Chapter I

Introduction

1.1 Introduction and Background

Radiofrequency radiation is part of the non-ionizing electromagnetic radiation, which is used mainly for telecommunication purposes, wireless communication technologies and since radiofrequency radiation penetrates the matter, it is also used for heating as in microwave ovens.

People are exposed to radiofrequency radiation in many ways. The primary natural source of radiofrequency fields is the sun. Manmade sources are the main source of RF radiation exposure (WHO, 2008). Wireless communications sources have increased greatly in recent years and there is continuing change in the frequencies used and variety of applications. External sources of indoor RF radiation are AM and FM radio broadcasting towers, TV broadcasting towers, radar and mobile base stations. On the other hand internal sources of indoor RF radiation exposure are cellular phones, wireless LAN (WLAN), Bluetooth devices, cordless phones [Digital Enhanced Cordless Telecommunications (DECT)], wireless computer periphery and microwave ovens. However, the most prevalent and rapidly growing exposure is related to the increasing use of mobile telephones in society. Recently there are more than 3 billion mobile phone users worldwide (Kheifets, and Oksuzyan, 2008). Moreover, the dominant source with respect to local and cumulative exposure will remain the cellular phone (Kühn, Kramer1, Lott, and Kuster, 2005).

Study of indoor radiofrequency radiation in the environment is one of the most important topics, for many reasons:
First of all, despite the rapid growth of new technologies using RF radiation, very limited numbers of studies about indoor RF exposure are available world wide**.** Little is known about this subject, because most studies and researches focus on outdoor radiofrequency exposure.

Secondly, the recent developments in telecommunication and wireless technology have led to increasing numbers of new devices and systems that emit radio frequency RF electromagnetic energy.
In addition, implementing these developments has resulted in large numbers of individuals at the workplace or in the general public being exposed to RF radiation, so the total level of indoor RF exposure has increased (ICNIRP, 2008).
Finally, people spend most of their time indoor at houses and in public places, so they are concerned about indoor RF exposure.

Although all wireless technology and microwave ovens are restricted to relatively low maximum transmit power levels by regulations, concerns arises among the public about the personal RF exposure due to these sources . Concerned people often want to know the level of exposure due to various RF sources, especially mobile base stations and if these levels of exposure comply with international standards and guidelines.

In Palestine there are more than 2.5 millions of mobile phone users. There are two Palestinian companies that introduce services to Palestinians. The Palestine Cellular Communications Ltd (Jawwal) operates about 880 mobile base stations in the West Bank and Gaza Strip. A year ago, new company (Wataniya Mobile) operated nearly 400 mobile base stations in the West Bank only the mobile base stations in the country. There are also base stations that are operated by Israel and are located in areas that are not accessible for Palestinians in the West Bank. These base stations contribute to the total exposure of the Palestinian population from RF radiation and have become a reason for concerns in recent years.

In the City of Hebron, highly populated regions in Palestine, there are more than 67 mobile base stations operated by Jawwal Company, 3 TV broadcasting towers and 17 FM radio broadcasting towers. Public concern has increased about the possible health effects arising from indoor RF radiation exposure after the spread of mobile base stations antennas over the city , and the wide spread of wireless local area networks (WLAN) and microwave ovens in the city houses.

Published studies in Palestine are about outdoor RF exposure only .The present study is the first in Palestine for the assessment of indoor radiofrequency radiation levels. The main scientific contribution of this study is to determine the population exposure in the City of Hebron indoor from radiofrequency radiation in real life conditions at houses and in general public places from external sources, such as FM radio, television (TV), radar and mobile-phone base stations, as well as internal sources, such as microwave ovens, cordless phones; Digital Enhanced Cordless Telecommunications (DECT) and wireless LAN (WLAN), while distinguishing between the exposures from different RF sources in a sample representative of the general population.

1.2 Statement of the Problem

In Hebron, lack of information of the people concerned and fears about indoor RF exposure, high lighted the importance of having accessible scientific information about levels of indoor RF radiation in our environment from various sources. As a result, it is necessary for such big city to measure indoor radiofrequency radiation levels and take appropriate recommendations to protect people and environment if the RF exposure exceeds the international safe limits.

The present study is important for studying any increase in the levels of RFR in future because the levels of indoor radiofrequency radiation in the environment may change with the development of new cellular base stations or TV , AM ,FM transmitters or any new device used for public people at homes and offices such as wireless LAN, DECT ,Bluetooth and microwave ovens.

1.3 Objectives

As expected the RF levels varies from house to house depending on several factors such as building materials , distance from mobile base stations and wireless devices used in the house .The present study (work) is a survey in houses and other public places in Hebron, the biggest city in Palestine .

The main objective of this work is to determine the indoor RFR exposure of the general public in Hebron city from various external and internal RF sources.

Specific objectives of the present study are:

- To establish a data base of indoor radiofrequency sources in Hebron city.
- To perform measurements of indoor radiofrequency power densities from external and internal sources in Hebron city.
- To compare the measured power densities of indoor radiofrequency radiation with public exposure limits advised by the International Commission on Non-Ionizing Radiation Protection (ICNIRP).
- To evaluate the contribution of various environmental signals to the total public exposure and to find the dominant RF source in the region under investigation (City of Hebron –Palestine).
- To measure the leakage from microwave ovens at 1 meter in real life conditions.
- To investigate the variations of power density over distance from WLAN, DECT and microwave oven at some public places.
- To compare measurements of indoor RF exposure with outdoor RF exposure on balconies and roofs in some houses.

1.4 Hypothesis

The present study has the following hypothesis:

- ♦ Indoor radiofrequency levels in residential area without any mobile phone base stations are less than in residential area in vicinity to mobile base stations.
- ♦ The radiofrequency level in general is below the maximum permissible recommended by ICNIRP.
- ♦ Indoor radiofrequency levels indoor residential area is less than outdoor levels.
- ♦ Power density level decreases with distance increase from DECT, WLAN and microwave oven.

Chapter II

Indoor Radiofrequency Radiation Exposure

2.1 Electromagnetic Radiation

An electromagnetic wave consists of two components — electric and magnetic fields. The electric field results from the force of voltage, the higher the voltage, the stronger will be the resultant electric field, and the magnetic field results from the flow of current, the greater the current, the stronger the magnetic field.

Electromagnetic radiation may be considered as a series of waves of energy composed of oscillating electric and magnetic fields that travel through space with the speed of light (Irwin, 2002).

Electric field is perpendicular to magnetic field and both are perpendicular to the direction of the propagation of the electromagnetic wave as represented in Figure 2.1.

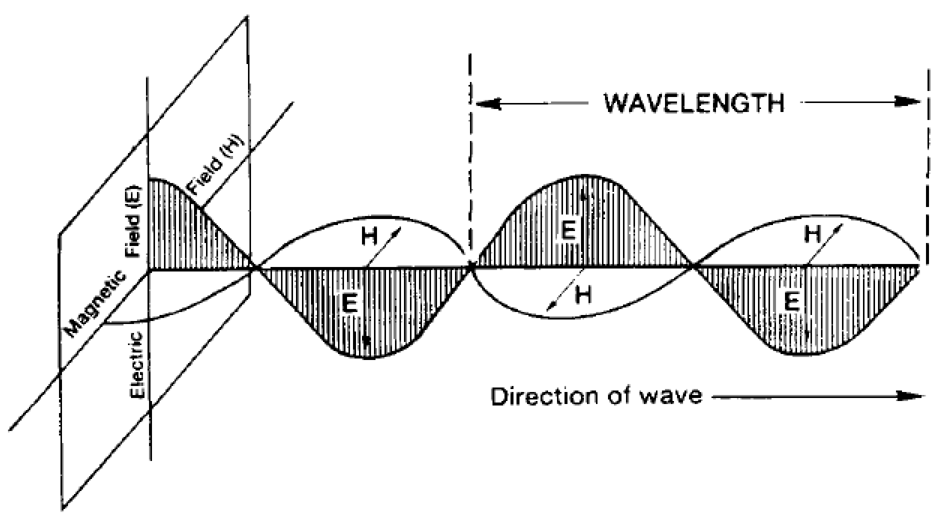

Figure 2.1: The electric field and magnetic field components of electromagnetic wave (Kitchen, 2001).

The electromagnetic spectrum represents a continuum from high-frequency gamma rays and x-rays through radiation of progressively lower frequencies, including ultraviolet, visible and infrared light, RF radiation, and very-low-frequency and extremely-low-frequency radiation (including the 60 Hz frequency associated with power lines) (House, 1999).

For any type of radiation, the higher the frequency and shorter the wavelength, the higher the quantum of energy. Gamma rays and x-rays have sufficient energy to ionize tissue. Non-ionizing radiation, which has lower energy, will not result in ionization but can still cause the vibration and rotation of molecules. Figure 2.2 represents electromagnetic spectrum.

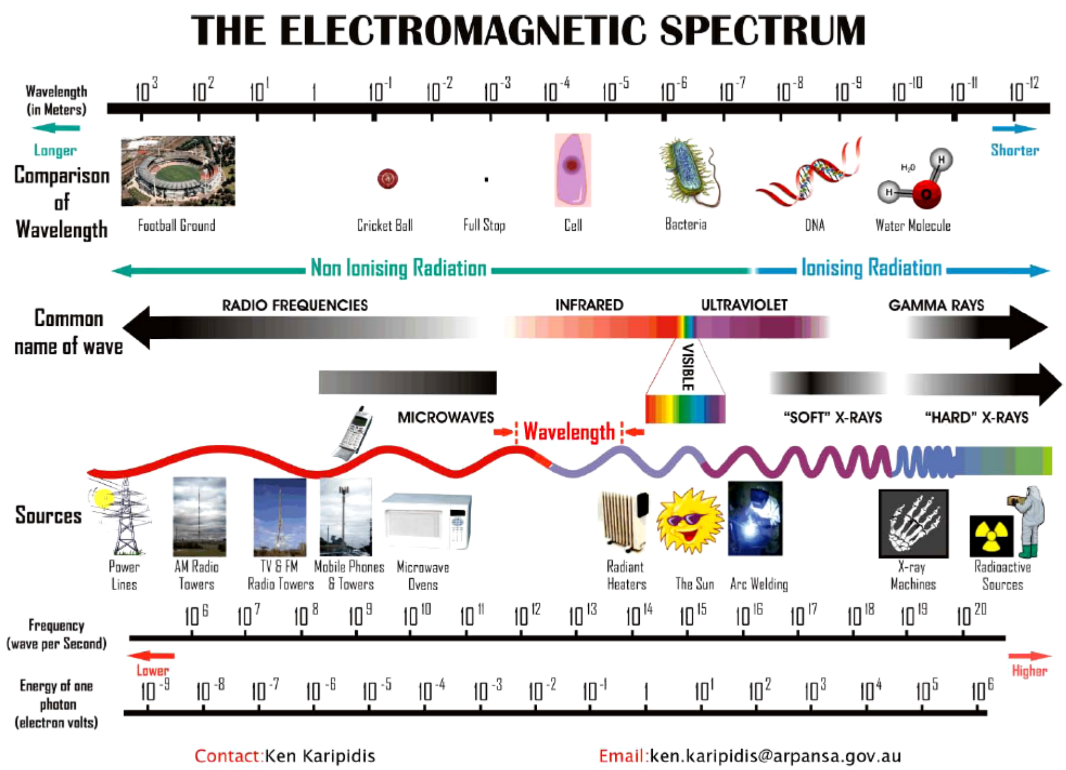

Figure 2.2: The electromagnetic spectrum (ARPANSA, 2009).

2.2 Radiofrequency Radiation

Radiofrequency electromagnetic radiation is generally defined as including frequencies range between 3 Kilohertz (kHz) to 300 Gigahertz (GHz) (Howard and Vaughan, 1998). Sometimes RF radiation is divided into bands; Table 2.1 summarizes frequency bands and sources of RF radiation.

Table2.1: Radiofrequency bands and sources (Mantiply, Pohl, Poppell and Murphy, 1997).

Descriptive band designation	**Abbreviation**	**Frequency range**	**Sources included**
Very-low frequency	VLF	3-30 KHz	Navigational transmitters, communication transmitter. Visual display terminals, induction stoves.
Low frequency	LF	30-300 KHz	Navigational transmitters. Long-range radio navigation
Medium frequency	MF	300-3000 KHz	AM broadcast, amateur radio, induction heaters, and electrosurgical units.
High frequency	HF	3-30 MHz	International broadcast, amateur and citizens band radio, dielectric heaters, shortwave diathermy.
Very- high frequency	VHF	30-300 MHz	FM broadcast, VHF television.
Ultra- high frequency	UHF	300-3000 MHz	UHF television, cellular telephones, microwave ovens, microwave diathermy, mobile base stations, cordless telephones (DECT) and air traffic radars.
Super-high frequency	SHF	3-30 GHz	Microwaves, satellite communications, radar, point to point microwaves communications.
Extra- high frequency	EHF	30GHz-300GHz	Fixed microwave links (military), radio astronomy space research, radio meteorology and radio spectroscopy.

2.2.1 Radiofrequency Radiation in Our Environment

In our environment RF electromagnetic radiation is produced by both natural and artificial sources.Natural sources like the sun, the earth and the ionosphere all emit low level RF electromagnetic fields. Until recently the natural RF electromagnetic background was relatively constant, but the situation changed with the development of modern communications and wireless devices. The environment is now full of man-made electromagnetic fields from radio AM, FM, TV broadcasting stations and cellular base stations, microwave applications, and many similar sources that propagate through space with the speed of light (Marino, 1985).

Artificial sources of RF electromagnetic radiation are mainly used for telecommunications purposes. Table 2.2 represents typical RF sources contributing to modern radio wave background. Amplitude and frequency modulated (AM and FM) signals are used in broadcasting and telecommunications, radio and television broadcasting, cellular base stations, point-to-point links and satellite communications all produce RF electromagnetic radiation .

Another RF application is heating, used for example in microwave ovens and industrial applications. Since RF fields penetrate the matter, not just the surface of the object is heated, which provides a fast, time saving heating process (Wilén, 2002).

Medical exposures could come from medical diathermy equipment to treat pain and inflammation, electrosurgical devices for cutting tissues, and diagnostic equipment such as magnetic resonance imaging (Ahlbom, Green, Kheifets, Savitzand and Swerdlow, 2004).

Table 2.2: Typical RF sources contributing to modern –day radio –wave background (Valberg, Deventer and Repacholi, 2007).

RF Sources	Frequency (MHz)	Exposure potential
AM commercial radio	0.5-1.7	U^+
Ionosphere research program S (e.g., HAARP)	2.8-10	L
FM commercial radio	88-108	U^+
VHF commercial television (analog) [a]	54-88, 174-216	U^+
UHF commercial television (analog and digital)	512-700	U^+
Maritime mobile, radio –navigation	0.003-0.30	L
Radar (aviation, marine, police)	10000-33000	L
Millimeter-wave length radar(meteorological , military)	~100000	L
Satellite transmissions (global positioning , military)	220-400	U
Satellite transmissions (television)	4000-6000	U
Amateur radio operators ,international short –wave broadcasts	~ 50	U
Cellular telephones, analog	806-890	U
Cellular telephones, GSM.	890-960	U
Cellular telephones, digital	1850-1990	U
Dispatch radio :(pagers ,aviation ,marine ,fire, emergency ,police)	900-950	U
Fixed microwave links (computers ,television ,telephone ,military)	~> 30000	L
Cordless telephones ,baby monitors, wireless toys ,wireless telemetry	27-60, 900, 2400, 5800	L
Computer monitors ,wireless computer connectivity ,RF identification tags (e.g., Bluetooth ,Wi-Fi)	~1900, ~2500, ~5700	L
Remote controls ,light dimmer controls, door openers ,surveillance devices	Broadband	L
Microwave ovens ,diathermy machines	2450	L^+
Industrial scientific and medical (ISM) band data links	~2400-5400	L
RF noise (lightening ,solar flares ,florescent fixtures ,neon lights ,spark ignition ,power –line corona discharge)	Broadband	U

U, ubiquitous RF sources
L, localized RF sources
+, those sources, among the ones listed, that typically contribute to the major fraction of total ambient RF exposure.
[a] The VHF band is split into two parts, with FM radio in the middle.

2.2.2 Indoor Radiofrequency Radiations

In a typical house, non-occupational exposure could come from external sources, such as radio (FM), television (TV), radar and mobile-phone base stations, as well as internal sources, such as a microwave oven, in-house bases for cordless phones (DECT), or use of mobile phones, local area network (WLAN), wireless personal computer peripherals (wireless mouse and wireless keyboard), baby surveillance devices and Bluetooth (Ahlbom, Green, Kheifets, Savitzand and Swerdlow, 2004).

The most important indoor radiofrequency sources people concerned about are mobile base stations, microwave ovens, wireless LAN and DECT.

2.2.3 Internal Sources of Indoor RF Radiation

Microwave ovens, in-house bases for cordless phones (DECT), or use of mobile phones, wireless local area network (WLAN), wireless personal computer peripherals, baby surveillance devices and Bluetooth applications are internal sources of indoor radiofrequency radiation exposure.

2.2.3.1 Microwave Oven

Microwave ovens are extensively used in restaurants and home kitchens. Microwave ovens produce 60 Hz fields outside the oven, but they also create microwave radiation inside the appliance that is at a much higher frequency, about 2.45 GHz. Every microwave oven contains a magnetron, a tube in which electrons are affected by magnetic and electric fields in such a way as to produce micro wavelength radiation at about 2.45 GHz in a continuous wave. As shown in Figure 2.3 the microwave energy from the magnetron is transferred to the oven cavity through a waveguide section. A mode stirrer spreads the microwave energy more or less evenly throughout the oven (Food and Environmental Hygiene Department, 2005).

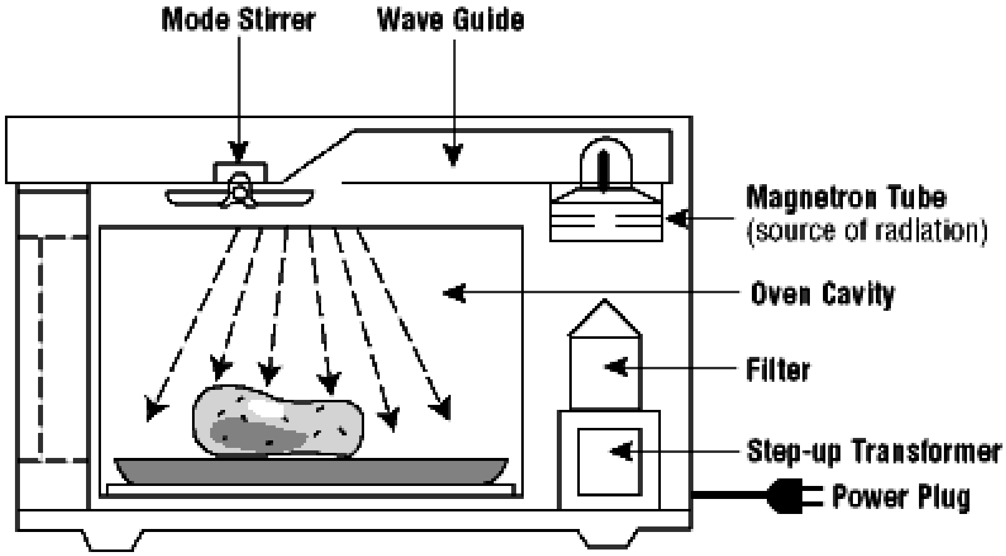

Figure 2.3: Basic structure of microwave oven (CCOHS, 2008).

Microwaves can pass through materials like glass, paper, plastic and ceramic, and be absorbed by food and water; but they are reflected by metals.
Heat is produced when the water molecules in the food vibrate (at a rate of 2.45 GHz), when the food absorbs the microwave radiation. The movement of the molecules especially the molecules of water (have a positive and negative end) produces friction which causes heat. This heat cooks or warms up the food (Sharshar, and Noaman, 2004).

Public concern about the possible harmful effects from microwave oven cooking is on increase. Leakage from microwave oven could cause heating of human tissue resulting in burns if the radiation intensity is sufficient, also the possible interference of heart pacemaker devices .Leakage from microwave ovens is relatively low and the evaluation of the possible health risk is based on measurements of the radiation emission from ovens that are in domestic use (Malhes, 1992).

In terms of exposure limits, most international standards such as ICNIRP (1998), limit exposure of the general public to RF power is 1mW/cm^2 at 2.45GHz. Microwave radiation leakage at 5 cm from any outer surface of the oven must not exceed 1mW/cm^2 with a test load in the cavity, and 5 mW/ cm^2 without a test load. These standards are designed to

protect against the thermal effect of microwave power (Thansandote, Lecuyer and Gajda, 2000).
The expected exposure for a microwave oven user is far below the 1 $mWcm^{-2}$ limit because of the diverging nature of the microwave radiation. Some countries also require that microwave ovens are checked every 3 years (Alhekail, 2001).

2.2.3.2 Wireless Local Area Networks (WLAN)

Wireless local area networks (WLAN) are an increasingly common technology employing radiofrequency RF energy. The technology is popularly known name Wi-Fi, Wi-Fi “hot spots” are found in many coffee shops, houses, university campuses, office buildings, airports, train stations, and other heavily traveled areas throughout the world, as well as in a great many homes of individual users (Office of the Telecommunications Authority, Hong Kong, 2008).

WLANs have been standardized through the Institute of Electrical and Electronic Engineers (IEEE) an international professional organization, has published a family of 802.11 standards for WLANs such as 802.11a, 802.11b, 802.11g and upcoming 802.11 technologies. Allowing operation at higher speeds and in additional frequency bands (Firoozbakhsh, 2007).
The main features of the different extensions of the IEEE 802.11 Standard, commonly identified by letters of the alphabet, are summarized in Table 2.3.

The trademark Wi-Fi (acronym stands for Wireless Fidelity) was originally used to certify IEEE 802.11b compliant devices to ensure their interoperability. However, it is now used by the Wi-Fi Alliance to certify all IEEE 802.11 compliant devices, independent of the particular standard extension used (a, b, g, or h)(ICNIRP, 2008).

Table 2.3: The main features of the different extensions of the IEEE (Institute of Electrical and Electronic Engineers) 802.11 Standard.

Standard	Description	Frequency (GHz)	Data rate (Mbit/s)	year
IEEE 802.11	Original standard, exploiting the ISM band	2.4	2	1997
IEEE 802.11b	Enhanced data rate in the ISM band	2.4	11	1999
IEEE 802.11a	Fastest version of the standard, exploiting the UNII band	5.7	54	1999
IEEE 802.11g	Same 802.11a speed, but in the ISM band	2.4	54	2003
IEEE 802.11h	Modification of 802.11a to ensure usability in Europe	5.7	54	2003

A wireless LAN, WLAN, is a data transmission system designed to provide location-independent network access between computing devices by using RF radiation rather than a cable infrastructure (Schmid, Preiner, Lager, Uberbacher, and Georg, 2007),as shown in Figure 2.4 .It allows mobility of terminals in a well-defined area. As the popularity of portable devices such as laptop computers, WLAN has become the communication infrastructure of choice.

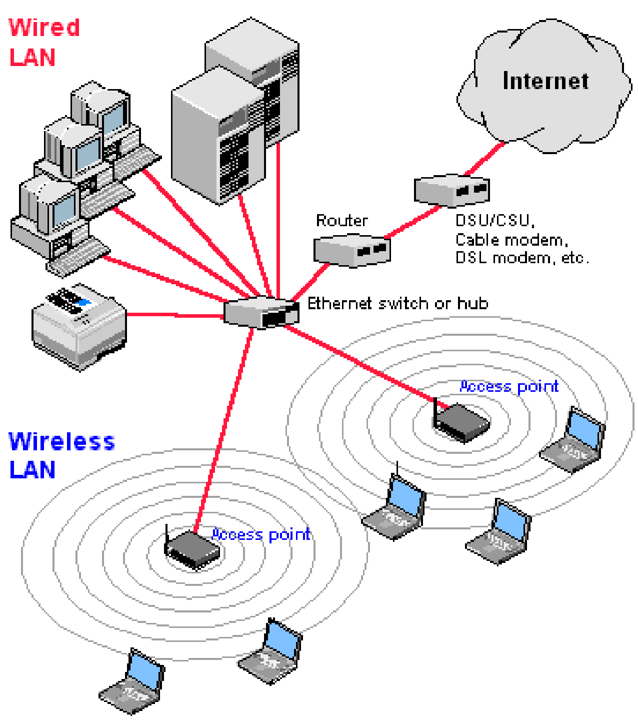

Figure 2.4: Wireless LAN and wired LAN infrastructure (Computer Desktop Encyclopedia, 2004).

Figure 2.5 represents a typical WLAN (called an infrastructure network), a wireless network adapter (alternatively known as client card) in a user's computer communicates with an access point (alternatively known as a wireless router, wireless gateway, or base station) that provides connectivity with a network infrastructure that may include wired and wireless devices. An access point usually consists of a radio, a wired network interface, and bridging software (Kühn and Kuster, 2006).

Wireless LANs work similarly to cellular telephone systems. An access point is like a cell phone tower, but, instead of transmitting over a radius of some number of miles, it transmits over a radius measured in feet. Just as a cell phone conversation keeps flowing when traveling into the range of the next cell tower, users can roam between Wi-Fi access points in a building without losing their connection.

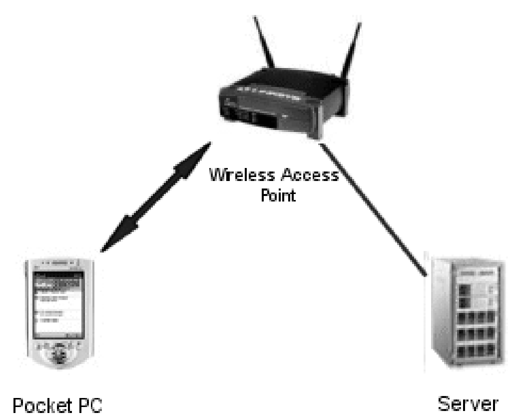

Figure 2.5: Typical WLAN (ZCOM, 2007)

WLAN transmissions are intermittent, which leads to power fluctuations at the data rates or higher (ICNIRP, 2008). A faster data rate means shorter transmission times and correspondingly lower exposures to the user. At any given location, the total RF signal present from a WLAN is a combination of that from the access point and client card, with the closest source (usually, the client card in the computer) usually providing the major contribution to the signal (Foster, 2007).

2.2.3.3 Digital Enhanced Cordless Telecommunications (DECT)

The Digital Enhanced Cordless Telecommunications (DECT) standard provides a general radio access technology for wireless telecommunications, with range requirements up to a few 100 m, operating in the 1880 to 1990 MHz frequency band (Simunic, and Zivkovic, 2000).

DECT technology and especially cordless phones are very popular in today's society. Millions of people around the world use DECT cordless phones in their daily life. With so many people using DECT technology, it is natural that there are people asking whether it is safe.

DECT system comprises a fixed part, or base station, and one or more portable parts as shown in Figure 2.6.

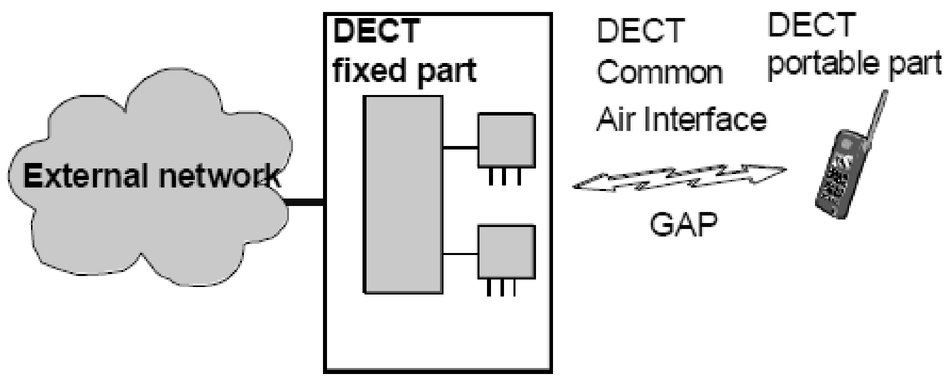

Figure 2.6: The DECT access technology using air interface (DECT Forum, 1997).

According to the DECT standard, the maximum normal transmit power is 250mW. The initiative to set up radio links in basic DECT applications is always taken by the portable part. The portable parts only radiates if a connection is to be activated from its own location or if it has to respond to a connection call from the base station. It should be noted that the continuous transmission of the base station is a unique property of the DECT system, which potentially makes DECT the dominant RF source in homes and offices (Kramer, Kühn, Lott, and Kuster, 2005).

2.2.3.4 Baby Surveillance Devices

Within the range of so-called baby phones there are numerous devices on the market. Most operate without a specific communication standard. Baby surveillance devices comprise a baby unit and one or more parent units. The baby unit, installed in the infant's room, is a transmitter (producing emissions), and parent units are mainly receivers. In some cases, however, both units are capable of transmitting and receiving.
Some systems also monitor whether the parent unit is still within range of the baby unit, by transmitting brief test signals (i.e. emissions) every few seconds.

In general the communication of baby surveillance devices use range of frequency from 27 MHz up to 2.4 GHz. In Europe a specific band for baby phone communication is defined at 864MHz. Some devices use the Private Mobile Radio band at 446MHz. Others are based on DECT technology. It is interesting that many devices are able to cover a relatively large range of reception with distance coverage of 150m up to 1000m.

To reduce the electromagnetic exposure in stationary applications, some devices provide the capability to adjust the transmitting power manually. Basically, all baby surveillance devices available on the market do not transmit signals (produce emissions) continuously but they are voice controlled (i.e., no radio frequency signal is transmitted if there is no environmental sound above a specific threshold) (Kramer, Kühn, Lott, and Kuster, 2005).

2.2.3.5 Wireless Personal Computer (PC) Peripherals

Wireless PC peripherals such as wireless mouse and wireless keyboard transmit for small distances up to 10 m at low level of power using variety frequencies from 27 MHz up to 2.4 GHz.

In general the emitted power of these devices is very low, since their intended operational radius is very small and they are additionally optimized for power consumption. Some devices only transmit if they detect movement or another action (clicking, scrolling) (Kramer, Kühn, Lott, and Kuster, 2005).

2.2.3.6 Bluetooth

Bluetooth is a Radio Frequency specification for short-range, point-to-point and point-to multi-point voice and data transfer. It enables users to connect to a wide range of computing and telecommunications devices without the need for cables that often fall short in terms of ease-of-use. Bluetooth technology was developed by the Bluetooth Special Interest Group (SIG), a trade association comprised of leaders in the telecommunications, computing, automotive, industrial automation and network industries.

Bluetooth operates in the 2.4 GHz range referred to as the Industrial, Scientific, and Medical (ISM) band. Before Bluetooth wireless technology, the only ways to connect two devices were either cable or infrared, each of which had limitations. Bluetooth now allows devices to work together within a range of 10-100 meters (Firoozbakhsh, 2007).

2.2.4 External Sources of Indoor RF Radiation

External numerous broadcasting sources in addition to mobile telephony can be found in the environment. For example, radio and television systems and commercial (communication) radio systems contribute to indoor radiofrequency exposure. For telecommunication purposes, radiofrequency fields between a few MHz to some GHz are of particular interest.

2.2.4.1 FM Radio and Television Transmitters

Worldwide the number of television and radio broadcasting stations increased considerably over the past three decades and the need for full coverage with television and radio has resulted in many lower power repeater transmitters being used to bring the services to local communities (Kitchen, 2001).

Broadcast towers are used for transmitting RF-EMF of services including AM and FM radio and UHF, VHF and digital television. The tower will either act as an antenna itself or support one or more antennas on its structure, including microwave dishes. There are two major types of broadcast towers (Hammash, 2009).

The first type is used at medium frequency (MF) (approximately 530 kHz to 1600 kHz) amplitude modulated (AM) radio stations. This tower is usually relatively slim, tall structure of triangular cross-section that is supported by guy wires. The tower itself is the radiating antenna.

The second type is used for very-high frequency and ultra-high frequency (VHF/UHF) television transmissions and FM radio. These towers may be either self-supporting structures with four main vertical members and consisting of a tapered structure of large cross-section at the bottom, or a triangular guyed slim structure similar to MF radio towers. The tower is not the radiating element but a support for the transmitting antennas (ARPANSA, 2003).

Radio and TV terrestrial transmitters provide an omni-directional coverage area in order to serve the whole population around the site. Omnidirectional radiating antenna is used for this purpose (Dawoud, 2003). Broadcasting service, providers have a number of requirements to fulfill when selecting a site for broadcast towers. Since broadcast towers transmit radio signals, which travel in straight lines, it is desirable to have a clear path between the transmitter and receiver to reduce interference. Figure 2.7 illustrates the direct path and the reflected path from transmitting antenna to the receiving antenna. The higher the tower is sited, the greater the range at which the signal can be received. That is why antennas are placed on hills, buildings and tall structures (Howard and Vaughan, 1998).

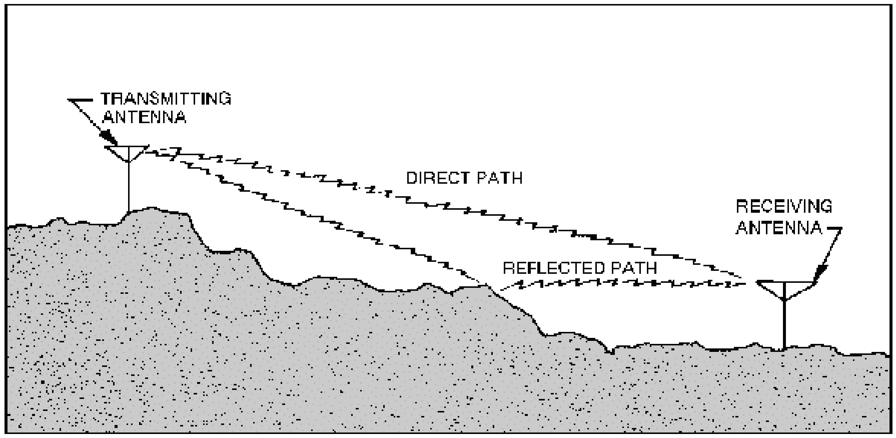

Figure2.7: Propagation of FM radio and TV broadcasting signals (Howard and Vaughan, 1998).

The transmit antenna pattern is designed so that the radiating beam is projected away from the tower almost horizontally so a wide area is covered. This minimizes the signal strength at the ground level near the tower. The higher level fields therefore occur at a height not accessible to general public (ARPANSA, 2003). Usually a restricted zone around the transmitting antennas is provided to limit the exposure of the general public to the RF electromagnetic waves with relatively high concentration of energy (Dawoud, 2003).

2.2.4.2 Mobile Phone Base Stations

The most rapidly growing wireless technology using RF radiation is related to the increase use of mobile telephones. Handhold mobile phones have only been available since the later part of the 1980s and yet the growth in use during the last three decades has been enormous (Abuaalkbash, 2006). Recently there are more than 3 billion mobile phone users worldwide, with a penetration in some countries reaching 90%. This technology typically uses the frequencies from 450 to 2500 MHz, although new technology may extend this range (Kheifets, and Oksuzyan, 2008).

Different operational frequencies are used in mobile phone base stations. The GSM 900(GMS : Global System for Mobile Telecommunication) system is using two frequency bands, 890-915 MHz for the uplink (mobile phone to base station) and 935-960 MHz for the downlink (base station to mobile phone) (Abdelati, 2005). The downlink of a particular channel is 45 MHz higher than the uplink (duplex operation). The GSM 1800 system uses bands of 1710- 1785 and 1805-1880 MHz, respectively, while the coming UMTS (Universal Mobile Telecommunications System) is allocated bands of 1900-2025 and 2110-2200 MHz (Bergqvist, et al., 2000).

The radio access network contains base stations which share a number of frequencies. Each base station sends and receives RF signals to mobile phones within a small area called a cell. When it detects a weakening signal due to a phone moving out of range, the system hands the phone over to another cell with a stronger signal. The network is planned to re-use the same frequencies as often as possible to give a high network capacity without excessive self-interference in order to maintain a good service quality (Ramsdale and Wiener, 1999). Figure 2.8 represents structure of the mobile telephone system (here with three cells).

For any operating frequency, all cellular systems have similar characteristics in the design of the radio access and fixed infrastructure network, in order to provide coverage and capacity. Adequate signal strength is necessary to cover the entire service area, and a sufficient capacity is needed to provide enough free channels to accommodate any user within the cell who might wish to use the system. As the number of users grows, more base stations are installed closer together to increase capacity. However, they are operated at lower power levels, to provide comparable signal strength and to prevent interference among neighboring base stations. Thus, in urban areas, base stations (or cells) are closer together, but are operated at lower power levels than in rural areas, where the cells tend to be larger (Lin, 2002).

The size of cells varies depending on the topography of the area and the density of users requiring access to the network, leading to three types of cells macrocell, microcell and picocell base stations (Mann, Cooper, Allen, Blackwell and Lowe, 2000).

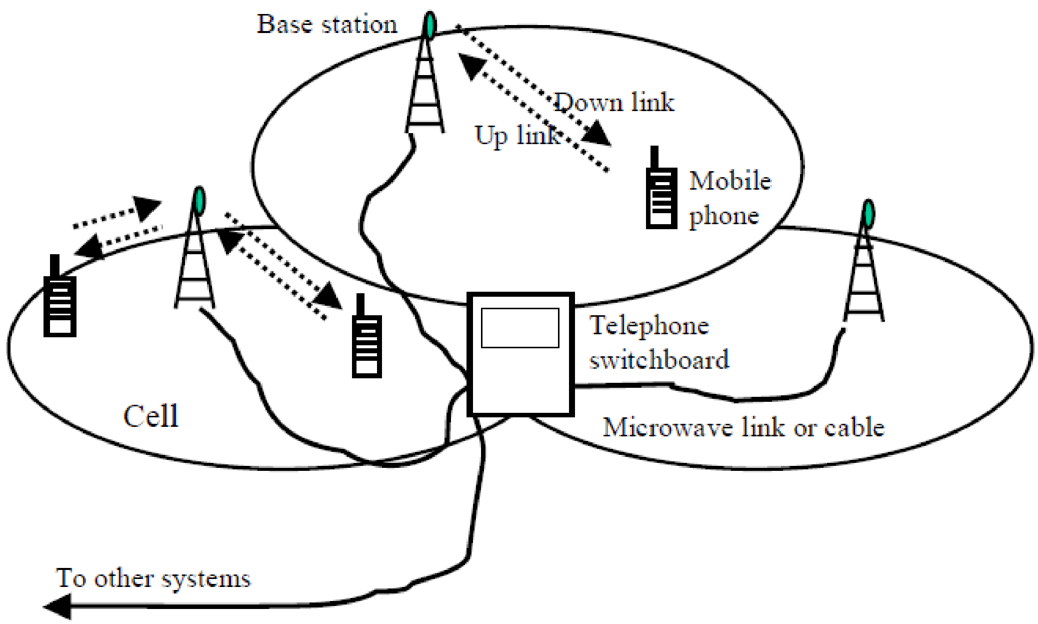

Figure 2.8: Typical structure of the mobile phone system (here with three cells) (Bergqvist, et al., 2000).

Antennas used with macrocellular base stations are generally placed between 15and 50 m above ground level because they are designed to provide communications over distances of several kilometers. However, microcellular base stations have their antennas mounted near ground level as communications are only carried out over distances of a few hundred meters, antennas tend to be mounted directly on exsisting structures such as buildings, ground based lattice towers, shorter masts mounted on roofs, and lamp-post type systems are also used (Mann, Cooper, Allen, Blackwell and Lowe, 2000). While picocellular base stations, provide indoor coverage at locations with high density of users such as airports, shopping centers, and railway stations. Both microcellular and picocellular base stations have lower output powers than macrocellular base stations ,usually a few watts, their antennas are mounted at street level and can often be approached more closely by the general public (Cooper, Mann, Khalid and Blackwell, 2006).

The antennas used on base sites are either of the omni or sectored type. Omni antennas radiate in a nominally uniform direction in the horizontal plane. While sector antennas effectively only radiate in a (horizontal) sector. In addition to this horizontal directionality, the antenna lobe will also have a strong vertical directionality, with a fairly narrow beam, which is often tilted slightly downward as shown in Figure 2.9 (Kitchen, 2001).

A tri-sectored site has antennas mounted in an equilateral triangle pattern to illuminate three different cells. The effect of sectorisation increase the re-use of frequencies, since it reduces interference .Most base stations in high traffic density areas such as cities are of the sector type. The exposure behind a sector antenna could be 300 times weaker than in the main lobe (Ramsdale and Wiener, 1999).

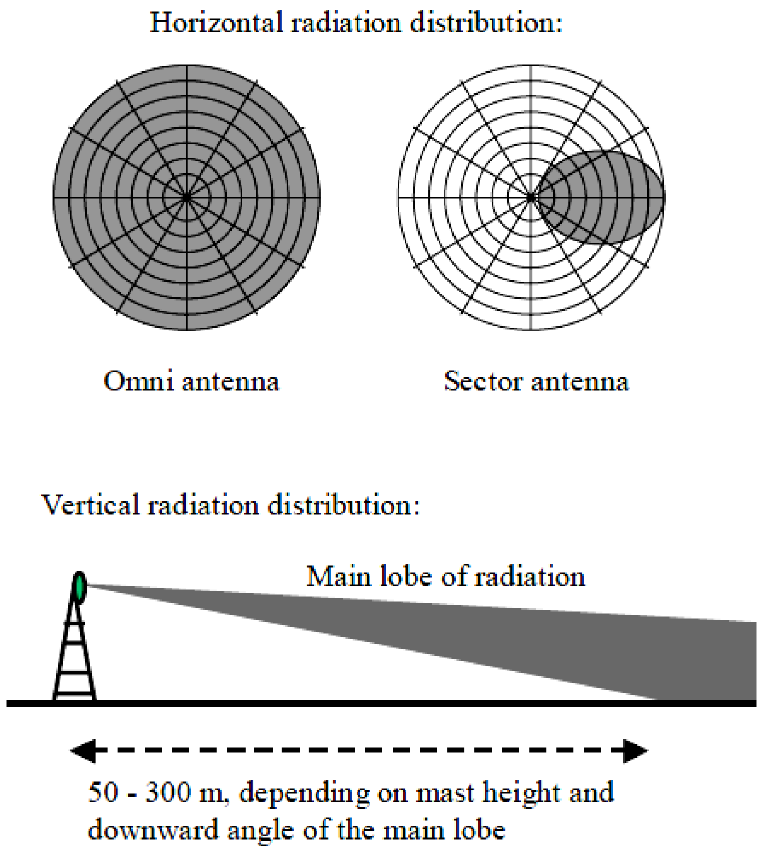

Figure 2.9: The direction of main radiation (main lobe) from base station antennas, both in the horizontal direction (above) and in the vertical direction (below) (Bergqvist, et al., 2000).

Microwave links or using cables to communicate base stations with other neighboring base stations. Dish antennas produce narrow conical beams that are 1 to 2 ˚wide .Typical powers are no more than a few tens of milliwatts because the power is selectively towards the receiver, so the powers used by dish antennas are very much lower than those used by base station antennas so the exposure produced by signals from dish antennas will be negligible in comparison with sector antennas (Mann, Cooper, Allen, Blackwell, and Lowe, 2000).

In Palestine Jawwal Company which is a mobile phone service provider, Jawwal (GSM900 MHz), and the new telecommunication company Wataniya Mobile introduce its services to Palestinians this year. These two companies use mobile phone sector antennas and microwave dish antennas. As these antennas are being placed within meters of homes, schools, and other sensitive areas, public concern has increased about indoor RF radiation exposure from these sources in Palestinian community.

Exposure from a mobile phone is concentrated in the part of the head closest to the handset and the antenna, highest in the temporal lobe that takes in at least half of all of the RF energy absorbed by brain. Exposure from mobile phone base stations is several orders of magnitude lower than that of the mobile phones. However, base stations expose the whole body, and the exposure duration is considerably longer (Kheifets, and Oksuzyan, 2008).

2.2.4.3 Radar

The term *Radar* is an acronym made up of the words (radio detection and ranging). The term is used to refer to electronic equipment that detects the presence, direction, height, and distance of objects by using reflected electromagnetic radiation. You probably use it yourself when referring to a method of recording the speed of a moving object. It permits radar systems to determine the positions of ships, planes, and land masses that are invisible to the naked eye because of distance, darkness, or weather.

The radio-frequency RF energy is transmitted to and reflected from the reflecting object as Figure 2.10 illustrates. A small portion of the energy is reflected and returns to the radar set. This returned energy is called an echo, just as it is in sound terminology. Radar sets use the echo to determine the direction and distance of the reflecting object.
Since the speed of electromagnetic energy is the same as the speed of light, range is determined by measuring the time required for a pulse of energy to reach the target and return to the radar. Because the speed of the pulse is known, the two-way distance can be

determined by multiplying the time by the speed of travel. The total must be divided by two to obtain the one-way range because the time value used initially is the time required for the pulse to travel to the target and return (Sloan, and Cote', 1998).

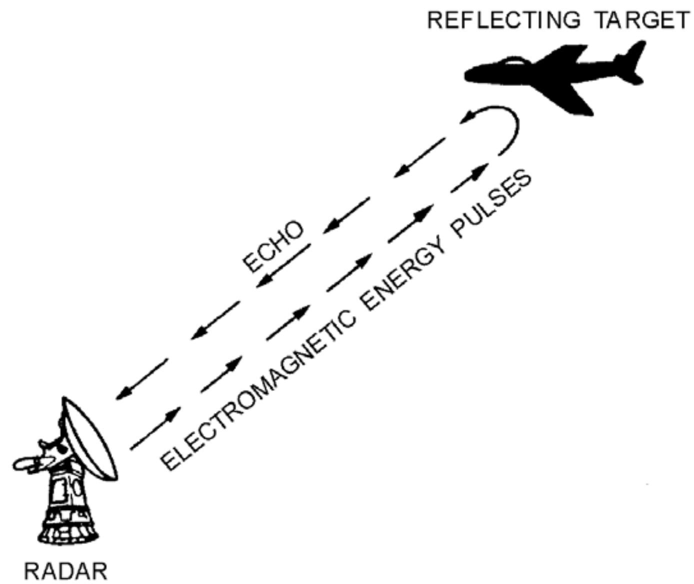

Figure 2.10: Radar echo (Sloan, and Cote', 1998).

Air traffic radars generally operate at about 1.3 or 2.8 GHz. Police radar units can be operated continuously with no modulation (Mantiply, Pohl, Poppell and Murphy, 1997).

There are many varieties of radar equipment in use around the world. Most involve movement of the antenna system, i.e. rotation or movement in azimuth, movement in elevation, etc. Leaving aside HF radar, radar systems are generally characterized by using microwave beams which are usually relatively narrow in azimuth but the characteristic in the elevation plane depends on the nature and function of the radar. The applications of radar include:

1 -Defense.

2 -Air traffic control.

3 -Meteorology and the study of weather changes.

4 -Mapping the earth.

5 -Specialized applications ranging from radars for measuring the state of the sea and sea wave motion, to hand held police radar speed meters for checking motor vehicle speeds (Kitchen, 2001).

Chapter III

Methods of Assessing Indoor Radiofrequency Radiation Exposure

A theoretical prediction of indoor RF power density by calculations varies from simplest form of calculations, assuming free space conditions, to complicated computer modeling. Propagation of RF radiation inside building is very complicated process.

The environmental RF exposure levels are influenced by many environmental and technical factors. As a result, experimental methods are a difficult and expensive.

Selection of methods and instrumentation depends on the frequency, output source power, modulation type, type of exposure (continuous or pulsed), and number of radiating sources (Simunic, 2006).

3.1 Radiofrequency Radiation Quantities

RF electromagnetic radiation has both electric and magnetic field components. It is often convenient to express the strength of the RF field in terms of each component. For example, the unit "volts per meter" (V/m) is used to express the electric field strength, and the unit "amperes per meter" (A/m) is used to express the magnetic field strength. Another common way to characterize RF field is by means of its power density.

Power density (S) is defined as power per unit area and is expressed in units of milliwatts per square centimeter (mW/cm^2) or microwatts per square centimeter ($\mu W/cm^2$) (Valberg, Deventer, and Repacholi, 2007).

Power density is proportional to the square of the electric field intensity (*E*):

$$S = \frac{E^2}{\eta} = \frac{E^2}{377} \qquad (1)$$

Where (η) is the intrinsic impedance of free space η=377 Ω.

The quantity used to measure how much RF electromagnetic radiation is actually absorbed by the body is called the Specific Absorption Rate or SAR.

SAR is defined as the rate at which energy is absorbed in body tissues; SAR is usually expressed in units of watts per kilogram (W/kg) or milliwatts per gram (mW/g) (Bangay, and Zombolas, 2004).

3.2 Theoretical Background of Exposure Assessment

The physics of electromagnetic emission from an antenna produces different circumstances for measurements depending on the distance **R** from the source. For practical purposes, this is commonly described as the existence of three zones as shown in Figure3.1; the reactive near-field, radiating near-field and the far-field.

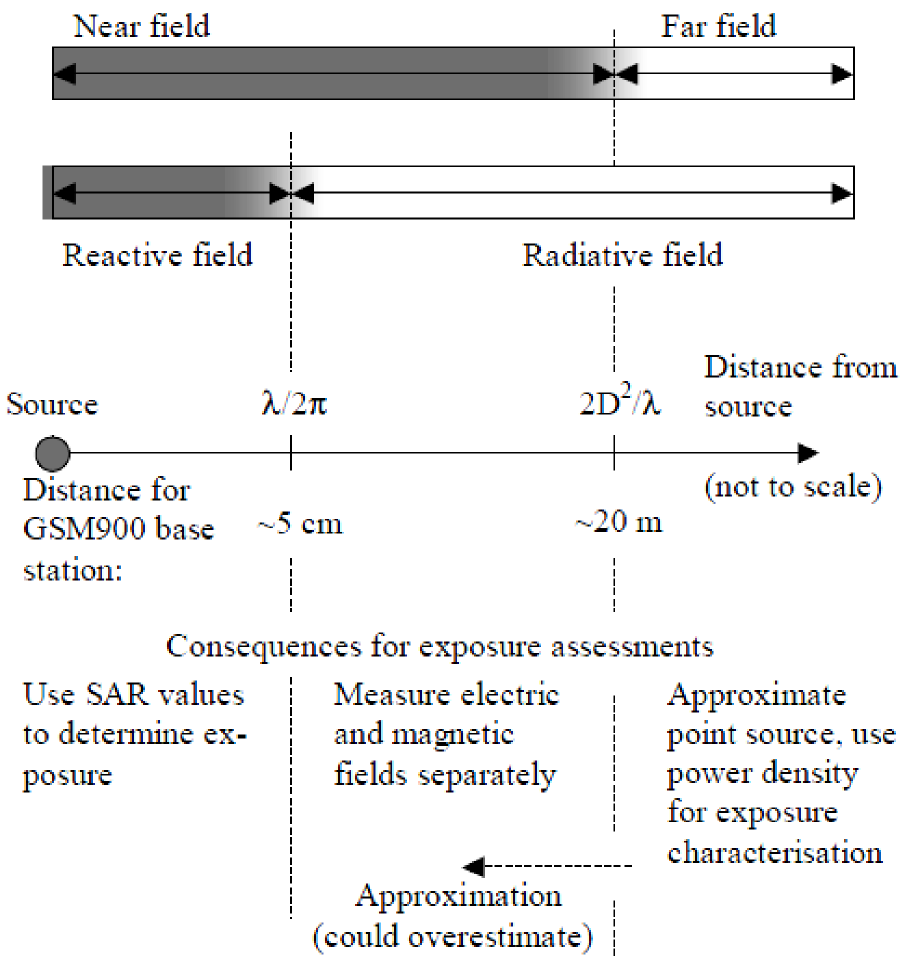

Figure 3.1: Illustration of three zones: reactive near field, radiative near field and far field, and its consequences for exposure assessments. D = largest dimension of source .λ = wavelength (33 cm for 900 MHz). SAR = Specific Absorption Rate (Bergqvist, et al., 2000).

For most antennas it is very difficult to solve the antenna fields everywhere in space. However, approximations can be made, especially for the far-field region, which is usually the one of most practical interest (Bardwell, 2003).

At a sufficiently large distance from the source, in the so-called far-field region, the electric and magnetic field components are closely related, and it is sufficient to evaluate only one of them. This region can be expected at a distance:

$$R > \frac{2D^2}{\lambda} \qquad (2)$$

R: is the distance to the antenna.
D: is the largest dimension of the antenna.
λ: is the wavelength.

Under these conditions the relation between the electric and magnetic fields is simple, and then the power density can be calculated based only on measurements of the electric field, according to equation (1).

In this far field region, the source can be approximated as a point, suggesting that the power density for an isotropic antenna, and in the absence of any interfering objects, will decrease as $1/R^2$ (Apollonio, et al., 2001).

The related power density (S) can be calculated as:

$$S = \frac{PG}{4\pi R^2} \qquad (3)$$

P: is the power fed into the antenna.
G: is the antenna gain (in linear units), which is normally a function of direction relative to the antenna.

Equation (3) can be rewritten as:

$$S = \frac{EIRP}{4\pi R^{2}} \qquad (4)$$

Where:

EIRP=equivalent isotropic radiated power

The reactive near-field region is the region of space immediately surrounding the antenna in which there is a dynamic energy interaction between the source and the human body. As a consequence, the external field strengths are not good indicators of the actual exposure and other methods of evaluations must be used – primarily the determination of the exposure directly into SAR levels.

The size of this region varies for different antennas. For most antennas, however, the outer limit is on the order of a few wavelengths or less (D << λ), the reactive field predominates to a distance of approximately (Kitchen, 2001).

$$R = \frac{\lambda}{2\pi} \qquad (5)$$

Beyond the reactive near-field region, the radiating field predominates. In the radiative near field, the relationships between the electric and the magnetic fields are much more complex, and separate evaluation of them should be performed. Measuring the electric fields and using the far-field approximations in this zone would often lead to the exposure overestimate (Bergqvist, et al., 2000).

Far-field-based calculations are suitable for determining and surveying the exposures, but in the near field, SAR is the most relevant measure of exposure.

3.3 Experimental Exposure Assessment

As described earlier, the RF spectrum between a few MHz to some GHz is allocated to a large number of different communication services. In terms of the frequencies involved, two kinds of measurement requirements can be used for measurements of this exposure to radiofrequency fields: broadband and frequency selective measurements.

The principal difference between both is that in broadband measurements, the total contribution over a large frequency range is obtained without distinction of the contribution of different sources operating at different frequencies. This is actually obtained using frequency selective devices that allow distinction between the specific contributions in the different frequency ranges.

Broadband measurements are performed with probes and hand-hold measuring instruments, while for frequency selective measurements spectrum analyzers attached to antennas in use.

If one wishes to evaluate the contribution to the RF field exposure from base station antennas, frequency-selective measurements must be performed. A precise compliance evaluation requires frequency-specific data, in order to weigh the contribution at different frequencies before summing them up (Neubauer et al., 2005).

3.3.1 Broadband Measurements

The broadband measurements integrate the detected exposure over a specified frequency range, and include all radiofrequency sources in the specified part of the spectrum.

For broadband measurements an isotropic probe and a field meter are usually used. Probes can be distinguished whether they are only able to measure the fields in one direction or they are isotropic and measure the field components in the three orthogonal directions in space and calculate the magnitude of the resultant field strength, and thus facilitating the assessment procedure.

It is important to note that a typical broadband field probe is not designed to distinguish between emissions of different frequencies such as radio and TV broadcast stations, GSM mobile phones, or a base station. Therefore, the field probe provides no information as to whether the meter reading corresponds to e.g. base station's emissions or to some other signal within the probe's measurement range. In fact, the reading will correspond to the sum of several signals.

Broadband measurements may be sufficient in some monitoring schemes, which are often performed for a rough survey evaluation of compliance (Cooper, Mann, Khalid, and Blackwell, 2004).

3.3.2 Frequency-Selective Measurements

Frequency selective measurements means that only a narrow part of the spectrum is measured at each time – the bandwidth describes the width of the selected part of the spectrum. By varying the selected frequency, either manually or automatically, the exposure over a larger frequency range can be evaluated. Frequency selective measurements are normally required for most measurement purposes precise compliance testing or for comparison purposes and necessary to determine the worst-case exposure from base stations by selectively measuring a channel of known power (Kramer, Kühn, Lott, and Kuster, 2005).

Frequency-selective measurements are conducted with a calibrated receiving antenna combined with a spectrum analyzer and RF-cable to connect the antenna to the spectrum analyzer. The antenna receives the energy of the signals at the location of investigation, these signals are fed to the spectrum analyzer through the RF-cable, and the analyzer will display the voltage corresponding to the field strengths in the frequency range chosen using a filter.

Spectrum analyzers are well suited for detailed frequency selective measurements, because the purpose of the measurement is often to obtain the maximum value of the emission, the spectrum analyzer might be set to MAXHOLD a function which indicates the maximum RF radiation level (Neubauer et al., 2005).

3.4 Factors Affecting Indoor Radiofrequency Exposure

Indoor radiofrequency exposure could come from both external and internal sources**.** Precise experimental determination of indoor radiofrequency exposure in complex environment is still a difficult task. This is because the emission and propagation of electromagnetic waves are influenced by a large variety of technical and environmental factors.

The environmental exposure depends on several factors, among the characteristics of the signal emitted from the RF source, which have to be taken into account. The output power, as well as the directional characteristic of the antenna is important. Some antennae are omni-directional (i.e., the field strengths are the same in all directions), while others may have a relatively narrow main beam, with small power is emitted in other directions Also, the frequency, or the frequency range, and the modulation describe the RF signal characteristics (Thurczy. et al., 2008).

Most commonly, exposed people are in the far field region of the signal from fixed sources. So variations in the distance from a single source – in principle – have a strong influence on the signal strength. Neglecting interference from other objects, the signal strength is expected to decline with the square of the distance relation according to equation (3) the power density, decreases with increasing distance (Lin, 2002).

Electromagnetic wave propagation is a complex phenomenon and its complexity is increased in indoor spaces. Indoor places typically contain many objects; furniture and equipments, so electromagnetic waves experience reflection, diffraction, transmission and scattering effects due to all present objects. This produces multi-path propagation conditions, with a possible direct ray between the transmitter and receiver, and a large number of weaker rays reaching the observation point (Simunic and Zrno, 2009).

In this multi-path environment, the phase of the reflected and diffracted signals can be at any angle with respect to that of the direct signal. Thus, the reflection and diffraction can either enhance or diminish the strength of a direct signal. So, persons are exposed to non-uniform fields subjected to fading, multiple reflections, diffractions and scattering (Simunic, 2006).

For external radiofrequency sources such as FM, TV transmitters and mobile base stations, when signals passing through buildings and vegetation in the line of sight as well as exterior and interior walls of the rooms result in strong damping of RF radiation . Attenuation, when the wave passes building materials, depends on the frequency of the incoming electromagnetic wave, the properties of the material and the length of the absorption path (Neitzke, Osterhoff, Peklo, and Voigt, 2007).

As a result of RF radiation attenuation, the power density levels inside a building can be smaller than outside by a factor that varies from 1 to 100 .In addition, exposure can vary substantially within the building (Burch, et al., 2006). For example, exposure was found to be about twice as high (and more variable) as in the upper floors compared with the lower floors of a building (Viel, et al., 2009).

For internal radiofrequency sources fluctuations of indoor radiofrequency exposure would vary from place to another inside the building. This is because of the attenuation through concrete walls, wooden doors, and large glass windows on outside walls (Neitzke, Osterhoff, Peklo, and Voigt, 2007).

Also, the radiofrequency exposure varies with time, since the emitted power from the base stations may be varies over the day and night. An estimate of the maximum field strength might be obtained by making exposure measurements at that time of day. For example, the total power transmitted by a given GSM antenna at a particular time would be dependent on output power per channel and the number of channels transmitting so time variations should be taken into account (Bergqvist,et al., 2000) .

3.5 Experimental Versus Theoretical Exposure Assessment

Assessment of indoor radiofrequency human exposure may be done by using computational models in order to simulate the propagation of radiofrequency waves in the space of interest and compute the electric field *E*-value or the power density *S*-value. This requires of professional software that takes into account complex environmental conditions in high details, by taking into account wave propagation mechanisms like reflection, diffraction, absorption, interference, may be used. Much cheaper assessment may be obtained by using simplified analytical calculations by using mathematical equations like equation (3), but the computed values are more accurate.

On the other hand, actual measurement values by using appropriate system and methodology either wideband survey meters or frequency-selective receivers/spectrum analyzers with calibrated receptor antennas are needed for in situ measurements or compliance assessment.

Since emission and propagation of electromagnetic waves are influenced by a large variety of technical and environmental parameters, poor agreement between theoretical and experimental assessment of radiofrequency exposure especially for indoor situations are expected (Miclaus and Bechet, 2007).
Reliable assessments are only possible by having actual measurements .However, computational methods can be used to preselect probably exposed and non-exposed subjects thus reducing the effort for measurements considerably (Neitzke, Osterhoff, Peklo, and Voigt, 2007).

3.6 Safety Guideline and Radiofrequency Radiation Exposure

Exposure standards and limits for radiofrequency energy have been developed by various organizations and countries. These standards recommend safe levels of exposure for both general public and workers based on established scientific studies (Abdelati, 2005).

The International Commission on Non-ionizing Radiation Protection (ICNIRP) is an independent scientific organization responsible for providing guidance and advice on the health hazards of non-ionizing radiation exposure. ICNIRP in 1998 adopted the guidelines on exposure limits for electromagnetic fields in the frequency range from 0 Hz up to 300GHz. These guidelines are based on acute health effects such as elevation of tissue temperatures resulting from absorption of energy during exposure to electromagnetic fields between 100 kHz and 300 GHz (ICNIRP, 1998).

In Palestine, safety limit are laid down by the Environmental Quality Authority (EQA). Since there is no specific law for protection of health from electromagnetic field issued (EQA) have adopted same regulations in Palestine for the protection from non ionizing radiation on the basis of ICNIRP's recommendations. EQA also controls the compatibility and the levels of emissions from the mobile base stations. (EQA, 2009).

The ICNIRP guidelines specify basic restrictions on SAR that apply to frequencies within the range 10 MHz to 10 GHz for occupational and public exposure are given in Table 3.1.All restrictions are to be time –averaged over a six minutes period .The restrictions on localized SAR permit averaging over a 10 g mass of contiguous tissue(ICNIRP, 1998).

Table 3.1: ICNIRP basic restrictions on SAR exposure to electric and magnetic fields in the frequency range 10 MHz to 10 GHz for occupational and general public exposure (ICNIRP, 1998).

Exposure quality	**Occupational**	**General public**
SAR averaged over the body and over any 6 minutes period	0.4 W kg^{-1}	0.08 W kg^{-1}
SAR averaged over any 10 g in the head and trunk and over any 6 minutes period	10 W kg^{-1}	2 W kg^{-1}
SAR averaged over any 10 g in the limbs and over any 6 minutes period	20 W kg^{-1}	4 W kg^{-1}

The reference levels for occupational and general public exposure to electromagnetic fields in the frequency range 10 MHz to 300 GHz are given in Table 3.2. The basic restrictions are 50 Wm^{-2} for occupational exposure and 10 Wm^{-2} for exposure of the general public; the levels reflect the factor of five differences between the public and occupational basic restrictions.

Table 3.2: ICNIRP reference levels for occupational and general public exposure to electromagnetic fields in the frequency range 10MHz to 300GHz (ICNIRP, 1998).

	Frequency (Hertz)	**Electric field strength (Vm^{-1})**	**Magnetic field strength (Am^{-1})**	**Power density (Wm^{-2})**
Occupational	10-400 MHz	61	0.16	10
	400-2000 MHz	$3 f^{1/2}$	$0.008 f^{1/2}$	f/40
	2-300 GHz	137	0.36	50
General public	10-400 MHz	28	0.073	2
	400-2000 MHz	$1.375 f^{1/2}$	$0.0037 f^{1/2}$	f/200
	2-300 GHz	61	0.16	10

f is the frequency in MHz.

As it is too difficult to estimate in situ the SAR value, reference levels have been adopted concerning measurable quantities of electromagnetic fields such as electric field strength, magnetic field strength and equivalent plane wave power density. If compliance to the reference level exists then compliance to the basic restriction is granted (Stratakis, Miaoudakis, Xenos, and Zacharopoulos, 2008).

To evaluate the compliance to the established reference level of wireless communication systems far field measurements are performed, regarding the above mentioned electromagnetic quantities at places of interest, especially in residential areas.

In our environment exposure to single frequencies in general become rare .It is common that the exposure situation is characterized by multiple frequencies. Table: 3.3 show the sources with frequency range and ICNIRP exposure limits advised for general population from known sources in our environment.

Table 3.3: Sources of radio signals commonly found in the environment.

Radiofrequency Sources	**Frequency range (MHz)**	**General public ICNIRP Limit (Wm^{-2})**
Broadcast FM radio.	87.5-108.0	2
Walkie-talkies	420-425	2
Broadcast television TV.	470-862	2.35-4.5
GSM base stations 900 downlink.	935-960	4.5
GSM base stations 1800 downlink.	1805-1880	9
Digital enhanced cordless telecommunication (DECT).	1880-1900	9
Universal Mobile Telecommunications System (UMTS) base stations downlink.	2110-2170	10
Wireless personal computer peripherals.	27-2400	2-10
Baby surveillance devices.	27-2400	2-10
Wireless LAN (IEEE 802.11b/g).	2400-2484	10
Wireless LAN (IEEE 802.11a/h).	5250-5350, 5470-5725	10
Wireless peripherals interconnection (Bluetooth).	2402-2480	10
Microwave oven.	2450	10
Radar.	1300 or 2800	6.5 or 10

For exposure to RF wave emitted at a single frequency, a dimensionless quantity known as exposure quotient may be calculated using the relation:

Exposure Quotient $= \dfrac{S}{Sref}$ (6)

S : is measured power density corresponding to a certain signal frequency.

S_{ref} : is the power density reference level advised in the ICNIRP guidelines corresponding to the frequency of the signal (Mann, Cooper, Allen, Blackwell, and Lowe, 2000).

In multiple frequency environment , all individual signals will contribute to the personal exposure, since their effects are additive so the total exposure can be expressed in terms of a quotient based on the measured power density *S* of each detected signal and the ICNIRP reference level corresponding to the frequency of the signal, thus(Cooper, Mann, Khalid, and Blackwell, 2004).

$$Total\ \ Exposure\ \ Quotient = \sum_{i=1}^{Nt} \frac{Si}{Sref,i} < 1 \qquad (7)$$

*N*t : is the total number of signals producing the exposure.

S_i : is the power density measured corresponding to the frequency of the signal

$S_{ref,i}$: is the power density reference level advised in the ICNIRP guidelines corresponding to the frequency of the signal.

Total exposure quotient not exceeding unity indicates compliance with the ICNIRP guidelines. Exposure quotient may also be used to investigate the contributions of various individual signals to the total (Cooper, Mann, Khalid, and Blackwell, 2006).

Chapter IV

Methodology

4.1 Study Area

This study is performed in Hebron city which is located in the southern part of the West Bank-Palestine Hebron city is located on latitude of 31:31′ in the north and longitude of 35:8′ in the east. Hebron is about 35 kilometers south of Jerusalem and it extends over an area of about 45 km^2. The city is highly populated with more than 200,000 people. It is the most populated city in the West Bank (Palestinian Central Bureau of Statistics, 2008).

The City of Hebron is highly influenced by the Mediterranean climate, which is characterized by long, hot, dry summer and short, cool, rainy winter. Its general topography is hilly with range of mountains and heights from 800 m-1030 m above sea level.

The location of Hebron city at the Historical Palestine map is shown in Figure 4.1.

Figure 4.1: Location of the study area (Palestinian Central Bureau of Statistics, 2008).

4.2 Data Collection about RF sources in Hebron city

For external sources of RF radiation, a database giving details (location, height, power, frequency, antenna gain and coordinates) for all antennas located in Hebron city was supplied by the Ministry of Telecommunication and in the case of mobile base stations by the Palestine Cellular Communications Ltd. (Jawwal) company. These databases include information about 17 FM transmitters, 3 TV transmitters and 67 mobile telephony base stations. There are also a number of Israeli mobile base stations and other RF transmitters in areas close to the Hebron city but not accessible to the Palestinians.

Wataniya Mobile base stations are excluded because this company introduces its services to the people at (1/11/2009), after the surveys are finished.

Digital map was constructed for external RF radiation sources in Hebron city as shown in Figure 4.2.

Mobile base stations are distributed over the whole city, while, most TV and FM transmitters are located in the northern part specifically at (Ras Al Joura), the highest place in Hebron.

Data base of internal RF has been constructed for all places where measurements were conducted .This data base include type, model, date of manufacturing, frequency used and other relevant information of RF emitting devices (WLAN, DECT, microwave ovens…etc). A data sheet especially designed was filled for each location and stored into a laptop computer.

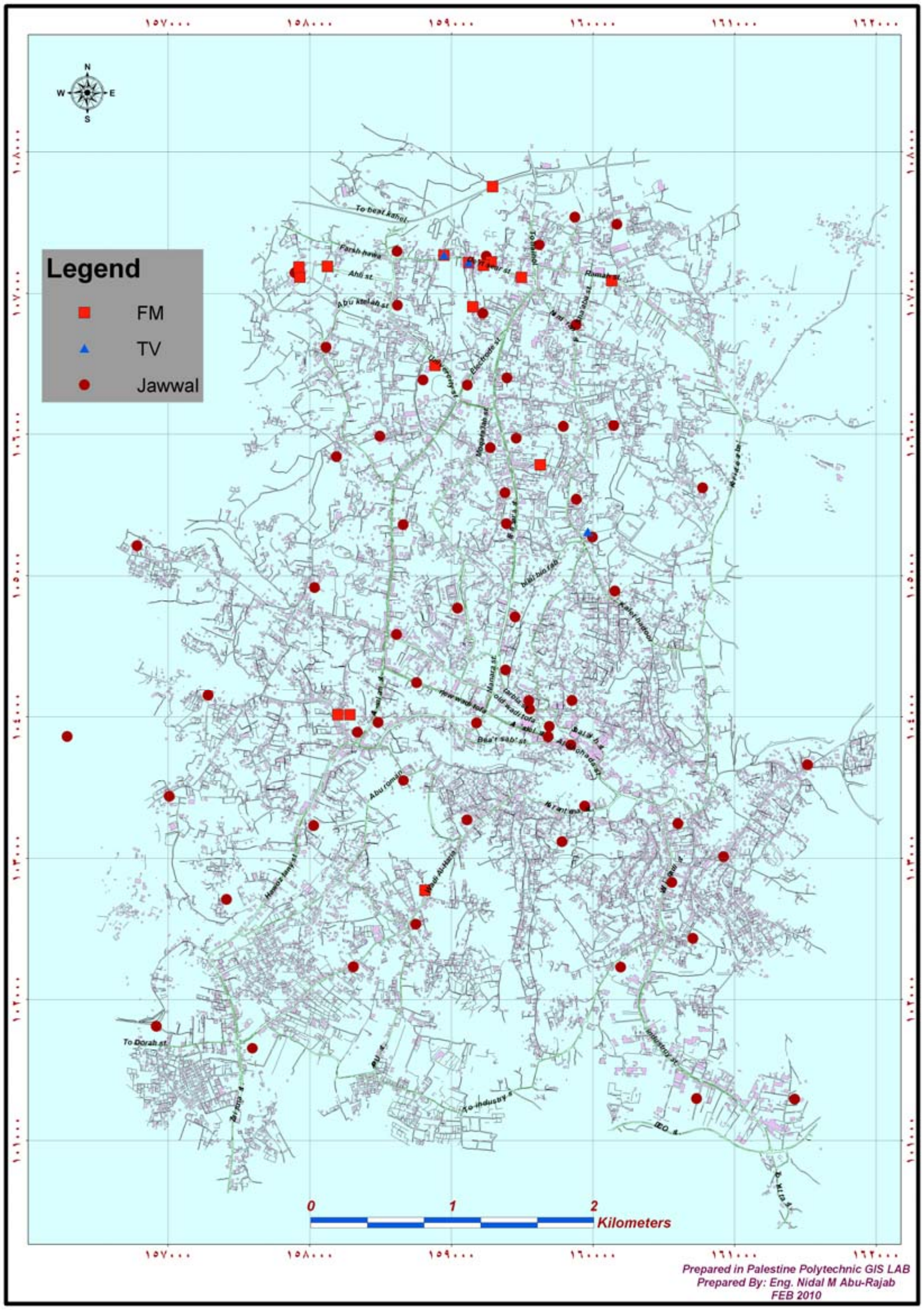

Figure 4.2: Locations of external radiofrequency radiation stations in Hebron city.

4.3 Measurement Locations

In order to assess the indoor RF exposure in the City of Hebron from all environmental signals, surveys have been conducted from May to September 2009. Measurements are performed in sunny days and include 343 randomly selected locations in areas accessible to the general public .All these locations are distributed over the whole city. Table 4.1 summarizes all types of investigated sites. Data are collected from selective locations that include the following:

- Houses, measurement are performed in bedrooms, sitting room and kitchen.
- Public places, include shops, offices, clinics, shopping centers, cultural centers and restaurants.
- Universities, measurements are performed in lecture rooms, computer labs, scientific labs, libraries and faculty offices.
- Hospitals, measurements performed in patient rooms, emergency, clinics, pediatric rooms and staff offices.
- Schools, in classrooms, school labs and libraries.
- Coffee nets where WLAN access points are used.

Table 4.1: Distribution of investigated locations in Hebron city.

Buildings	**Number of Sites**	**Percentage % of total**
Houses	236	68.01%
Public places	57	16.43%
Schools	33	9.51%
Universities	3(6 locations)	2.88%
Hospitals	4	1.15%
Coffee Shop	7	2.02%
Total	343	100%

Coordinates of measurement points are determined for each site by a GPS and painted on a digital map of the city as illustrated in Figure 4.3.

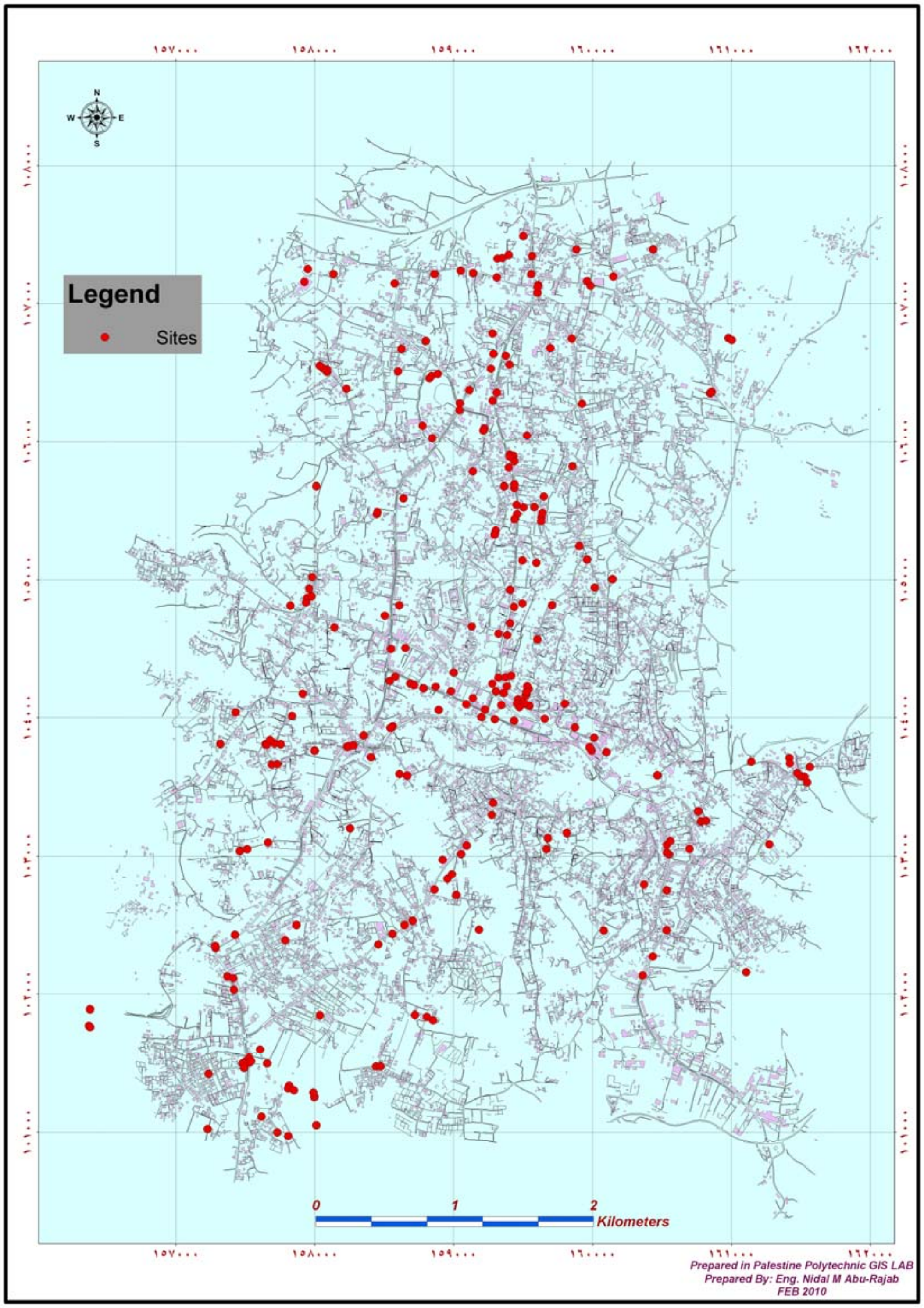

Figure 4.3: The study area map where the investigated locations (Survey locations) of indoor radiofrequency radiation in Hebron city are represented by red circles.

4.4 Instrumentation

In this work, frequency selective measurements are performed using a selective radiation meter Narda (SRM-3000) and BK 2650 handhold spectrum analyzer are used in measuring the power density of indoor RF radiation in the region under investigation.
Brief descriptions of the instruments are given below:

4.4.1 Narda's Selective Radiation Meter SRM-3000

Narda SRM-3000 selective radiation meter (Narda Safety Test Solutions)used to measure RF fields . This instrument is a portable spectrum analyzer that covers the range 75 MHz–3 GHz with high sensitivity, equipped with an isotropic (three-axis) antenna**.** Narda meter measures RF energy no mater the source was. However, the sources of the measured signals could often be identified due to the use of a small resolution bandwidth and the spectral characteristics of the signals.

The instrument calculates the power spectrum of the signal (averaged over the three axes of the antenna) and stores the data for subsequent export to a computer for further analysis. Several operating modes are designed to give immediate on site results .These modes are described as follows:

"Spectrum Analysis" mode, in multi –frequency environments, within the chosen frequency range, the Spectrum Analysis mode provides an overview of all frequency components with their field strengths. The spectrum is clearly displayed and determines maximum values measured directly on site.

"Safety Evaluation" mode is based on spectrum analysis followed by integration across certain frequency ranges, the frequency bands for individual services can be used. The Safety Evaluation mode provides the user with an immediate overview of contributions from individual services which make up the total field strength level within which the field strength is to be measured. The results in each frequency band are displayed in units of field strength or as a percentage of a selected safety standard. The displayed value 100% indicates that the limit value defined in the standard has been reached.

“Time Analysis” mode, the SRM makes selective, continuous measurements at a fixed, user-defined center frequency and with a selectable resolution bandwidth between 6.4 KHz and 6 MHz. This allows detection of even short duration spikes, e.g. from pulsed radar equipment. The operating mode is ideal for timer-controlled measurements.

The antenna connected to the SRM 3000 is:

Isotropic antenna: A three axis antenna(isotropic antenna) for measuring electric field strength which covers the frequency range from 75 MHz to 3 GHz, covering FM radio up to 3 rd generation mobile radio system.

Isotropic (non-directional) measurement mode is selected automatically. All three axes are measured one after the other and the isotropic result is then calculated and displayed by the SRM-3000.

4.4.2 Handhold 3.3 GHz Spectrum Analyzer (model 2650)

The BK 2650 handhold spectrum analyzer is a high-performance spectrum analyzer providing excellent performance and functions perfect for many different applications.

Different antennas can be used with BK 2650 they are:

- AN301 BK Precision AN 301 Dipole Antenna (0.8 to 1) GHz.
- AN302 BK Precision AN 302 Dipole Antenna (1.25 to 1.65) GHz.
- AN303 BK Precision AN 303 Dipole Antenna (1.7 to 2.2) GHz.
- AN304 BK Precision AN 304 Dipole Antenna (2.25 to 2.65) GHz.
- AN305 BK Precision AN 305 Dipole Antenna (390 to 410) MHz.

4.5 Methodology of Measurements

Several different measurements of power density indoor were employed assuming far field conditions from all radiofrequency sources in the range 75 MHz to 3 GHz according to the following protocol:

*All measurements are performed in Hebron city and referred to as the indoor RFR levels.

*The coordinates of each measurement location are determined by using a GPS and digital map for Hebron city and a questionnaire which is used for each location. Data were subsequently entered into the computer.

* Measurements are performed for all known signals of indoor RFR including external and internal signals in the frequency range from 75 MHz to 3 GHz.

*The indoor RF radiation levels were averaged over approximately 6-minutes interval in all cases.

*All measurements are conducted at suitable heights between 0.5m and 1.7m above the ground level corresponding to the head position of an average adult (Schmid, Lager, Preiner, U berbacher, and Cecil, 2007) according to the following:

- Measurements in bedrooms are performed at bed height with average 60 cm (Breckenkamp, Neitzke, Bornkesse, and Berg-Beckhoff, 2008).
- Measurements in sitting rooms are performed at the height of head position of an average sitting adult with an average height of 120 cm.
- Measurements in kitchens are performed at the height of head position of an average adult where the person was standing at 150 cm (Amoako, Fletcher, and Darko, 2009).
- Measurements in the working places are performed at the height of head position of an average sitting adult with an average height of 120 cm (Fritschi et al., 2006).
- Measurements are conducted at the height of the devices (DECT, WLAN access point and microwave oven).

* Locations of measurements are selected where the exposure is expected to be the maximum according to the following:

- For external RF sources the measurements are performed in the places where the exposure expected to be the maximum; near windows and in the direction of main beam.
- The maximum leakage at the center of the door screen of microwave oven so measurements are performed at the height of center of the door (Thansandote, Lecuyer and Gajda, 2000)

*Far field measurements are conducted at a distance of approximately 1 m from devices (DECT, WLAN and microwave oven) (Schmid, Lager, Preiner, Uberbacher, and Cecil, 2007).

*In addition people, are asked not to use a mobile phone during the measurement process, and only downlink frequencies of GSM cellular base stations are considered.

*The power density levels were expressed in $\mu W/cm^2$ and the electric field levels are given in V/m.

Chapter V

Results and Discussion

5.1 Indoor RF- Radiation Levels Measured in Hebron City

This chapter presents and discusses the results of indoor RF power density levels detected within the frequency range 75 MHz to 3 GHz at 343 different locations in the City of Hebron. The measured data is analyzed in order to evaluate the indoor exposure from all internal and external RF sources. Also, the contributions from different sources to the total exposure for general population living in Hebron city are determined.

5.1.1 Indoor RF- Radiation Levels in Hebron Houses

The measurements are performed at 236 houses selected nearly at random according to the population density distributed all over the city. Measurements are conducted in most used rooms in each house such as bedrooms, sitting rooms and kitchens. The maximum power density levels are detected at suitable heights 60 cm, 120 cm and 150cm above the ground level respectively, corresponding to the adult head position for about six minutes over the maximum range of the SRM 3000 from 75 MHz to 3 GHz in real life conditions.

Figure 5.1 presents a typical indoor radiofrequency spectrum in the frequency range 75 MHz -3GHz detected in a sitting room. The spectrum includes four main external RF sources (FM, TV, GSM 900 and GSM 1800), two main internal RF sources (DECT and WLAN) and other RF sources such as radar signal and another signal at about 870 MHz probably resulted from other RF transmitters in the city.

The average indoor RF radiation power density levels over six minutes for the different sources in the 236 houses in kitchens, bedrooms and sitting rooms are summarized in Table 5.1. The bottom of each column represents the average evaluated indoor power density levels as well as the maximum and minimum values detected for each source.

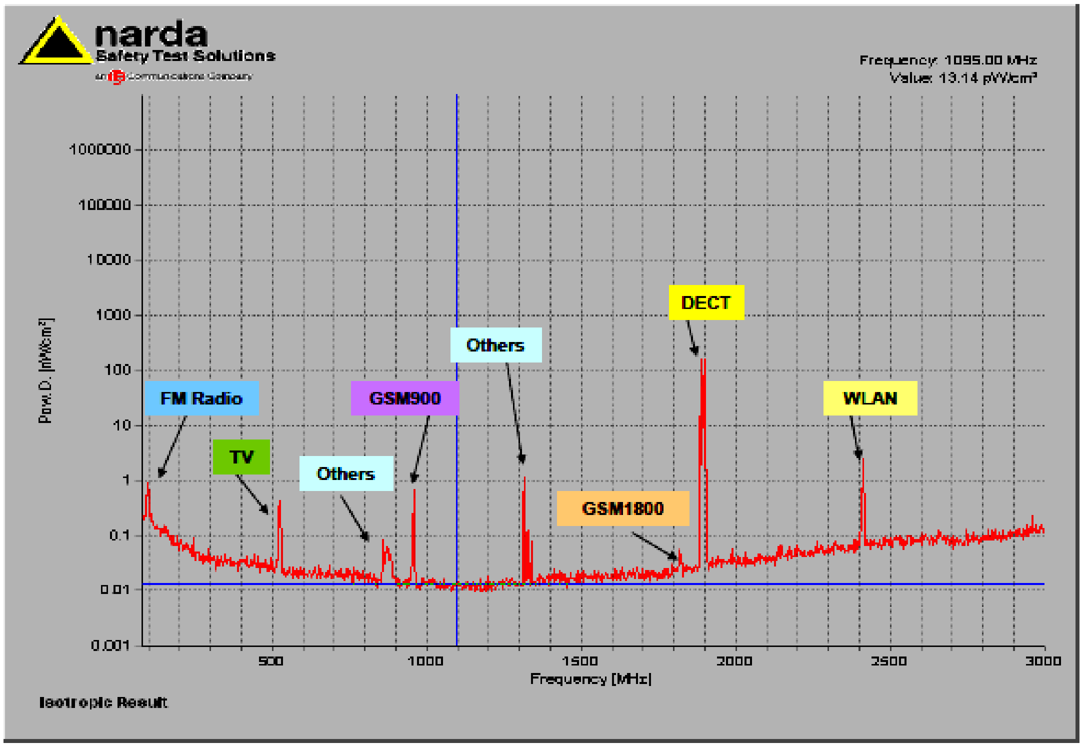

Figure 5.1: Indoor radiofrequency spectrum, in the frequency range 75 MHz to 3 GHz detected in a sitting room in Hebron city.

Table 5.1: Results of average indoor RF radiation power density levels evaluated in 236 houses in Hebron city.

House	**External Sources**				**Internal Sources**			
Site	**FM**	**TV**	**GSM900**	**GSM1800**	**DECT**	**WLAN**	**Others**	**Total**
	μW/cm²	μW/cm²	μW/cm²	μW/cm²	μW/cm²	μW/cm²	μW/cm²	μW/cm²
Sitting rooms	0.024	0.0012	0.015	0.0003	0.103	0.0041	0.001	0.15
Kitchens	0.019	0.00075	0.0104	0.0004	0.0033	0.00081	0.0009	0.036
Bedrooms	0.034	0.00092	0.0084	0.00018	0.032	0.0053	0.00081	0.081
Min	0.00021	0.00056	0.000015	0.000025	0.00005	0.00034	0.00012	0.0015
Max	2.27	0.0508	1.27	0.0293	0.531	0.381	0.072	2.28
Average	**0.026**	**0.00095**	**0.011**	**0.00029**	**0.046**	**0.0034**	**0.001**	**0.089**

Figure 5.2 shows the average indoor RF power density levels measured in 236 sitting rooms from different RF sources. The highest average indoor RF power density level is resulted from DECT signals; this is probably due to the survey results that most people in Hebron locate DECT base stations in sitting rooms.

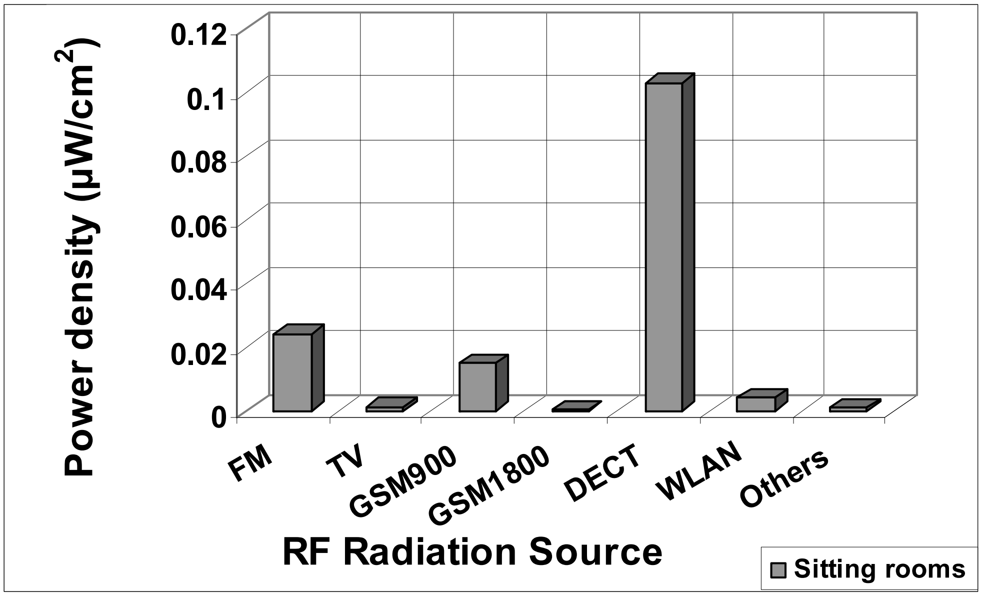

Figure 5.2: Average indoor radiofrequency power density levels form various RF sources evaluated in 236 sitting rooms in Hebron city.

The total indoor RF radiation power density levels from all RF sources in the range 75 MHz to 3 GHz in 236 sitting rooms are found to vary from 0.0015 $\mu W/cm^2$ to 1.28 $\mu W/cm^2$ with an average value of about 0.15 $\mu W/cm^2$.

Figure 5.3 illustrates the FM spectrum detected in a bedroom in Ras Al- Joura in the northern part of Hebron. The spectrum includes about 16 FM radio signals, 12them are located in within the inspected area and the rest are out of area. The maximum peak levels are at 105.49 MHz (Radio Ajyal) and 98.8 MHz (Radio Dream). This might be due to the fact that most FM and TV transmitters are located at the northern part of the city (Ras Al-Joura), which is the highest place in the city.

The average indoor radiofrequency power density levels evaluated in 236 bedrooms related to different RF sources is shown in Figure 5.4. As it can be seen, the highest average indoor RF power density level is obtained from FM radio signals and DECT signals are also relatively high in bedrooms, probably due to the fact that many people in Hebron locate their DECT base stations in bedrooms.

In the frequency range 75 MHz to 3 GHz, the total indoor RF radiation levels from all RF sources in 236 bedrooms are found to vary from 0.0015 $\mu W/cm^2$ to 2.28 $\mu W/cm^2$ with an average value of about 0.081 $\mu W/cm^2$.

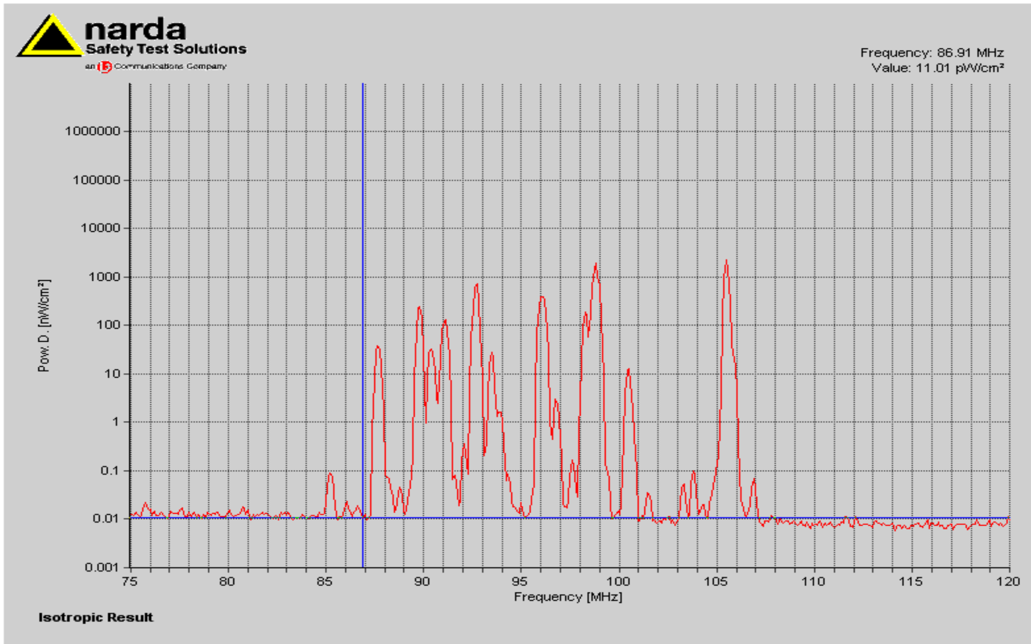

Figure 5.3: FM spectrum, in the frequency range 75 MHz to 108 MHz detected in a bedroom in Hebron city.

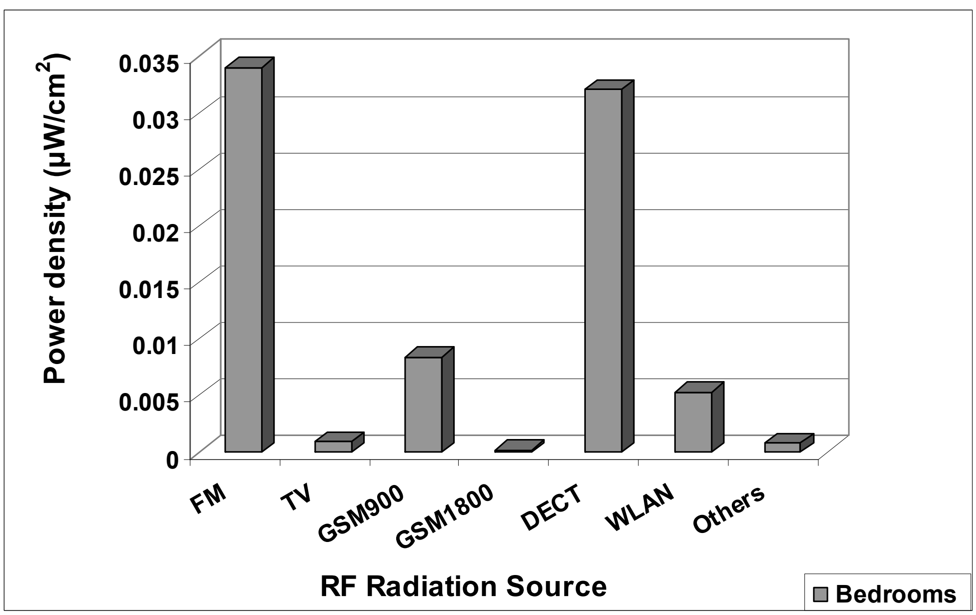

Figure 5.4: Average indoor radiofrequency power density levels form various RF sources evaluated in 236 bedrooms in Hebron city.

In kitchens, the situation is different as illustrated in Figure 5.5. Power densities measured in kitchens are mainly from external sources especially from FM transmitters, which contribute by large amount of indoor RF exposure in kitchens. That is probably because non of the used DECT base stations or WLAN access points are located in kitchens ,the signals detected from DECT or WLAN are coming from bedrooms or sitting rooms.

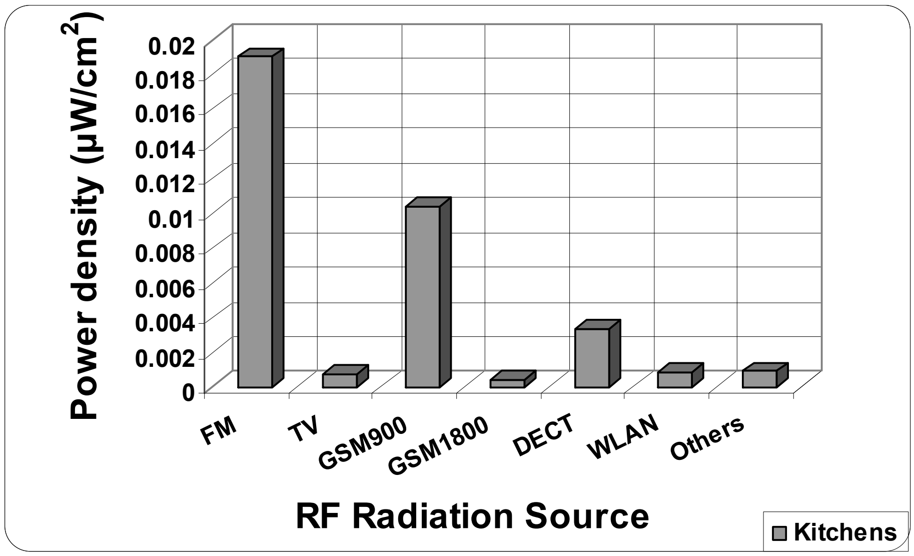

Figure 5.5: Average indoor radiofrequency power density levels form various RF sources evaluated in 236 kitchens in Hebron city.

The total indoor RF radiation power density level from all RF sources in the range 75 MHz to 3 GHz in 236 kitchens are found to vary from 0.0015 $\mu W/cm^2$ to 1.24 $\mu W/cm^2$ with an average value of about 0.036 $\mu W/cm^2$.

All measured indoor RF exposure levels are far below the limits recommended by ICNIRP for general public see table 5.1. The measured indoor RF radiation levels are found to be highly variable from one house to another depending on the devices used in the house and the characteristics and distribution of external RF sources. Variations are also high from one location to another at the same house depending on many factors such as attenuation through concrete walls, glass windows, wooden doors and existence of different RF devices.

The maximum indoor RF power density detected in any house in Hebron city is about 2.27 $\mu W/cm^2$.This value represents the cumulative power density resulted from FM radio stations (frequency interval 88 MHz – 108 MHz) and is resulted from FM radio broadcasting in a bedroom in Ras Al- Joura in the northern of the city as shown in Figure

5.3.This maximum measured value is about 88 times below the limit recommended by ICNIRP for the general public (200 μW/cm^2).

The maximum indoor RF power density form TV broadcasting is about 0.0508 μW/cm^2 measured in a sitting room in Ras Al- Joura northern part of Hebron .This house is near Al-Nawras TV tower .This value is 7,874 times below the limit recommended by ICNIRP for the general public (400 μW/cm^2) .

The measurement of the maximum indoor RF power density from mobile phone base stations (GSM 900) is about 1.27 μW/cm^2 that is measured in a sitting room in the southern part of the city and is located near Jawwal mobile phone base station .This value is 354 times below the limit recommended by ICNIRP for the general public (450 μW/cm^2).The maximum indoor RF power density measured from (GSM 1800) is about 0.0293 μW/cm^2 and is reported in a kitchen in the city center with clear line of sight with GSM (1800) base station. This value is about 30,758 times below the limit recommended by ICNIRP for the general public (900 μW/cm^2).

For DECT, the maximum indoor RF power density measured is about 0.531 μW/cm^{2}in a sitting room .This value is 1,694times below the limit recommended by ICNIRP for the general public (900 μW/cm^2). Moreover, WLAN has a maximum indoor RF radiation power density of about 0.381 μW/cm^2 detected in a bedroom .This value is 2,624 times below the limit recommended by ICNIRP for the general public (1000 μW/cm^2). In the location, the access point of WLAN is located in the bedroom.

The maximum indoor RF radiation power density detected from (other sources than mentioned above) in a sitting room probably due to UMTS, radar and walkie-talkie is about 0.072 μW/cm^2 . This value is about 12,500 times below the recommended limit by ICNIRP for the general public (900 μW/cm^2).

In the 236 investigated houses, the total indoor RF radiation levels from all RF sources in the frequency range 75 MHz to 3 GHz is found to vary from 0.0015 μW/cm^2 to 2.28 μW/cm^2 with an average value of about 0.089 μW/cm^2.

The minimum total indoor RF power density measured from all RF sources in any house in Hebron is about 0.0015 μW/cm^2 and it is found in 5 different houses which are far away from any external RF transmitters, and there is no direct line of sight with any local FM or TV transmitters or mobile base stations .Also these houses are in lower floors, shielded by large buildings. In addition, there is no use of any RF devices in the range 75 MHz to 3 GHz in these houses.

A three dimensional (3D) plot of all internal and external RF sources from the 236 houses including FM,TV,GSM 900, GSM 1800 ,DECT ,WLAN and Others is shown in Figure 5.6.as it can be seen from the figure the highest average indoor RF power density level is observed from DECT signals in sitting rooms.

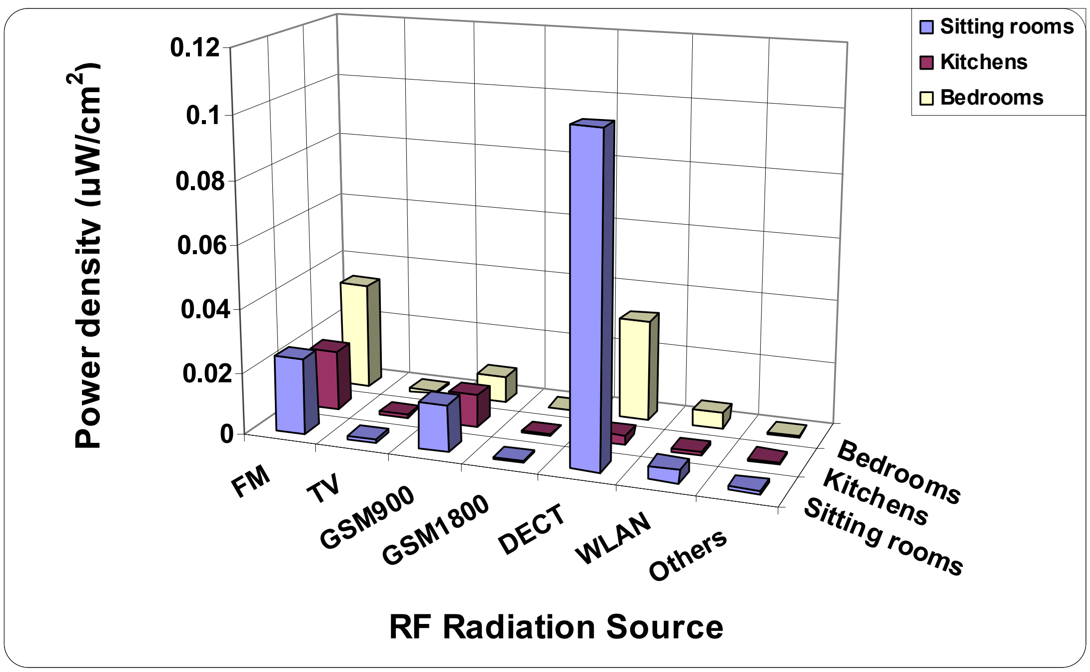

Figure 5.6: Average indoor radiofrequency power density levels evaluated in 236 houses form various RF sources evaluated in Hebron city.

Figure 5.7 illustrates the relative contributions of various RF sources to the total indoor exposure received by the population in 236 houses in Hebron city. DECT signals contribute by the largest amount of indoor radiofrequency radiation. The result obtained in our work is in consistence with the work published by (Kramer, Kühn, Lott, and Kuster, 2005). Where, the DECT indoor RF radiation is found to be the dominant source. This might be due to the continuous transmission of the DECT base stations.

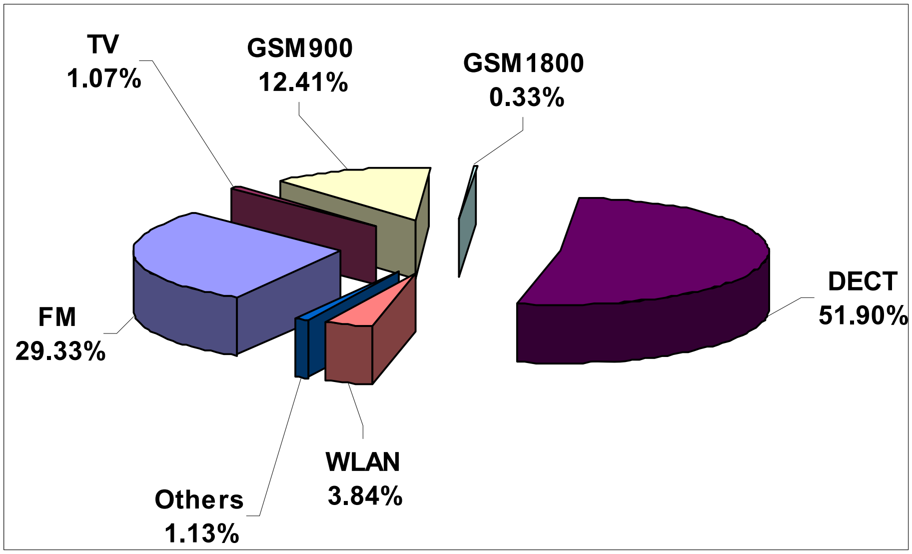

Figure 5.7: Relative contributions to the total indoor radiofrequency exposure from various radiofrequency radiation sources evaluated in 236 houses in Hebron city.

The relative contributions to the total exposure from different rooms in 236 houses evaluated in Hebron city are shown in Figure 5.8. The figure shows that, sitting rooms contribute by the largest amount of indoor radiofrequency radiation in the total exposure in houses. This is because the main source of RFR (DECT) is almost located in sitting rooms in Hebron.

Figure 5.9 shows a comparison between internal and external RF sources .Internal sources in sitting rooms, as seen from the figure, have more contribution than that of external sources to the total indoor RF exposure.

Figure 5.10 illustrates the relative contributions of internal and external RF sources in the total indoor RF exposure received by the population in 236 houses in Hebron**.** Internal sources contribute by higher values of the total indoor RF exposure in houses.

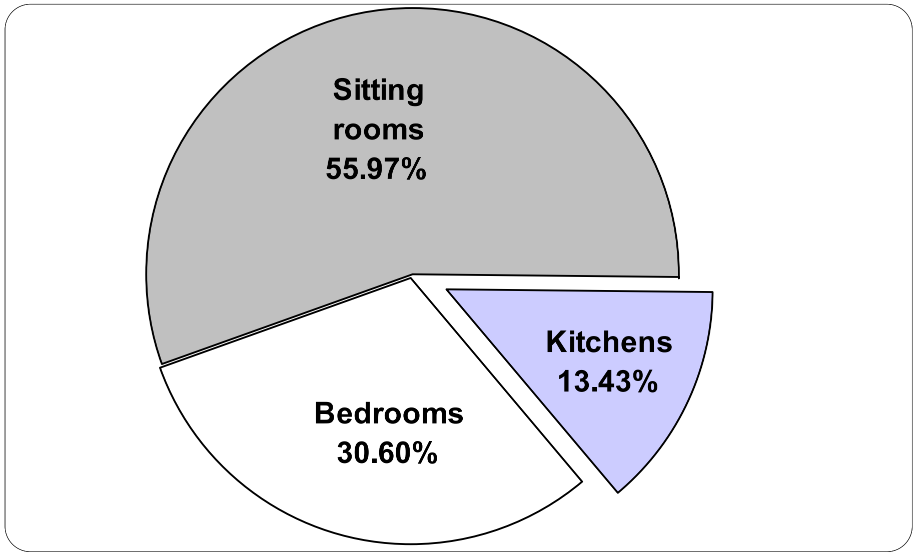

Figure 5.8: Relative contributions to the total indoor exposure in different locations evaluated in the 236 houses in Hebron city.

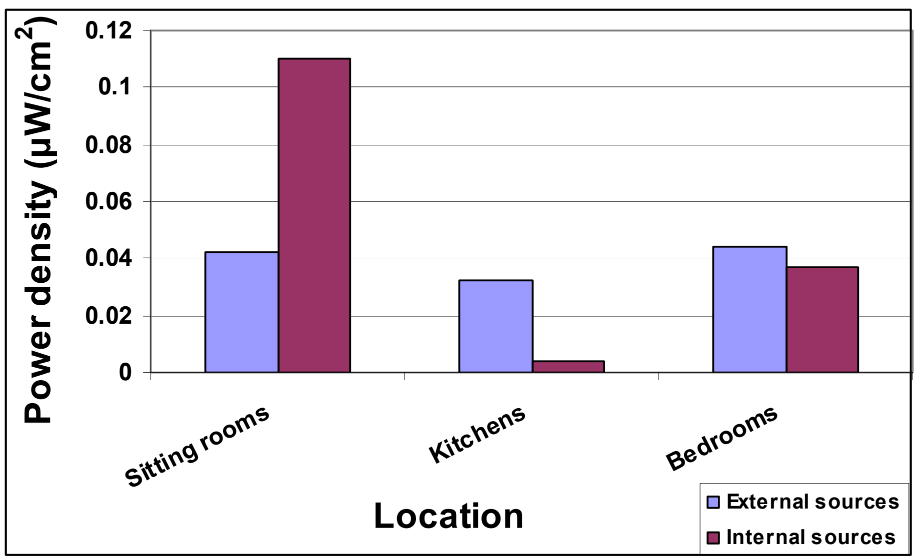

Figure 5.9: Average indoor RF power density levels from internal and external RF sources evaluated in different locations in 236 houses in Hebron city.

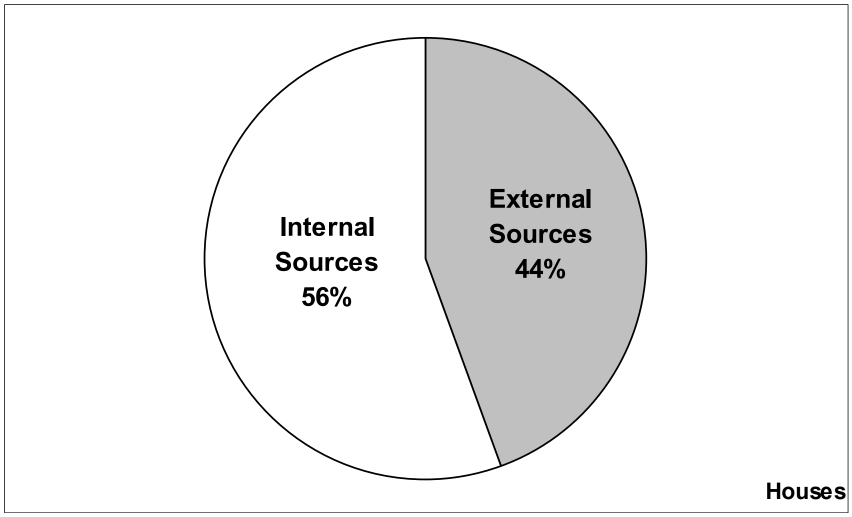

Figure 5.10: Relative contributions to the total indoor RF exposure from both external and internal RF sources evaluated in 236 houses in the City of Hebron.

5.1.2 Indoor RF- Radiation Levels in Public Places in Hebron City

Measurements are performed at 57 public places selected nearly at random according to the population density in Hebron city with different locations. Inspected places including: municipality, district office, cultural centers, clinics, commercial buildings, shopping centers, offices, banks and restaurants.

The maximum power density levels are detected in normal conditions, at heights (120-170) cm above the ground level.

The results over six minutes from different sources in the 57 investigated public places are represented in Table5.2. The average indoor RF power density levels as well as the maximum and minimum values detected for each source are estimated.

Figure 5.11 shows a typical indoor RF spectrum in the frequency range 75 MHz to 3 GHz detected in a commercial building .The spectrum includes FM, TV, and GSM 900 and DECT signals. It is noticeable, that DECT signal is relatively high.

Table 5.2: Results of indoor RF radiation power density levels evaluated in 57 public places in Hebron city.

Location	**External Sources**				**Internal Sources**			
Public places	**FM**	**TV**	**GSM900**	**GSM1800**	**DECT**	**WLAN**	**Others**	**Total**
	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2
Min	0.00017	0.000633	0.00004	0.00003	0.00013	0.00037	0.00015	0.0016
Max	0.212	0.00475	2.03	0.0997	0.413	0.455	0.166	2.068
Average	**0.017**	**0.00086**	**0.073**	**0.0017**	**0.058**	**0.014**	**0.0053**	**0.17**

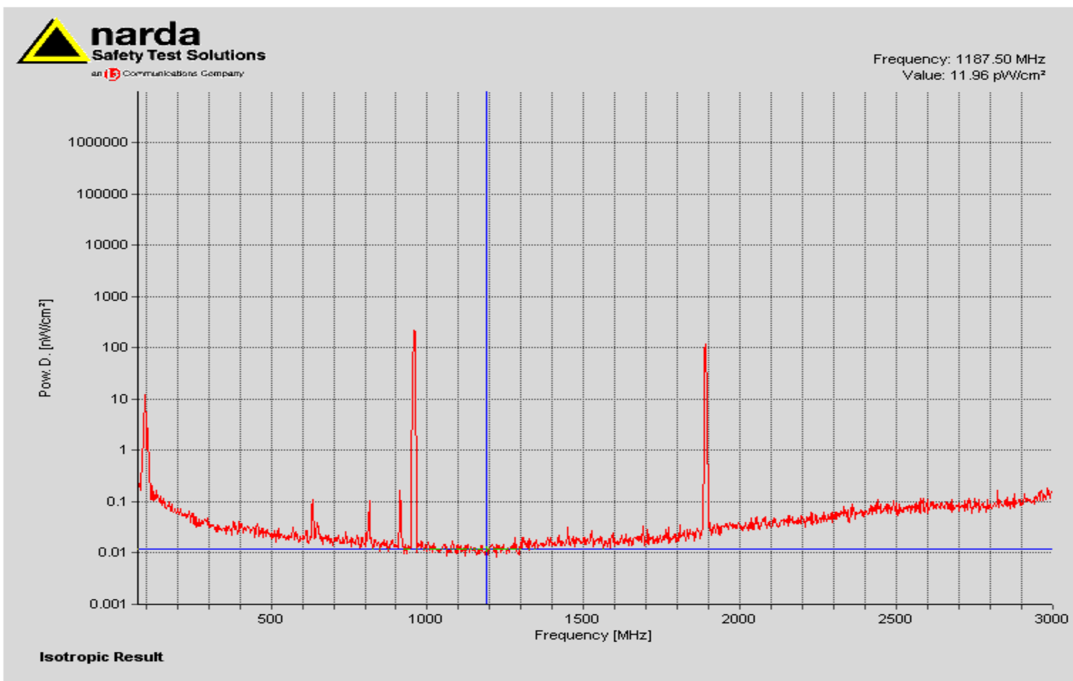

Figure 5.11: Indoor radiofrequency spectrum, in the frequency range 75 MHz to 3GHz detected in a commercial building in Hebron city.

Figure 5.12 represents the average indoor radiofrequency power density levels evaluated in 57 public places from different RF sources. It can be seen, that the maximum average indoor RF power density level is from GSM 900 mobile base stations, DECT signals being in the second place in all investigated 57 public places.

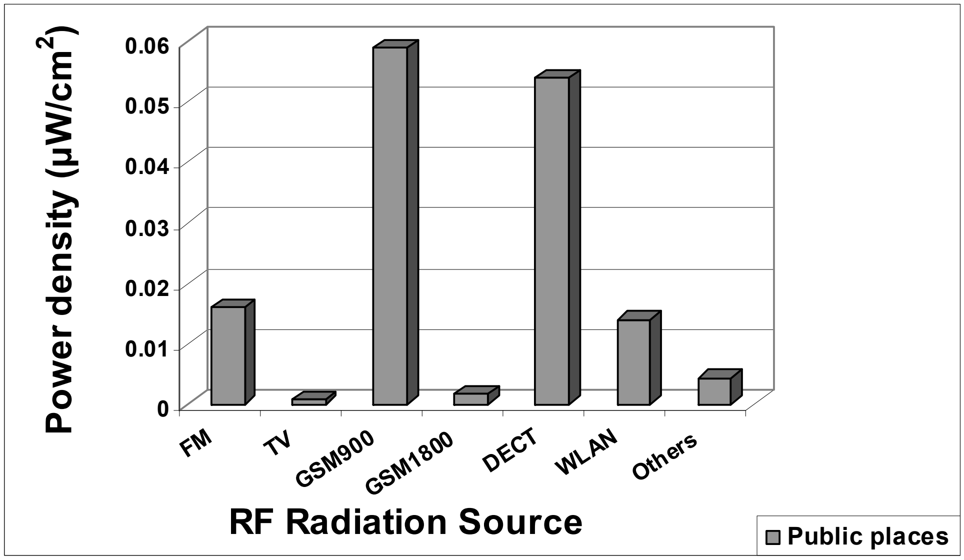

Figure 5.12: Average indoor radiofrequency power density levels form various RF sources evaluated in 57 public places in Hebron city.

The maximum measured indoor RF power density at any public place in Hebron city is 2.03 $\mu W/cm^2$ that is probably resulted from GSM (900) Jawwal mobile phone base station in Hebron center. This value is about 221 times below the limit recommended by ICNIRP for the general public (450 $\mu W/cm^2$).

The maximum indoor RF power density detected form FM radio is about 0.212 $\mu W/cm^2$ in the fourth floor of a restaurant at Ras Al Joura area. This value is 943 times below the limit recommended by ICNIRP for the general public (200 $\mu W/cm^2$). The maximum indoor RF power density measured form TV broadcasting is about 0.00475 $\mu W/cm^2$ in the fourth floor of a commercial building near Hebron University . This value is about 84,210 times below the limit recommended by ICNIRP for the general public (400 $\mu W/cm^2$).

The measurement of the maximum indoor RF power density form GSM(1800) is about 0.0997 $\mu W/cm^2$ in Al Rashad center in the city center .This value is about 9,027 times below the limit recommended by ICNIRP for the general public (900 $\mu W/cm^2$) .

The measurement of the maximum indoor RF power density form DECT is about 0.413 $\mu W/cm^2$ in a dental clinic in the city center. This value is about 2,179 times below the limit recommended by ICNIRP for the general public (900 $\mu W/cm^2$). The maximum indoor RF power density measured form WLAN access point is 0.455 $\mu W/cm^2$ in Hebron

Municipality .This value is about 2,197 times below the limit recommended by ICNIRP for the general public (1000 μW/cm^2).

The maximum indoor RF power density measured form others (other sources than mentioned before) is about 0.166 μW/cm^2 in Hebron Center from Talkie-Walki. This value is about 1,204 times below the limit recommended by ICNIRP for the general public (200 μW/cm^2).

In the frequency range 75 MHz to 3 GHz, the total indoor RF radiation levels from all RF sources in 57 public places is found to vary from 0.0016 μW/cm^2 to 2.068 μW/cm^2 with an average value of about 0.17 μW/cm^2.

The minimum total indoor RF power density evaluated from all RF sources at any public place is about 0.0016 μW/cm^2 and found in a pharmacy in the southern part of the city. This location is far away from any local FM and TV transmitters and there is no direct line of sight with any mobile base stations. Also, there is no use of WLAN or DECT at that pharmacy.

Figure 5.13 illustrates the relative contributions of various RF sources to the total indoor exposure received by the population in 57 public places in the City of Hebron. It can be seen, that GSM 900 mobile base stations contribute by the largest amount of indoor RFR in the total exposure at public places. This is might be due to the fact, that public places are overcrowded so subscribers need mobile base stations for providing coverage and capacity.

Figure 5.14 illustrates the relative contributions of internal and external RF sources to the total indoor RF exposure received by the population at 57 public places in Hebron city. External sources contribute by larger amount to the total exposure.

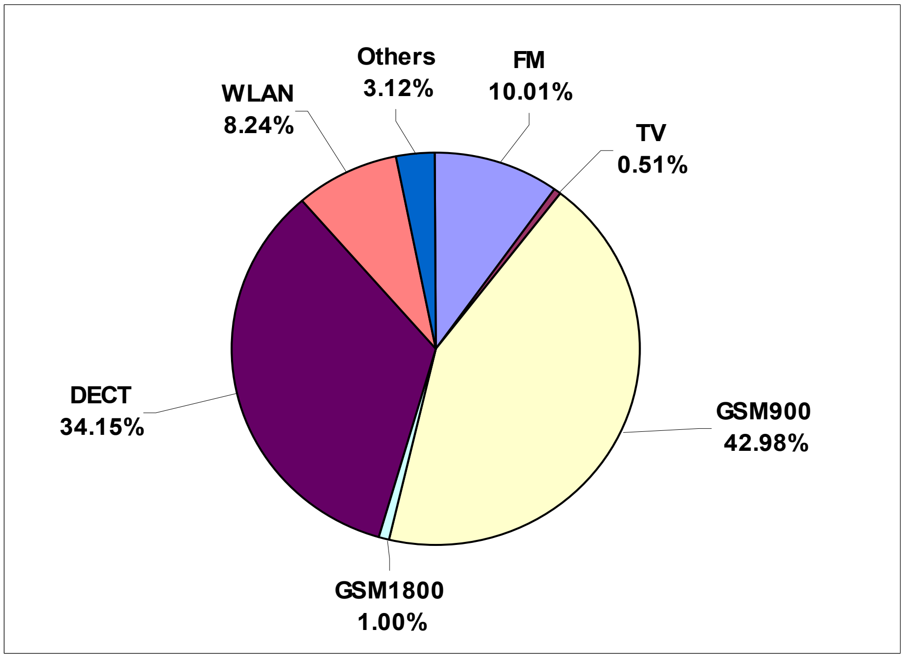

Figure 5.13: Relative contributions to the total indoor exposure from various radiofrequency radiation sources evaluated in 57 public places in Hebron city.

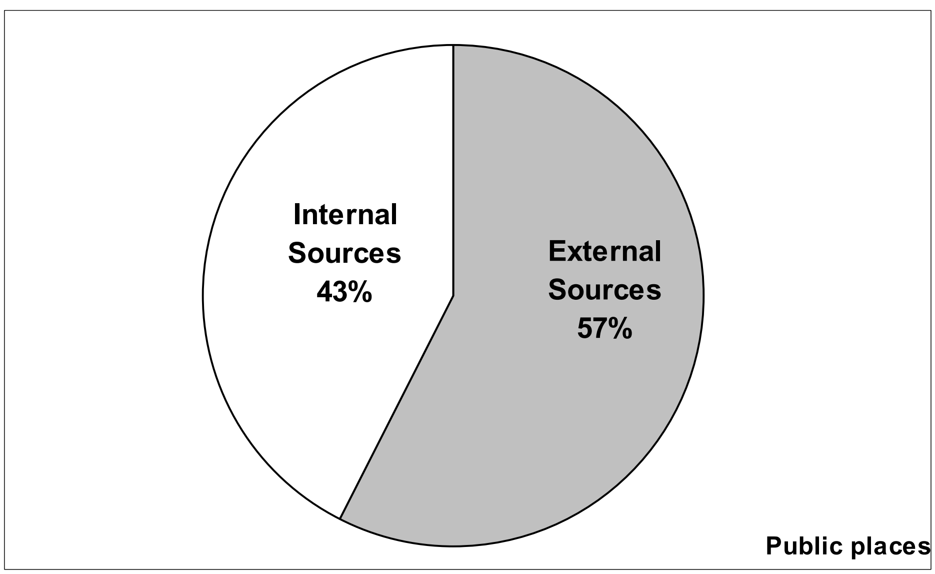

Figure 5.14: Relative contributions to the total indoor exposure from external and internal radiofrequency radiation sources evaluated in 57 public places in Hebron city.

5.1.3 Indoor RF- Radiation Levels Measured in Hebron Schools

The measurements are performed in 33 schools selected nearly at random according to the population density. They were conducted in classrooms, school labs, libraries and secretary or head office rooms. The maximum power density levels are detected at suitable heights (100-150) cm above the ground level for six minutes in real life conditions.

Figure 5.15 represents typical indoor RF spectrum in the frequency range 75 MHz to 3 GHz detected in King Khalid School .The spectrum includes FM, TV, and GSM 900 and radar signal.

Table 5:3 lists the results of indoor RF radiation power density levels averaged over six minutes for the different sources in the 33 schools in Hebron city .The average indoor RF power density levels as well as the maximum and minimum values for each source are evaluated .

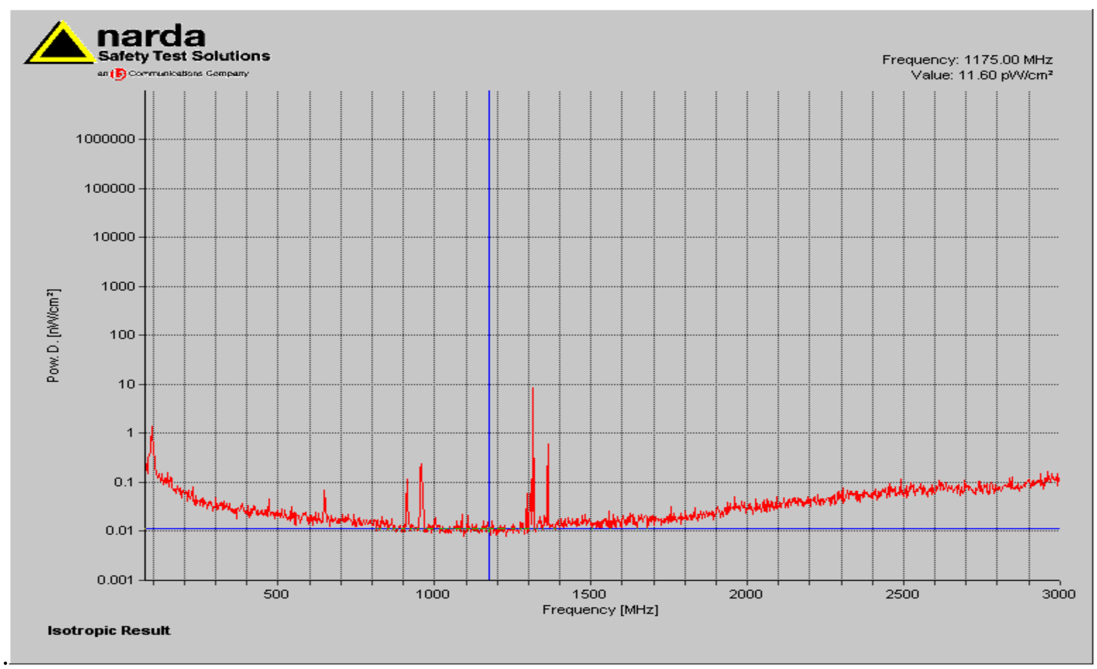

Figure 5.15: Indoor radiofrequency spectrum, in the frequency range 75 MHz to 3GHz detected in King Khalid School in Hebron city.

Table 5.3: Results of indoor RF radiation power density levels evaluated in the 33 schools in Hebron city.

Location	**External Sources**				**Internal Sources**			
Schools	**FM**	**TV**	**GSM 900**	**GSM 1800**	**DECT**	**WLAN**	**Others**	**Total**
	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2
Min	0.00019	0.00061	0.00002	0.00002	0.0001	0.00037	0.00011	0.0015
Max	0.159	0.00096	0.347	0.0147	0.00489	0.202	0.00977	0.35
Average	**0.0044**	**0.00067**	**0.0078**	**0.00048**	**0.0011**	**0.0038**	**0.0006**	**0.019**

Figure 5.16 represents average indoor RF power density levels for various RF sources evaluated in the 33 schools. The Figure show that, the maximum average indoor RF power density in 33 schools is from GSM 900 mobile base stations. This result might be due to the fact, that most schools in the City of Hebron are located in highly populated regions or near overcrowded city center.

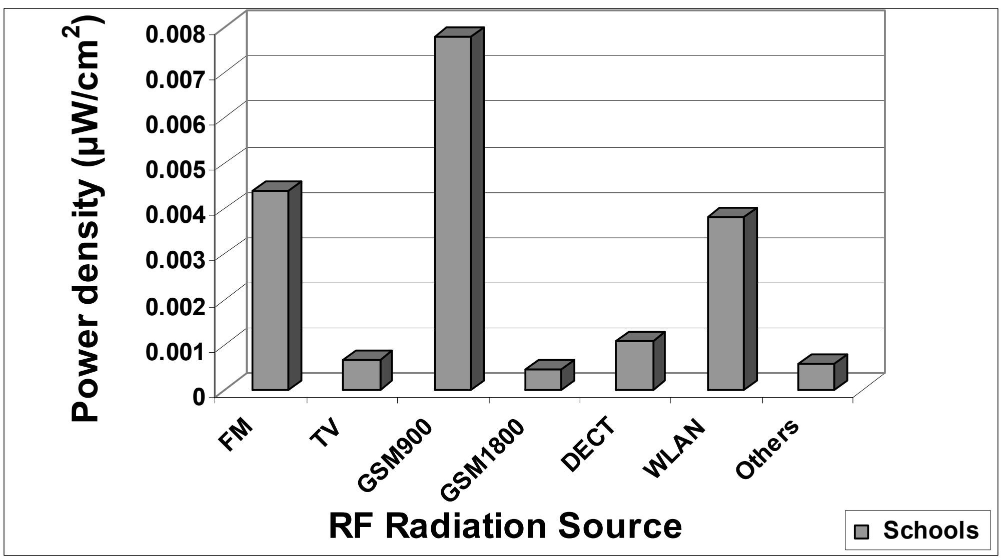

Figure 5.16: Average indoor radiofrequency power density levels form various RF sources evaluated in the 33 schools in Hebron city.

The measurement of the maximum indoor power density at any school in Hebron city is about 0.347 μW/cm^2, which is measured in a classroom in the third floor of Radi School resulted probably from GSM 900 mobile base station. This value is about 1,296 times below the limit recommended by ICNIRP for the general public (450 μW/cm^2).

The detection of the maximum indoor RF power density from FM radio is about 0.159 $\mu W/cm^2$ in a classroom in the third floor of Al-Sid School probably resulted from Radio AL-Mareh transmitter. This value is 1,257 times below the limit recommended by ICNIRP for the general public (200 $\mu W/cm^2$). While the maximum indoor RF power density from TV is about 0.00096 $\mu W/cm^2$ measured in the computer lab in Al-Hussain School probably resulted from Al-Aml TV broadcasting .This value is 416,666 times below the limit recommended by ICNIRP for the general public (400 $\mu W/cm^2$) .

The maximum indoor RF power density measured from GSM (1800) is about 0.0147$\mu W/cm^2$ in a classroom in the third floor of Khadija Abdeen School. This value is about 61,224 times below the limit recommended by ICNIRP for the general public (900 $\mu W/cm^2$).

The measurement of the maximum indoor RF power density from DECT is about 0.00489 $\mu W/cm^2$ in the school head office room of Al-Hussain School. This value is 184,049 times below the limit recommended by ICNIRP for the general public (900 $\mu W/cm^2$). Also the maximum indoor RF power density form WLAN access point is about 0.202 $\mu W/cm^2$ detected in the computer lab in Al-Hussain School .This value is about 4,950 times below the limit recommended by ICNIRP for the general public (1000 $\mu W/cm^2$).

The maximum indoor RF power density measured from others is about 0.00977 $\mu W/cm^2$ in the head office room of King Khalid School ,resulted probably from Radar signal as Figure 5.15 represented .This value is about 92,118 times below the limit recommended by ICNIRP for the general public (900 $\mu W/cm^2$).

The total indoor RF radiation levels from all RF sources in the range 75 MHz to 3 GHz in 33 schools is found to vary from 0.0015 $\mu W/cm^2$ to 0.35 $\mu W/cm^2$ with an average value of about 0.019 $\mu W/cm^2$. The minimum total indoor RF power density evaluated at any school from all RF sources is about 0.0015 $\mu W/cm^2$ and found in Yaseen Taha School. This school is located in southern part of the city far away from all local FM and TV transmitters or mobile phone base stations and none of DECT or WLAN are used in it.

Figure 5.17 illustrates the relative contributions of various RF sources to the total indoor RF exposure received by the population in 33 investigated schools in Hebron .It is noticeable from the Figure that, GSM 900 mobile base stations contribute by the largest amount of indoor radiofrequency radiation to the total exposure at schools.

Figure 5.18 illustrates the relative contributions of internal and external RF sources in the total indoor RF exposure received by the population in 33 schools in Hebron city . External sources contribute by larger amount to the total indoor RF exposure. This is because many schools don't use DECT or WLAN applications. Also, the schools used DECT or WLAN only in computer lap or head office room and not in the classes where most of our measurements done.

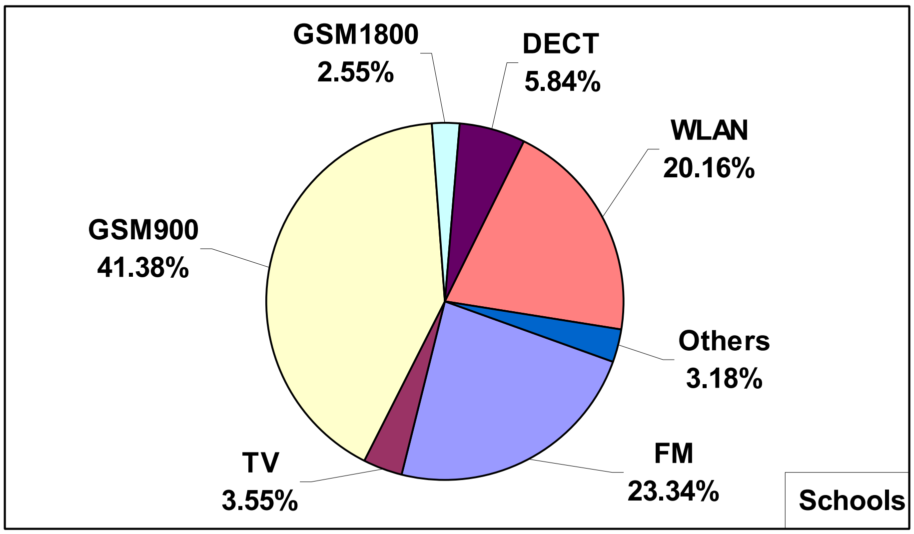

Figure 5.17: Relative contributions to the total indoor RF exposure from various radiofrequency radiation sources evaluated in the 33 schools in Hebron city.

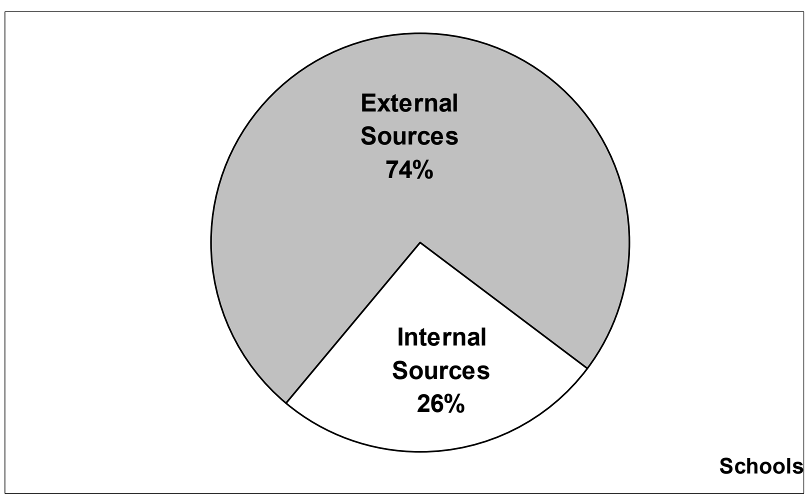

Figure 5.18: Relative contributions to the total indoor RF exposure from external and internal radiofrequency radiation sources evaluated in the 33 schools in Hebron city.

5.1.4 Indoor RF- Radiation Levels in Universities in Hebron

The measurements are performed at the three existing universities in Hebron city. In each university measurements are performed in different rooms including staff offices, lecture rooms, scientific labs, computer labs, cafeterias and libraries.

The maximum power density levels are detected at suitable heights between (120 -170) cm for about six minutes, in real life conditions.

The three universities in Hebron are located in different regions:

- Hebron University is located north west of Hebron. There is FM radio transmitter at the University Campus Radio Alem; also, there is a clear line of sight with Jawwal mobile base station at the library. Inside the university, there is no DECT or WLAN used.

- Al-Quds Open University is located west of Hebron in a highly populated area, no direct line of sight with any local FM and TV transmitters from the university. There is a mobile base station at about 500 m from the university. Inside the university, WLAN is used.

- There are four different campuses for Palestine Polytechnic University (PPU) in different geographical regions in the City of Hebron:

* Palestine Polytechnic University (PPU-Ein Sara) located at the city center .There is no direct line of sight with any of the local FM and TV transmitters, but clear line of sight with Jawwal mobile base station at that location. Moreover, the university uses a WLAN internet.

* Palestine Polytechnic University (PPU-Abu-Ktala) is located north west of the city .There is a clear good line of sight FM radio transmitter and Jawwal mobile base stations .

* Palestine Polytechnic University (PPU-Wadi Al-Hariya) is located south of the city .There is no direct line of sight with any of the local FM and TV transmitters, 2 Km away from the University there is GSM 1800 base station . The university uses a complete WLAN internet but there is no use of DECT devices.

* Palestine Polytechnic University (PPU-Abu-Ruman) is located south east of the city; there is no direct line of sight with any of the local FM and TV transmitters or mobile base station. The university uses a complete WLAN internet but there is no use of DECT devices.

Figure 5.19 shows a typical indoor radiofrequency spectrum in the frequency range 75 MHz -3GHz detected during downloading large files from the internet in PPU- Abu-Ruman . The spectrum includes RF sources (FM, GSM 900 and GSM 1800, WLAN), as well as, others RF sources (radar).The spectrum shows WLAN signals are the highest.

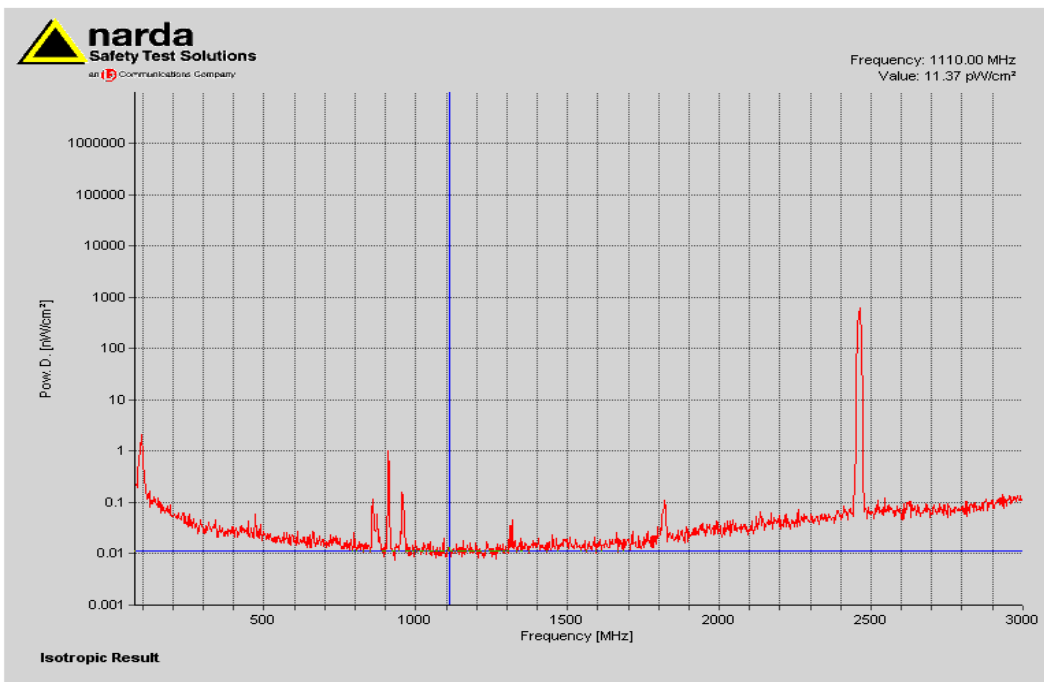

Figure 5.19: Indoor radiofrequency spectrum, in the frequency range 75 MHz to 3GHz detected in PPU- Abu- Ruman in Hebron city (during downloading large files from the internet).

Table 5.4 presents the results of average indoor RF power density levels measured at universities in Hebron city, from FM radio, TV Broadcasting, Mobile base stations, DECT, WLAN and Others.

Table 5.4: Results of average indoor RF radiation power density levels evaluated in the 3 universities (6 campuses) in Hebron city.

Site	External Sources				Internal Sources			
University	FM	TV	GSM 900	GSM 1800	DECT	WLAN	Others	Total
	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2
Hebron U.	0.059	0.0011	0.031	0.000043		0.0011	0.00034	0.093
Al-Quds Open U.	0.00093	0.00067	0.013	0.000045		0.0033	0.00052	0.018
PPU-Ein Sara	0.00036	0.00074	0.014	0.000056		0.021	0.00045	0.037
PPU-Abu-Ktala	0.0052	0.00066	0.0032	0.000043		0.00089	0.00033	0.0103
PPU.Wadi Al-Hariya	0.00028	0.00067	0.0015	0.00059		0.016	0.014	0.033
PPU-Abu-Ruman	0.00076	0.00069	0.00062	0.000058		0.18	0.0013	0.18
Min	0.00024	0.00064	0.00005	0.00004		0.00036	0.0002	0.00175
Max	0.206	0.00253	0.217	0.0025		0.706	0.0909	0.708
Average	**0.011**	**0.00076**	**0.011**	**0.00014**		**0.037**	**0.0028**	**0.063**

The detection of the maximum indoor power density in any university in the City of Hebron is about 0.706 μW/cm^2 resulted from WLAN access point at PPU-Abu-Ruman in the main courtyard at the campus as can be seen from Figure 5.19, where students use their laptops. This value is about 1,416 times below the limit recommended by ICNIRP for the general public (1000 μW/cm^2).

For FM radio transmitters, the maximum indoor RF power density measured is about 0.206 μW/cm^2 from Radio Alem at Hebron University in an office room on the fifth floor. This value is 970 times below the limit recommended by ICNIRP for the general public (200 μW/cm^2). For TV broadcasting, the maximum indoor RF power density detected is about 0.00253 μW/cm^2 in Hebron University lecture room on the third floor. This value is 158,102 times below the limit recommended by ICNIRP for the general public (400 μW/cm^2).

For mobile base stations GSM(900), the maximum indoor RF power density is about 0.217 μW/cm^2 detected in Hebron University library near Jawwal mobile phone base station .This value is 2,073 times below the limit recommended by ICNIRP for the general public (450 μW/cm^2).While for GSM(1800),the maximum indoor RF power density measured is about 0.0025 μW/cm^2 in a computer lab in PPU-Wadi Al-Hariya .This value is 360,000 times below the limit recommended by ICNIRP for the general public (900 μW/cm^2) .

No detection of DECT in all of the universities since they don't use DECT phones for communication.

The measurement of the maximum indoor RF power density from others is about 0.0909 μW/cm^2 in a science lab on the third floor in PPU-Wadi Al-Hariya University resulted probably from other RF transmitters in the south of Hebron. This value is 9,900 times below the limit recommended by ICNIRP for the general public (900 μW/cm^2).

The total indoor RF radiation levels from all RF sources in the range 75 MHz to 3 GHz in the three investigated universities in Hebron city is found to vary from 0.00175 μW/cm^2 to 0.708 μW/cm^2 with an average value of about 0.063 μW/cm^2.

The minimum total indoor RF power density evaluated at any location in the 3 investigated universities from all RF sources is about 0.00175 μW/cm^2 and found at Al-Quds Open University in a computer lab which is far away from local FM and TV transmitters and there is no direct line of sight with any mobile base stations. Also there is no use of WLAN or DECT at that lab.

Average indoor RF power density levels for various RF sources evaluated in Hebron University is displayed in Figure 5.20 .The Figure shows that, the maximum average indoor RF power density at Hebron University is from FM Radio signals. This might be due to Radio Alem transmitter which is located at the university campus.

At Al-Quds Open University the maximum average indoor RF power density is due to GSM 900 mobile base stations. This is shown in Figure 5.21.This result probably because of the existence of mobile base station near the university in a highly populated area.

The maximum average indoor RF power density at Palestine Polytechnic University (PPU-Ein Sara) is from WLAN access point signals as it can be seen in Figure 5.22 .This result in our work is in consistence with the work published by (Rafiqul Islam, et al., 2006) where they found that, strong WLAN signals detected in university campus near WLAN access point.

Average indoor RF power density levels for various RF sources evaluated in Palestine Polytechnic University (PPU- Abu-Ktala) is displayed in Figure 5.23 .The Figure shows that, the maximum average indoor RF power density at that University is from FM Radio signals. This might be due to Radio Alem transmitter which is located at about 1 Km from the university campus with clear line of sight.

Figure 5.24 shows that the maximum average indoor RF power density at Palestine Polytechnic University (PPU- Wadi Al-Hariya) is from WLAN access point signals as expected .While signals from others are relatively high probably due to the existence of other RF transmitters in the southern part of Hebron city.

Figure 5.25 shows that the maximum average indoor RF power density at Palestine Polytechnic University (PPU- Abu-Ruman) is from WLAN access point signals. This result because a complete WLAN internet is used inside the university .Also, there is no clear line of sight with any local FM, TV transmitters or mobile base stations from the university so these signals are very small .

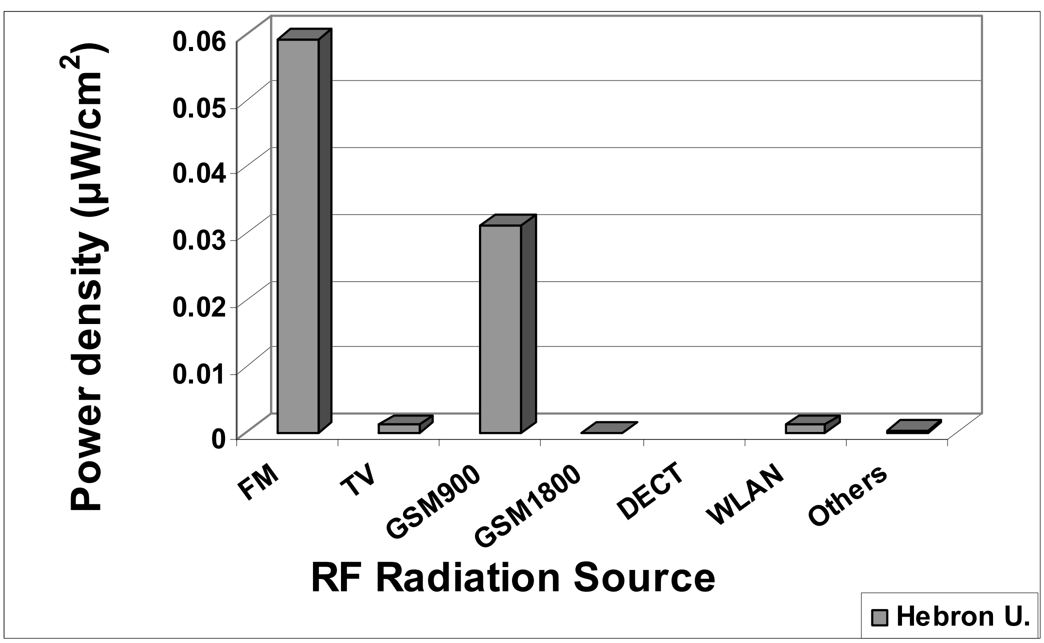

Figure 5.20: Average indoor radiofrequency power density levels form various RF sources evaluated in Hebron University.

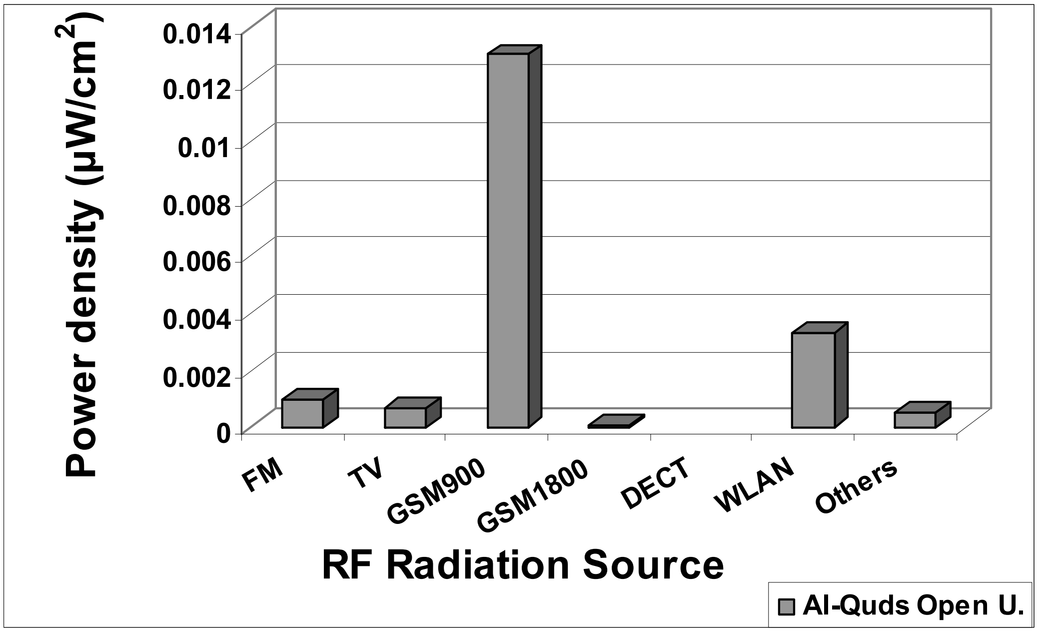

Figure 5.21: Average indoor radiofrequency power density levels form various RF sources evaluated in Al-Quds Open University.

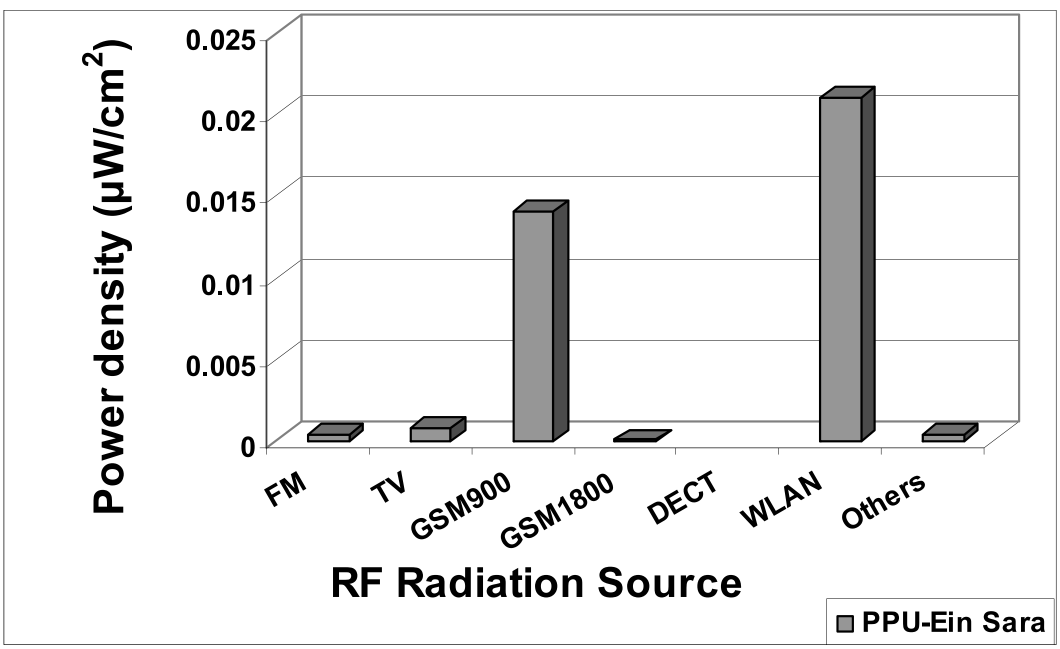

Figure 5.22: Average indoor radiofrequency power density levels form various RF sources evaluated in PPU-Ein Sara in Hebron city.

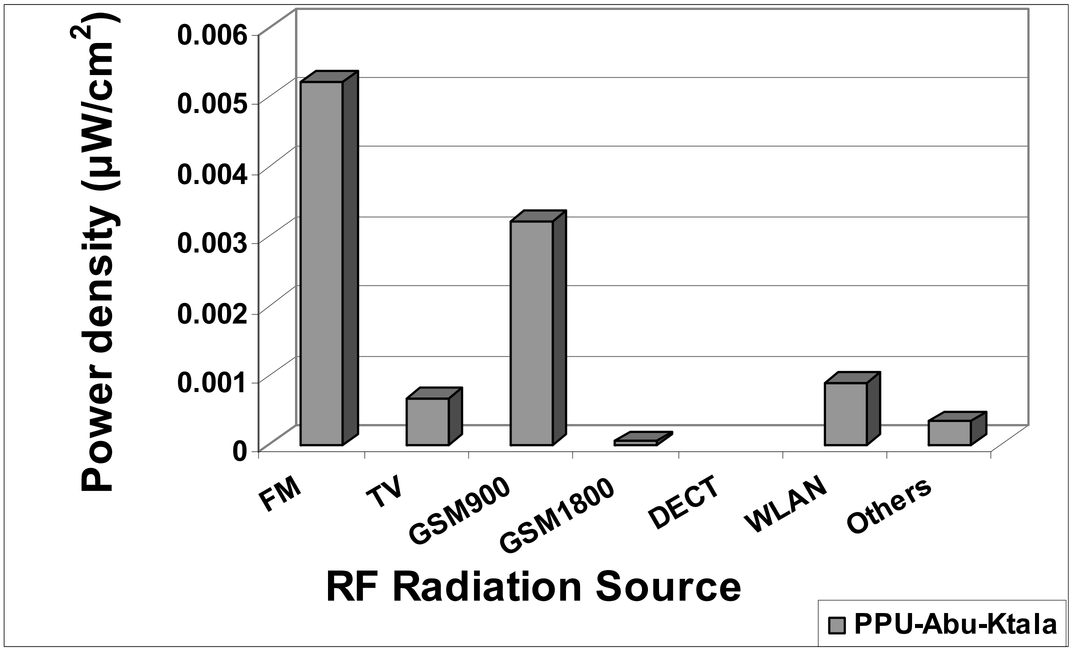

Figure 5.23: Average indoor radiofrequency power density levels form various RF sources evaluated in PPU-Abu-Ktala in Hebron city.

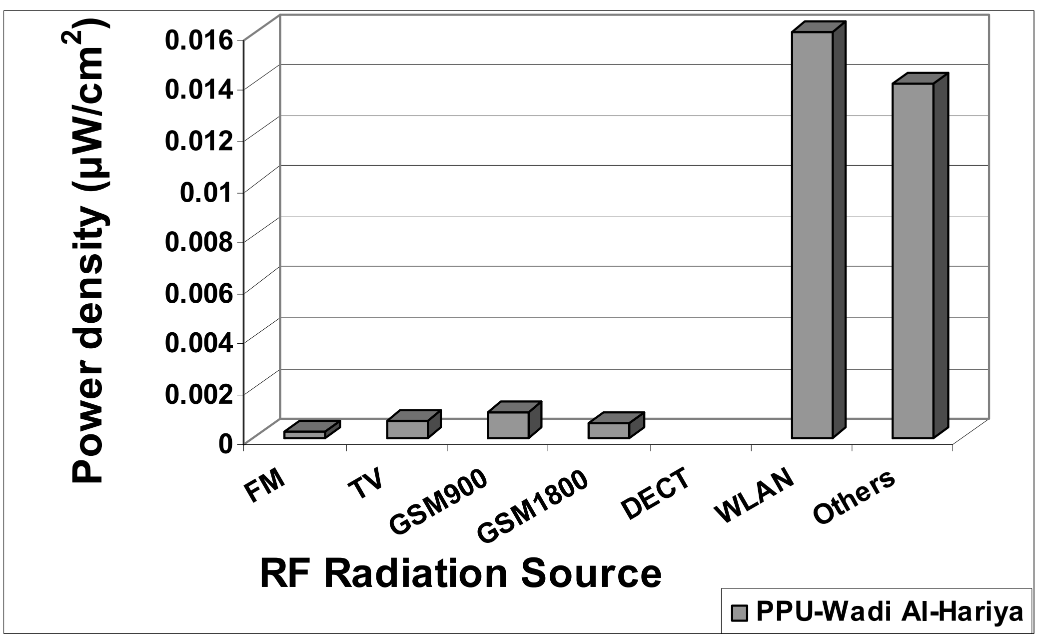

Figure 5.24: Average indoor radiofrequency power density levels form various RF sources evaluated in PPU-Wadi Al- Hariya in Hebron city.

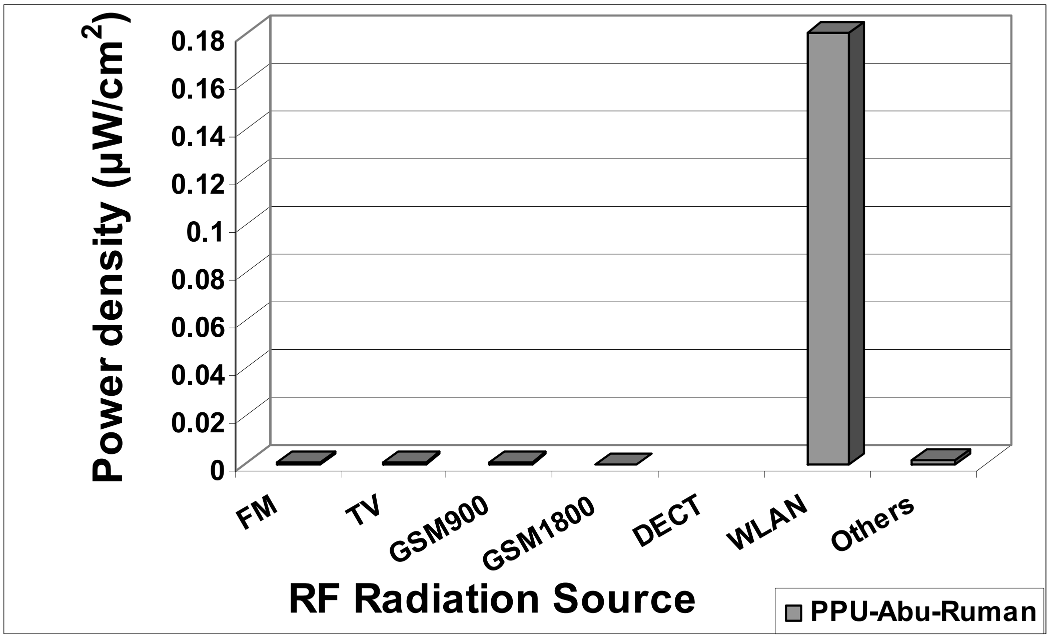

Figure 5.25: Average indoor radiofrequency power density levels form various RF sources evaluated in PPU-Abu-Ruman in Hebron city.

Average indoor RF power density levels for various radiofrequency sources evaluated in the three universities are displayed in Figure 5.26. This Figure shows that, WLAN signals in PPU-Abu-Ruman are the highest over all other signals. Figure 5.27 shows the same data in Figure 5.26, except that the indoor RF levels for WLAN have been excluded so as to show more clearly the indoor RF levels produced by other sources. It can be seen from Figure 5.27 that, FM radio signals in Hebron University are the highest over all other signals (except WLAN).

The average indoor RF levels are noticed to be highly variable from one university to another. This is because the universities are located at different locations so the distribution and characteristics of external RF transmitters varies from one location to another. Moreover, the existence of RF devices in each university causes more variations.

Relative contributions of various indoor RF sources to the total indoor exposure received by the population at the three investigated universities are shown in Figure 5.28. This Figure shows that, WLAN signals contribute by the largest amount of indoor RF radiation to the total RF exposure at the three investigated universities.

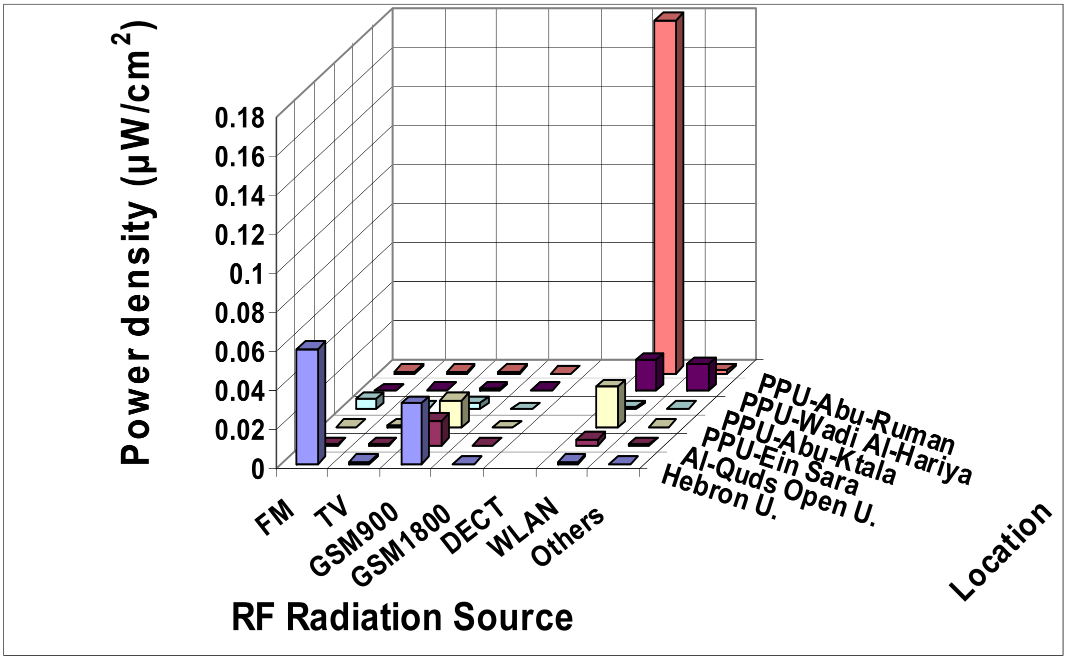

Figure 5.26: Average indoor radiofrequency power density levels form various radiofrequency sources evaluated in the three universities in Hebron city.

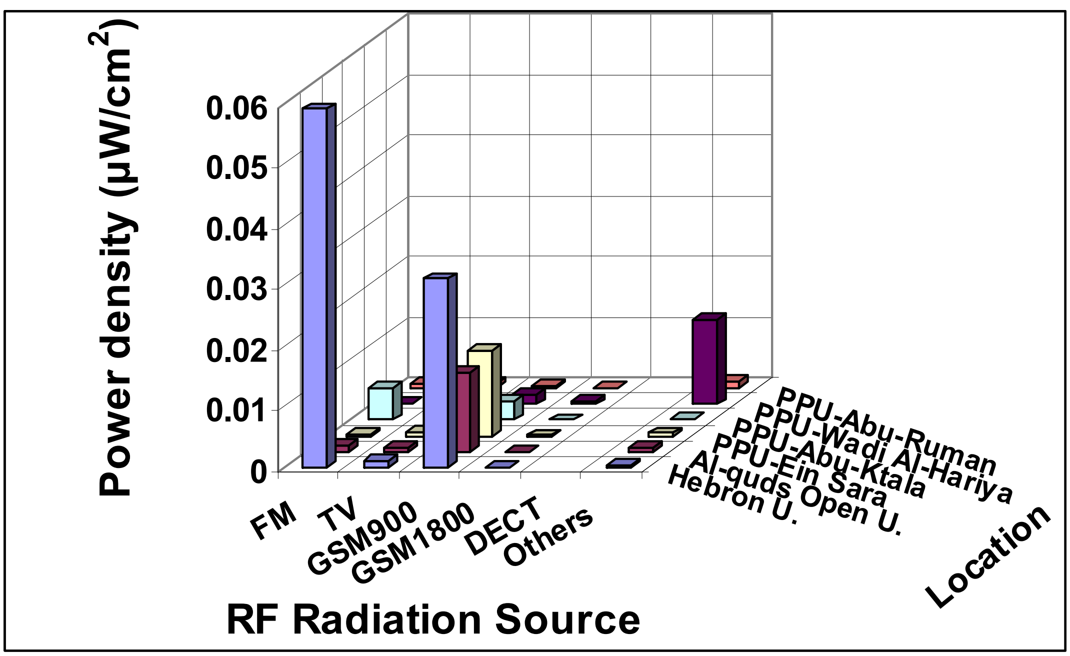

Figure 5.27: Average indoor radiofrequency power density levels form various radiofrequency sources evaluated in the three universities in Hebron city (WLAN excluded).

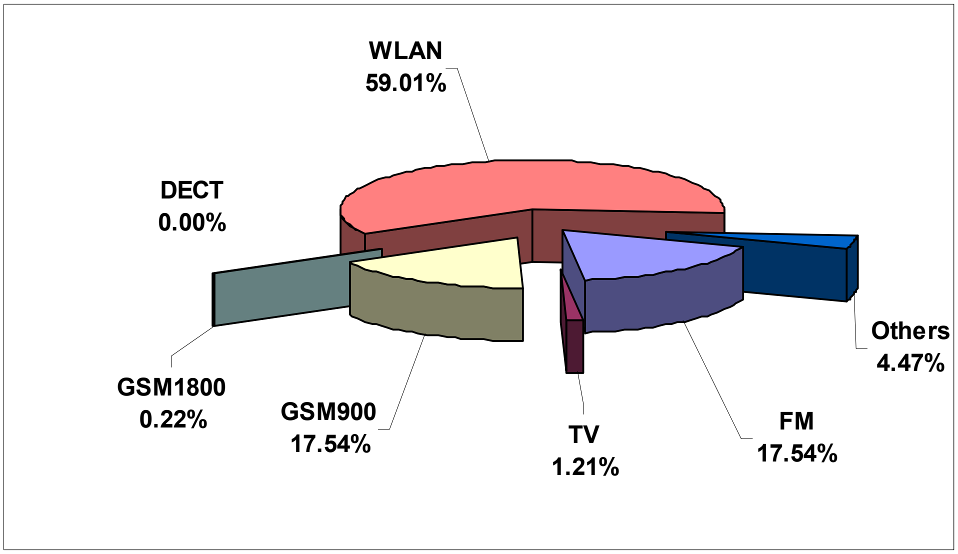

Figure 5.28: Relative contributions to the total indoor exposure from various radiofrequency radiation sources evaluated in universities in Hebron city.

Figure 5.29 illustrates the relative contributions of various universities to the total indoor RF exposure in universities in Hebron city. PPU- Abu- Ruman contributes by the largest amount of indoor RF exposure to the total exposure at the three investigated universities.

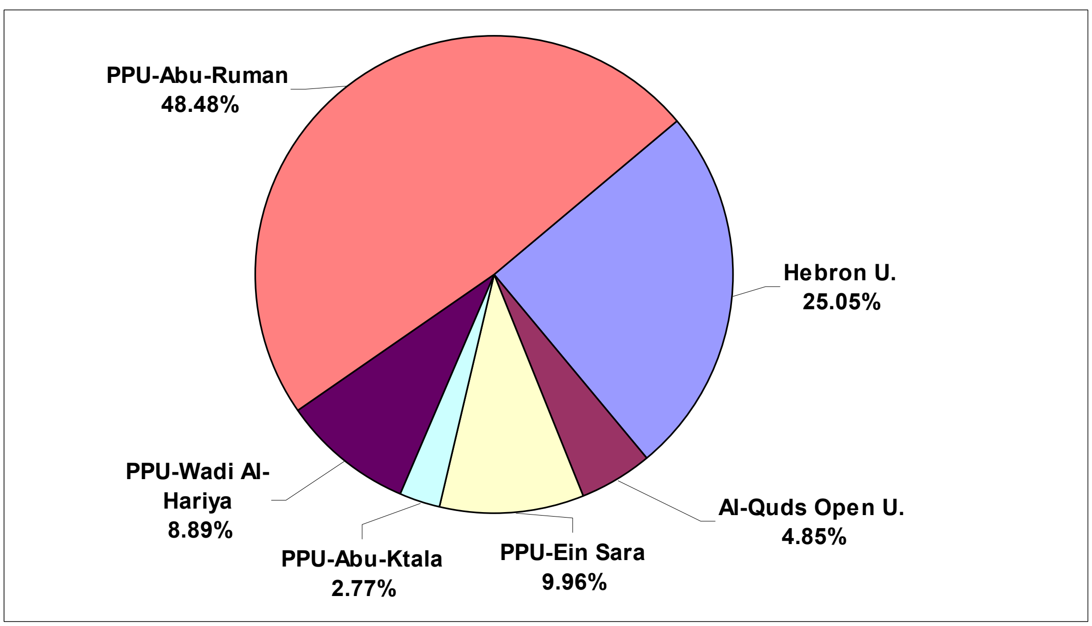

Figure 5.29: Relative contributions to the total indoor RF exposure from various universities in Hebron city.

Figure 5.30 illustrates the relative contributions of internal and external RF sources to the total indoor RF exposure received by the population at the three universities in Hebron. Internal sources contribute by larger amount to the total exposure.

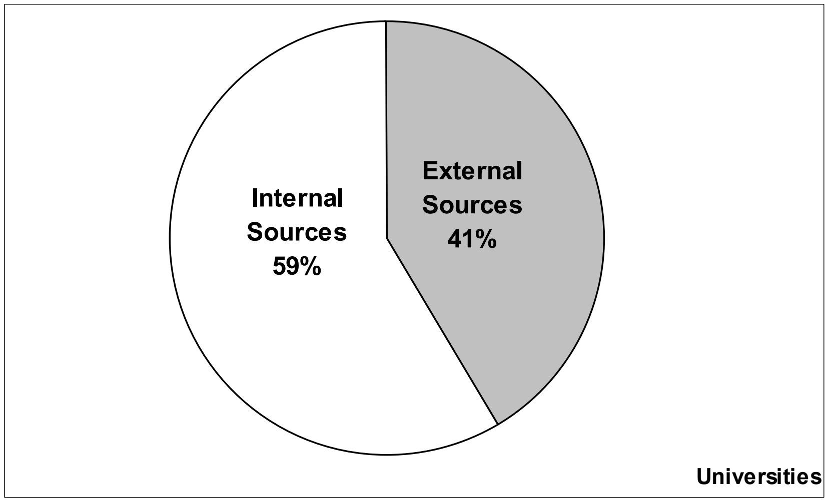

Figure 5.30: Relative contributions to the total indoor RF exposure from internal and external RF sources evaluated in the three universities in the City of Hebron.

5.1.5 Indoor RF- Radiation Levels in Hospitals in Hebron City

The measurements are performed at four hospitals in Hebron city in different rooms including patient rooms, pediatric rooms ,clinics, staff offices ,ICU, CCU ,X-ray , emergency, labs, and cafeterias.

The maximum power density levels are detected at heights between (120 – 170) cm for about six minutes, in normal conditions.

The following hospitals are considered:

*Alia Hospital is located in the city center surrounded by high buildings, there is no clear line of sight with FM radio towers or TV broadcasting or Jawwal mobile base station .Inside the hospital there is no DECT or WLAN applications used.

*M. Ali Al-Muhtaseb Hospital is located in the south of the city in a highly populated region, there is no clear line of sight with FM radio, TV transmitter's .Inside the hospital there is no DECT but WLAN internet is used.

*Al- Ahli Hospital is located in the north-west of the city at the roof of the hospital there were two reinforcement FM radio, there is clear line of sight with Jawwal mobile base station. The hospital is also about 1.5 Km from Ras Al- Joura area where most of TV, FM towers are located. Moreover, DECT and WLAN are used.

*Al-Mizan Hospital is located in the north of the city, there is a clear sight with local FM radio and TV transmitters and about 300 m Jawwal mobile base station, but there is no use of WLAN or DECT applications.

Figure 5.31 illustrates a typical indoor RF spectrum in the frequency range 75 MHz - 3GHz detected at Al- Ahli Hospital in Hebron city .The spectrum includes four main external RF sources (FM,TV,GSM 900and GSM 1800) ,and two main internal RF sources (DECT and WLAN),as well as , Other RF sources (Talki- walki, UMTS and emergency pagers).

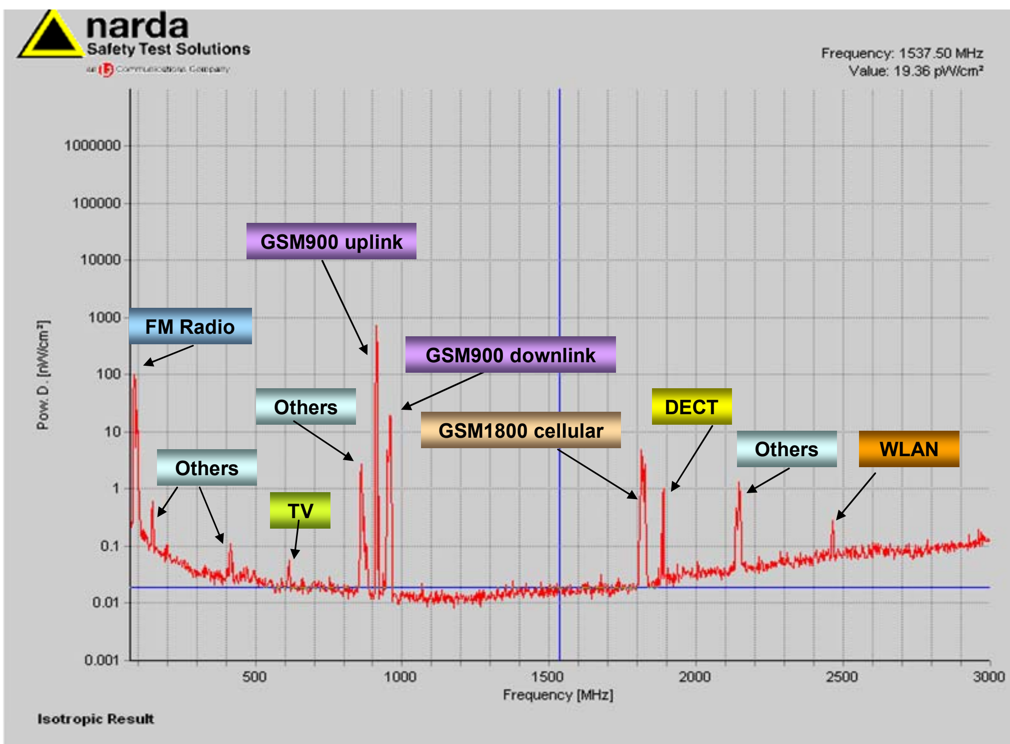

Figure 5.31: Indoor radiofrequency spectrum, in the frequency range 75 MHz to 3GHz detected in Al- Ahli Hospital in Hebron city.

Table 5:5 presents the results of average indoor RF radiation power density levels over six minutes for different RF sources in four investigated hospitals in Hebron city. The average indoor power density levels as well as the maximum and minimum values detected for each source are evaluated.

Table 5.5: Average indoor RF radiation power density levels evaluated in four hospitals in Hebron city.

Location	**External Sources**				**Internal Sources**			
Hospital	**FM**	**TV**	**GSM900**	**GSM1800**	**DECT**	**WLAN**	**Others**	**Total**
	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2
Alia.Hospital	0.00052	0.00065	0.00038	0.00035		0.0004	0.00065	0.003
Al-Ahli Hospital	0.03	0.00075	0.0026	0.00059	0.0011	0.0049	0.063	0.1
Al-Mizan Hospital	0.047	0.00097	0.0034	0.00057		0.0004	0.0014	0.054
M. Ali Al-Muhtaseb Hospital	0.00025	0.00068	0.0015	0.000085		0.0057	0.00038	0.0086
Min	0.00023	0.00063	0.00003	0.00004	0.0011	0.00038	0.00015	0.00158
Max	0.245	0.00205	0.0231	0.0049	0.0011	0.053	0.615	0.672
Average	**0.019**	**0.00076**	**0.002**	**0.0004**	**0.0011**	**0.0029**	**0.016**	**0.042**

The maximum indoor power density at any hospital in Hebron city is found to be 0.615 μW/cm^2 detected in the emergency room at Al- Ahli Hospital at frequency 155.95 MHz resulted from Other RF sources probably due to Al-Hilal Emergency Communication Services .This value is about 325 times below the limit recommended by ICNIRP for the general public (200 μW/cm^2).

For FM radio transmitters, it has a maximum indoor RF power density of about 0.245 μW/cm^2 in a patient room in AL-Mizan Hospital resulted from Radio Al-Nawras. This value is about 816 times below the limit recommended by ICNIRP for the general public (200 μW/cm^2). For TV broadcasting has a maximum indoor RF power density of about 0.00205 μW/cm^2 found in a patient room in the fourth floor of AL-Mizan hospital. This value is about 219,512 times below the limit recommended by ICNIRP for the general public (400 μW/cm^2).

The maximum value of indoor RF power density for mobile phone base stations (GSM 900) is about 0.0231 μW/cm^2 measured in office room near Jawwal mobile phone base station at Al-Ahli hospital .This value is about 21,126 times below the limit recommended by ICNIRP for the general public (450 μW/cm^2). The maximum value of indoor RF power density for (GSM 1800) is 0.0049 μW/cm^2 measured in an office room at Al-Ahli hospital as shown in Figure 5.31 .This value is about 183,673 times below the limit recommended by ICNIRP for the general public (900 μW/cm^2) .

The maximum indoor RF power density measured from DECT is about 0.0011 μW/cm^2 in an office room at Al-Ahli hospital as displayed in Figure 5.31. This value is about 818,181 times below the limit recommended by ICNIRP for the general public (900 μW/cm^2). For WLAN, the maximum indoor RF power density measured is about 0.0.053 μW/cm^2 at M. Ali Al-Muhtaseb hospital in an office room. This value is about 81,518 times below the limit recommended by ICNIRP for the general public (1000 μW/cm^2).

In four investigated hospitals , the total indoor RF radiation levels from all RF sources is found to vary from 0.00158 μW/cm^2 to 0.672 μW/cm^2 with an average value of about 0.042 μW/cm^2.

The minimum total indoor RF power density evaluated at any hospital from all RF sources is about 0.00158 μW/cm^2 is found in the CCU room at Alia hospital. This room is an isolated room and far away from local FM and TV transmitters. There is no direct line of sight with any mobile phone base stations. Also there is no use of WLAN or DECT in that room.

An average indoor radiofrequency power density levels for various RF sources evaluated in M. Ali Al-Muhtaseb hospital are displayed in Figure 5.32. From the Figure it can be seen, that the maximum average indoor RF power density at M. Ali Al-Muhtaseb hospital is from WLAN access point signals. Because of the use of WLAN internet, while other RF sources are relatively small since the hospital is far away from TV, FM and mobile phone transmitters.

Figure 5.33 shows that, the maximum average indoor RF power density at Al-Mizan hospital is from FM Radio signals. This might be due to the location of the hospital in the northern part of the city where the line of sight with most FM radio broadcastings from the hospital is clearly seen.

Figure 5.34 shows that, the maximum average indoor RF power density at Al-Ahli hospital is from Others RF signals. This probably due to the existence of Al-Hilal Emergency communications antennas since the hospital is located at high mountain in the city.

In Alia hospital all RF signals are very low because the hospital is far away from all local RF transmitters .However, the maximum average indoor RF power density at Alia hospital is from Others and TV signals as shown in Figure 5.35.This probably because of the existence of other RF transmitters near the city center.

The high variations of average indoor RF levels in the four investigated hospitals caused by many factors such as : the distribution and characteristics of external RF sources in different geographical regions where these hospitals are located ,the existence of internal RF sources and the attenuation through walls, windows , surrounding buildings and vegetation.

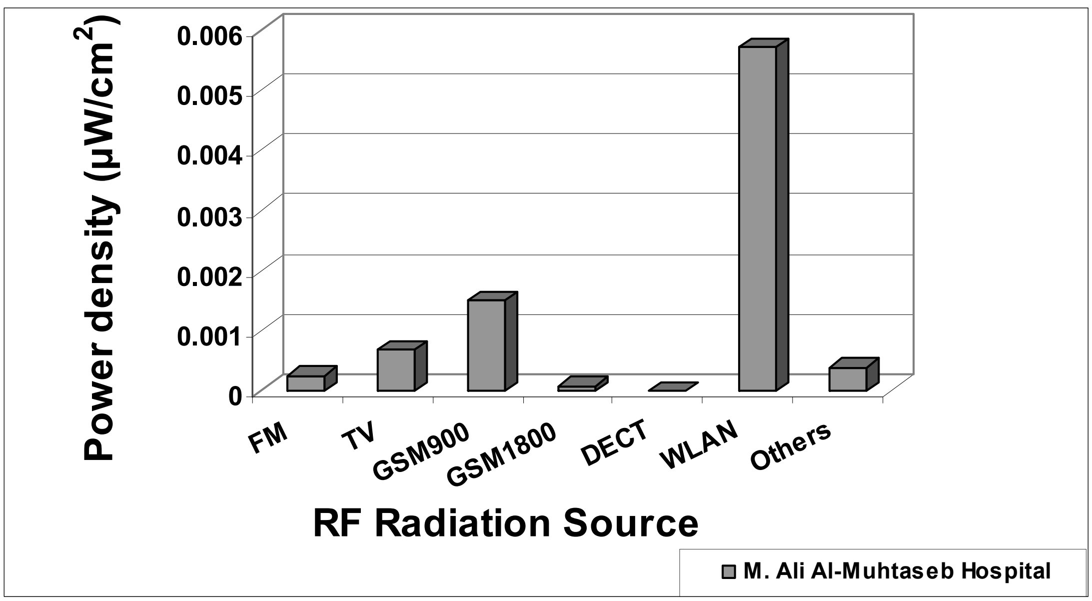

Figure 5.32: Average indoor radiofrequency power density levels form various RF sources evaluated in M. Ali Al-Muhtaseb hospital in Hebron city.

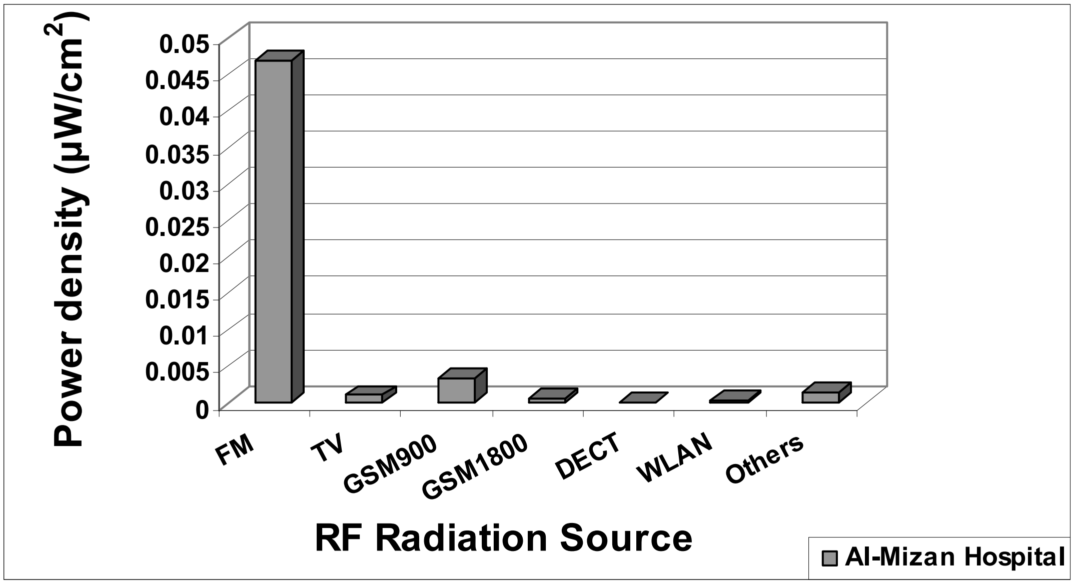

Figure 5.33: Average indoor radiofrequency power density levels form various RF sources evaluated in Al- Mizan hospital in Hebron city.

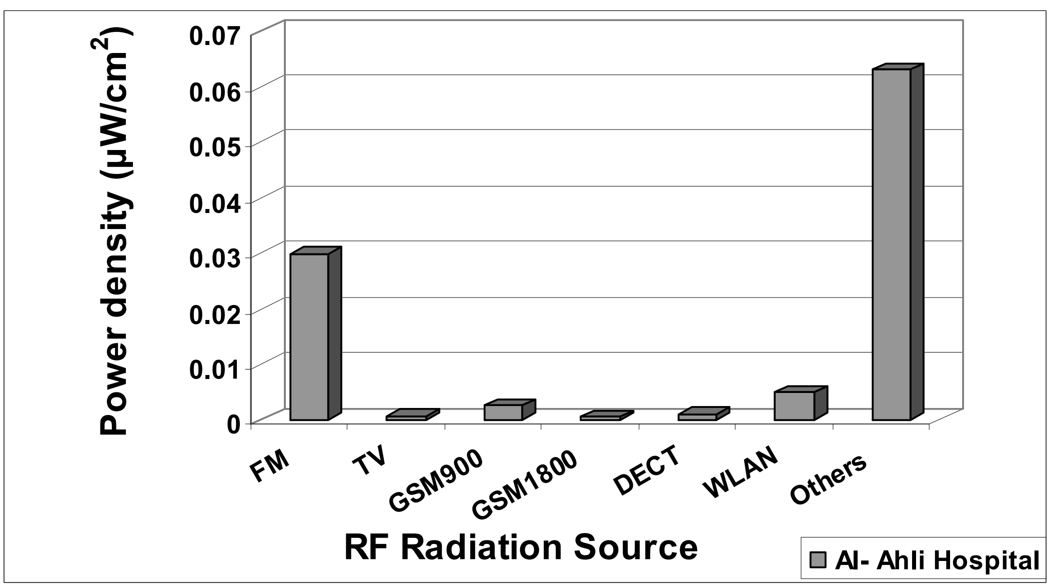

Figure 5.34: Average indoor radiofrequency power density levels form various RF sources evaluated in Al-Ahli hospital in Hebron city.

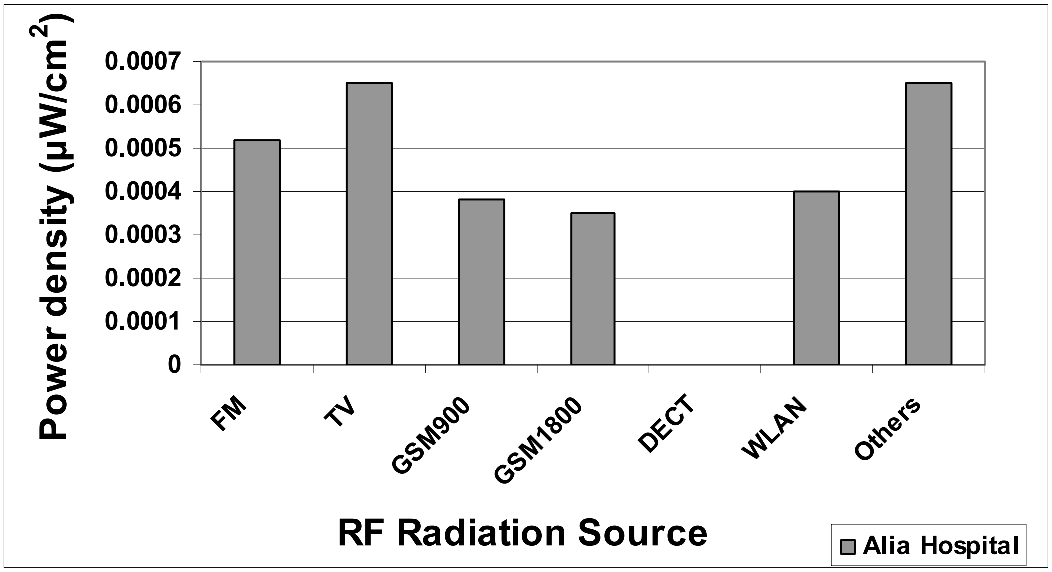

Figure 5.35: Average indoor radiofrequency power density levels form various RFR sources evaluated in Alia hospital in Hebron city.

A 3D plot of all internal and external RF sources at four hospitals including FM, TV, GSM 900, GSM 1800, DECT, WLAN and Others are shown in Figure 5.36. The signals resulted from Other RF sources are the maximum in Al-Ahli hospital.

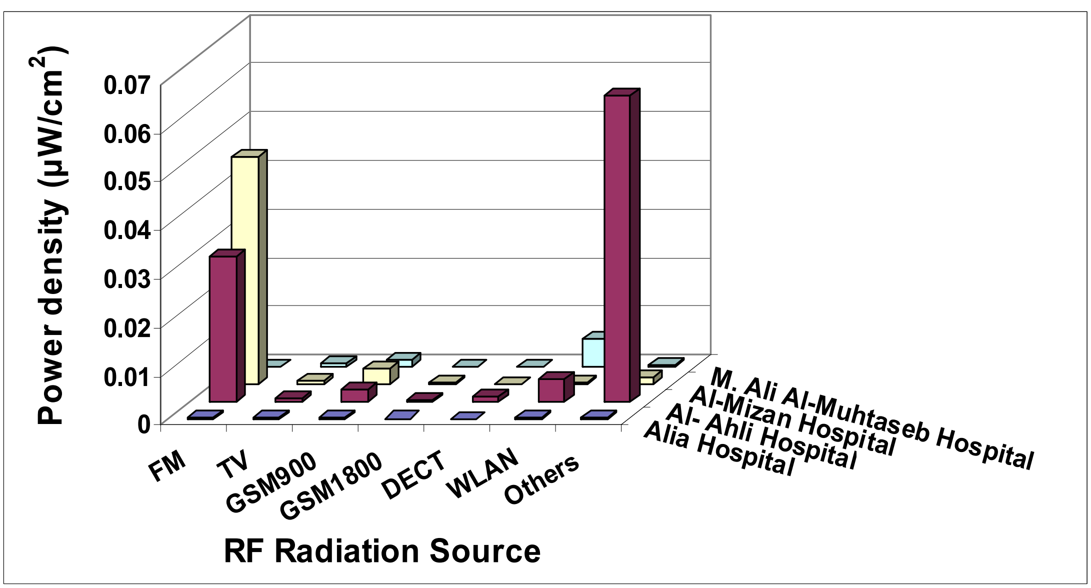

Figure 5.36: Average indoor radiofrequency power density levels form various RFR sources evaluated in four hospitals in Hebron city.

Figure 5.37 illustrates the relative contributions of various RF sources to the total indoor RF exposure received by the population in four investigated hospitals in of Hebron. FM radio signals are contributed by the largest amount of indoor radiofrequency radiation in hospitals.

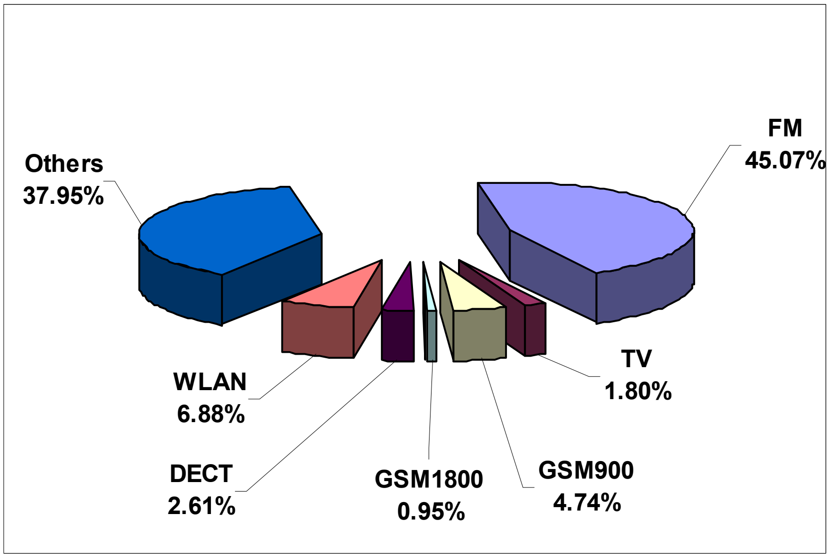

Figure 5.37: Relative contributions to the total indoor RF exposure from various indoor radiofrequency radiation sources evaluated in four hospitals in Hebron city.

Relative contributions of various hospitals to the total indoor RF exposure in the four investigated hospitals are shown in Figure 5.38. Al- Ahli hospital contributes by the largest amount of indoor RF exposure to the total RF in hospitals**.** I believe this result, mainly due to the higher contribution of Others RF radiation in Al-Ahli hospital, the relatively high FM signals detected in it and the use of WLAN and DECT in that hospital.

Figure 5.39 illustrates the relative contributions of internal and external RF sources to the total indoor RF exposure received by the population in four investigated hospitals. External sources contribute by larger amount to the total indoor RF exposure in hospitals.

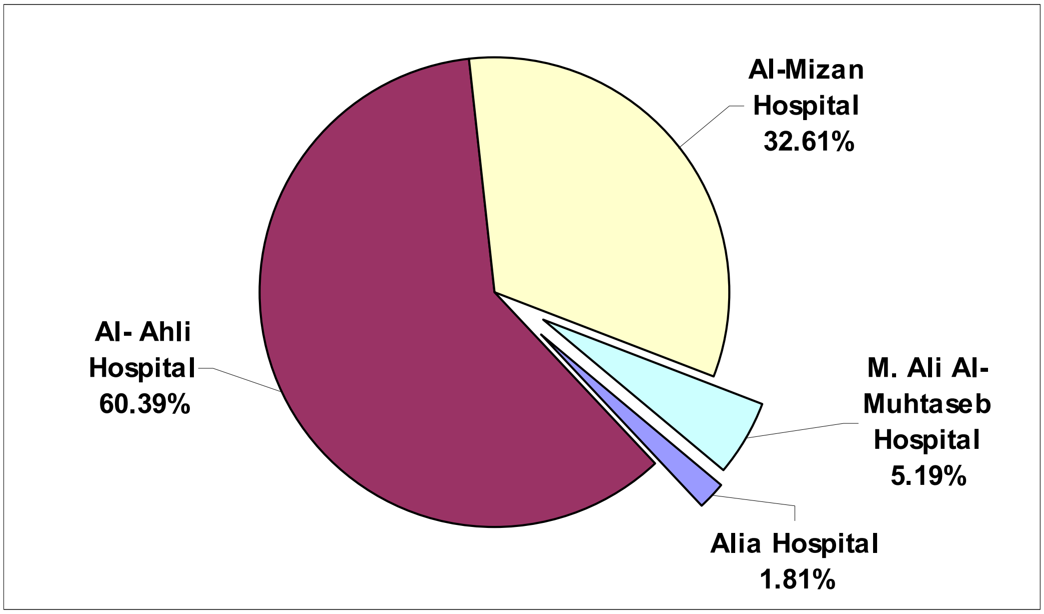

Figure 5.38: Relative contributions to the total indoor RF exposure from various hospitals in Hebron city.

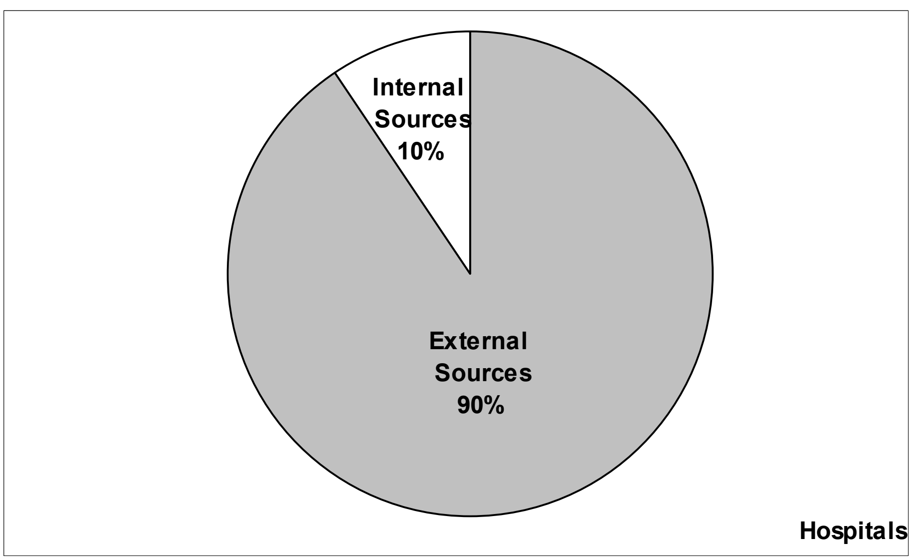

Figure 5.39: Relative contributions to the total indoor RF exposure from internal and external RF sources evaluated in four hospitals in Hebron city.

5.1.6 Indoor RF- Radiation Levels in Coffee Shops in Hebron City

The measurements are performed at 7 coffee shops selected nearly at random. Most of coffee shops in Hebron city are located in the northern part of the city. The maximum power density levels are detected at suitable heights 120 cm, corresponding to the adult head position for about six minutes, over the maximum range of the SRM 3000 from 75 MHz to 3 GHz in real life conditions.

Table 5:6 lists the results of indoor RF radiation power density levels over six minutes for the different sources at 7 coffee shops. The bottom of each column represents the average evaluated indoor power density levels as well as the maximum and minimum values detected for each source.

Average indoor RF power density levels for various RF sources evaluated in 7 coffee shops in Hebron are shown in Figure 5.40. It can be seen that, the highest average indoor RF power density level is from WLAN access points in coffee shops. This result is probably due to the use of WLAN internet in most investigated coffee shops.

Table 5.6: Results of indoor RF radiation power density levels evaluated in 7 coffee shops in Hebron city.

Location	External Sources				Internal Sources			
Coffee shop	FM	TV	GSM 900	GSM1800	DECT	WLAN	Others	Total
Site No.	μW/cm²	μW/cm²	μW/cm²	μW/cm²	μW/cm²	μW/cm²	μW/cm²	μW/cm²
1	0.0146	0.0112	0.0312	0.00003		0.0128	0.00015	0.058
2	0.00037	0.00067	0.0159	0.00003		0.0666	0.0002	0.084
3	0.00102	0.00067	0.00092	0.00003	0.0041	0.166	0.0003	0.17
4	0.00331	0.00066	0.00604	0.00034		0.00039	0.0003	0.011
5	0.0657	0.0007	0.00044	0.00003	0.011	0.00054	0.0004	0.079
6	0.0601	0.00102	0.0469	0.00003		0.00086	0.0003	0.11
7	0.00028	0.00066	0.00038	0.00003		0.00147	0.0003	0.0031
Average	**0.021**	**0.0022**	**0.015**	**0.000074**	**0.0076**	**0.036**	**0.00028**	**0.081**
Min	0.00028	0.00066	0.00038	0.00003	0.0041	0.00039	0.00015	0.0031
Max	0.0657	0.0112	0.0469	0.00034	0.011	0.166	0.0004	0.17

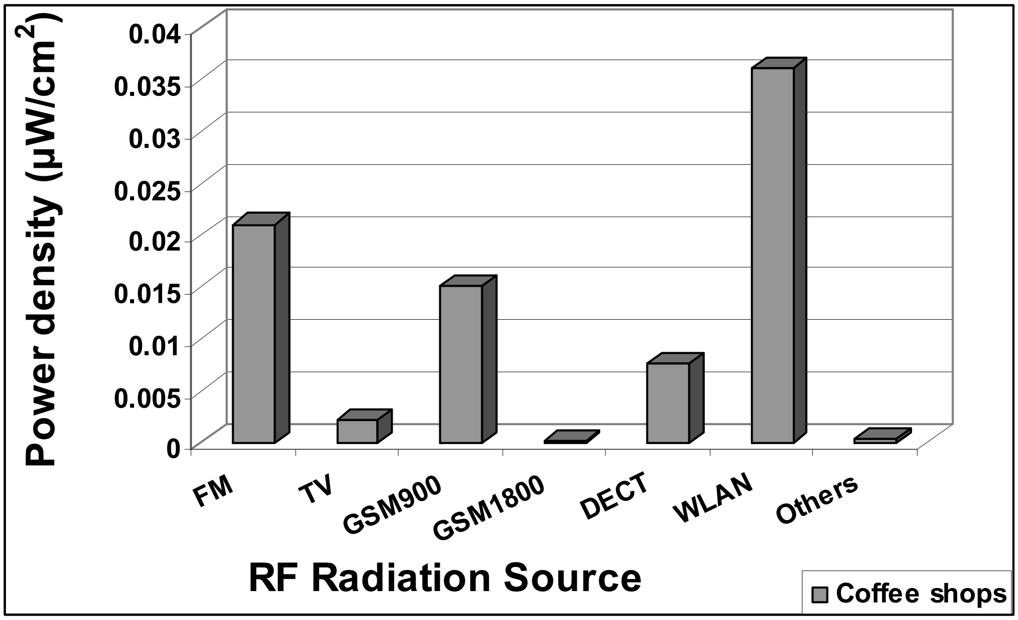

Figure 5.40: Average indoor radiofrequency power density levels form various RFR sources evaluated in 7 coffee shops in Hebron city.

The measurement of the maximum indoor RF power density at any coffee shop in Hebron is about 0.166 $\mu W/cm^2$ resulted from WLAN access point in coffee shop (3). This value is 6,024 times below the limit recommended by ICNIRP for the general public (1000 $\mu W/cm^2$).

For FM radio transmitters, the maximum indoor RF power density detected is about 0.0657 $\mu W/cm^2$ in coffee shop (6). This value is 3,044 times below the limit recommended by ICNIRP for the general public (200 $\mu W/cm^2$) .The maximum indoor RF power density measured from TV broadcasting is about 0.0112 $\mu W/cm^2$ in coffee shop (1). This value is 35,714 times below the limit recommended by ICNIRP for the general public (400 $\mu W/cm^2$).

The maximum indoor RF power density measured from mobile phone base stations (GSM 900) is about 0.0469 $\mu W/cm^2$ in coffee shop (6) near Jawwal mobile phone base station. This value is 9,594 times below the limit recommended by ICNIRP for the general public (450 $\mu W/cm^2$).For (GSM 1800) ,the maximum indoor RF power density measured is about 0.00034 $\mu W/cm^2$ in coffee shop (4) .This value was 2,647,058 times below the limit recommended by ICNIRP for the general public (900 $\mu W/cm^2$) .

For DECT, the maximum indoor RF power density measured is about 0.011 μW/cm^2 in coffee shop (5) .This value is 81,818 times below the limit recommended by ICNIRP for the general public (900 μW/cm^2).

The maximum indoor RF power density detected from others is about 0.0004 μW/cm^2 in coffee shop (5) .This value is 2,225,000 times below the limit recommended by ICNIRP for the general public (900 μW/cm^2).

The total indoor RF radiation levels from all RF sources in the range 75 MHz to 3 GHz in 7 investigated coffee shops in Hebron is found to vary from 0.0031 μW/cm^2 to 0.17 μW/cm^2 with an average value about 0.081 μW/cm^2 .The minimum total indoor RF power density evaluated at any coffee shop from all RF sources is about 0.0031 μW/cm^2 and found in coffee shop (7) which is located in south west of Hebron , far away from all local FM and TV transmitters and there is no direct line with any mobile base stations. Also there is no use of WLAN or DECT at that coffee shop.

The relative contributions of various indoor RF sources to the total indoor RF exposure received by the population in seven investigated coffee shops are shown in Figure 5.41. WLAN signals are contributed by the largest amount of indoor radiofrequency radiation in the total exposure in coffee shops as discussed before.

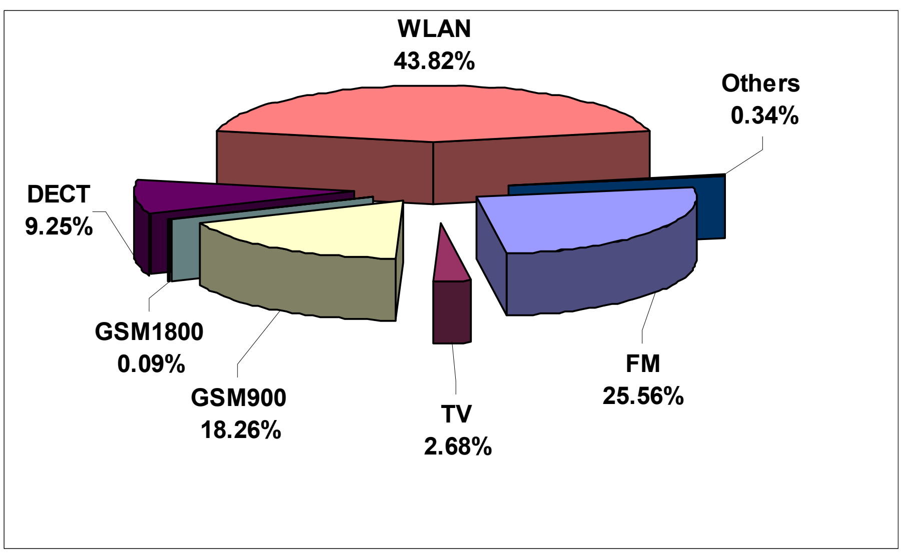

Figure 5.41: Relative contributions to the total indoor RF exposure from various indoor radiofrequency radiation sources evaluated in 7 coffee shops in Hebron city.

Figure 5.42 illustrates the relative contributions of internal and external RF sources in the total indoor RF exposure received by the population at 7 coffee shops in Hebron city. Internal sources are contributed by larger amount to the total indoor RF exposure.

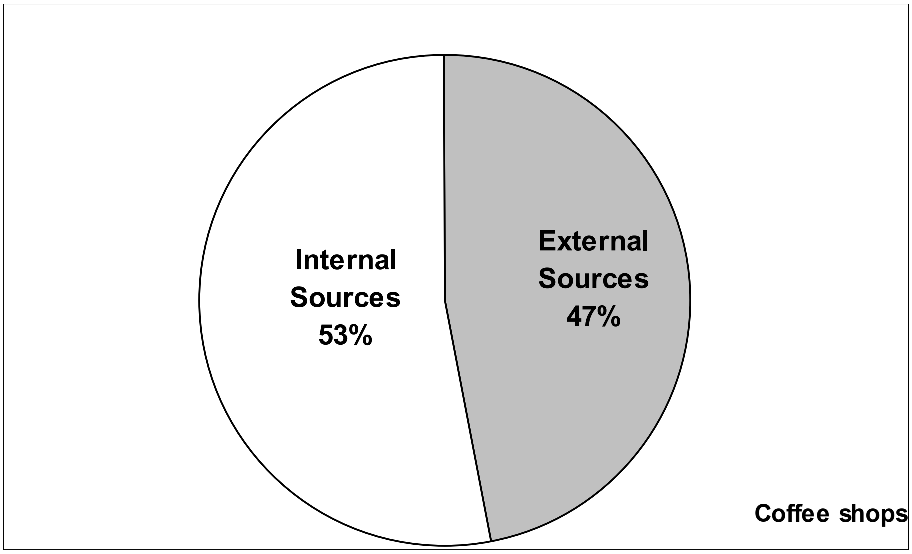

Figure 5.42: Relative contributions to the total indoor RF exposure from internal and external RF sources evaluated in 7 coffee shops in Hebron city.

5.1.7 Indoor RF- Radiation Exposure of the General Public in Hebron City

Indoor RFR levels from all RF sources in 343 different locations in Hebron city are summarized in Table 5.7. Average indoor RF power density levels are evaluated as well as the exposure quotient calculated for each source using equation (6).

The total indoor RFR levels from all RF sources in the frequency range 75 MHz to 3 GHz in 343 investigated locations in Hebron city is found to vary from 0.0015 $\mu W/cm^2$ to 2.28 $\mu W/cm^2$ with an average value of about 0.081 $\mu W/cm^2$.

The highest total indoor RF exposure from all RF sources in any location in the City of Hebron is about 2.28 $\mu W/cm^2$ in a bedroom in Ras Al-Joura in the north of the city. This maximum value is about 87 times below the limit of ICNIRP recommended for the general public. This value is about 1.14% of the maximum ICNIRP permissible level recommended for general public.

Table 5.7: Results of average indoor RF power density levels evaluated in 343 different locations in Hebron city.

	External Sources				Internal Sources			
Location	**FM**	**TV**	**GSM900**	**GSM1800**	**DECT**	**WLAN**	**Others**	**Total**
	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2
Houses	0.026	0.00095	0.011	0.00029	0.046	0.0034	0.001	0.089
Public places	0.017	0.00086	0.073	0.0017	0.058	0.014	0.0053	0.17
Schools	0.0044	0.00067	0.0078	0.00048	0.0011	0.0038	0.0006	0.019
Universities	0.011	0.00076	0.011	0.00014		0.037	0.0028	0.063
Hospitals	0.019	0.00076	0.002	0.0004	0.0011	0.0029	0.016	0.042
Coffee shops	0.021	0.0022	0.015	0.000074	0.0076	0.036	0.00028	0.081
Min	0.00019	0.00056	0.000015	0.00002	0.00005	0.00034	0.00011	0.0015
Max	2.27	0.0508	2.02	0.0997	0.531	0.706	0.615	2.28
Average	**0.016**	**0.001**	**0.02**	**0.00051**	**0.023**	**0.016**	**0.0043**	**0.081**
Exposure Quotient	**0.008**	**0.00025**	**0.0044**	**0.000054**	**0.0025**	**0.0016**	**0.00048**	**0.017**

The average value of indoor RF power density resulted from FM radio broadcasting in all 343 investigated locations is 0.016 μW/cm^2 ,from TV broadcasting is 0.001 μW/cm^2 , from GSM 900 mobile phone base stations is 0.02 μW/cm^2,from GSM 1800 mobile phone base stations is 0.00051 μW/cm^{2,} from DECT is 0.023 μW/cm^2, from WLAN is 0.016 μW/cm^2 and from Others is 0.0043 μW/cm^2 .

A three dimensional 3D plot of all internal and external RF sources from all 343 investigated locations in Hebron city including FM,TV,GSM 900, GSM 1800 ,DECT ,WLAN and others are shown in Figure 5.43. The maximum average indoor power density is from GSM 900 mobile base stations at public places.

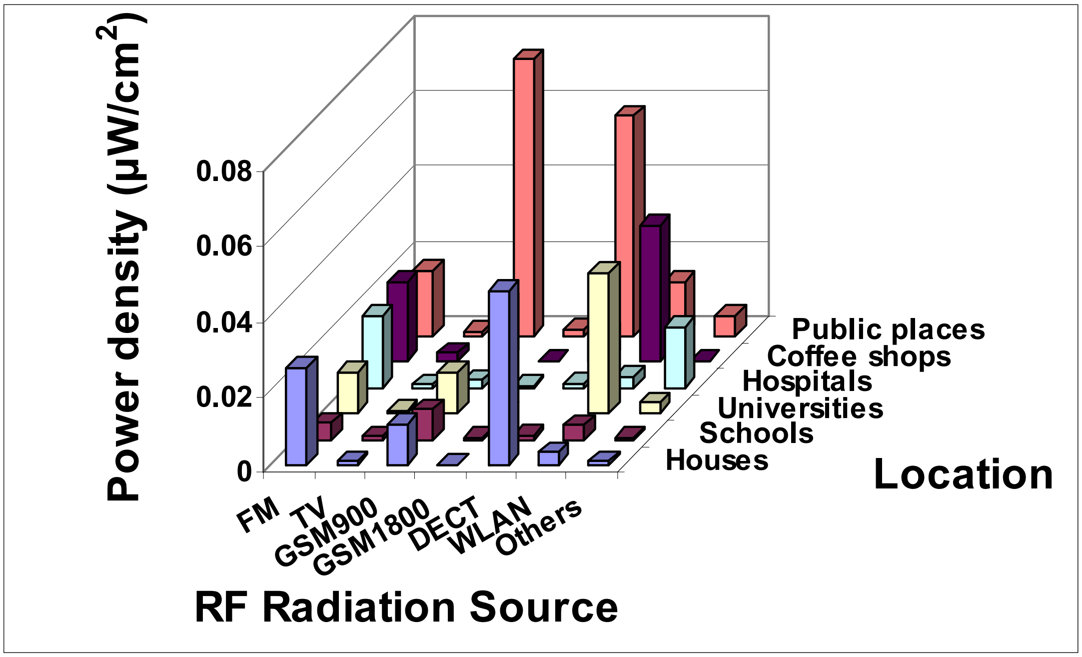

Figure 5.43: Average indoor radiofrequency power density levels form various radiofrequency sources evaluated in 343 different places in Hebron city.

The maximum average indoor RF power density level results from FM radio transmitters as indicated in Figure 5.44 .It can be seen that, the maximum average indoor RF power density from FM Radio signals is found in houses. Further more Figure 5.45 shows that, the maximum average indoor RF power density from TV broadcasting is found in coffee shops.

The maximum average indoor RF power density resulted from GSM 900 and GSM 1800 mobile base stations are found in public places as shown in Figure 5.46 and Figure 5.47 respectively. This result probably because of the overcrowded in public places as discussed before.

The maximum average indoor RF power density results from DECT are displayed in Figure 5.48. It can be seen that, DECT signals has a maximum average indoor RF in public places and relatively high in houses. This result is maybe due to the existence of DECT in many public places and houses in Hebron city while universities for example don't use DECT phones.

Figure 5.49 shows that, the maximum average indoor RF power density from WLAN access points are found at universities and coffee shops. This result is probably because of the extensive use of WLAN in universities and coffee shops.

Figure 5.50 shows that, the maximum average indoor RF power density from others is found in hospitals.

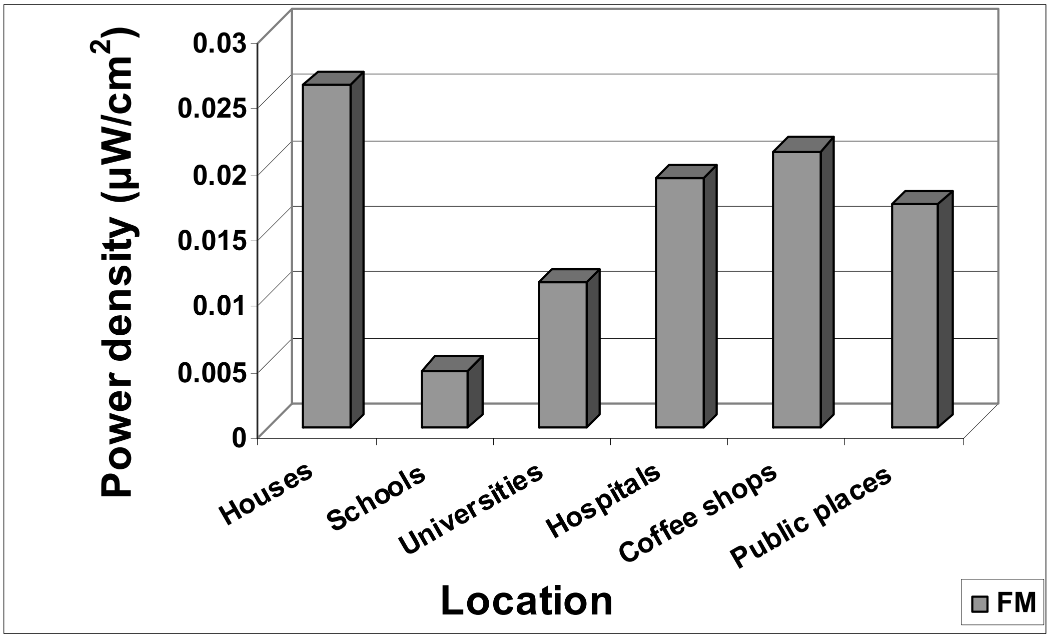

Figure 5.44: Average indoor radiofrequency power density levels form FM radio transmitters evaluated in 343 different locations in Hebron city.

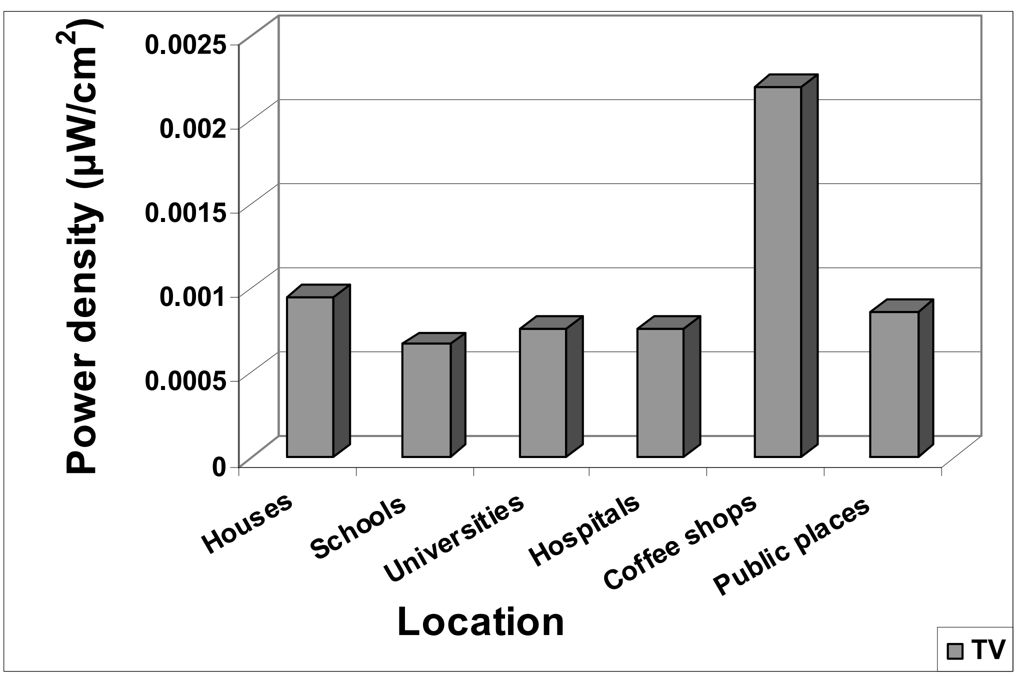

Figure 5.45: Average indoor radiofrequency power density levels form TV broadcasting towers evaluated in 343 different locations in Hebron city.

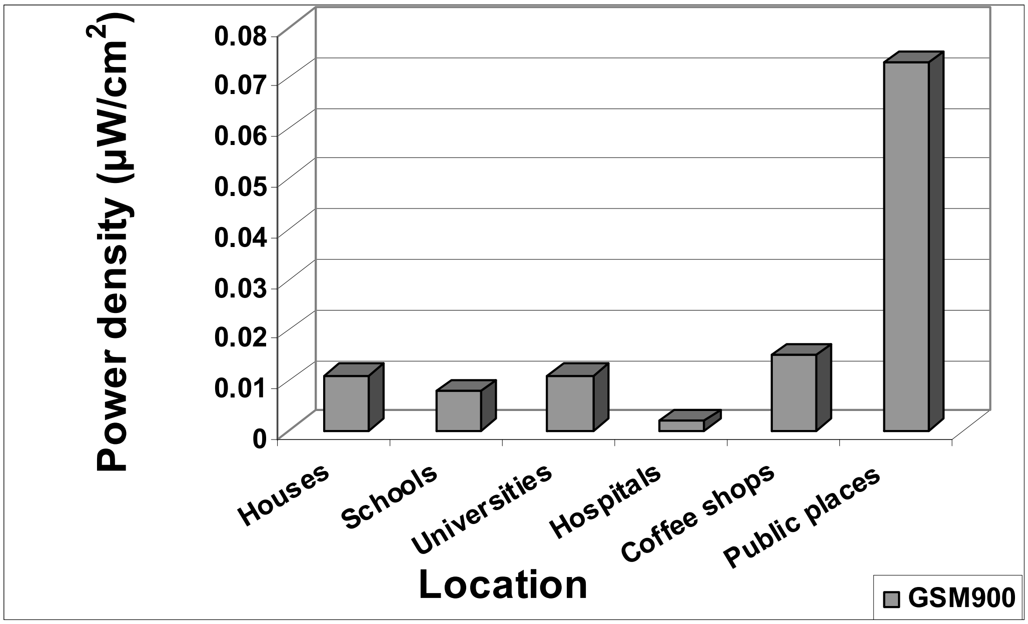

Figure 5.46: Average indoor radiofrequency power density levels form GSM 900 mobile base stations evaluated in 343 different locations in Hebron city.

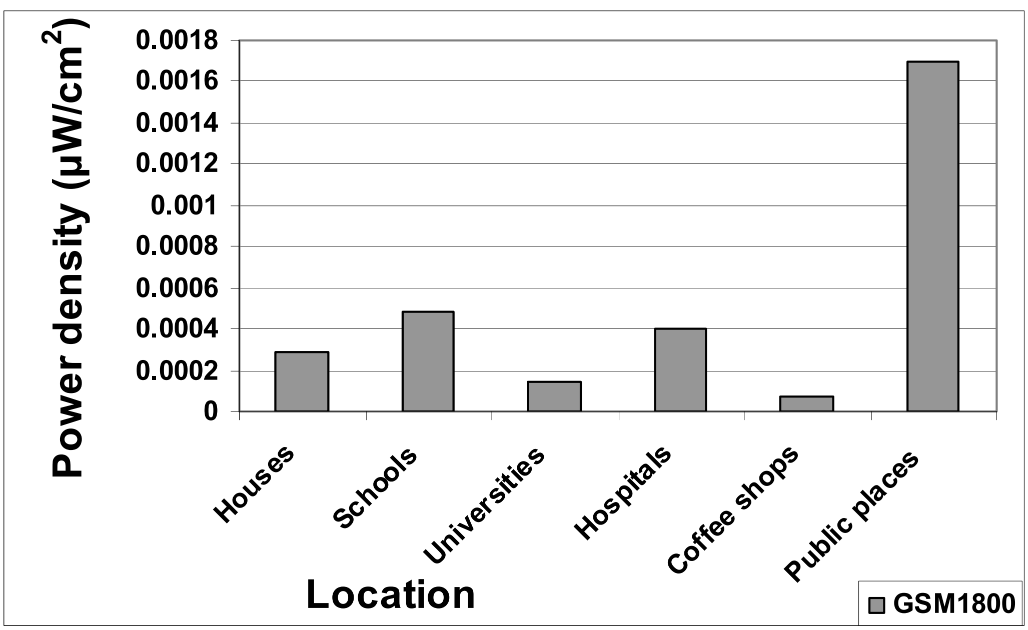

Figure 5.47: Average indoor radiofrequency power density levels form GSM 1800 mobile base stations evaluated in 343 different locations in Hebron city.

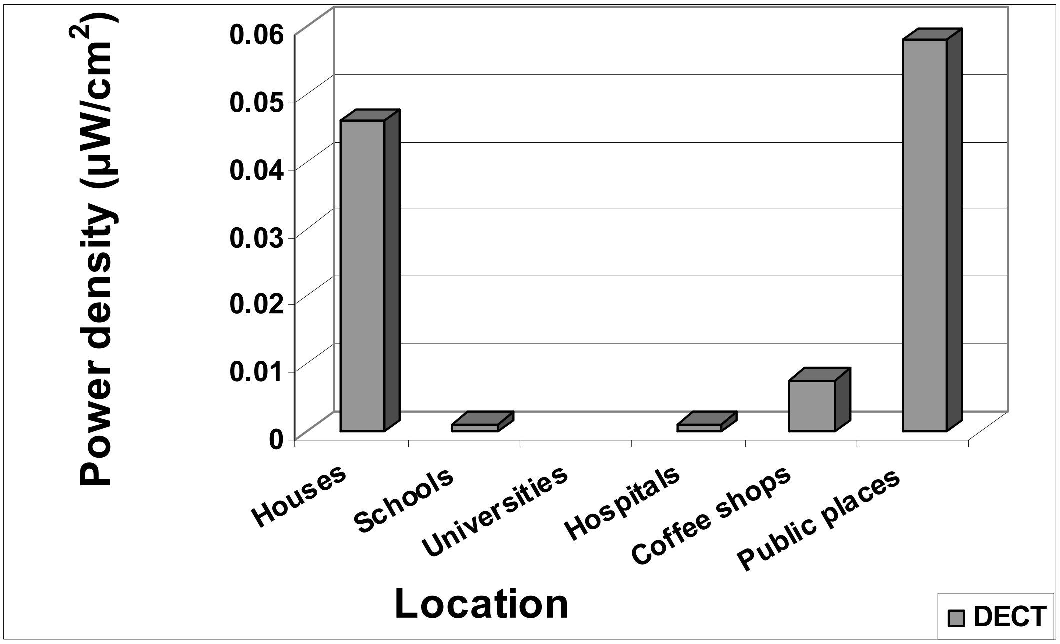

Figure 5.48: Average indoor radiofrequency power density levels form DECT evaluated in 343 different locations in Hebron city.

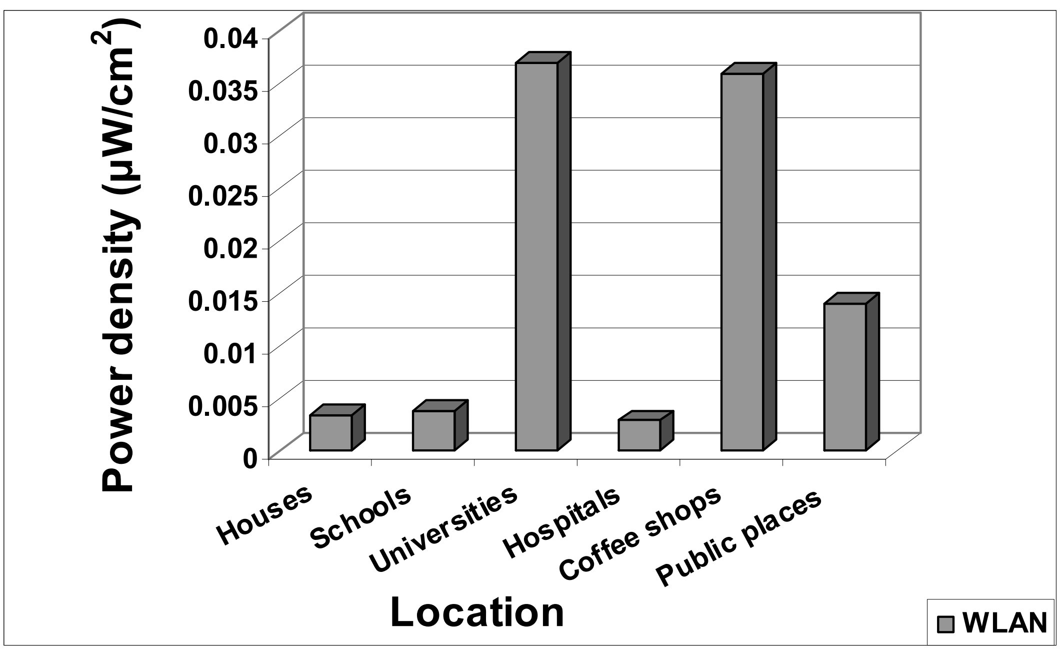

Figure 5.49: Average indoor radiofrequency power density levels form WLAN evaluated in 343 different locations in Hebron city.

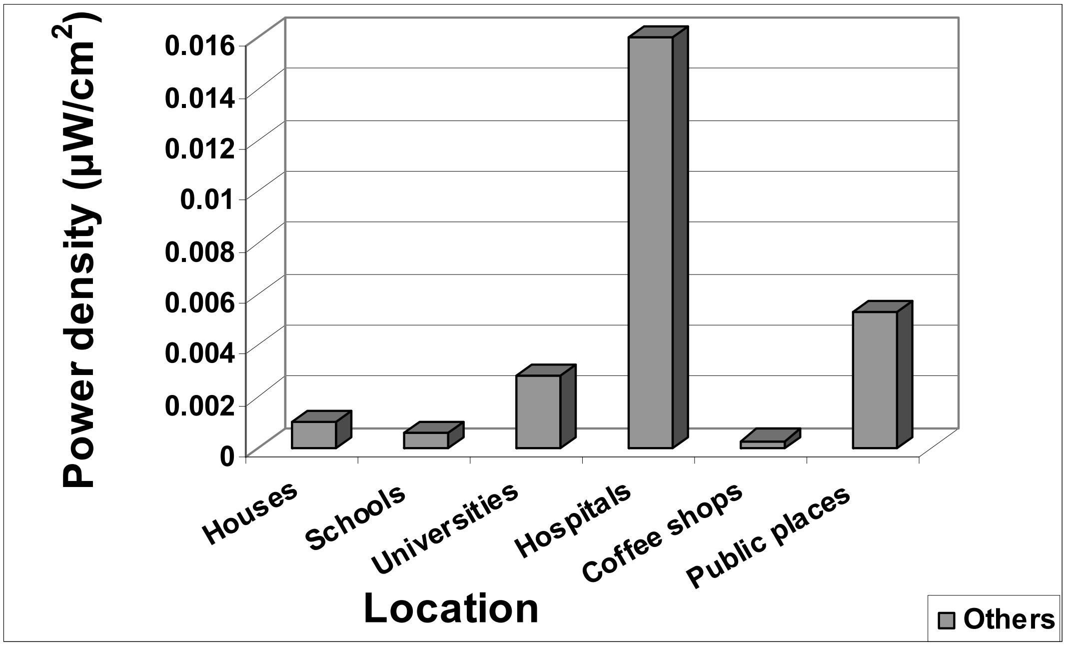

Figure 5.50: Average indoor radiofrequency power density levels form others evaluated in 343 different locations in Hebron city.

Contributions from all relevant indoor radiofrequency sources to the total indoor RF exposure are evaluated in the City of Hebron and found to be 19.80% from FM radio ,1.24% form TV broadcasting ,24.75% from GSM 900 ,0.63% from GSM 1800, 28.46% from DECT ,19.80% from WLAN and 5.32% from others .This indicates that the main source of indoor RF exposure in Hebron environment is DECT and GSM 900 mobile base stations are the second main source as Figure 5.51 illustrates .However , a more meaningful comparison is obtained when the signals have been weighted for frequency (see explanation at page 36) .When this is done the contributions from all relevant indoor radiofrequency sources to the total exposure quotient are 46.29% from FM radio signals, 1.45% from TV, 25.46% from GSM 900 , 0.31% from GSM 1800 , 14.46% from DECT ,9.26% from WLAN and 2.78% from others as shown in Figure 5.52 .This means that, FM radio transmitters are the dominant source in Hebron city when RF signals weighted to their frequencies(Line, Cornelius, Bangay , and Grollo,2000).

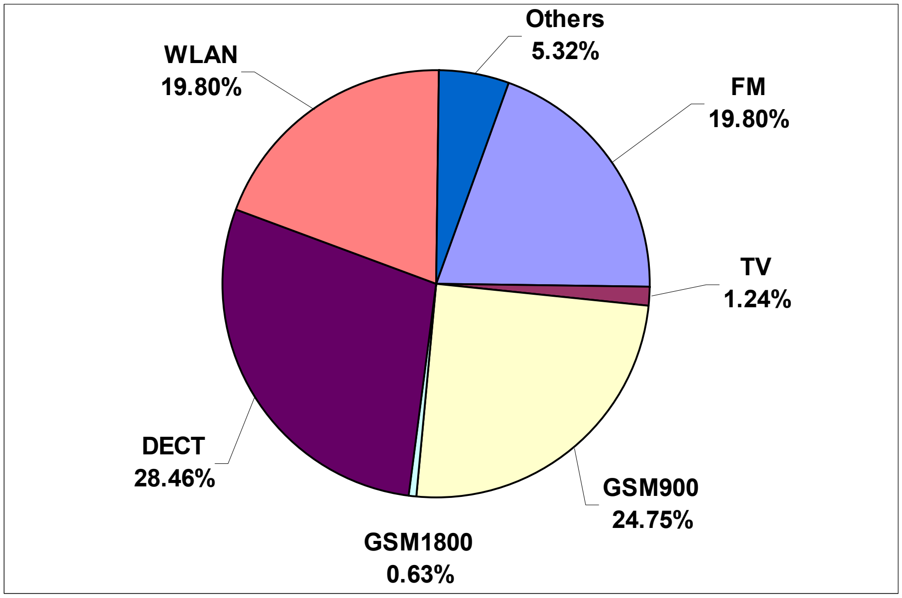

Figure 5.51: Relative contributions to the total indoor RF exposure from various indoor radiofrequency radiation sources evaluated in 343 different locations in Hebron city.

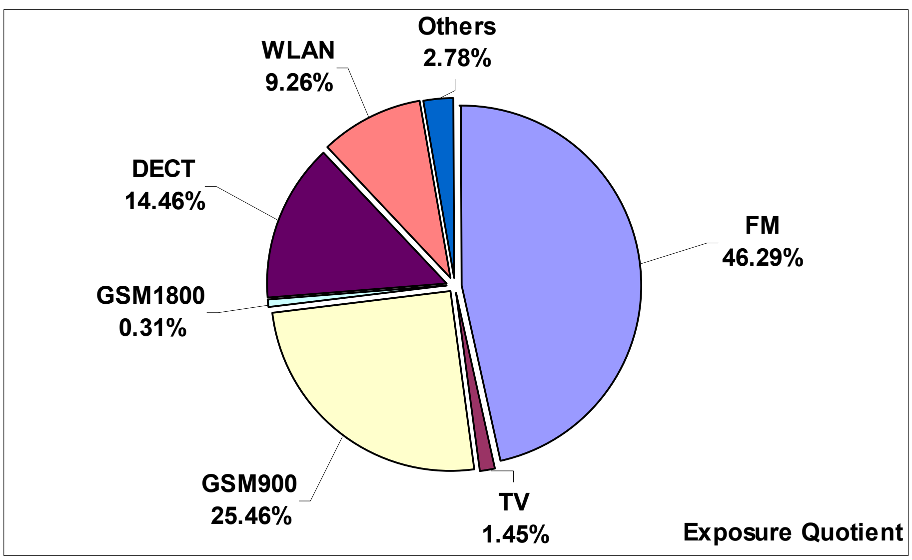

Figure 5.52: Relative contributions of exposure quotient to the total indoor RF exposure from various indoor radiofrequency radiation sources evaluated in 343 locations in Hebron city. (Signals have been weighted for frequency).

The average contributions to the total indoor RF exposure from various site type evaluated in 343 different places in Hebron city are as follows: public places are exposed by 36.64% of the total indoor RF exposure, houses by 19.18%, coffee shops by 17.46%, universities by 13.58%, hospitals by 9.05% and schools by 4.09% to the total indoor RF exposure (Figure 5.53). Public places are exposed by the large amount while schools are the lowest.

Figure 5.54 shows a comparison between internal and external RF sources in different categories of sites. External RF sources in public places are the highest among all sites .Moreover, internal RF sources in public places are high.

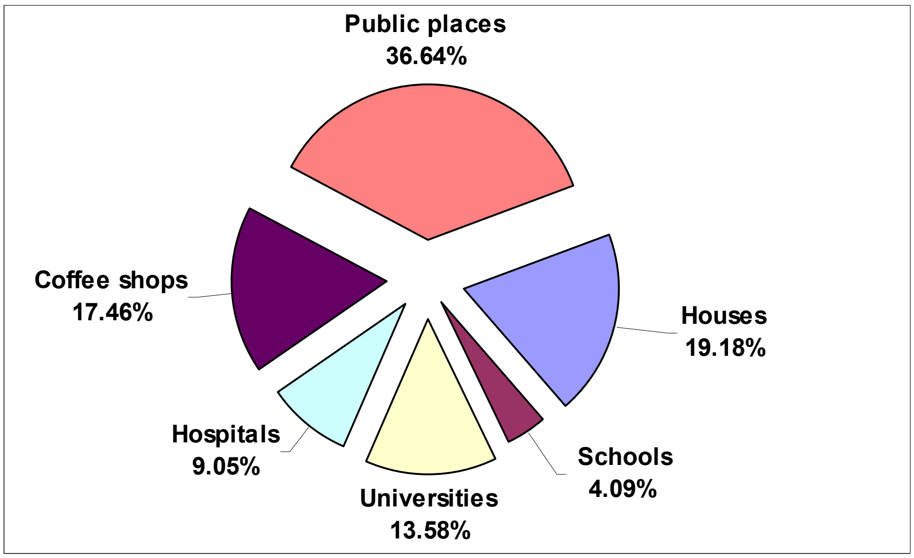

Figure 5.53: Relative contributions to the total indoor RF exposure from various categories of sites in Hebron city.

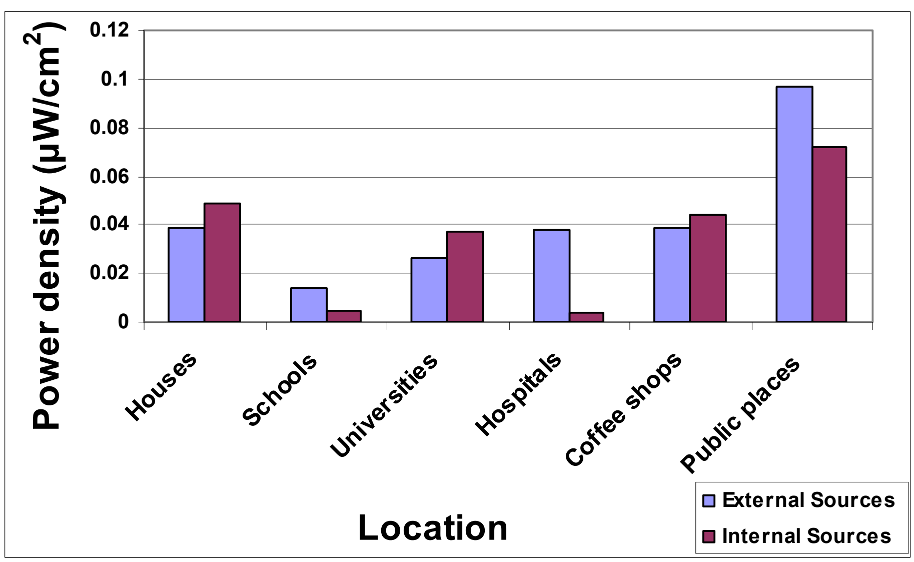

Figure 5.54: Average indoor radiofrequency power density levels form external and internal RF sources evaluated in 343 different locations in Hebron city.

As seen in Figure 5.55 internal sources contribute by larger amount to the total indoor RF exposure.

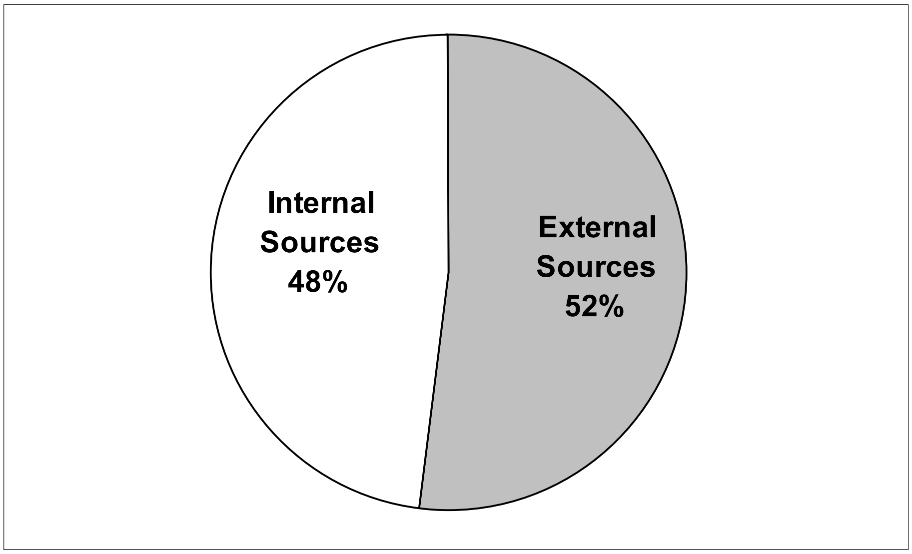

Figure 5.55: Relative contributions to the total indoor RF exposure from external and internal RF sources evaluated in 343 locations in Hebron city.

The frequency distribution of average indoor RF radiation level from all RF sources is plotted in Figure (5.56) .It can be noticed that the frequency distribution is a skewed distribution. It looks like log-normal. About 73% of the investigated locations have average indoor RF exposure less than 0.04 $\mu W/cm^2$ **,** these locations might have the same field strength, in which case the power density is skewed up .While, 0.3% of the locations have average indoor RF exposure greater than 1 $\mu W/cm^2$. This means that, indoor RF exposure levels in most investigated sites are low. In general all indoor RF power density measured in this study is far below the ICNIRP recommended limit for general public.

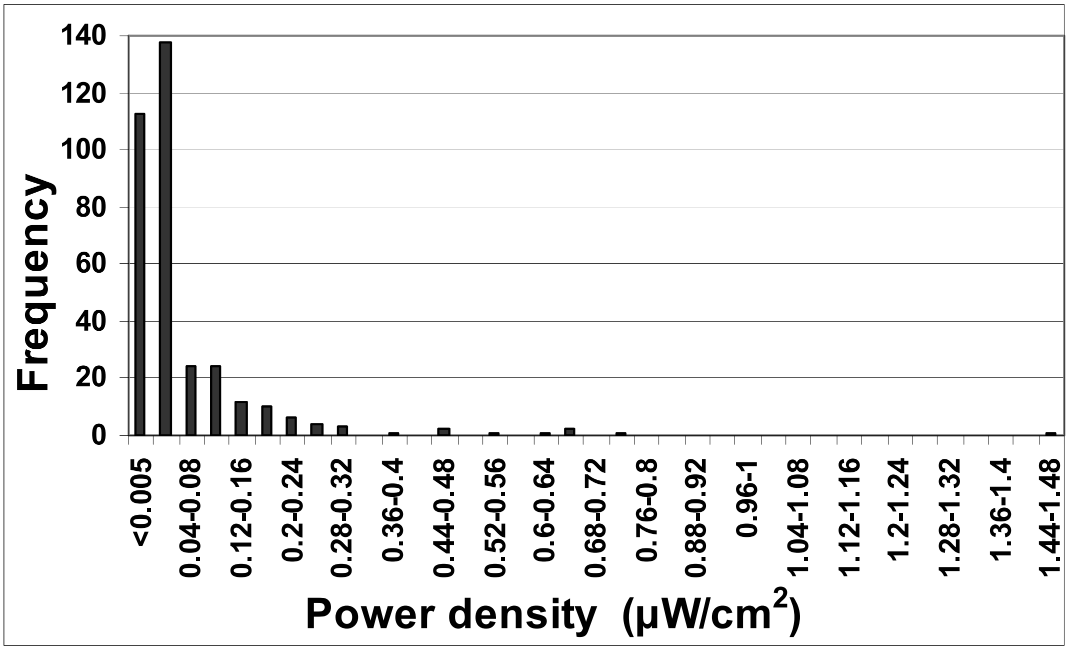

Figure: 5.56: Frequency distribution of indoor radiofrequency radiation levels in Hebron city.

5.2 Radiofrequency Radiation Emissions from Microwave Ovens in Hebron

This is the first survey for measuring the leakage from microwave ovens in Palestine. The survey is conducted in Hebron city for measuring the leakage from 117 microwave ovens with test load at 1 meter in real life conditions, by using the NARDA SRM 3000.Measurements are performed where the exposure is expected to be the maximum at the height of center of the door screen (Thansandote, Lecuyer and Gajda, 2000).

Most of microwave ovens operate at 2450 MHz; the surveyed ovens are different types, models and ages. They are between 1 month and more than 20 years old. Distribution of microwave oven age in years with number of ovens is shown in Figure 5.57 .It can be seen that, most of the ovens are 4-5 years age, while, there are 16 unknown ovens ages because some people buy (old used ovens).

Figure 5.58 represents the daily use of ovens with number of ovens. The daily use of ovens in Hebron is investigated and it is found that, 58% of the surveyed ovens are used for less than 15 minutes. The approximate daily use of microwave ovens in Hebron is very

short .This means that, microwave oven signals are not a continuous RF source in our environment like FM radio, TV broadcasting and mobile base stations.
A spectrum of RF from a microwave oven is studied as Figure 5.59 shows. It is noticeable that, microwave oven signals are the highest in indoor environment among all RF sources in the frequency range 75 MHz to 3 GHz. The leakage from that oven was about 4.185 $\mu W/cm^2$ at 1 meter distance.

Leakage from 117 microwave ovens ranged from 0.428 $\mu W/cm^2$ to 16.4 $\mu W/cm^2$. The average leakage is found to be about 3.64 $\mu W/cm^2$. This value is 3 times less than the specified limit at 1 meter (10 $\mu W/cm^2$) (WHO, 1993).

Based on the survey results, the leakage from all the microwave ovens are below the limit except for 7 ovens. All seven   ovens are more than 15 years old, except for 2 ovens which are about 7 years old.
The highest leakage is about 16.4 $\mu W/cm^2$ for 15 years old oven. This value is 1.64 times greater than the limit specified at 1 meter (10 $\mu W/cm^2$).

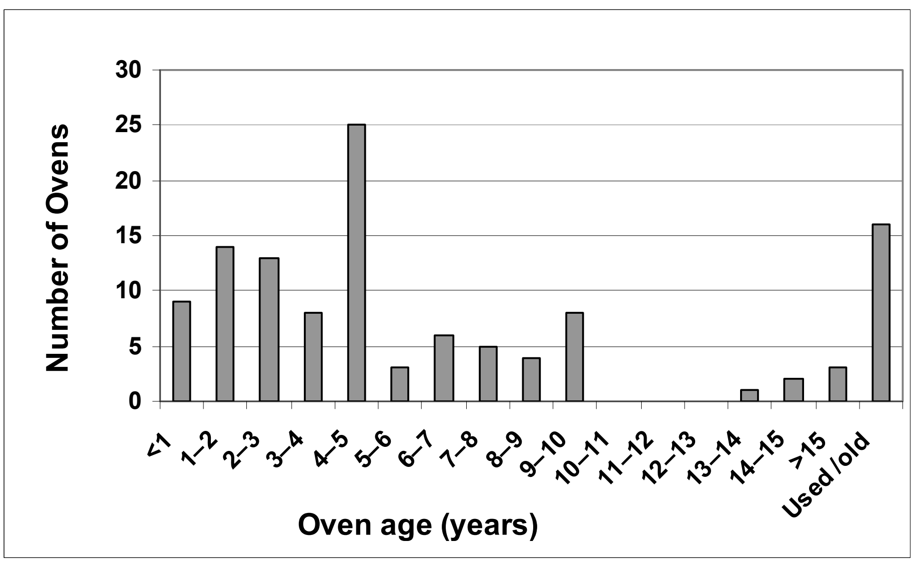

Figure 5.57: Distribution of microwave oven age in years with number of ovens for 117 microwave ovens.

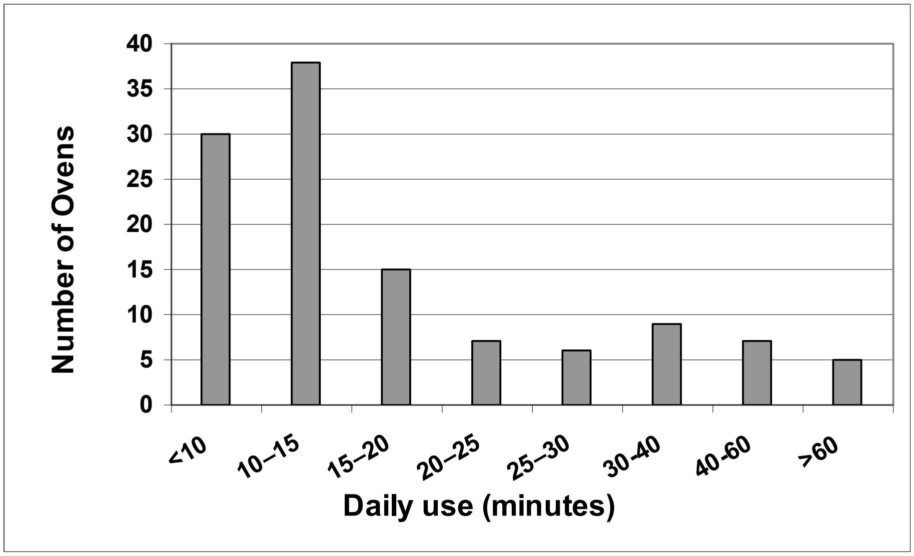

Figure 5.58: Distribution of daily use in minutes with number of microwave ovens for 117 microwave ovens.

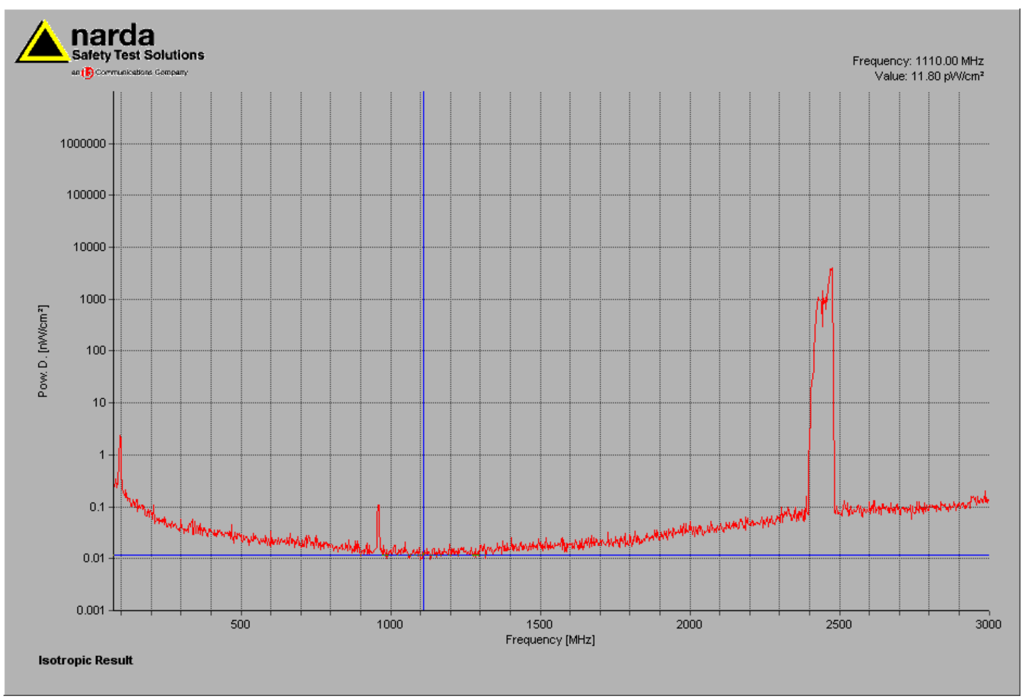

Figure 5.59: Microwave oven spectrum detected at 1 meter from the oven in a kitchen in Hebron city.

The frequency distribution of measured leakage from investigated microwave ovens is plotted in Figure 5.60 .It is noticeable, that the frequency distribution is a skewed distribution (long tail in one direction). The survey results show that, 58% of the ovens are leaking less than 3 μW/cm^2. While, about 6 % of the ovens are leaking more than (10 μW/cm^2) at 1 meter distance. This percentage is relatively high.

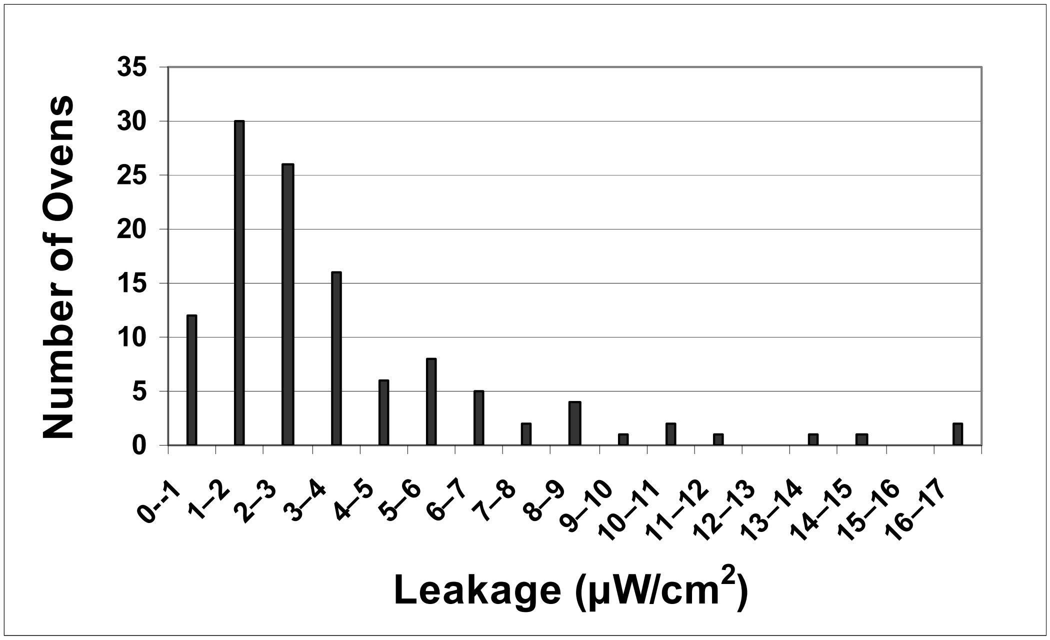

Figure 5.60: Frequency of measured leakage at 1 m from 117 microwave ovens.

Figure 5.62 shows the same data as in Figure 5.61, except that the 16 old (used ovens) have been excluded so as to show more clearly the correlation of microwave oven leakage with age .As illustrated in Figure 5.62 , positive linear correlation (r = 0.49) between microwave oven age and the measured leakage. Correlation with age does not mean an age effect only; it could be also noticeable that other parameters such as type, length of use, power and manufacturer are not the same for all microwave ovens .This result is inconsistence with (Alhekail, 2001).

The power density from microwave oven as a function of distance is shown in Figure 5.63. This Figure shows that, the measured power density, decreases with distance from the microwave oven as expected following the inverse square law.

Based on the survey results that the daily use of the microwave ovens is very short and the decrease of RF power density with increasing distance from the oven .Therefore, in general the exposure to microwave oven during cooking is very low except some old ovens.

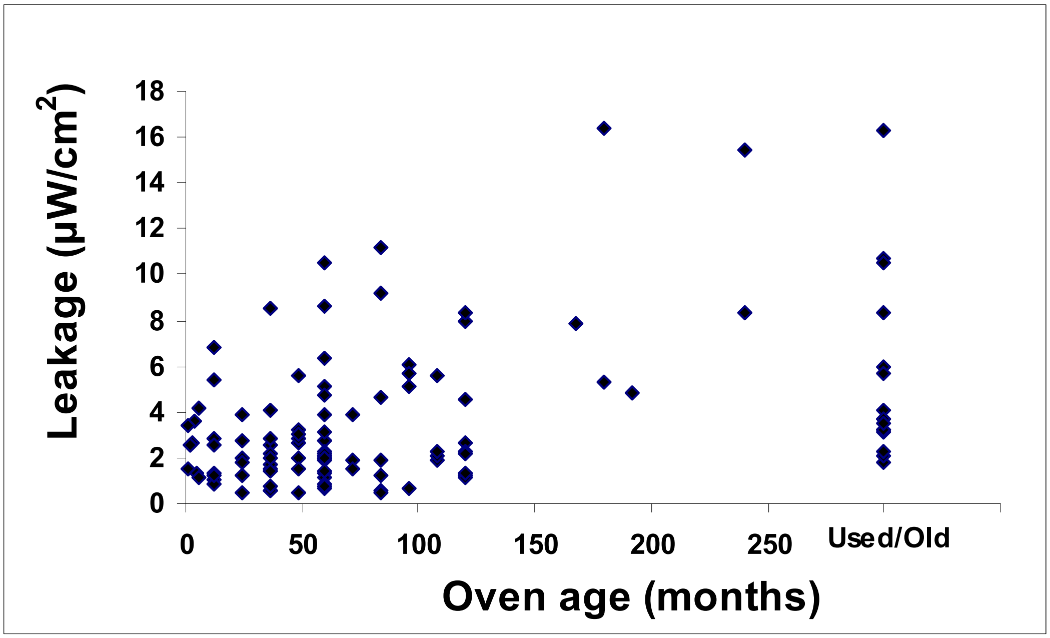

Figure 5.61: Measured microwave oven leakage from 117 microwave ovens versus oven age in months (measurements are performed at 1 m from the oven).

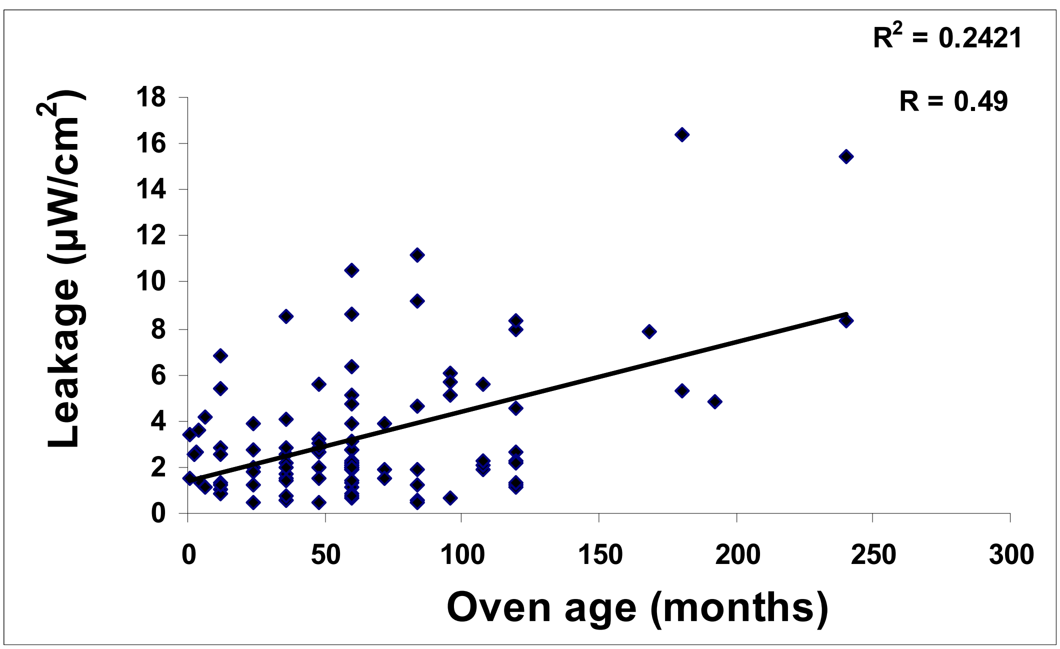

Figure 5.62: Linear correlation between microwave oven age and leakage for 101 microwave ovens.

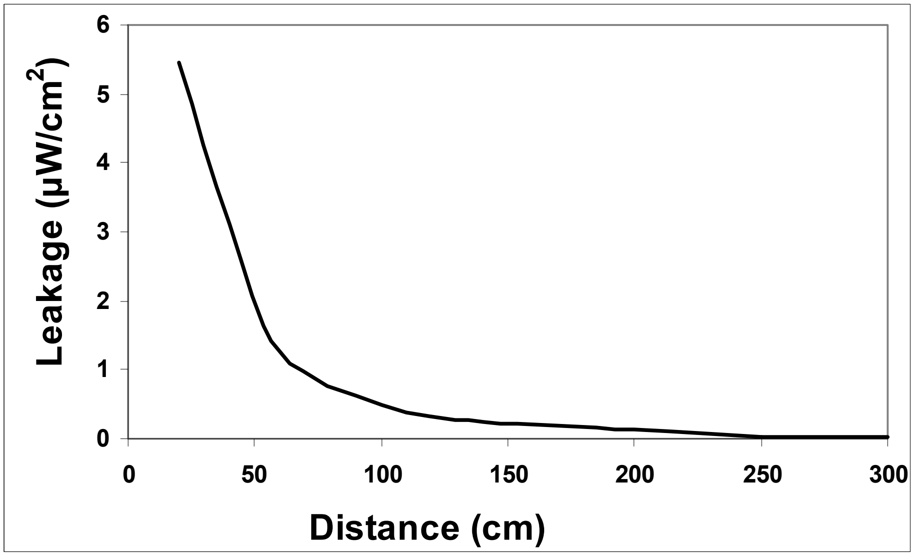

Figure 5.63: Measured RF radiation power density versus distance for microwave oven (during test load).

5.3 Indoor Versus Outdoor RF Radiation Levels

Measurements are performed in 30 selected houses, both indoor and outdoor, in far field conditions. Outdoor measurements are performed at 1.5 m above ground level on balconies and roofs. Indoor measurements are performed in sitting rooms, kitchens and bedrooms.

Figure 5.64 illustrates outdoor and indoor spectrums in a house which shows that the highest peaks measured outdoor are from FM, TV, GSM 900, GSM 1800 and radar transmitters. While, the highest peaks indoor are from DECT and WLAN signals.

It is obvious that the peaks from (FM, TV, GSM 900, GSM 1800 and radar) are less indoor than outdoor because propagation of electromagnetic waves is influenced by attenuation, scattering and absorption through concrete walls, windows, trees and vegetation.

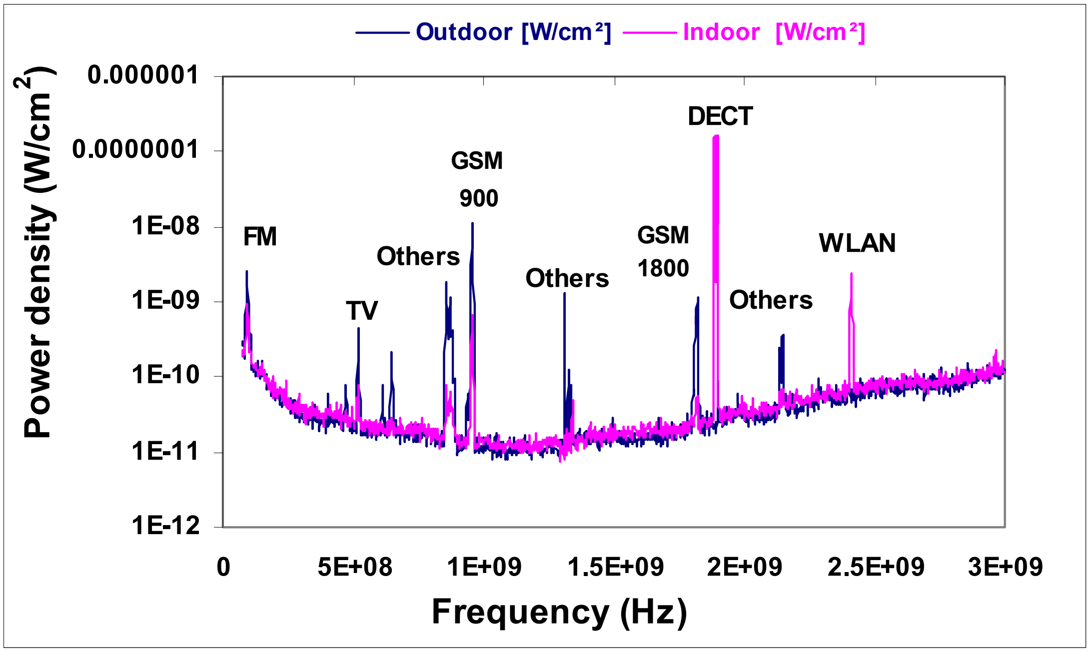

Figure 5.64: Indoor and Outdoor RF spectra, in the frequency range 75 MHz to 3 GHz detected in a house outdoor (balcony) and indoor (sitting room) in Hebron city.

Table 5.8 lists the results of average indoor RF radiation power density levels over six minutes for the different sources in the 30 selected houses in kitchens, bedrooms and sitting rooms and outdoor RF radiation power density levels on balconies and roofs .

Figure 5.65 illustrates average power density levels measured indoor and outdoor (balconies and roofs) in 30 selected houses in the city .This figure shows that FM Radio signals are the dominant on roofs and balconies ,while, DECT is the dominant indoor. Lower indoor RF levels than outdoor are observed for external RF sources such as FM Radio, TV transmitters and mobile phone base stations. Exposures indoor would normally be much lower than outdoor from external sources (Miclaus and Bechet, 2007).

Table 5.8: Results of average RF power density levels evaluated indoor and outdoor (balconies and roofs) in 30 selected houses in Hebron city.

	External Sources				**Internal Sources**			
Location	**FM**	**TV**	**GSM900**	**GSM1800**	**DECT**	**WLAN**	**Others**	**Total**
	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2	μW/cm^2
Indoor	0.049	0.002	0.02	0.00023	0.058	0.0075	0.0013	0.14
Balconies	0.2	0.0026	0.15	0.0056	0.00074	0.00054	0.011	0.38
Roofs	0.527	0.004	0.17	0.0088		0.00048	0.007	0.71
Average	**0.26**	**0.0029**	**0.11**	**0.0049**	**0.029**	**0.0028**	**0.0064**	**0.42**

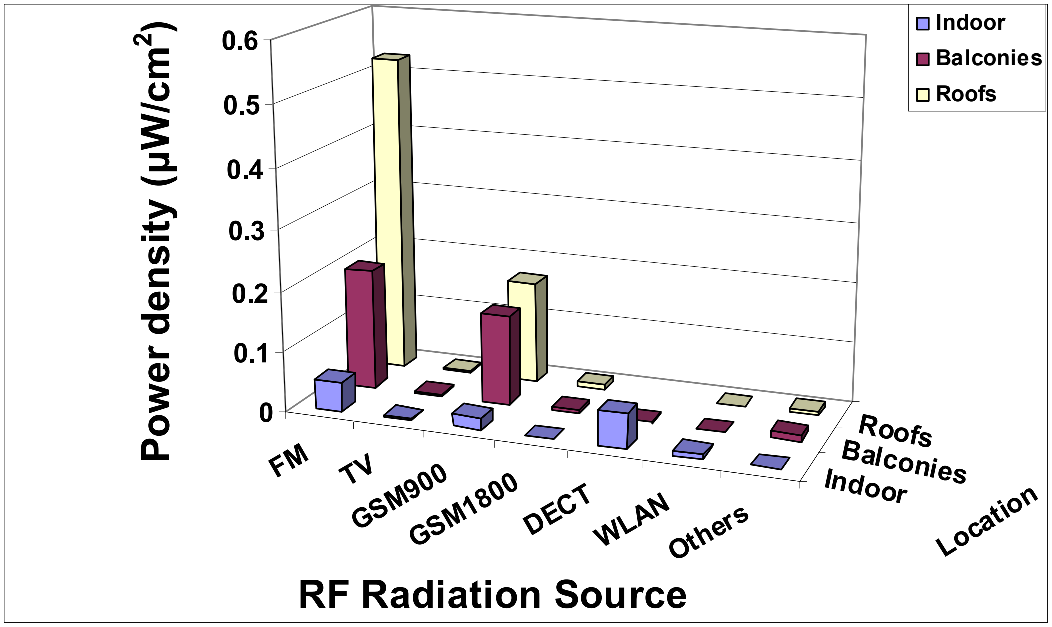

Figure 5.65: Average radiofrequency power density levels outdoor and indoor form various RF sources evaluated in 30 selected houses in Hebron city.

Figure 5.66 represents the relative contributions of RF exposure indoor and outdoor at balconies and roofs in the total RF exposure received by the population at the 30 selected houses. The average contributions to the total RF exposure from roofs 57.72 %, balconies 30.89%, and indoor 11.38% to the total RF exposure. Roofs RF exposure contributes by largest amount to the total exposure. While indoor RF exposure is the lowest.

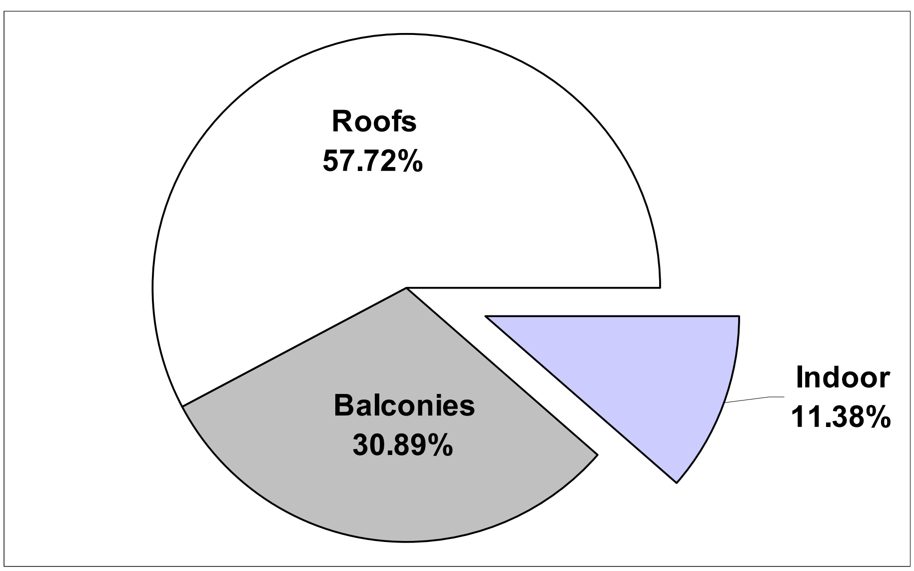

Figure 5.66: Relative contributions to the total RF exposure from various locations evaluated in 30 selected houses in Hebron city.

5.4 Variation of Indoor FM Radio Signals in Different Floors

Measurements are performed at classrooms in different floors at King Khalid School .The school is about 1 km from FM Radio Alem transmitter at Hebron University.

Measured indoor RF levels from FM radio signals in different floors in King Khalid School is shown in Figure 5.67. It is noticeable that, FM radio signals increase on the upper floors of the school than lower ones. This result is consistent with (Anglesio et al., 2001) where they found that, an increase in FM radio signals levels on the upper floors of buildings. This result can be discussed as the following, lack of external obstruction outside the upper floors of the buildings, cause less attenuation, scattering and reflections on the upper floors, and moreover, the line of sight with FM radio transmitter is clearer in upper floors than lower ones because the shielding and vegetation is less on upper floors.

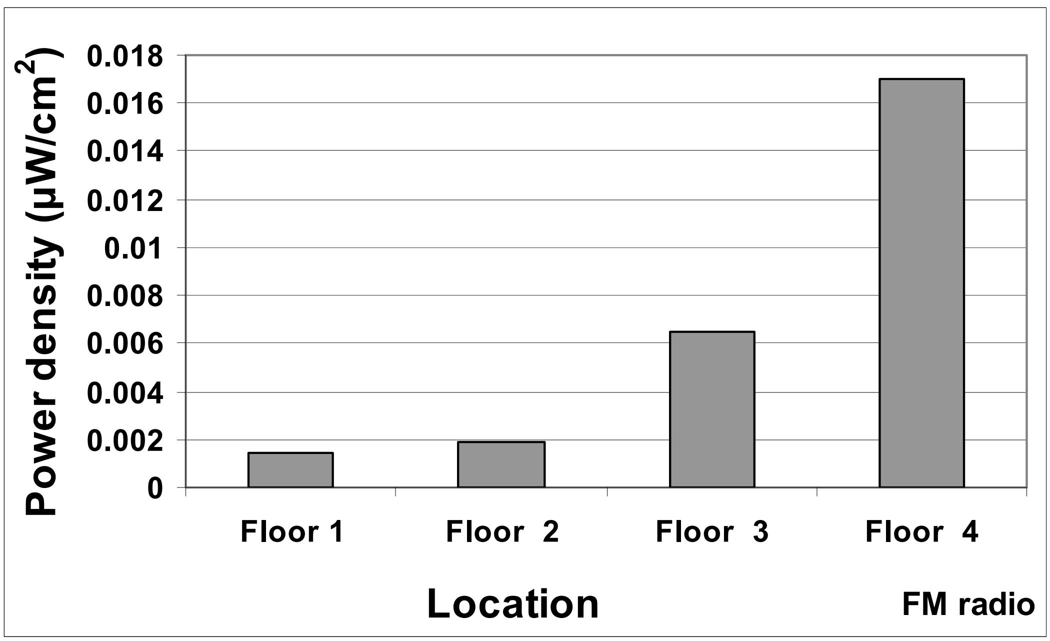

Figure 5.67: Measured indoor RF levels from FM radio signals in different floors in King Khalid School in the northern part of Hebron City.

5.5 Electric Field over Distance from WLAN and DECT

For wireless LAN access point, electric field in the antenna main beam is measured using the SRM-3000 radiation meter with isotropic antenna, in far field region from 20 cm to increasingly farther distances.

The electric field intensity from WLAN access point as a function of distance is shown in Figure 5.68 .It can be seen that, electric field intensity decreases rapidly with increasing distance from the WLAN access point.

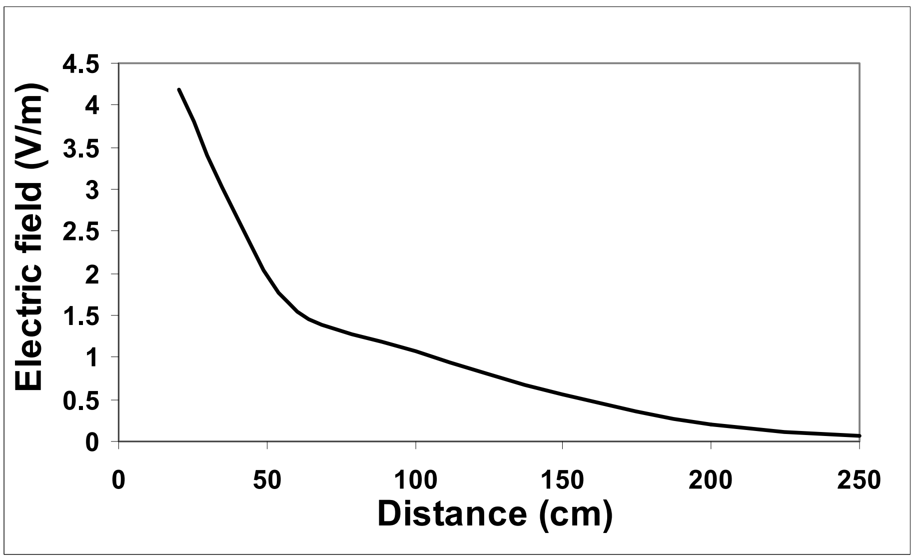

Figure 5.68: Electric field from WLAN access point over distance in the antenna main beam.

For DECT base station measurements of electric field over distance in the maim beam are performed to a distance larger than 20 cm in far field region. During the measurements the base station is in idle mode.

The electric field intensity from DECT base station as a function of distance is shown in Figure 5.69. The Figure shows that, electric field intensity decreases rapidly with increasing distance from the DECT base station.

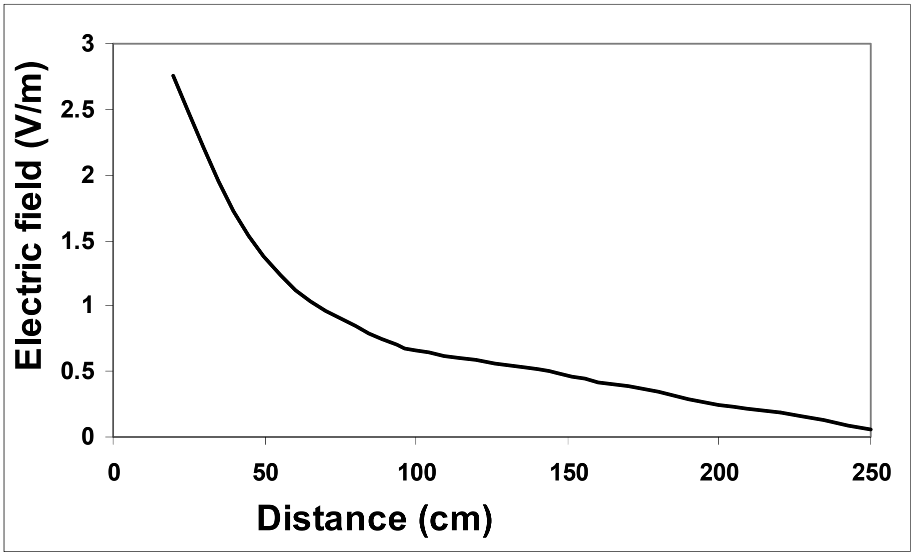

Figure 5.69: Electric field from DECT base station over distance in the antenna main beam.

Chapter VI

Conclusions and Recommendations

6.1 Conclusions

The strength of this first study in Palestine is the large number of measurements and measured locations distributed all over Hebron City.
The assessment of indoor RF exposure is only possible by actual measurements, since emission and propagation of indoor RF radiation are influenced by many technical and environmental factors.

The total indoor RF exposures from all RF sources in the frequency range 75 MHz to 3 GHz (except microwave ovens) are studied in the City of Hebron. Exposures are found to be highly variable from one location to another depending on devices used in the building and the characteristics and distribution of RF sources. The variations are also high from one place to another in the same building depending on many factors such as attenuation through concrete walls, glass windows, wooden doors and existence of different RF devices. The lowest indoor RF exposure from all RF sources are found in some locations far away from any local FM, TV transmitters and mobile base stations, and no use of WLAN and DECT applications there.

The total indoor RF radiation levels from all RF sources in the frequency range 75 MHz to 3 GHz in 343 investigated locations in Hebron city are found to vary from 0.0015 $\mu W/cm^2$ to 2.28 $\mu W/cm^2$ with an average value of about 0.081 $\mu W/cm^2$.

Contributions from all relevant indoor RF sources to the total exposure are evaluated at 343 different sites and found to be 19.80% from FM radio, 1.24% from TV broadcasting, 24.75% from GSM 900, 0.63% from GSM 1800, 28.46% from DECT, 19.80% from WLAN and 5.32% from others. This indicates that the main source of indoor RF exposure in Hebron environment is DECT. DECT signal is considered as the main source of indoor RF exposure especially at houses and offices, while GSM 900 mobile base station (which is the main source of public concern) are the second main source as evaluated in this study. Moreover, measured RF levels are far below limits recommended by ICNIRP for general public from previous RF sources.

The average contributions to the total indoor RF exposure from various site type evaluated in 343 different places in Hebron city are as follows: public places are exposed by 36.64% of the total indoor RF exposure, houses by 19.18%, coffee shops by 17.46%, universities by 13.58%, hospitals by 9.05% and schools by 4.09% to the total indoor RF exposure. Public places are exposed by the large amount while schools are the lowest.

Outdoor RF exposures on roofs and balconies are found to be higher than indoor RF exposures in sitting rooms, kitchens and bedrooms at 30 selected houses in Hebron city. Moreover, indoor FM radio signals in upper floors are higher than lower ones.

This study also investigates the leakage from 117 microwave ovens at 1 meter in real life conditions and found that, the average leakage is found to be about 3.64 $\mu W/cm^2$.Also the leakage from all the microwave ovens are below the limit specified at 1 meter (10 $\mu W/cm^2$) (WHO, 1993), except 7 old ovens . A positive linear correlation between microwave oven age and measured leakage is found.

6.2 Recommendations

Recommendations can be summarized as follows:

- General survey for microwave ovens leakage should be conducted in the West Bank.
- Further study in other cities in Palestine is important to evaluate indoor RF exposure all over the country.
- Further research to identify any health risks of the low indoor RF exposure is recommended.
- Long term studies about indoor RF exposure from various sources, taking in to account the duration of the exposure is recommended.
- Reducing indoor RF exposure at houses by putting DECT base stations and WLAN access points in houses in corridors instead of sitting rooms and bedrooms.
- Increased awareness of general public and inform people about the source-exposure and possible health effects from being exposed to this type of radiofrequency radiation.
- Microwave ovens must be checked every 3 years at least. People are recommended to buy only new microwave ovens.

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