	
WLAN	42			359		
LTE	59			607		
Other		1.8	10		17	60
Total	**505**	**376**	**463**			
Maximum				**1700**	**2300**	**2470**

Table (9-1): Mean and maximal power densities from the different types of sources.

The total mean value of the measurements was 505 µW/m^2. In table (9-1), the overall mean vale and maximum power densities from all types of sources are shown. The highest mean values were from GSM 900 and UMTS and the lowest mean values were from DECT system. The maximum value of measured power density from all packets was 1702 µW/m^2 which exposure from UMTS system at Vasagatan Street crossing Avenyn Street. Compared to the reference levels of ICNIRP, the mean value was 139 ppm but in 2004, the highest value was from analog television with a value of 2300 µW/m^2.

I found that the strongest measured values from cellular systems were around central locations in Gothenburg and the strongest power densities from digital television and radio were at places, which had free sight to the radio and television towers. As I could not access to some of the indoor sites and most of these sites were on the top floors, so my measured values from radio and television were lower than in the previous measurement in those places. The lowest values from radio and television were found at residential areas some distance from central of Gothenburg. The dominant sources were UMTS and GSM 900, which is similar to the results in the measurement 2004.

In figure (9-1) the average values of power densities from all sources are given and the average values of power densities from the indoor sites are given and in figure (9-2) the average of power densities from the outdoors sites are given and in figure (9-3) the maximum of power densities in each year is shown. I have to mention that the outdoors sites were in greater number than the indoors sites but in 2004, most of the measurement sites were indoors as you can see in the below table (9-2).

	1999	**2004**	**2011**
Indoors sites	6	28	14
Outdoors sites	20	20	34
Total	26	48	48

Table (9-2): The number of measurement sites in each year.

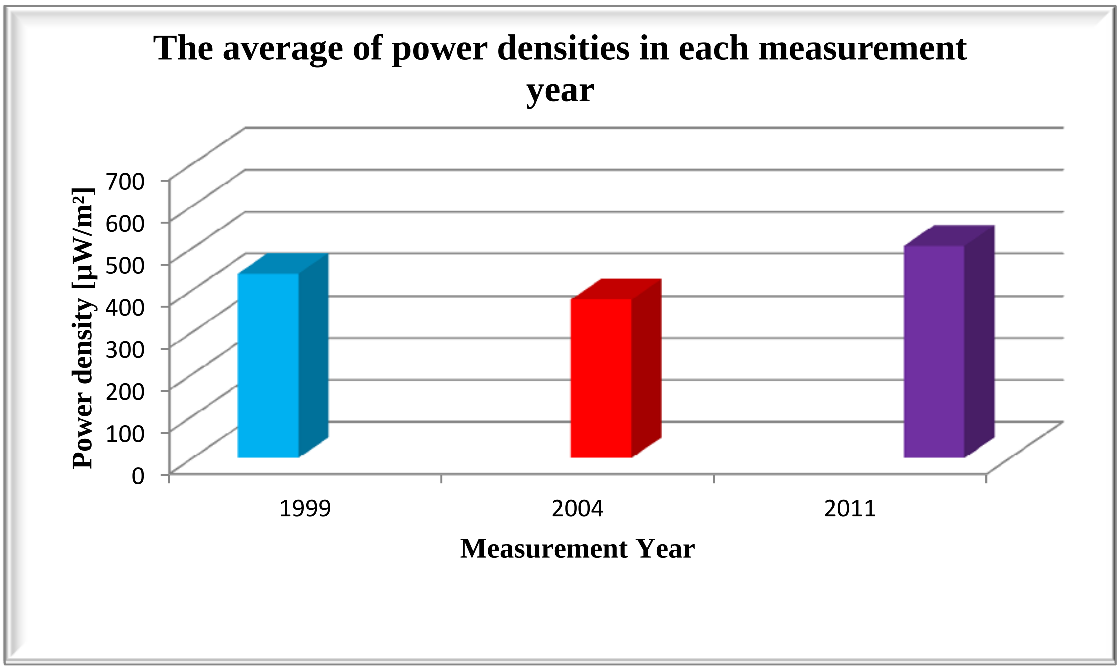

Figure (9-1): The average values of power densities from all sources.

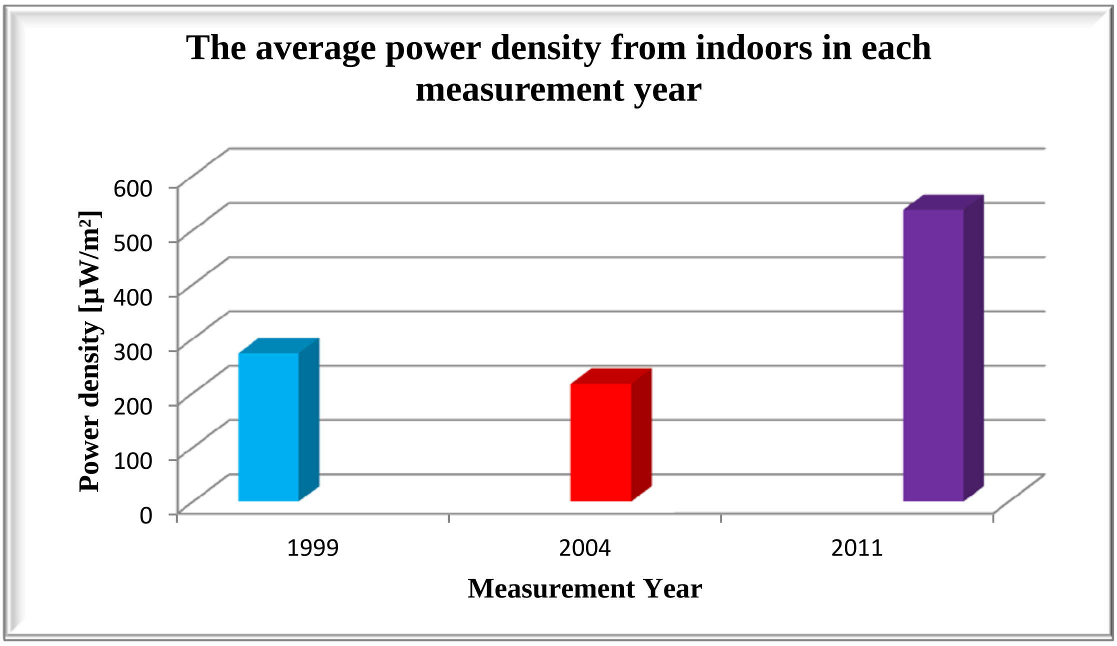

Figure (9-2): The average values of power densities from the indoor sites.

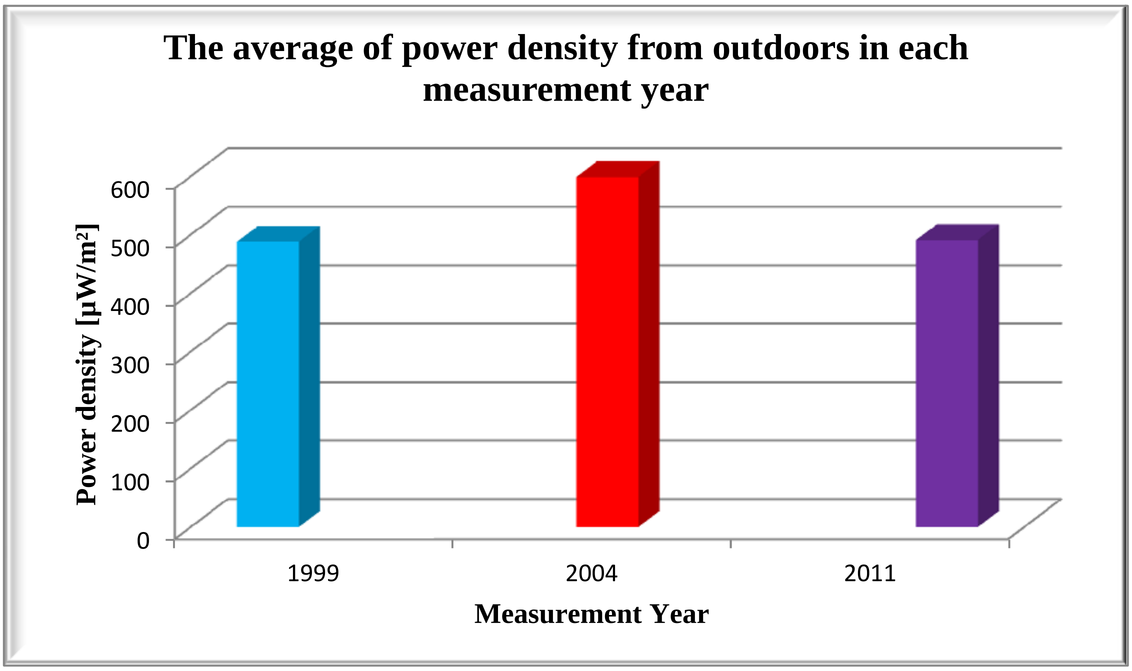

Figure (9-3): The average values of power densities from the outdoors sites in each year.

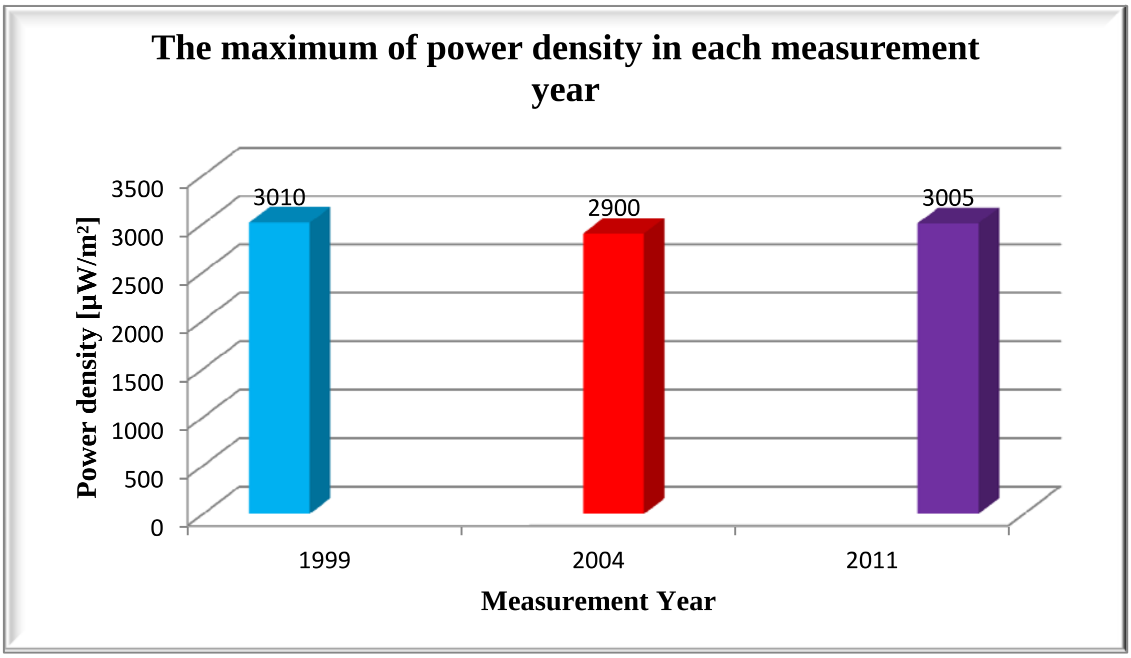

Figure (9-4): The maximum of power densities in each year.

In figure (9-5), the percentage of power density from each packet in 2011 is shown. It is shown that the UMTS is the dominant source but in 2004 the dominant source was GSM 900, on the other hand the GSM 900 still is the second dominant source in 2011. In figure (9-6) and figure (9-7) you can see the dominant source in each year.

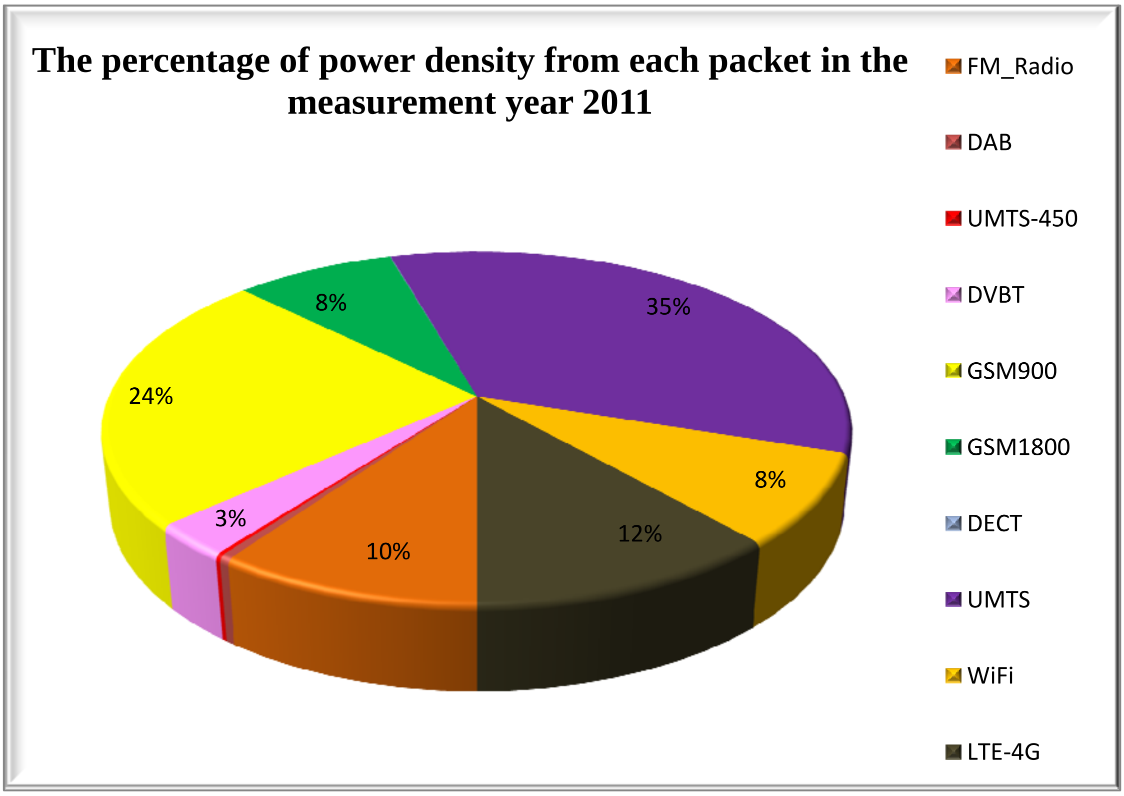

Figure (9-5): The percentage of power density from each packet in the measurement year 2011.

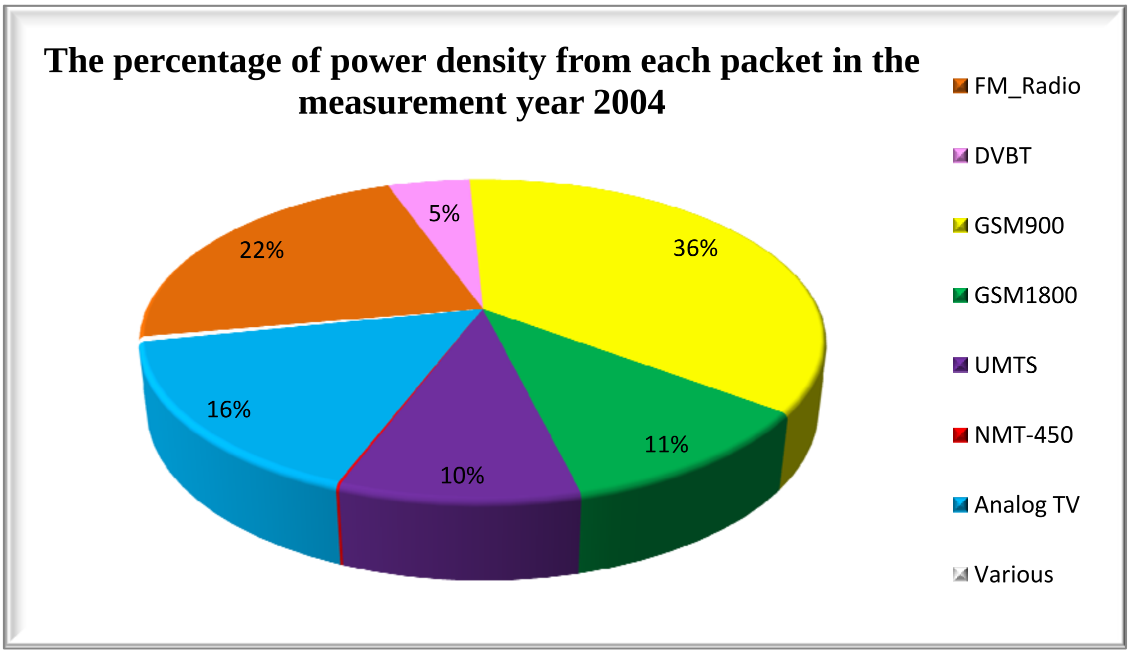

Figure (9-6): The percentage of power density from each packet in the measurement year 2004.

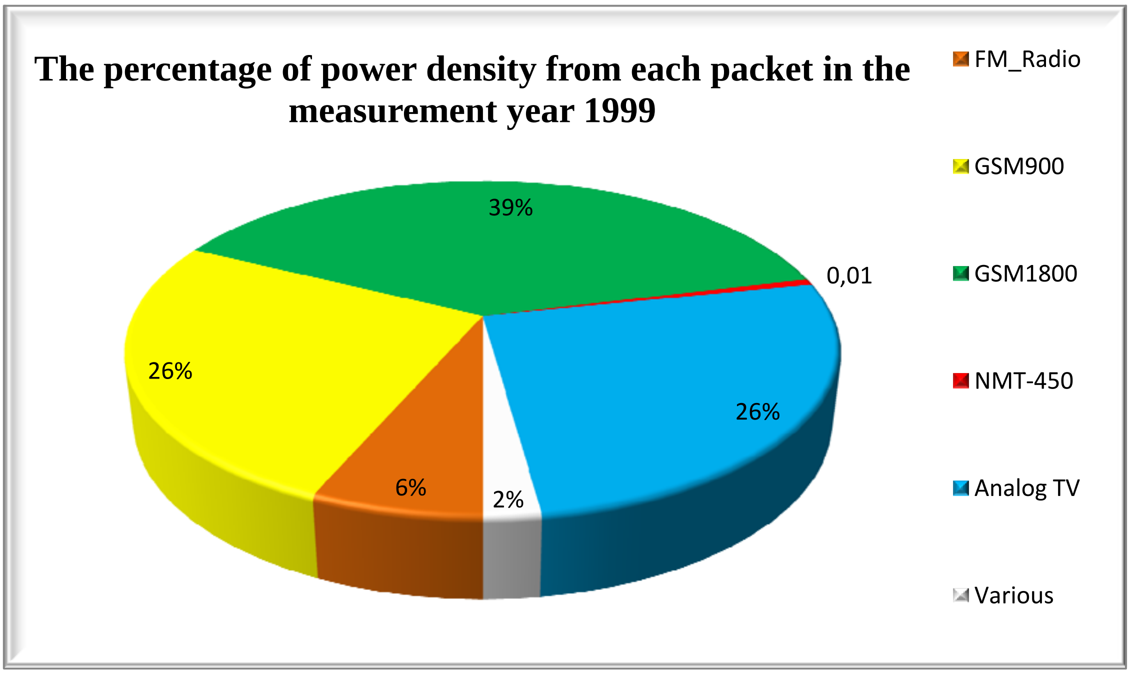

Figure (9-7): The percentage of power density from each packet in the measurement year 1999.

In table (9-3), the total average and median values of power densities from each year are compared.

Measurement Year	1999	2004	2011
	[μW/m²]	[μW/m²]	[μW/m²]
The average of power density	439	376	505
The average of power density from indoors	273	217	537
The average of power density from outdoors	488	599	491
The maximum of power density	3010	2900	3005
The median value of power density	41	120	228
The median value from indoors	34	43	151
The median value from outdoors	173	277	251

Table (9-3): Comparing the results from each year.

In table (9-4), the percentages of power density from each packet in the different years are shown.

Packet	1999	2004	2011
	[%]	[%]	[%]
FM_Radio	6.5	22.4	9.8
DAB			0.5
UMTS-450			0.2
DVBT		4.7	2.7
GSM900	25.8	36	24
GSM1800	38.9	10.9	8.2
DECT			0.04
UMTS		9.5	34.5
WLAN			8.3
LTE-4G			11.7
NMT-450	0.6	0.1	
Analog TV	26.1	15.9	
Various	2.2	0.5	

Table (9-4): The percentages of power density from each packet in different years.

Table (9-4) shows that LTE system was 12% of total exposure from wireless systems in 2011. The UMTS system has the strongest exposure in 2011, because more mobile users and broadband Internet users use 3G for surfing in web. Comparing with 2004, it shows that GSM 900 is still one of the strongest sources in wireless systems and also GSM 1800 is not changed.

9.1 The Results from indoors and outdoors sites

Here are the locations' results sorted in the order of the site-number. In each measurement site, there is a notification above a page which shows that if the location of measurement is same with 2004 and 1999 or not and also shows that a measurement site is indoor or outdoor. To compare the values, as there were analog TV, NMT-450, various values; I used "other" to show them in the result's table.

1. The Chemistry building at Chalmers, indoor

Year	2011	2011	2011	2011	2004
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]
FM_Radio	0.5	1	99.4	0.2	7.1
DAB	3.2	1.3	239.2	3.2	
UMTS,450	1.8	0.9	468	1.8	
DVBT	2.1	0.9	570	2.1	0.9
GSM900	5.9	2.3	940.6	3.8	0.24
GSM1800	0.7	0.4	1845.4	0.6	0.12
DECT	0.0022	0.015	1897.3	0.0022	
UMTS	22.6	6.9	2158.8	22.6	2.1
WLAN	9.1	3.4	2442	3.9	
LTE-4G	3	1.2	2645	3	
Other					2
Total	**49**	**18**			**13**

Table (9-5): Results from site 1, Chemistry building at Chalmers, entrance floor.

The low total value 49 µW/m² was measured on Tuesday 13th Sep at 10:00 in Chemistry building at Chalmers. The main source was UMTS.

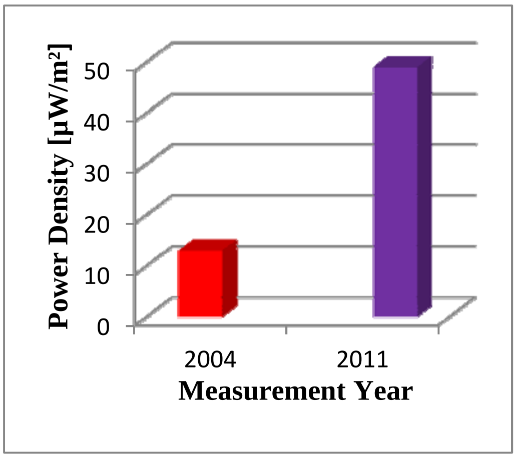

Figure (9-8): The total power densities [µW/m²].

Figure (9-9): Measurement site 1, Chemistry building at Chalmers

2. Drottningtorget, outdoor

Year	**2011**	**2011**	**2011**	**2011**	**2004**	**1999**
Packet	**Power density [µW/m²]**	**Reference Ratio [ppm]**	**Dominant frequency [MHz]**	**Peak density [µW/m²]**	**Power density [µW/m²]**	**Power density [µW/m²]**
FM_Radio	2.6	1	99.4	1.1	12	2
DAB	2.8	1.2	239.2	2.8		
UMTS,450	1.7	0.8	468	1.7		
DVBT	7.4	3	570	7.4	5.5	
GSM900	27.3	9	953.4	10.4	93	533
GSM1800	35.4	13	1874.4	11.1	43	20
DECT	0.0016	0.013	1897.3	0.0016		
UMTS	338	79.9	2124.3	237.4	87	
WLAN	33.5	10.7	2437	18.8		
LTE-4G	226.8	47.8	2660	175.6		
Other					3	19.3
Total	**676**	**166**			**244**	**573**

Table (9-6): Results from site 2, Drottningtorget.

A total value of 676 µW/m² was found at Drottningtorget on Tuesday13th Sep at 12:30. The dominant source was UMTS**.**

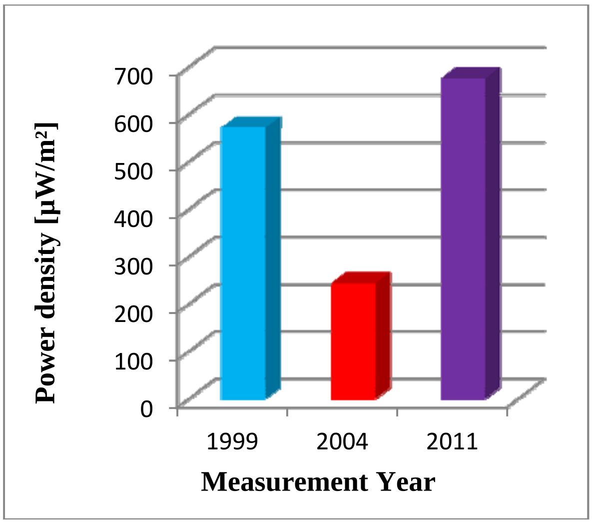

Figure (9-10): The total power densities [µW/m²]

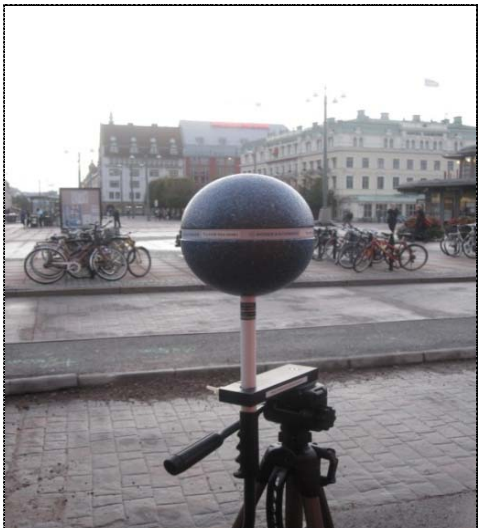

Figure (9-11): Measurement site 2, Drottningtorget.

3. Signal and System Building at Chalmers, indoor. This is a new measurement site.

Year	**2011**	**2011**	**2011**	**2011**
Packet	**Power density [µW/m²]**	**Reference Ratio [ppm]**	**Dominant frequency [MHz]**	**Peak density [µW/m²]**
FM_Radio	15.1	3	101.9	5.7
DAB	3.2	1.3	239.2	3.2
UMTS,450	2.1	1	468	2.1
DVBT	26.2	6.3	626	9.7
GSM900	18	3.9	941	5.5
GSM1800	4.1	1.3	1848.6	1.6
DECT				
UMTS	115.3	35.5	2116.6	70.7
WLAN	23.2	7.6	2462	15.7
LTE-4G	14.1	3.4	2625	4.7
Other				
Total	**221**	**63**		

Table (9-7): Results from site 3, signal and system department in the 7th floor.

A total power density of 221 µW/m² was measured at signal and system department on Tuesday 13th Sep at 16:30. The main source was UMTS.

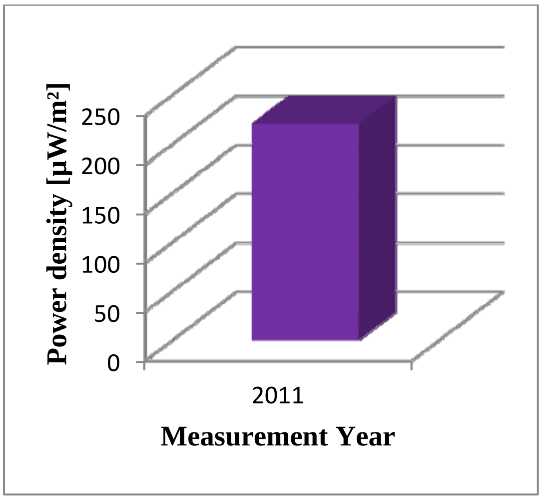

Figure (9-12): The total power densities [µW/m²]

Figure (9-13): Measurement site 3, Signal and system Dep. at Chalmers.

4. Civil Engineering at Chalmers, indoor

Year	2011	2011	2011	2011	2004
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]
FM_Radio	0.9	1.3	89.3	0.4	1.8
DAB	3.1	1.2	239.2	3.1	
UMTS,450	1.8	0.9	468	1.8	
DVBT	1.3	0.7	570	1.3	
GSM900	0.6	1.5	948.4	0.1	0.95
GSM1800	0.5	0.3	1862.8	0.3	1.3
DECT	0.0096	0.032	1897.3	0.0096	
UMTS	9.7	3.3	2167.2	9.7	1.9
WLAN	7.4	3	2462	4.2	
LTE-4G	4.5	1.2	2630	4.5	
Other					0.2
Total	**30**	**13**			**6**

Table (9-8): Results from site 4, Civil Engineering at Chalmers, entrance floor.

The low value 30 µW/m² was measured on Wednesday 14th Sep at 09:00 in the Civil Engineering building at Chalmers. The main source was UMTS.

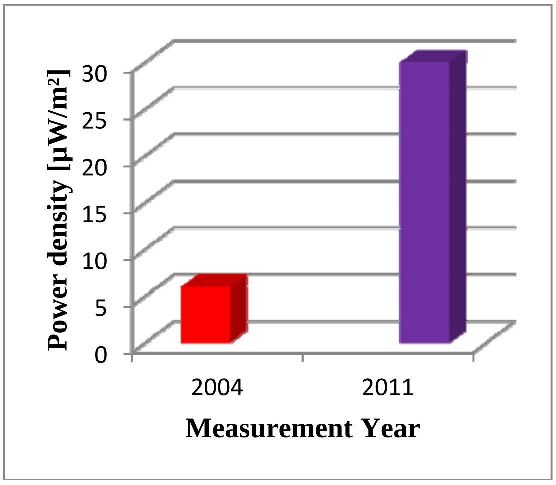

Figure (9-14): The total power densities [µW/m²].

Figure (9-15): Measurement site 4, Civil Engineering building at Chalmers.

5. Technology Management and Economics at Chalmers, indoor

Year	2011	2011	2011	2011	2004
Packet	Power density [μW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [μW/m²]	Power density [μW/m²]
FM_Radio	0.2	0.4	99.4	0.1	0.27
DAB	3	1.2	239.2	3	
UMTS,450					
DVBT	0.7	0.4	622	0.7	
GSM900	2.9	0.8	943.4	2.9	0.16
GSM1800					
DECT					
UMTS	50.6	21.7	2139.6	21.1	
WLAN	19.9	7.4	2437	16.2	
LTE-4G	1.4	0.4	2690	1.4	
Other					0.26
Total	**79**	**32**			**0.5**

Table (9-9): Results from site 5, Technology Managment and Economics at Chalmers, entrance floor.

In measurement site, at Technology and Economics ground floor, a total value of 79 μW/m² was found on Wednesday 14th Sep at 12:30. The dominant source was UMTS.

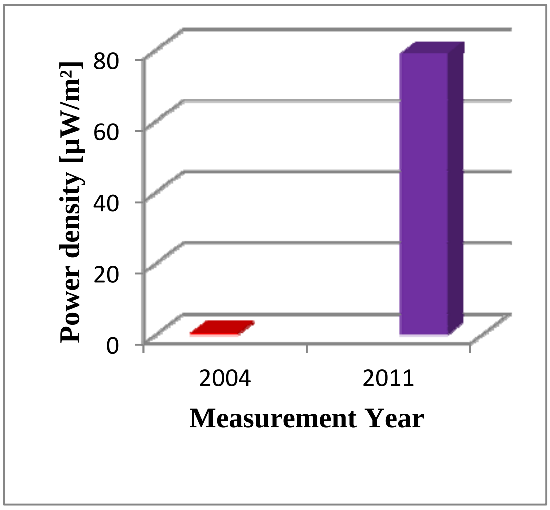

Figure (9-16): The total power densities [μW/m²].

6. The architecture building at Chalmers, indoor

Year	**2011**	**2011**	**2011**	**2011**	**2004**
Packet	**Power density [μW/m²]**	**Reference Ratio [ppm]**	**Dominant frequency [MHz]**	**Peak density [μW/m²]**	**Power density [μW/m²]**
FM_Radio	0.8	1.3	99.4	0.3	7.8
DAB					
UMTS,450					
DVBT	1.3	0.7	546	1.3	0.18
GSM900	5.1	3.8	959.2	1.1	11
GSM1800	9.1	2.2	1830.8	5.7	3
DECT					
UMTS	12.4	1.1	2167.2	12.4	26
WLAN	14	5.6	2417	14.4	
LTE-4G	4.5	0.7	2630	4.5	
Other					1
Total	**47**	**15**			**48**

Table (9-10): Results from site 6, The articheture building at Chalmers in 5th floor.

In the Architecture building at Chalmers, the value of 47 μW/m^2 was found. The dominating source was WLAN. The measurement was done on Wednesday 14th Sep at 15:30.

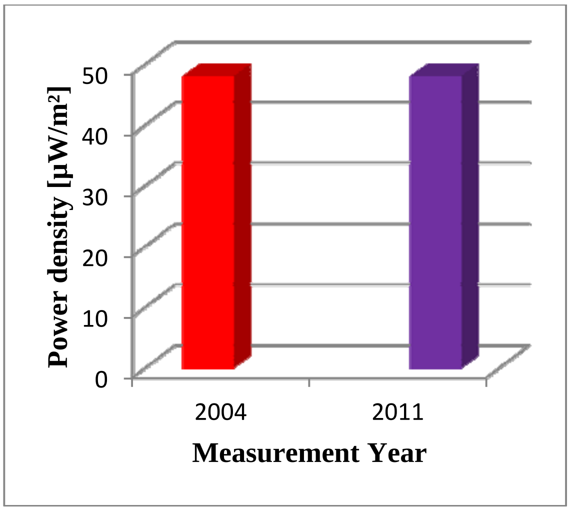

Figure (9-17): The total Power densities [μW/m²].

7. Chalmers Science Park, outdoor

Year	2011	2011	2011	2011	2004
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]
FM_Radio	4.2	2.8	99.4	1.6	140
DAB	2.9	1.2	239.2	2.9	
UMTS,450	1.7	0.9	468	1.7	
DVBT	15	4	626	15	34
GSM900	32.3	8	954.8	25.5	69
GSM1800	55.6	13	1840.4	49.9	34
DECT	0.1155	0.1	1886.9	0.1155	
UMTS	22.5	6	2147.3	22.5	19
WLAN	6.7	3.1	2412	4.6	
LTE-4G	87.8	24	2640	82.4	
Other					11.3
Total	**229**	**63**			**310**

Table (9-11): Results from site 7, Chalmers Science Park at the entrance door.

The value 229 µW/m² was measured on Thursday 15th Sep at 11:00 in Chalmers Science Park at the entrance door. The main source was LTE**.**

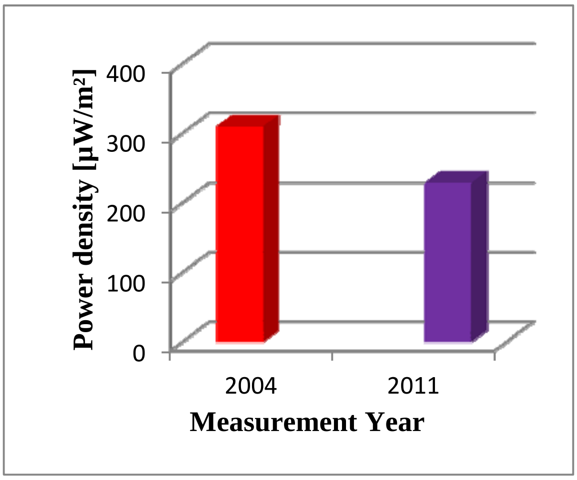

Figure (9-18): The total power densities [µW/m²].

8. E and D&IT building at Chalmers, indoor

Year	2011	2011	2011	2011	2004	1999
Packet	Power density [μW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [μW/m²]	Power density [μW/m²]	Power density [μW/m²]
FM_Radio	1.6	1.8	96.3	0.5	30	17
DAB	3	1.2	239.2	3		
UMTS,450	1.7	0.9	468	1.7		
DVBT	8.7	2.3	674	6.5	2.2	
GSM900	1103	414.5	943.8	945.7	570	6
GSM1800	299.4	90.1	1846.2	116.6	300	1475
DECT	0.1879	0.1	1885.2	0.1879		
UMTS	184	66.3	2143.2	59.2	350	
WLAN	2.1	0.5	2462	2.1		
LTE-4G	607.5	203.5	2635	581.9		
Other					18	35.6
Total	**2211**	**781.2**			**1300**	**1533**

Table (9-12): Results from site 8, E and D&IT building at Chalmers, sixth floor.

The great value 2211 μW/m² was measured on Thursday 15th Sep at 14:45 in E and D&IT building at Chalmers in the sixth floor. The main source was GSM 900**.**

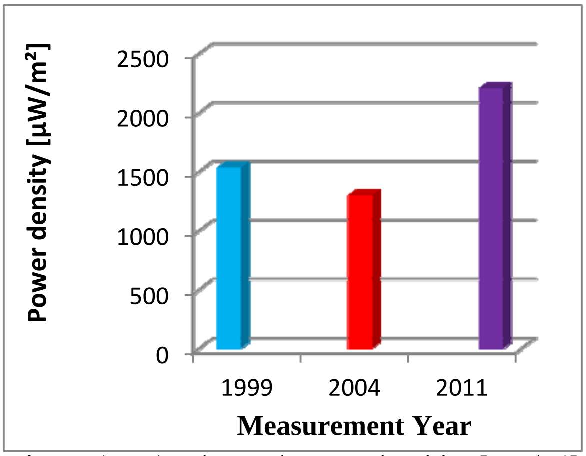

Figure (9-19): The total power densities [μW/m²].

9. The physics building at Chalmers, indoor

Year	2011	2011	2011	2011	2004
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]
FM_Radio	901	278	108	8.9	1600
DAB	3	1.2	239.2	3	
UMTS,450	1.7	0.9	468	1.7	
DVBT	23.4	9.3	622	23.4	78
GSM900	0.006	0.036	948.6	0.006	6.2
GSM1800					1.4
DECT					
UMTS	9.4	3.4	2167.2	9.4	11
WLAN	73.1	21.6	2412	58.9	
LTE-4G	1.4	0.4	2690	1.4	
Other					84
Total	**1013**	**315**			**1800**

Table (9-13): Results from site 9, The physics building at Chalmers, seventh floor.

The value 1013 µW/m² was measured on Friday 16th Sep at 09:00 in Physics building at Chalmers. The main source was Fm-Radio.

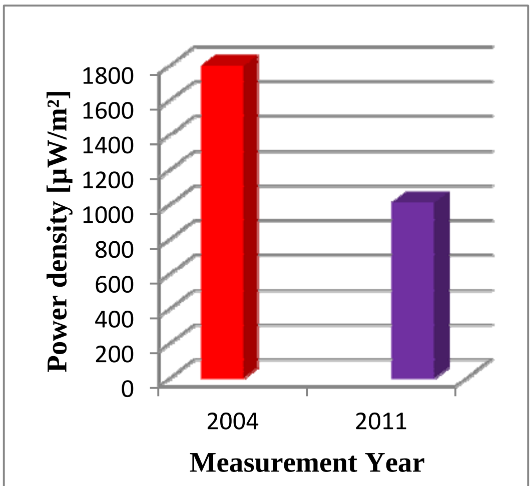

Figure (9-20): The total power densities [µW/m²]

Figure (9-21): Measurement site 9, Physics building at Chalmers, seventh floor.

10. Mechanical Engineering at Chalmers at fifth floor, North, indoor

Year	2011	2011	2011	2011	2004
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]
FM_Radio	6.4	2.8	89.3	5.7	45
DAB	3.1	1.3	239.2	3.1	
UMTS,450	1.8	0.9	468	1.8	
DVBT	0.7	0.4	574	0.7	1.4
GSM900	520.2	147.8	943	236.9	470
GSM1800	198.8	57	1824.4	157.1	150
DECT					
UMTS	300.4	69.5	2143.5	90.2	160
WLAN	1.1	0.3	2472	1.1	
LTE-4G	188.2	39	2645	159.1	
Other					5
Total	**1221**	**319**			**820**

Table (9-14): Results from site 10, Mechanical Engineering (north) at Chalmers, fifth floor.

The value 1221 µW/m² was measured on Friday 16th Sep at 12:15 in Mechanical Engineering (north) at Chalmers. The main source was GSM 900.

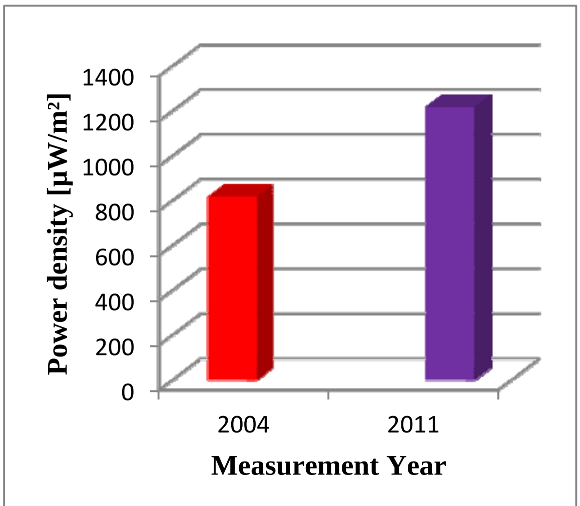

Figure (9-22): The total power densities [µW/m²].

11. Mechanical Engineering at Chalmers at fifth floor, South, indoor

Year	**2011**	**2011**	**2011**	**2011**	**2004**
Packet	**Power density [μW/m²]**	**Reference Ratio [ppm]**	**Dominant frequency [MHz]**	**Peak density [μW/m²]**	**Power density [μW/m²]**
FM_Radio	14.3	4.3	101.9	8.9	70
DAB	3	1.2	239.2	3	
UMTS,450	1.7	0.9	468	1.7	
DVBT	0.7	0.4	778	0.7	2.1
GSM900	46.2	9.8	940.6	21.1	61
GSM1800	11.4	4.3	1848.6	10.8	23
DECT					
UMTS	59	11.6	2132	32	3.4
WLAN	1	0.3	2472	1	
LTE-4G	20.6	7	2630	13.3	
Other					7.1
Total	**158**	**40**			**170**

Table (9-15): Results from site 11, Mechanical Engineering (south) at Chalmers, fifth floor.

The value 158 μW/m² was measured on Friday 16th Sep at 15:30 in Mechanical Engineering (south) at Chalmers. The main source was UMTS.

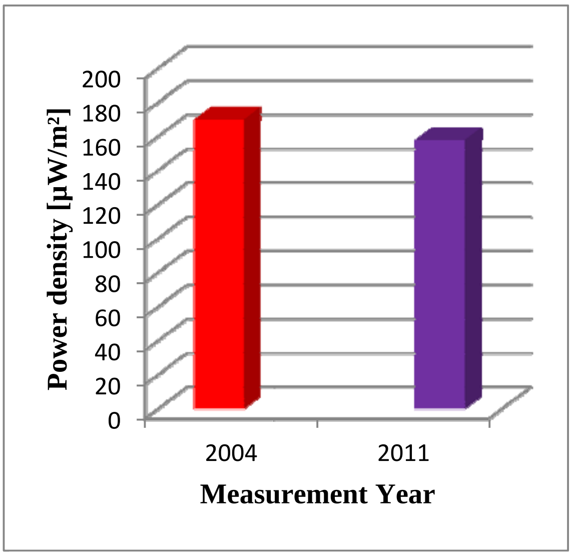

Figure (9-23): The total power densities [μW/m²].

12. Teknologgården at Chalmers, outdoor

Year	2011	2011	2011	2011	2004
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]
FM_Radio	4.4	1.6	99.4	1.7	8.9
DAB	2.9	1.2	239.2	2.9	
UMTS,450	1.7	0.8	468	1.7	
DVBT	0.7	0.4	778	0.7	1.4
GSM900	23.5	7.2	942.4	13.8	69
GSM1800					3.1
DECT	0.49	0.39	1886.9	0.1729	
UMTS	19	6.9	2116.6	19	12
WLAN	2.6	1	2412	2.6	
LTE-4G	1.3	0.4	2690	1.3	
Other					3
Total	**57**	**20**			**97**

Table (9-16): Results from site 12, Teknologgårdenat Chalmers.

The value 57 µW/m² was measured on Saturday 17th Sep at 11:30 in Teknologgårdenat Chalmers. The main source was GSM 900**.**

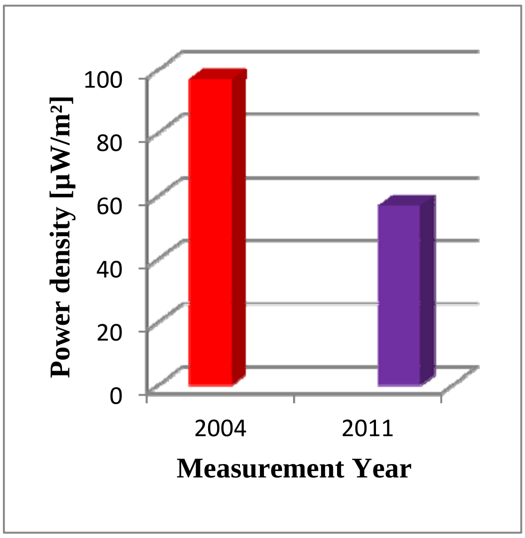

Figure (9-24): The total power densities [µW/m²]

Figure (9-25): Measurement site 12, Teknologgården.

13. Central Station, outdoor

Year	2011	2011	2011	2011	2004	1999
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]	Power density [µW/m²]
FM_Radio	1.8	1.9	96.3	0.7	31	0.6
DAB	2.9	1.2	239.2	2.9		
UMTS,450	1.7	0.8	468	1.7		
DVBT	0.6	0.4	574	0.6	1.3	
GSM900	211.5	38.4	955.8	194.1	130	0.4
GSM1800	10.2	3.9	1841.2	9.4	16	271
DECT	0.0129	0.037	1897.3	0.0129		
UMTS	202.6	27.4	2155	103.9	22	
WLAN	68	21.5	2462	52.2		
LTE-4G	11.3	4.9	2660	5.8		
Other					2	24
Total	**511**	**100**			**200**	**297**

Table (9-17): Results from site 13, Central Station, ground floor.

The value 511 µW/m² was measured on Saturday 17th Sep at 14:30 in Central Station, at ground floor. The main source was GSM 900.

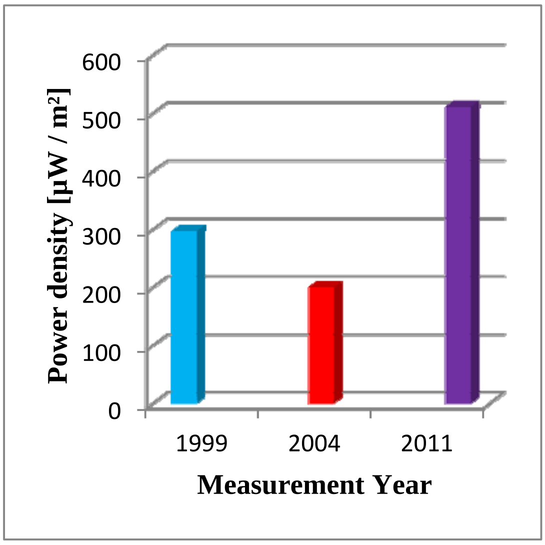

Figure (9-26): The total power densities [µW/m²]

Figure (9-27): Measurement site 13, Central Station

14. Trollspisgatan – Olof Rudbecksgatan 12, outdoor

Year	2011	2011	2011	2011	2004
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]
FM_Radio	97	33.2	96.3	58.5	64
DAB	3	1.2	239.2	3	
UMTS,450	2.5	1	468	2.5	
DVBT	10.8	4.2	778	5.8	6.6
GSM900	13.9	5.1	952.4	12.2	2.7
GSM1800	0.5	0.4	1862.6	0.2	0.6
DECT					
UMTS	52	16.6	2135.8	26.6	12
WLAN	47.9	13.2	2467	37.8	
LTE-4G	12.3	3.7	2665	8.8	
Other					16
Total	**240**	**79**			**90**

Table (9-18): Results from site 14, Trollspisgatan-Olof Rudbecksgatan 12.

In the measurement site, at Trollspisgatan-Olof Rudbecksgatan 12, the value of 240 µW/m^2 was found. The dominating source was FM-Radio. The measurement was done on Sunday 18th Sep at 09:00.

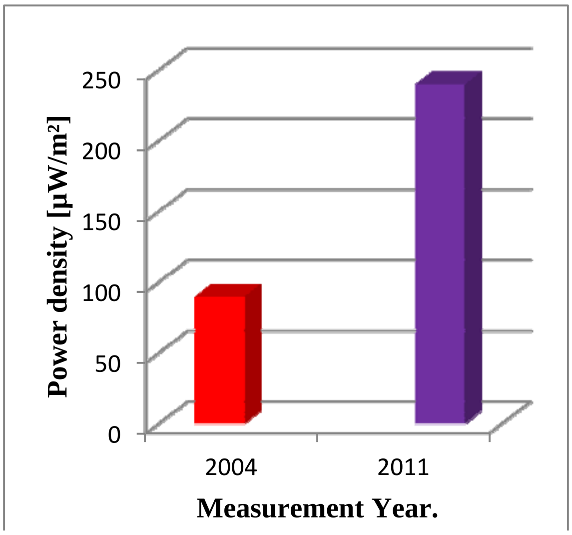

Figure (9-28): The total power densities [µW/m²].

15. KortedalaTorg, outdoor

Year	2011	2011	2011	2011	2004
Packet	Power density [μW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [μW/m²]	Power density [μW/m²]
FM_Radio	5.5	3.1	99.4	3.3	6.8
DAB	2.9	1.2	239.2	2.9	
UMTS,450	1.7	0.8	468	1.7	
DVBT	0.6	0.4	626	0.6	1.9
GSM900	12.4	4.8	943	4.7	91
GSM1800	5.3	1.8	1840.4	1.6	16
DECT					
UMTS	137.1	33.8	2155	137.1	1.1
WLAN	171	39.1	2462	110.8	
LTE-4G	32.5	8	2625	10.6	
Other					2
Total	**369**	**93**			**120**

Table (9-19): Results from site 15, Kordedala Torg.

In the measurement site, at Kortedala Torg, a total value of 369 µW/m² was found on Sunday 18th Sep at 12:30. The dominant source was WLAN.

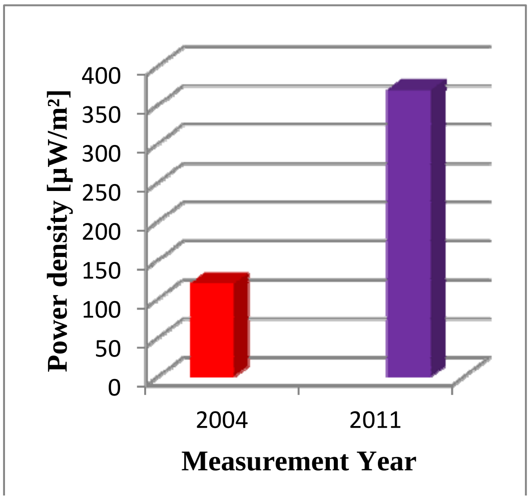

Figure (9-29): The total power densities [µW/m²].

Figure (9-30): Measurement site 15, KortedalaTorg.

16. Korsvägen–Liseberg, outdoor

Year	2011	2011	2011	2011	2004
Packet	**Power density [µW/m²]**	**Reference Ratio [ppm]**	**Dominant frequency [MHz]**	**Peak density [µW/m²]**	**Power density [µW/m²]**
FM_Radio	37.8	8.6	99.4	12.8	69
DAB	2.8	1.2	239.2	2.8	
UMTS,450					
DVBT	15	4.7	778	15	11
GSM900	528	127.1	948.6	188.3	510
GSM1800	123.6	23.6	1862.8	83.9	16
DECT					
UMTS	272.1	65	2124.3	214.4	64
WLAN	36.8	18.7	2467	21.1	
LTE-4G	143	37.6	2640	138.4	
Other					59
Total	**1160**	**286**			**710**

Table (9-20): Results from site 16, Korsvägen -Liseberg.

In the measurement site, at Korsvägen-Liseberg, a total value of 1160 µW/m² was found on Sunday 18th Sep at 15:45. The dominant source was GSM 900.

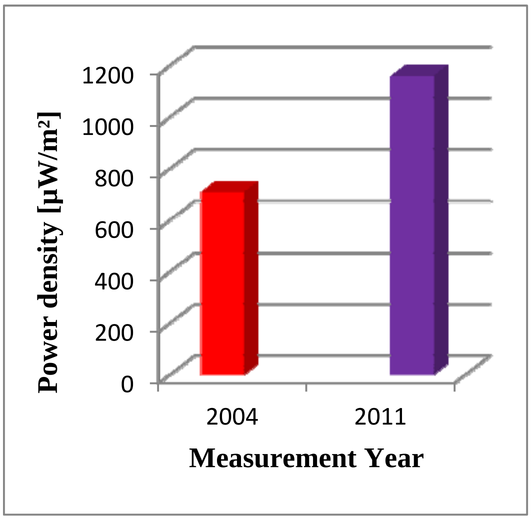

Figure (9-31): The total power densities [µW/m²].

Figure (9-32): Measurment site 16, Korsvägen-Liseberg.

17. Korsvägen-Svenska Mässan, outdoor

Year	2011	2011	2011	2011	2004	1999
Packet	Power density [μW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [μW/m²]	Power density [μW/m²]	Power density [μW/m²]
FM_Radio	33.7	12.3	99.4	12.9	58	36
DAB	3.1	1.2	239.2	3.1		
UMTS,450						
DVBT	23.1	7.7	574	23.1	19	
GSM900	213.5	51	946.8	74.9	380	0.4
GSM1800	48.2	17.8	1854.2	17.1	77	2740
DECT						
UMTS	117.7	37.4	2116.6	35	74	61
WLAN	98.5	26.3	2462	51.1		
LTE-4G	2.2	0.5	2660	2.2		
Other					41	169
Total	**540**	**154**			**650**	**3010**

Table (9-21): Results from site 17, Korsvägen-Svenska Mässan.

The value 540 µW/m² was measured on Monday 19th Sep at 09:00 in Korsvägen-Svenska Mässan. The main source was GSM 900.

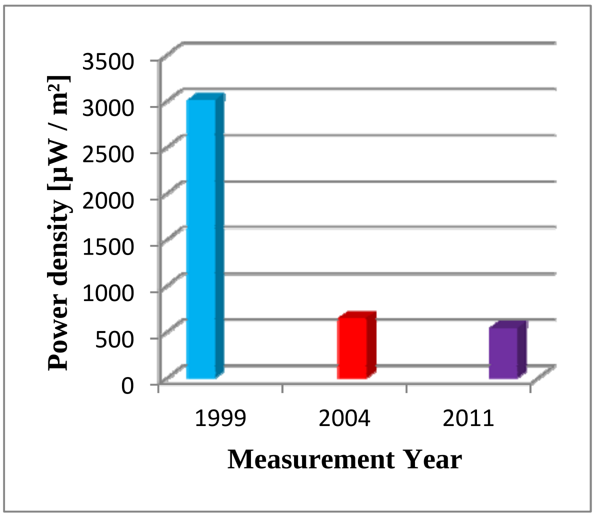

Figure (9-33): The total power densities [µW/m²]

18.Järntorget, outdoor

Year	2011	2011	2011	2011	2004	1999
Packet	**Power density [µW/m²]**	**Reference Ratio [ppm]**	**Dominant frequency [MHz]**	**Peak density [µW/m²]**	**Power density [µW/m²]**	**Power density [µW/m²]**
FM_Radio	4.4	3.1	89.3	1.7	9.1	6
DAB	2.9	1.2	239.2	2.9		
UMTS,450	1.7	0.9	468	1.7		
DVBT	7.2	2.6	622	7.2	3.4	
GSM900	394	89.7	955.8	209.1	950	731
GSM1800	54.7	13.5	1872.2	42.3	19	12
DECT						
UMTS	104.4	23.4	2116.6	82	22	
WLAN	36.9	8.7	2462	21.7		
LTE-4G	95.6	19	2665	70.4		
Other					5	35
Total	**702**	**162**			**1000**	**788**

Table (9-22): Results from site 18, Järntorget.

A total power density of 702 µW/m^2 was measured at Järntorget on Monday 19th Sep at 12:30. The main source was the GSM 900 system.

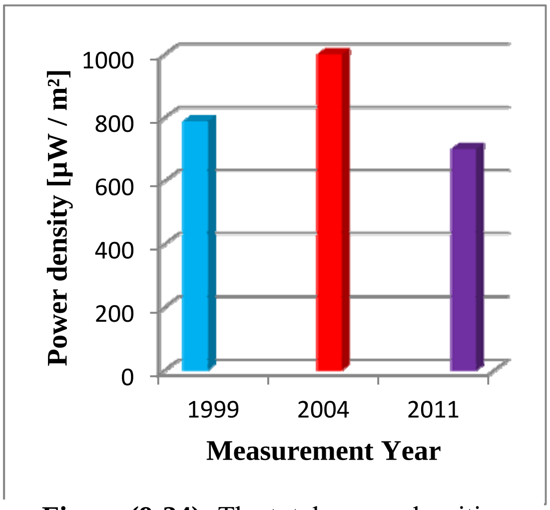

Figure (9-34): The total power densities [µW/m^2]

Figure (9-35): Measurement site 17, Järntorget.

19. Slottskogen, outdoor

Year	2011	2011	2011	2011	2004
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]
FM_Radio	2.7	1.6	99.4	2.5	5.6
DAB					
UMTS,450					
DVBT	0.6	0.4	574	0.6	1.3
GSM900	7.8	3	957.8	7.8	0.59
GSM1800	0.5	0.3	1863.4	0.4	0.4
DECT					
UMTS	20	5.3	2143.5	20	0.46
WLAN	9.4	3.9	2457	5.3	
LTE-4G	1.4	0.4	2690	1.4	
Other					1
Total	**42**	**15**			**9.7**

Table (9-23): Results from site 19, Slottskogen.

In the measurement site, at Slottskogen, a total value of 42 µW/m² was found on Monday 19th Sep at 15:30. The dominant source was UMTS.

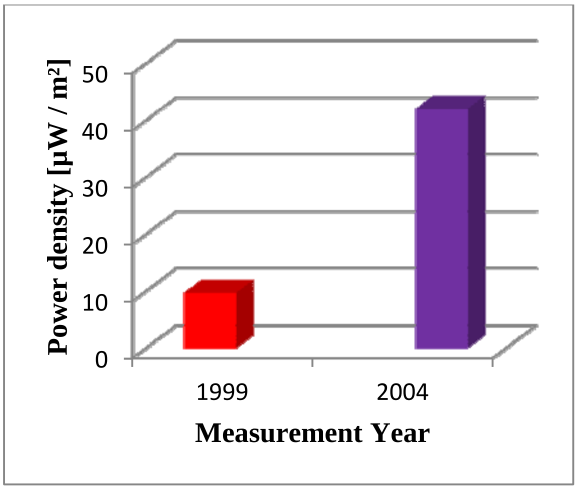

Figure (9-36): The total power densities [µW/m^2]

Figure (9-37): Measurement site 19, Slottskogen.

20. Föreningsgatan 14, outdoor

Year	2011	2011	2011	2011	2004	1999
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]	Power density [µW/m²]
FM_Radio	0.2	0.3	96.3	0.2	26	4
DAB	2.9	1.2	239.2	2.9		
UMTS,450						
DVBT	7.3	2.3	570	7.3	7.3	2
GSM900	2.8	1	924	1.3	7.3	1
GSM1800	4.2	2	1846.4	2.7	0.8	0.04
DECT	0.0069	0.03	1897.3	0.0069		
UMTS	8.8	3.8	2167.2	8.8	1.8	
WLAN	19.6	7	2412	6.7		
LTE-4G	1.3	0.4	2690	1.3		
Other					20	0.7
Total	**47**	**18**			**64**	**8**

Table (9-24): Results from site 20, Föreningsgatan 14.

The value 47 µW/m² was measured on Thursday 20th Sep at 11:15 in Föreningsgatan 14. The main source was WLAN.

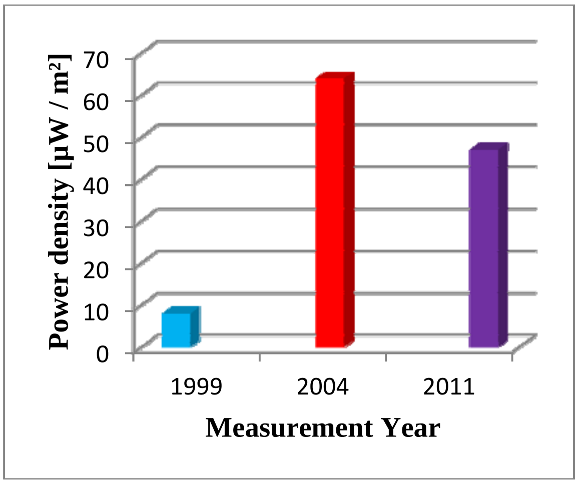

Figure (9-38): The total power densities [µW/m²].

Figure (9-39): Measurement site 20, Föreningsgatan 14.

21. FrölundaTorg (at the bus station), outdoor

Year	2011	2011	2011	2011	2004
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]
FM_Radio	0.7	1.2	99.4	0.2	1.2
DAB	2.8	1.2	239.2	2.8	
UMTS,450					
DVBT	0.6	0.4	626	0.6	0.97
GSM900	19.6	4.3	957.8	7.7	85
GSM1800	1.7	1	1869.6	0.7	3.6
DECT					
UMTS	91.5	35.1	2158.8	39.8	19
WLAN	66.9	23	2467	37.5	
LTE-4G	6.5	3.2	2630	3.3	
Other					1.7
Total	**190**	**69**			**110**

Table (9-25): Results from site 21, Frölunda Torg.

In Thursday 20th Sep at 14:30, a total value of 190 µW/m² was found. The dominant source was UMTS system.

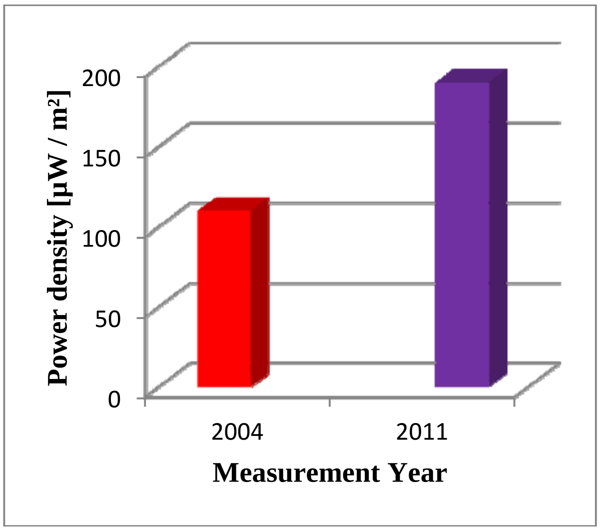

Figure (9-40): The total power densities [µW/m²].

22. Richertsgatan 2D, outdoor (2004 indoor)

Year	2011	2011	2011	2011	2004
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]
FM_Radio	161.1	39.8	96.3	67.2	1700
DAB	3.1	1.2	239.2	3.1	
UMTS,450	1.8	0.9	468	1.8	
DVBT	45.4	14	778	18.5	
GSM900	12.5	4.3	944	9.4	5.6
GSM1800	4.6	1.4	1875.4	4.621	1
DECT					
UMTS	9.2	3.9	2167	9.2	0.79
WLAN	131.6	29.7	2462	56.3	
LTE-4G	1.4	0.4	2690	1.4	
Other					305
Total	**371**	**96**			**1900**

Table (9-26): Results from site 22, Richertsgatan 2D.

The value 371 µW/m² was measured on Wednesday 21th Sep at 09:30 in Richertsgatan 2D. The main source was FM-Radio.

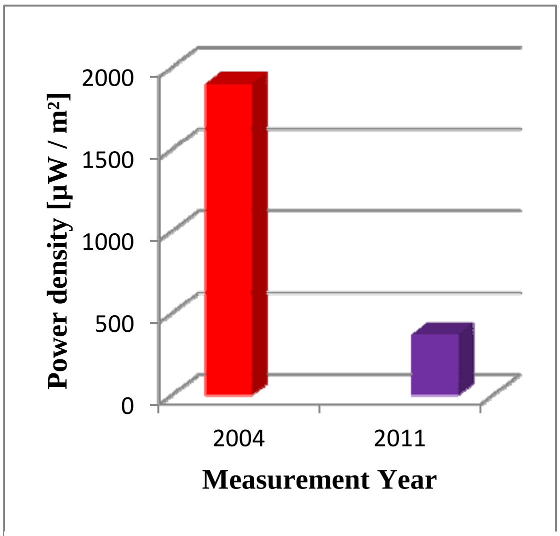

Figure (9-41): The total power densities [µW/m²].

Figure (9-42): Measurement site 22, Richertsgatan 2D, ground floor.

23. Doktor Forselius Backe 42, outdoor (2004 indoor)

Year	2011	2011	2011	2011	2004
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]
FM_Radio	66	11.2	99.4	23.3	750
DAB	2.9	1.2	239.2	2.9	
UMTS,450	1.8	0.9	468	1.8	
DVBT	27.1	11.4	626	10.7	40
GSM900	12.5	5	940.8	5.4	0.59
GSM1800	2	1.1	1863.6	0.9	0.017
DECT	0.0063	0.03	1897.3	0.0063	
UMTS	8.3	3.1	2167.2	8.3	0.21
WLAN	0.9	0.3	2472	0.9	
LTE-4G	10.7	4	2660	5.8	
Other					19.2
Total	**132**	**38**			**810**

Table (9-27): Results from site 23, Doktor Forselius Backe 42.

In the measurement site, at Doktor Forselius Backe 42, a total value of 132 µW/m² was found on Wednesday 21th Sep at 12:30. The dominant source was FM-Radio.

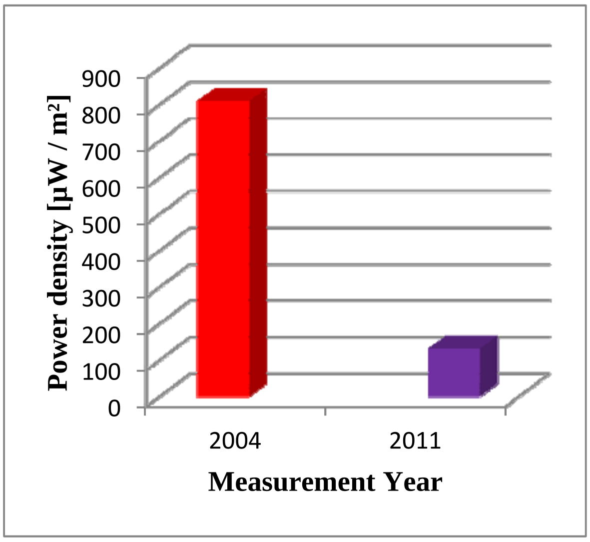

Figure (9-43): The total power densities [µW/m²].

24. Brudaremossen, outdoor (at the cross section with Alfred Gärdes väg)

Year	2011	2011	2011	2011	2004	1999
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]	Power density [µW/m²]
FM_Radio	83.5	14.8	89.3	57.8	410	240
DAB	2.8	1.2	239.2	2.8		
UMTS,450	1.6	0.8	468	1.6		
DVBT	116	32	674	54.5	180	
GSM900	1.7	1.5	955	0.5	0.04	731
GSM1800	0.4	0.4	1838	0.2	19	12
DECT	0.0016	0.01	1897.3	0.0016		
UMTS	8.5	3	2167.2	8.5	22	
WLAN	100.7	23	2462	44.1		
LTE-4G	1.3	0.4	2690	1.3		
Other					2302	2036
Total	**317**	**77**			**2900**	**2274**

Table (9-28): Results from site 24, Brudaremossen at the cross section with Alfred Gärdes väg.

A total power density of 317 µW/m^2 was measured at Brudaremossen on Wednesday21th Sep at 15:45. The main source was the DVBT. Because of I could not find the exact place so the results are lower than the previous measurements. The strongest values from 1999 and 2004 were from analog TV.

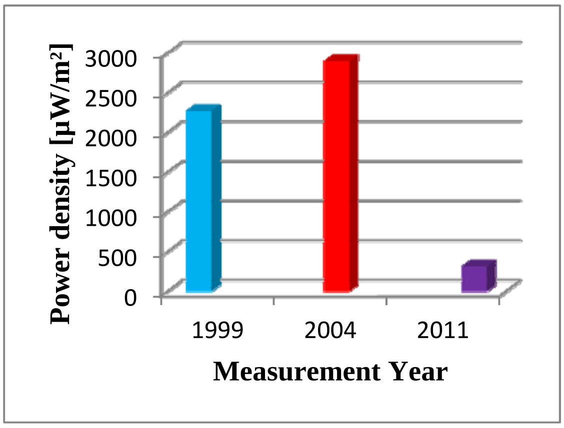

Figure (9-44): The total power densities [µW/m²].

25. Lindholmen Science Park (at entrance of IT-building), outdoor

Year	**2011**	**2011**	**2011**	**2011**
Packet	**Power density [µW/m²]**	**Reference Ratio [ppm]**	**Dominant frequency [MHz]**	**Peak density [µW/m²]**
FM_Radio	31.7	11	101.9	16
DAB	3	1.2	239.2	3
UMTS,450				
DVBT	10.3	3	626	10.3
GSM900	404	104	949.8	251.8
GSM1800	67	16.7	1824.2	66
DECT				
UMTS	309.6	67	2128.1	164
WLAN	56	19.7	2457	45.9
LTE-4G	16.1	4.5	2625	11.1
Other				
Total	**898**	**227**		

Table (9-29): Results from site 25, Lindholmen Science Park (entrance of IT-building).

In the measurement site, at Lindholmen Science Park, a total value of 898 µW/m² was found on Thursday 22th Sep at 09:00. The dominant source was GSM 900.

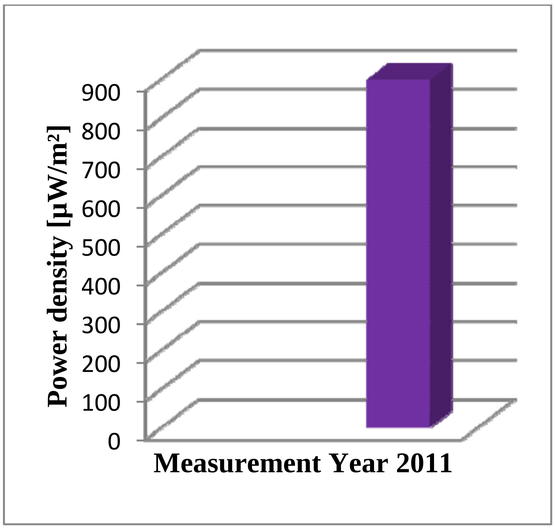

Figure (9-45): The total power densities [µW/m²].

26. Gamlestadstorget, outdoor

Year	2011	2011	2011	2011	2004
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]
FM_Radio	21	6.4	101.9	8.9	22
DAB	2.8	1.2	239.2	2.8	
UMTS,450	2.9	1.3	468	2.9	
DVBT	37.8	13.8	570	21.3	26
GSM900	13.7	3.8	938.6	3.5	15
GSM1800	12.3	2.3	1863	5.8	25
DECT					
UMTS	284	64.5	2116.6	208.7	11
WLAN	63.9	21	2462	23.5	
LTE-4G	61.2	19.8	2630	26.2	
Other					17
Total	**499**	**134**			**120**

Table (9-30): Results from site 26, Gamlestadstorget.

In the measurement site, at Gamlestadstorget, a total value of 499 µW/m² was found on Thursday 22th Sep at 12:50. The dominant source was UMTS.

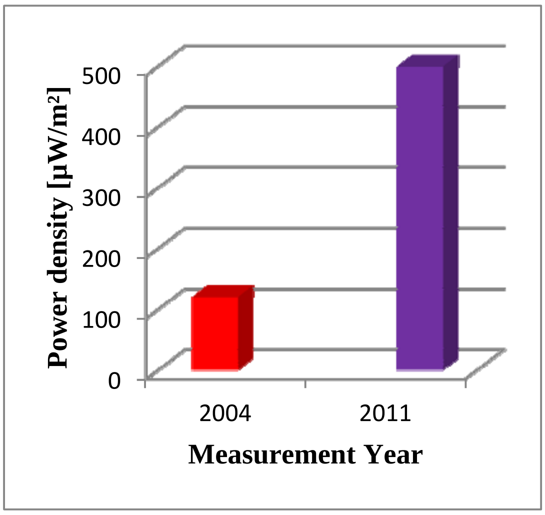

Figure (9-46): The total power densities [µW/m²].

Figure (9-47): Measurement site 26, Gamlestadstorget.

27. Vasagatan 48, indoor

Year	**2011**	**2011**	**2011**	**2011**	**2004**	**1999**
Packet	**Power density [µW/m²]**	**Reference Ratio [ppm]**	**Dominant frequency [MHz]**	**Peak density [µW/m²]**	**Power density [µW/m²]**	**Power density [µW/m²]**
FM_Radio	19.8	6.2	101.9	7	27	2
DAB	3.1	1.2	239.2	3.1		
UMTS,450	1.9	0.9	468	1.9		
DVBT	0.7	0.4	778	0.7	1.9	
GSM900	2.4	1.3	945.8	1.1	4.1	4
GSM1800	1.1	0.7	1869.8	0.6	2.9	0.8
DECT	0.0018	0.01	1897.3	0.0018		
UMTS	70	15.4	2162.7	35.3	2	
WLAN	42.8	9.1	2467	16.1		
LTE-4G	2.3	0.5	2645	2.3		
Other					3	4.5
Total	**144**	**36**			**41**	**8**

Table (9-31): Results from site 27, Vasagatan 48, fourth floor.

The value 144 µW/m² was measured on Saturday 24th Sep at 14:15 in Vasagatan 48, fourth floor. The main source was UMTS.

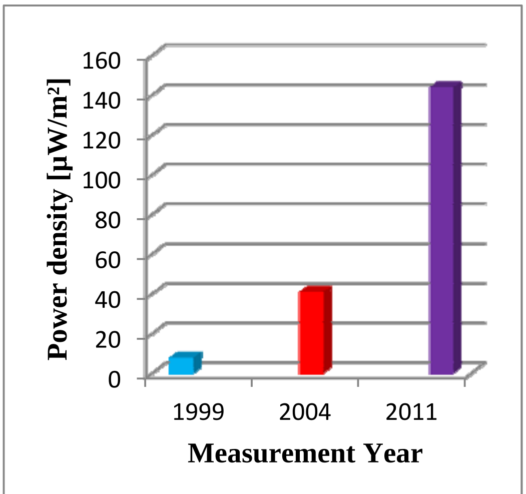

Figure (9-48): The total power densities [µW/m²].

Figure (9-49): Measurement site 28, Vasagatan 48 at fourth floor.

28. Vasagatan 48-balcony, indoor

Year	2011	2011	2011	2011	2004	1999
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]	Power density [µW/m²]
FM_Radio	45.2	13.4	89.3	15.8	81	17
DAB	3.1	1.2	239.2	3.1		
UMTS,450	1.8	0.9	468	1.8		
DVBT	0.7	0.4	778	0.7	3.5	
GSM900	57.5	17.8	953	40.4	48	29
GSM1800	41.1	10.5	1874.8	31.7	16	3
DECT	0.0021	0.01	1897.3	0.0021		
UMTS	324	75.4	2162.7	201.2	23	
WLAN	28.4	7.3	2462	11.3		
LTE-4G	76.8	23	2645	37.4		
Other					4	23
Total	**578**	**150**			**180**	**72**

Table (9-32): Results from site 28, Vasagatan48-balcony, fourth floor.

The value 578 µW/m² was measured on Saturday 24th Sep at 15:00 in Vasagatan 48-balcony, fourth floor. The main source was UMTS.

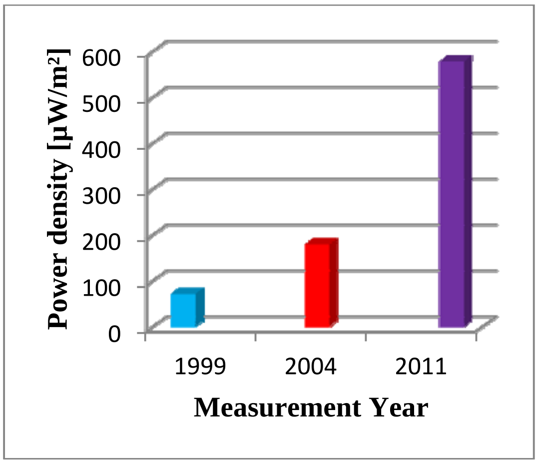

Figure (9-50): The total power densities [µW/m²].

Figure (9-51): Measurement site 28, Vasagatan 48, balcony at fourth floor.

29.Vasagatan Street crossing of Avenyn Street, outdoor

Year	**2011**	**2011**	**2011**	**2011**	**2004**	**1999**
Packet	**Power density [μW/m²]**	**Reference Ratio [ppm]**	**Dominant frequency [MHz]**	**Peak density [μW/m²]**	**Power density [μW/m²]**	**Power density [μW/m²]**
FM_Radio	6.6	3.6	101.9	2.3	18	2
DAB	3	1.2	239.2	3		
UMTS,450	1.7	0.9	468	1.7		
DVBT	23.9	4.7	778	9.9	3	
GSM900	255.1	60.6	940.8	177.8	1300	656
GSM1800	357.8	83.2	1870.8	161.7	650	61
DECT						
UMTS	1702	439.8	2132	723.4	710	
WLAN	358.5	85.9	2467	225.8		
LTE-4G	296.9	68.1	2630	72		
Other					2	62
Total	**3005**	**748**			**2700**	**782**

Table (9-33): Results from site 29, Vasagatan Street crossing of Avenyn Street.

The value 3005 μW/m² was measured on Saturday 24th Sep at 16:00 in site 29, in Street crossing of Avenyn Street. The main source was UMTS.

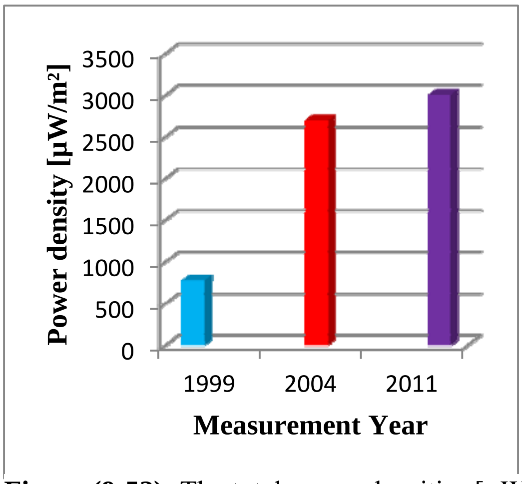

Figure (9-52): The total power densities [μW/m²].

Figure (9-53): Measurement site 29, Vasagatancrossing of Avenyn.

30. Viktoriagatan 36, outdoor (indoor in 2004)

Year	2011	2011	2011	2011	2004
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]
FM_Radio	1.1	0.9	101.9	1.1	3.1
DAB	2.8	1.2	239.2	2.8	
UMTS,450					
DVBT	0.6	0.4	574	0.6	1.7
GSM900	30	7.5	954.8	17.7	21
GSM1800	10.6	3.5	1840.6	9.8	6.4
DECT					
UMTS	9	2.8	2167.2	9	1.4
WLAN	9.2	3.2	2457	5.2	
LTE-4G	1.9	0.4	2625	1.9	
Other					0.6
Total	**65**	**20**			**34**

Table (9-34): Results from site 30, Viktoriagatan 36.

The value 65 µW/m² was measured on Saturday 24th Sep at 17:15 Viktoriagatan 36. The main source was GSM 900.

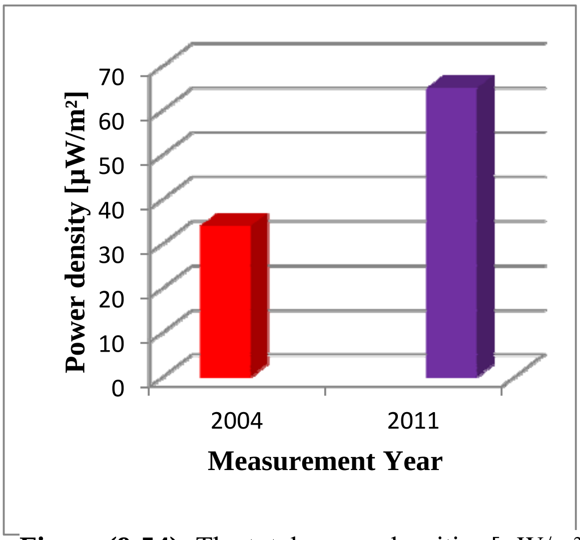

Figure (9-54): The total power densities [µW/m²].

31. Framnäsgatan 6, outdoor (2004 indoor 2nd floor)

Year	2011	2011	2011	2011	2004
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]
FM_Radio	114	39.2	99.4	64.8	300
DAB	2.9	1.2	239.2	2.9	
UMTS,450	1.6	0.8	468	1.6	
DVBT	28.9	9	574	10.8	12
GSM900	90.5	30.5	943.8	46	170
GSM1800	9.8	3.3	1848.6	5.8	13
DECT					
UMTS	8.8	3	2167.2	8.8	1.4
WLAN	29.4	10.2	2412	6.7	
LTE-4G	1.3	0.4	2690	1.3	
Other					9
Total	**287**	**98**			**500**

Table (9-35): Results from site 31,Framnäsgatan 6.

In the measurement site, at Framnäsgatan 6, a total value of 287 µW/m² was found on Saturday 24th Sep at 19:00. The dominant source was FM-Radio.

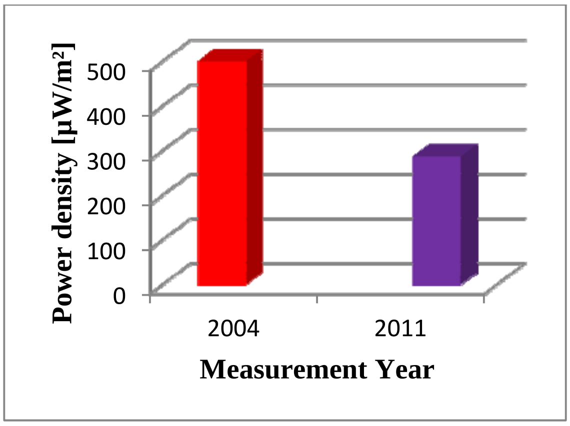

Figure (9-55): The total power densities [µW/m²].

32. Otterhällan (Kastellgatan 1), outdoor

Year	2011	2011	2011	2011	2004	1999
Packet	Power density [μW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [μW/m²]	Power density [μW/m²]	Power density [μW/m²]
FM_Radio	111.3	25.6	101.9	60	63	5
DAB	3.1	1.3	239.2	3.1		
UMTS,450						
DVBT	30.1	11	626	17.1	5.1	
GSM900	1108	264.5	948.6	803	740	319
GSM1800	110	34.7	1864	90.3	50	71
DECT						
UMTS	64.6	17	2120.4	29.3	9.7	
WLAN	3	0.6	2442	3		
LTE-4G	5.8	1.3	2625	3		
Other					24	70
Total	**1436**	**356**			**890**	**465**

Table (9-36): Results from site 32, Otterhällan (Kastellgatan 1).

The value 1436 μW/m² was measured on Sunday 25th Sep at 09:00 in Otterhällan. The main source was GSM 900.

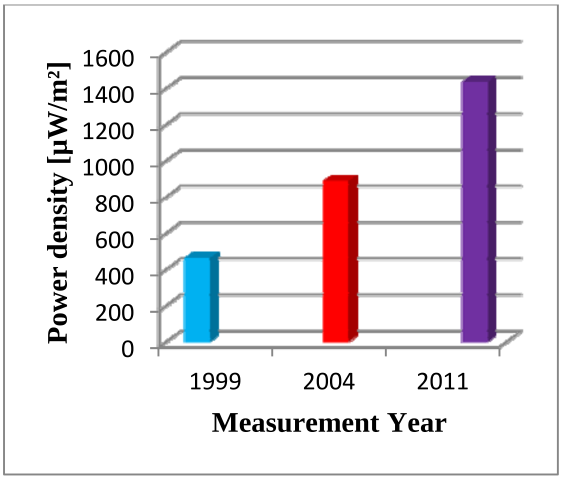

Figure (9-56): The total power densities [μW/m²].

33. Stackmolnsgatan 3, outdoor (2004 indoor)

Year	**2011**	**2011**	**2011**	**2011**	**2004**	**1999**
Packet	**Power density [µW/m²]**	**Reference Ratio [ppm]**	**Dominant frequency [MHz]**	**Peak density [µW/m²]**	**Power density [µW/m²]**	**Power density [µW/m²]**
FM_Radio	63	19.1	89.3	27.2	49	4
DAB	3	1.1	239.2	3		
UMTS,450						
DVBT	17.6	4.2	574	9	38	
GSM900	9.4	3.6	952.8	5	1.5	0.8
GSM1800	3.3	2	1821.8	1.6	0.2	0.02
DECT						
UMTS	164	36.3	2162.7	89		
WLAN						
LTE-4G	1.8	0.9	2640	1.8		
Other					12	6.1
Total	**262**	**67**			**120**	**12**

Table (9-37): Results from site 33, Stackmolnsgatan 3.

The value 262 µW/m² was measured on Sunday 25th Sep at 12:45 in Stackmolnsgatan 3. The main source was UMTS.

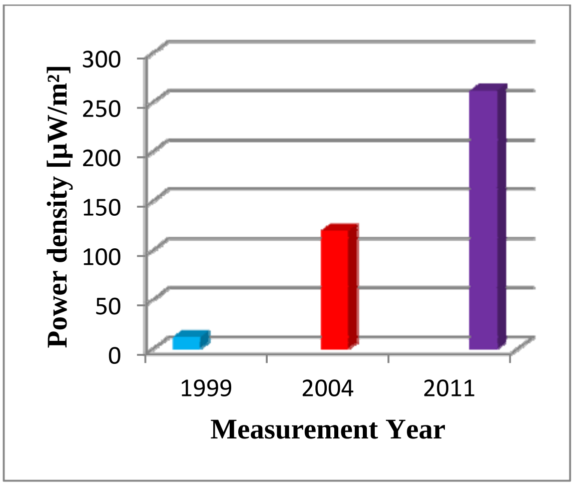

Figure (9-57): The total power densities [µW/m²].

34. Brunnsparken, Gustav Adolfstorg, outdoor (new measurement site)

Year	2011	2011	2011	2011
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]
FM_Radio	5.2	3.2	96.3	1.5
DAB	3	1.2	239.2	3
UMTS,450	1.7	0.9	468	1.7
DVBT	0.7	0.4	778	0.7
GSM900	248	60	955	119.9
GSM1800	207.3	54.6	1824.4	143.9
DECT	0.0051	0.02	1897.3	0.0051
UMTS	759	187	2158.8	342.2
WLAN	188.8	43.9	2462	110.5
LTE-4G	395.6	95.6	2660	202.6
Other				
Total	**1810**	**447**		

Table (9-38): Results from site 34, Brunnsparken, Gustav Adolfstorg.

A total power density of 1810 µW/m² was measured in Brunnsparken, Gustav Adolfstorg on Sunday 25th Sep at 16:00. The main source was UMTS.

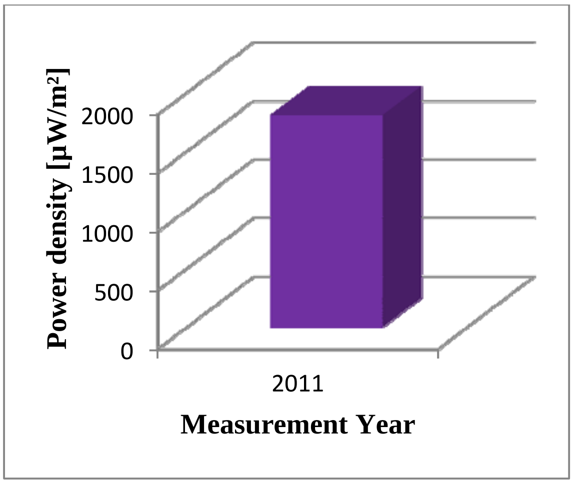

Figure (9-58): The total power densities [µW/m²].

Figure (9-59): Measurement site 34, Brunnsparken, Gustav Adolfstorg.

35. Backaplan (Södra Deltavägen), outdoor

Year	2011	2011	2011	2011	2004
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]
FM_Radio	27.5	9.7	96.3	12.2	17
DAB	3.1	1.3	239.2	3.1	
UMTS,450					
DVBT	43.2	11.5	570	24.1	33
GSM900	188.2	46.6	957.8	167.1	280
GSM1800	255.3	66.1	1862.8	189.2	430
DECT					
UMTS	411	91	2132	387.1	24
WLAN	68.3	15.7	2462	49	
LTE-4G	181.2	40.3	2630	181.2	
Other					26
Total	**1178**	**282**			**810**

Table (9-39): Results from site 35, Backaplan.

In the measurement site, Backaplan, a total value of 1178 µW/m² was found on Monday 26th Sep at 09:00. The dominant source was UMTS.

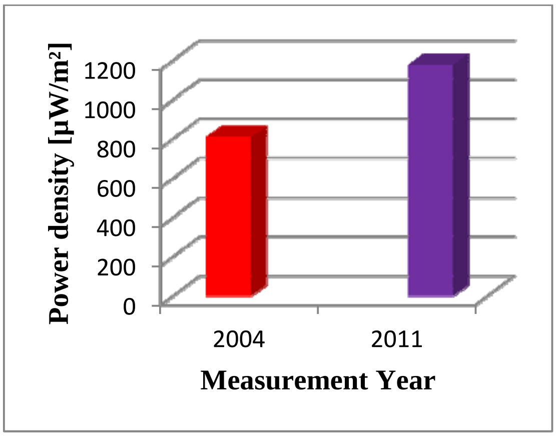

Figure (9-60): The total power densities [µW/m²].

36. Gibraltargatan 82, outdoor (2004 indoor)

Year	2011	2011	2011	2011	2004
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]
FM_Radio	11.4	4.4	96.3	6.8	72
DAB	3	1.2	239.2	3	
UMTS,450					
DVBT	16.5	5.1	778	9	2.9
GSM900	4.9	2.4	957	1.9	1.3
GSM1800	3.3	1.2	1839	1.8	0.58
DECT					
UMTS	102	38.9	2158.8	37.9	0.75
WLAN	4.9	2.1	2437	4.9	
LTE-4G	4.1	1.9	2625	2.1	
Other					4
Total	**150**	**57**			**81**

Table (9-40): Results from site 36, Gibraltargatan 82.

In the measurement site, Gibraltargatan 82, a total value of 150 µW/m² was found on Monday 26th Sep at 12:15. The dominant source was UMTS.

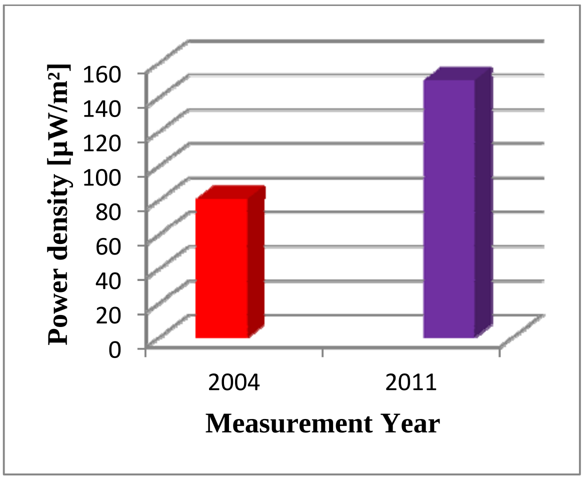

Figure (9-61): The total power densities [µW/m²].

37. Årstidsgatan 30, outdoor (2004 indoor)

Year	**2011**	**2011**	**2011**	**2011**	**2004**
Packet	**Power density [µW/m²]**	**Reference Ratio [ppm]**	**Dominant frequency [MHz]**	**Peak density [µW/m²]**	**Power density [µW/m²]**
FM_Radio	9.3	3.1	101.9	5.1	14
DAB					
UMTS,450					
DVBT	4.4	1.7	778	4.4	0.41
GSM900	37.5	10	955.6	16.2	11
GSM1800	3	2	1865.6	1.7	0.99
DECT					
UMTS	69	21.8	2158.8	26.2	0.43
WLAN	26.4	13.2	2472	21.3	
LTE-4G	30	17.1	2640	17.9	
Other					10
Total	**180**	**69**			**37**

Table (9-41): Results from site 37, Årstidsgatan 30.

In the measurement site, Årstidsgatan30, a total value of 180 µW/m² was found on Monday 26th Sep at 15:30. The dominant source was UMTS.

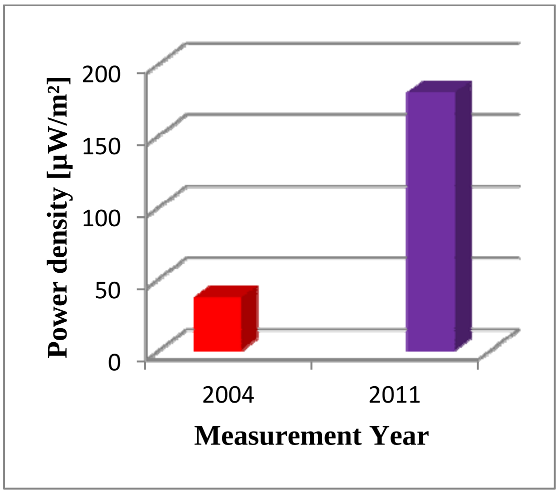

Figure (9-62): The total power densities [µW/m²].

38. Marklandsgatan 71, outdoor (2004 indoor)

Year	2011	2011	2011	2011	2004
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]
FM_Radio	5.5	2.5	99.4	4.8	3.2
DAB					
UMTS,450					
DVBT	0.7	0.4	574	0.7	0.93
GSM900	1.3	2	942.6	0.3	4.4
GSM1800	2.3	1.2	1851	0.7	1.9
DECT	0.0016	0.01	1897.3	0.0016	
UMTS	9	2.7	2167.2	8.5	0.74
WLAN	2.4	0.5	2442	2.4	
LTE-4G	2.2	0.5	2625	2.2	
Other					1
Total	**23**	**10**			**12**

Table (9-42): Results from site 38, Marklandsgatan 71.

In the measurement site, Marklandsgatan71, a total value of 23 µW/m² was found on Tuesday 27th Sep at 08:00. The dominant source was UMTS.

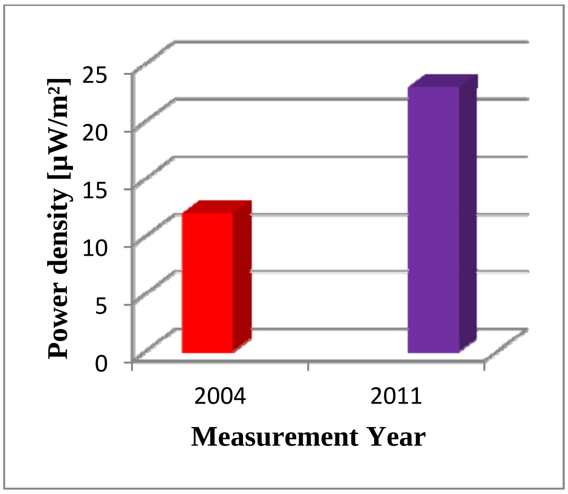

Figure (9-63): The total power densities [µW/m²].

39. Mejerigatan 2B, indoor (new measurement site)

Year	2011	2011	2011	2011
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]
FM_Radio	4.6	2.8	89.3	2.5
DAB	3.2	1.3	239.2	3.2
UMTS,450	1.9	0.9	468	1.9
DVBT	28.3	7.5	626	9.5
GSM900	18.4	6.2	949.8	13.3
GSM1800	3.7	1.5	1863	1.6
DECT				
UMTS	1463	354.7	2116.6	1121.6
WLAN	58.4	19.6	2462	20.6
LTE-4G	17.9	5.7	2630	6.6
Other				
Total	**1599**	**400**		

Table (9-43): Results from site 39, Mejerigatan 2B at eighth floor.

A total power density of 1599 µW/m² was measured Mejerigatan 2B at eighth floor on Tuesday 27th Sep at 10:45. The main source was UMTS.

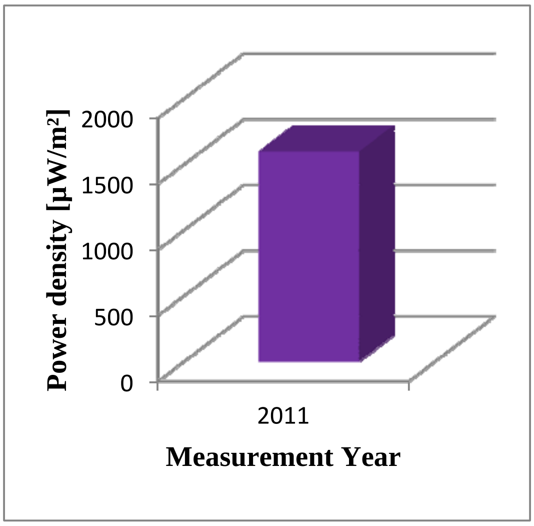

Figure (9-64): The total power densities [µW/m²].

Figure (9-65): Measurement site 39, Mejerigatan 2B at eighth floor.

40. Trollspisgatan-VolratThamsgatan, outdoor

Year	2011	2011	2011	2011	2004	1999
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]	Power density [µW/m²]
FM_Radio	94.3	32	99.4	57.3	170	135
DAB						
UMTS,450						
DVBT	41.7	10.5	626	18.2	43	
GSM900	12.4	3.4	940.4	7.5	2.4	4
GSM1800	2	1.2	1838.6	0.6	1.4	0.2
DECT						
UMTS	183.5	40.1	2162.7	118.2	7.6	
WLAN	61.7	13	2462	30		
LTE-4G	197	48.9	2640	170.2		
Other					141	285
Total	**592**	**149**			**370**	**425**

Table (9-44): Results from site 40, Trollspisgatan-Volrat Thamsgatan.

The value 592 µW/m² was measured on Tuesday 27th Sep at 12:30 in Trollspisgatan-Volrat Thamsgatan. The main source was LTE-4G.

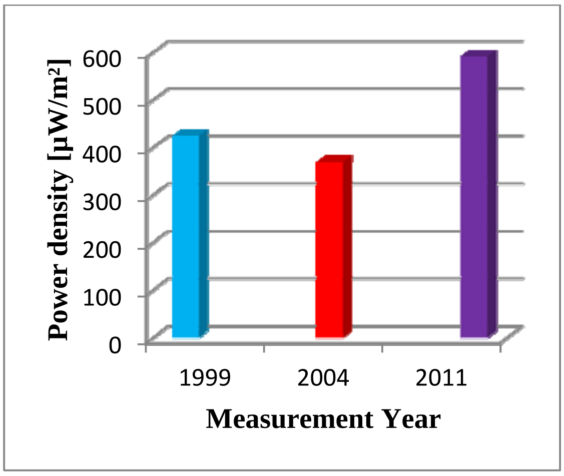

Figure (9-66): The total power densities [µW/m²].

41. Uppstigen 110, indoor (new measurement site)

Year	2011	2011	2011	2011
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]
FM_Radio	49	14.6	99.4	29.1
DAB				
UMTS,450				
DVBT	8.3	3.4	570	6.1
GSM900	5.3	3.2	923.2	2.4
GSM1800	1.6	1	1868	0.9
DECT				
UMTS	14.1	5.4	2158.8	14.1
WLAN	12.2	4.8	2432	12.2
LTE-4G	3.1	0.6	2630	3.1
Other				
Total	**94**	**33**		

Table (9-45): Results from site 41, Uppstigen 110 at second floor.

In the measurement site, Uppstigen 110 at second floor, a total value of 94 µW/m² was found on Tuesday 27th Sep at 14:40. The dominant source was FM-Radio.

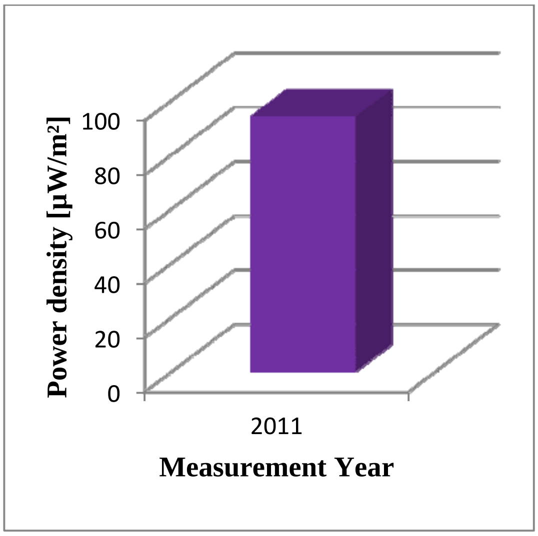

Figure (9-67): The total power densities [µW/m²].

42. Kaponjärgatan 4C, outdoor (2004 indoor)

Year	2011	2011	2011	2011	2004
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]
FM_Radio	5.9	2.9	101.9	3.1	5.6
DAB	3	1.3	239.2	3	
UMTS,450					
DVBT	3.7	2.2	570	3	0.49
GSM900	2	2.3	957.8	0.9	1.7
GSM1800					0.45
DECT					
UMTS	8	1.3	2120.4	8	0.27
WLAN					
LTE-4G					
Other					2
Total	**23**	**10**			**10**

Table (9-46): Results from site 42, Kaponjärgatan 4C.

In the measurement site, Kaponjärgatan 4C, a total value of 23 µW/m² was found on Tuesday 27th Sep at 16:00. The dominant source was UMTS.

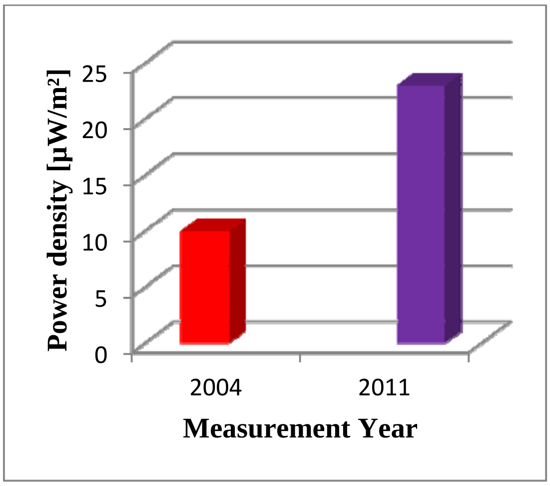

Figure (9-68): The total power densities [µW/m²].

43. Mandolingatan 19, outdoor (2004 indoor)

Year	**2011**	**2011**	**2011**	**2011**	**2004**
Packet	**Power density [μW/m²]**	**Reference Ratio [ppm]**	**Dominant frequency [MHz]**	**Peak density [μW/m²]**	**Power density [μW/m²]**
FM_Radio	50	14.7	89.3	27	54
DAB					
UMTS,450	1.7	0.9	468	1.7	
DVBT	39.4	9.7	674	23.3	72
GSM900	33.4	7.7	958.4	20.2	27
GSM1800	5.7	1.7	1864.4	2.4	10
DECT					
UMTS	39.2	9.3	2139.6	23.3	0.91
WLAN	6.7	2.8	2437	4	
LTE-4G	4.8	3.1	2635	4.8	
Other					29
Total	**181**	**50**			**190**

Table (9-47): Results from site 43, Mandolingatan 19.

In the measurement site, Mandolingatan 19, a total value of 181 μW/m² was found on Tuesday 27th Sep at 18:15. The dominant source was FM-Radio.

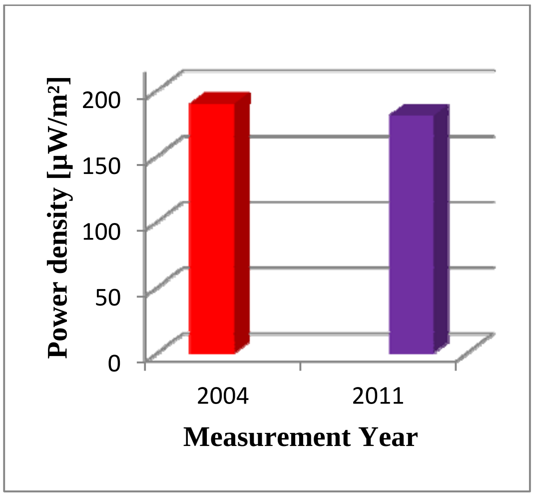

Figure (9-69): The total power densities [μW/m²].

44. Mandolingatan 41, outdoor (2004 indoor)

Year	2011	2011	2011	2011	2004
Packet	Power density [μW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [μW/m²]	Power density [μW/m²]
FM_Radio	6.5	3.1	89.3	4	2.6
DAB					
UMTS,450					
DVBT	8.1	3.7	674	8.1	11
GSM900	51.2	14.9	943.6	39.1	39
GSM1800	7.3	4.2	1863	5.2	5.6
DECT					
UMTS	60	16.7	2116.6	34	0.67
WLAN	10.4	5.2	2467	7.1	
LTE-4G	5	0.8	2640	5	
Other					4
Total	**148**	**49**			**65**

Table (9-48): Results from site 44,Mandolingatan 41.

In the measurement site, Mandolingatan 41, a total value of 148 μW/m² was found on Tuesday 27th Sep at 20:00. The dominant source was UMTS.

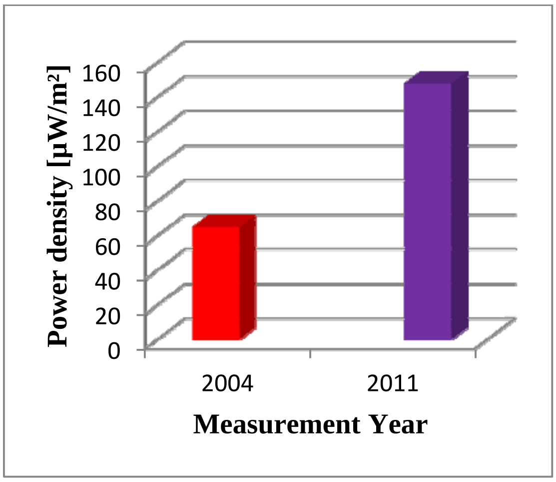

Figure (9-70): The total power densities [μW/m²].

45. Nordhemsgatan 66, outdoor (2004 indoor)

Year	**2011**	**2011**	**2011**	**2011**	**2004**
Packet	**Power density [µW/m²]**	**Reference Ratio [ppm]**	**Dominant frequency [MHz]**	**Peak density [µW/m²]**	**Power density [µW/m²]**
FM_Radio	176	65	89.3	63.9	340
DAB	3.1	1.3	0	3.1	
UMTS,450					
DVBT	12.4	3.5	570	12.4	3.3
GSM900	1.4	1.8	942.6	0.7	4.7
GSM1800					0.37
DECT					
UMTS	23	9.3	2116.6	23	
WLAN	2.4	0.5	2422	2.4	
LTE-4G	8.4	2.1	2650	6.4	
Other					6.7
Total	**227**	**83**			**360**

Table (9-49): Results from site 45, Nordhemsgatan 66.

In the measurement site, Nordhemsgatan 66, a total value of 227 µW/m² was found on Tuesday 27th Sep at 22:30. The dominant source was FM-Radio.

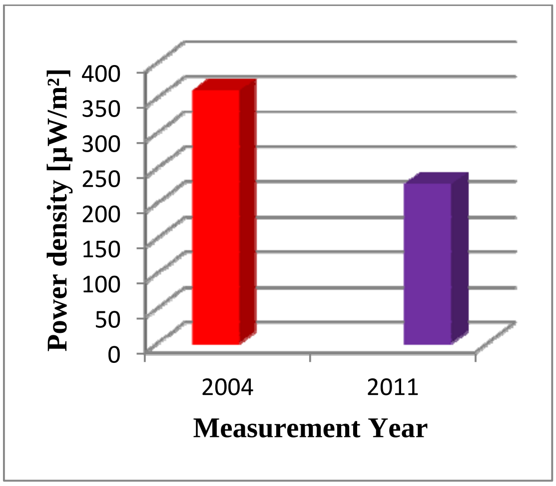

Figure (9-71): The total power densities [µW/m²].

46. Nordostpassagen 69, outdoor (2004 indoor)

Year	2011	2011	2011	2011	2004
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]	Power density [µW/m²]
FM_Radio	28	10.6	101.9	16	14
DAB					
UMTS,450					
DVBT	5.1	1.4	674	5.1	1.5
GSM900	2.8	1.9	940.6	1.3	0.3
GSM1800	0.8	0.5	1838	0.4	0.045
DECT					
UMTS	17	6.3	2143.5	17	0.28
WLAN					
LTE-4G					
Other					0.5
Total	**54**	**21**			**16**

Table (9-50): Results from site 46, Nordostpassagen 69.

In the measurement site, Nordostpassagen 69, a total value of 54 µW/m² was found on Wednesday 28th Sep at 06:00. The dominant source was FM-Radio.

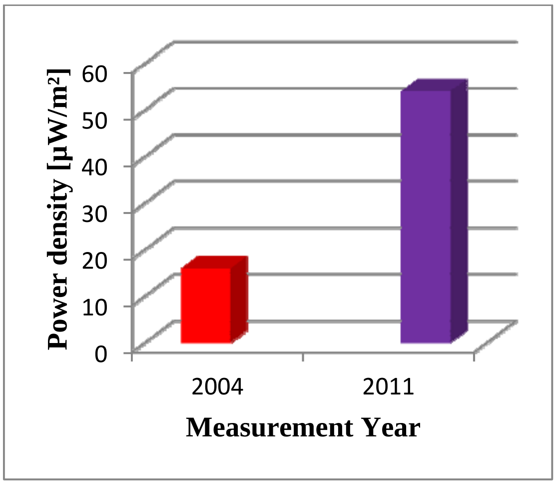

Figure (9-72): The total power densities [µW/m²].

47. Studiegången 4, indoor (new measurement site)

Year	2011	2011	2011	2011
Packet	Power density [µW/m²]	Reference Ratio [ppm]	Dominant frequency [MHz]	Peak density [µW/m²]
FM_Radio	28	9.3	101.9	21
DAB	3	1.2	239.2	3
UMTS,450	1.7	0.8	468	1.7
DVBT	17.2	5.1	778	9
GSM900	7.4	2.3	942.6	7.1
GSM1800	4.1	1.4	1831.4	3.1
DECT	0.0017	0.01	1897.3	0.0017
UMTS	8.9	3	2116.6	8.9
WLAN	1	0.3	2472	1
LTE-4G	2	0.4	2635	2
Other				
Total	**73**	**24**		

Table (9-51): Results from site 47,Studiegången 4, at second floor.

In the measurement site, Studiegången 4, at second floor, a total value of 73 µW/m² was found on Wednesday 28th Sep at 08:15. The dominant source was FM-Radio.

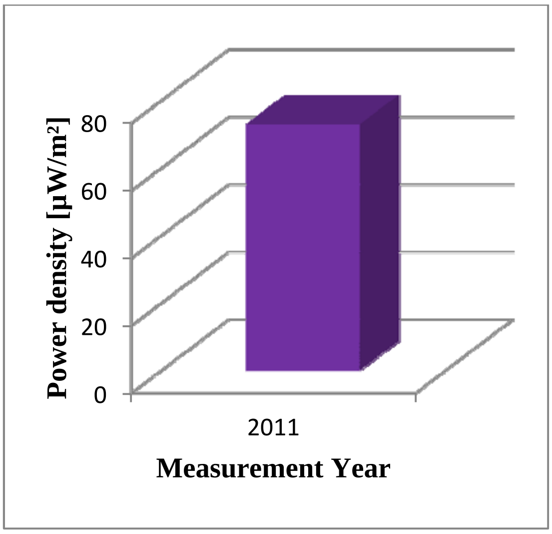

Figure (9-73): The total power densities [µW/m²].

48. Holländareplatsen 5A, outdoor (2004 indoor)

Year	**2011**	**2011**	**2011**	**2011**	**2004**
Packet	**Power density [µW/m²]**	**Reference Ratio [ppm]**	**Dominant frequency [MHz]**	**Peak density [µW/m²]**	**Power density [µW/m²]**
FM_Radio	25.1	8.1	96.3	13.1	38
DAB	3.2	1.3	239.2	3.2	
UMTS,450					
DVBT	4.2	2.1	574	3.5	0.95
GSM900					2
GSM1800					1.5
DECT					
UMTS	61	19.3	2124.3	61.1	0.82
WLAN	1.9	0.6	2462	1.9	
LTE-4G	8.5	3.3	2635	8.5	
Other					0.5
Total	**104**	**35**			**44**

Table (9-52): Results from site 48, Holländareplatsen 5A.

In the measurement site, Holländareplatsen 5A, a total value of 104 µW/m² was found on Wednesday 28th Sep at 11:30. The dominant source was UMTS.

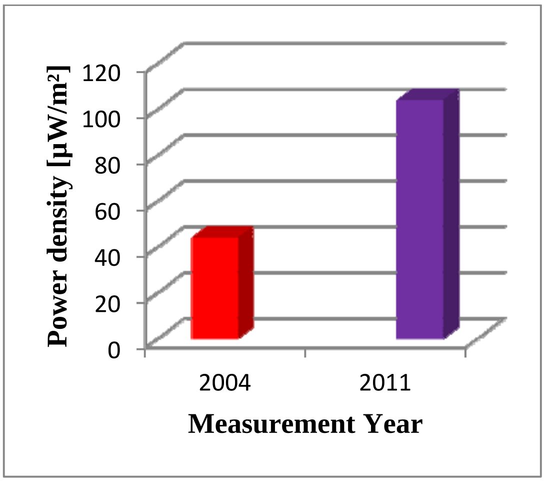

Figure (9-74): The total power densities [µW/m²].

10 Discussions

A mean power density of 505 μW/m^2 was found and the median value was 228 μW/m^2 the mean value 139 ppm of the reference level and the median value 69 ppm of the reference level. In indoor sites, the mean value was 537 μW/m^2 was obtained and the median value 151 μW/m^2 was found and for outdoors sites, the mean value was 491 μW/m^2 and the median value was 251 μW/m^2.

In general, both outdoor sites and indoor sites have same power density. The highest measured power density was found at an outdoor site, (site 29) with a value of 3005 μW/m^2. In the previous measurement (2004) in site 2 (Hällskriftsgatan), the maximum power density was 6700 μW/m^2 and it was dominated by FM-Radio, as it was an extreme value so I ignored to use this value because it had a big effect on comparing with my result. The two outdoor sites which gave the highest total power densities were site 8 and 29. Site 8 was placed at sixth floor of E and D&IT building at Chalmers which was near the base station of antennas which explains the high contribution of exposure from GSM 900 and LTE. This site had a highest value of exposure from LTE system.

In site 29 (Vasagatan Street crossing Avenyn Street) was a central city location with GSM 900, GSM 1800, UMTS and LTE base station antennas were placed nearby in this

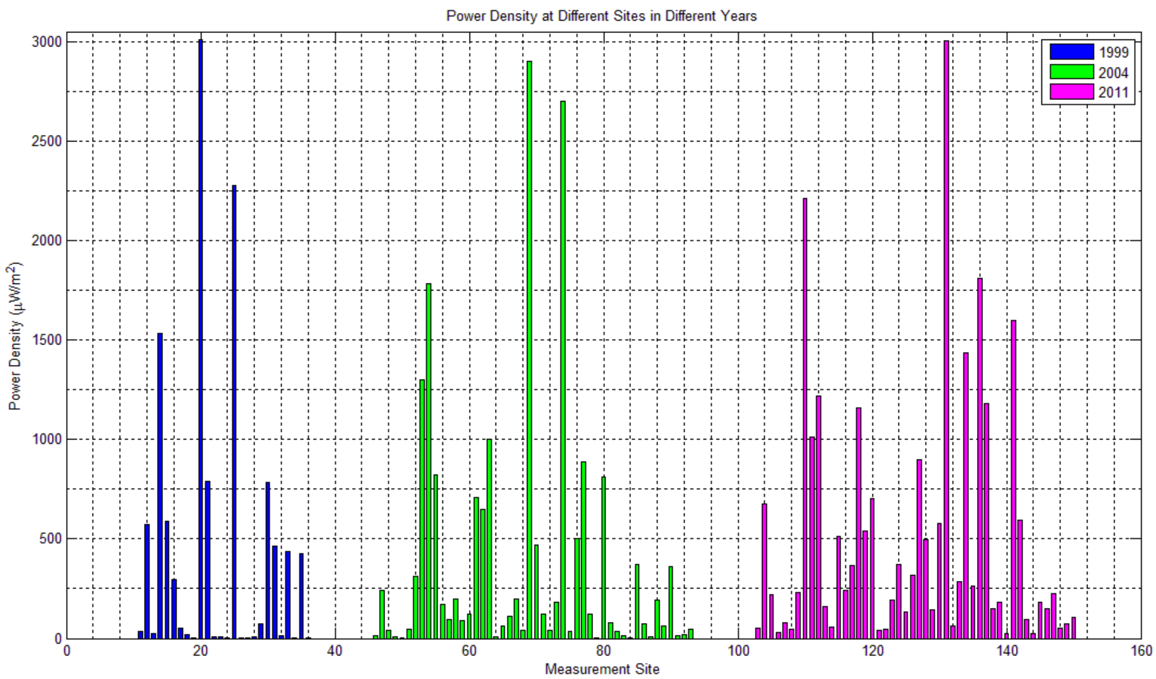

Figure (10-1): Power density at different sites in different years.

measurement location and also as it is shown in the measurement result. In the previous measurements, in site 24 (Brudaremossen) was placed near radio and TV towers which explain why the previous results were higher than my result in this location, because the main exposure were from analog TV in both 1999 and 2004, so my result was lower than their result. In figure (10-1) we can see the distribution in different years.

An observed tendency of the measurement result is that for the outdoor locations, mobile phone base stations had a high share of the total exposure and for the indoor locations the main contribution often FM-Radio and sometimes mobile phone base stations. There are many explanations for this result, for example electromagnetic fields with short wavelengths are faster absorbed in the building material, while long wavelengths like FM-Radio are able to penetrate walls without losing their power density.

Another explanation is that the fact that many of the indoor locations were placed in apartments, this might lead to higher power densities from radio transmitters which are placed on the high towers. In general, the strongest exposure from FM-Radio and TV was found at locations with free sight to the radio and TV towers. On the other hand, in the outdoor locations the strongest exposure was obtained from GSM, UMTS and LTE systems. In the central of Gothenburg, mobile phone systems had stronger EMF than in other parts of the city because of requiring higher capacity there are many base stations in the central parts which leads to a higher power density of base stations. The lowest values were commonly found from the outsides of the central parts of the city.

Both the mean and maximum power densities were much smaller than ICNIRP recommendations. The highest measured value was only 0.15 percent of ICNIRP's reference value.

A comparison with the results from 2004 and 1999 shows that the there were higher FM-Radio values than the results from 2011. In general, the power densities are in the same order for the three investigations but there are some differences. UMTS system has been introduced since 1999 and also NMT 450, NMT 900 and analog television system are not used any more. The exposure from UMTS system is a considerable part of the total exposure at most of the measurement sites.

Since LTE system is a relative new system, the exposure level from its base stations will probably increase as a result of more traffic which will demand higher capacity of base stations and better geographical coverage. There are already many base stations of LTE system however there were not any strong traffic in September 2011, most of the smart phones did not support 4G, there were just broadband systems that used 4G. Statistical report said that there were only 8600 users using 4G in Sweden [Computer Sweden, Nov 2011].

The spectrum analyzer was not the same in the three investigations, I have to mention that in 2004, they used the same spectrum analyzer and antenna in some of the measurement sites but in other measurement sites, both the spectrum analyzer and the antenna were different like in 1999. There were also some differences in the setting of the analyzer; I used 'Average' mode like in 2004, but in 1999, the 'Max Hold' was used instead for measuring GSM system. The selection between 'average' and 'max hold' modes may have an influence on the results, especially for GSM systems. By using 'max hold', the measured value does not take into account how many of the eight time-slots that are used at the moment. Another thing which differs from 1999 is that the introduction of frequency hopping (FH) in the GSM systems.

Another thing is that the antenna calibration in 1999 for the YORK antenna (ARA01) seems to be inferior [Nilsson and Rydh, 2004]. Due to this calibration problem the stated levels for FM are probably too low in 1999 report.

The measurement uncertainty for the probe and spectrum analyzer is ± 3.1 dB. There are also phenomena which are not measurement errors, but still will affect the measured exposure of a site. Multipath fading is probably the most crucial. An interesting thing would be to measure the field strength during one day or a whole week at the same place, to see the variations. Some other things to investigate are how the field changed, depending on the floor in a building and to which extent different house building materials shade fields of different frequencies.

11 Abbreviations

AF	Antenna Factor
AP	Access Points
BS	Base Station
BSS	Basic Service Set
CAPEX	Capital Expenditure
CCK	Complementary Code Keying technique
CDMA	Code Division Multiple Access
DAB	Digital Audio Broadcasting
dBm	Decibel, with regard to mW
dBμV	Decibel, with regard to μV
DECT	Digital Enhanced Cordless Telecommunications
DSSS	Direct Sequence Spread Spectrum
DVB	Digital Television Broadcasting
DwPTS	Downlink Pilot Time-Slot
E	Electric field (V/m)
EMF	Electro Magnetic Field
ESS	Extended Service Set
E-UTRA	Evolved UMTS Terrestrial
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FH	Frequency Hopping
FHSS	Frequency Hopping Spread Spectrum
GSM	Global System for Mobile Communication
GP	Guard Period
H	Magnetic field (A/m)
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IP	Internet Protocol
LTE	Long Term Evolution
MC-CDMA	Multi Carrier-CDMA
MS	Mobile Station
NMT	Nordisk Mobile Telephony
OFDMA	Orthogonal Frequency Division Multiple Access
OPEX	Operational Expenditure
PABX	Private Automatic Branch Exchange

PAPR Peak to Average the Power density Ratio
PTS Post och Telestyrelsen (National Post and Telecom agency)
PSTN Public Switched Telephone Network
RAN Radio Access Network
RBW Resolution Band Width
S Power density (W/m^2)
SC-FDMA Single Carrier-FDMA
SRS Sounding Reference Signal
SSM Strålsäkerhetsmyndighetens (Swedish Radiation Protection authority)
TA Timing Advanced
TDD Time Division Duplex
TDMA Time Division Multiple Access
UMTS Universal Mobile Telecommunications System
UpPTS Uplink Pilot Time-Slot
USIM Universal Subscriber Identity Module
VBW Video Band Width
VHF Very High Frequency
WC Wireless Clients
WCDMA Wideband Code Division Multiple Access
WNICs Wireless Network Interference Cards
WLAN Wireless Local Area Network
1G First Generation (of mobile phone systems)
2G Second Generation (of mobile phone systems)
3G Third Generation (of mobile phone systems)
3GPP Third Generation Partnership Project
4G Fourth Generation (of mobile phone systems)

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