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Al- Quds University

Personal Radio Frequency Exposure in the West Bank-Palestine

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Dedication

I dedicate this work to my family and friends, who has been a constant source of support and encouragement during the challenges during study period.

I dedicate this work to my mother, who always unconditionally supported me.

I dedicate this work to my supervisor, who believed in my abilities in times when I did not believe in them.

Declaration

I Certify that this thesis submitted for the degree of Master of Science is the result of my own research, except where otherwise acknowledged, and that this thesis (or any part of the same) has not been submitted for a higher degree to any other university or institution.

Signed: 

Haitham Mahmoud Ali Ayyad

Date: 10 / 5 / 2017

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I would like to thank my supervisor Dr. Adnan Lahham, for his invaluable and unlimited support during my research and writing. He allowed it to be my own work and at the same time keen to provide me with the support and guidance whenever I needed it. Also, I would like to thank everyone volunteered in this research.

Abstract

This study represents the results of personal radio frequency exposure assessment for general population in the West Bank-Palestine. Personal radio frequency measurements have been conducted using a personal exposure meter (PEM) for twenty four students from Al-Quds University. Every one of them participated in the measurement process for 24 hours period during the exercise of their daily life in the West Bank. Using measurements recorded by the personal exposure meter, time-averaged electric field strength for 14 predetermined frequency bands between 80-6000 MHz was calculated using the data recorded during the measurement period. Also, exposure levels and time series for 14 frequency bands were investigated in order to determine personal exposure patterns for each frequency band. All measurements were conducted using EME Spy 140 personal exposure meter. The PEM was carried by every volunteer at waist height. The Mean value of time-averaged total exposure for 24 hours is 0.45 V/m and range between 0.19 V/m and 0.92 V/m. It was found that Wi-Fi 2G (2.4 GHz) frequency band contributed the most to the total personal RF exposure followed by GSM 900 (Uplink) frequency band with mean RF exposure 0.32 V/m and 0.21 V/m, respectively. Also, the maximum total personal exposure measurement recorded at any time by all volunteers was found to be 7.1 V/m. Various conditions and factors have been investigated including common locations between volunteers and the usage of personal radio frequency emitting devices such as mobile phones and laptops. Also, personal RF exposure is calculated using Robust ROS statistical method in order to estimate data below detection limit. The results between normal results and ROS method are disparate in the radio frequencies that contain more than 95% of data below detection limit. Through the practice of daily life, personal RF exposure reached highest values during travel especially when volunteers used public transportation, and lowest during sleep. The number of personal portable devices and mobile phones carried by volunteer has been found to be positively correlated with RF exposure in Wi-Fi 2G, GSM 900 and GSM 1800 frequency bands. The results implied that the personal activities related to wireless technologies are the main factor affecting personal RF exposure making the use of personal exposure measure instruments the ideal method to measure these radiation.

التعرض الشخصي للأشعاعات الراديوية في الضفة الغربية - فلسطين

اعداد: هيثم محمود علي عياد

المشرف: الدكتور عدنان اللحام

الملخص

تعرض هذه الدراسة نتائج تقييم التعرض الشخصي للإشعاعات الكهرومغناطيسية في المجال الترددي الراديوي التي يتعرض لها عامة سكان الضفة الغربية – فلسطين. أجريت قياسات الترددات الراديوية الشخصية باستخدام مقياس التعرض الشخصي (بي اي ام) لأربع وعشرون طالبا من جامعة القدس. شارك كل منهم في عملية القياس لمدة 24 ساعة خلال ممارسة حياتهم اليومية في الضفة الغربية. باستخدام القياسات المسجلة بواسطة جهاز قياس التعرض الشخصي، تم حساب المعدل الزمني لقوة المجال الكهربائي ل 14 نطاقا ترددیا محددة مسبقا بين 80-6000 ميغا هيرتز. كما تم التحقق من مستويات التعرض والتغير الزمني ل 14 نطاق ترددي من أجل تحديد أنماط التعرض الشخصي لكل نطاق تردد . أجريت جميع القياسات باستخدام جهاز قياس التعرض الشخصي EME Spy 140. قام كل المشاركين بالدراسة بحمل الجهاز على منطقة الخصر خلال فترة القياس. بلغ المتوسط الحسابي للمعدل الزمني للتعرض الشخصي الكلي خلال 24 ساعة 0.45 فولت/م وتراوحت القيم بين 0.19 فولت/م و 0.92 فولت/م. لقد تم التوصل الى أن النطاق الترددي الراديوي واي فاي 2 جيجاهيرتز كان الأكثر مساهمة لمعدل التعرض الكلي يليه النطاق الترددي الراديوي جي اس ام 900 (الارسال) بمعدل 0.32 فولت/م و 0.21 فولت/م على التوالي. كما تبين أن قياس التعرض الشخصي الأقصى الذي سجله جميع المشاركين في أي وقت كان 7.1 فولت/م. وقد تم التحقيق في مختلف الظروف والعوامل بما في ذلك المواقع المشتركة بين المشاركين واستخدام أجهزة البث اللاسلكية التي تنبعث منها الترددات مثل الهواتف المحمولة وأجهزة الكمبيوتر المحمولة. كما تم حساب معدل التعرض الشخصي باستخدام الطريقة الاحصائية Robust ROS من أجل تقدير القراءات دون الحد الأدنى من قدرة الجهاز على كشفها, وكانت النتائج متباينة في المجالات الترددية الراديوية التي تحتوي على نسب تتجاوز 95% من القراءات ما دون حد الكشف. خلال ممارسة المتطوعين للحياة اليومية وصل أعلى معدل التعرض الشخصي خلال التنقل الخارجي باستخدام وسائل النقل العامة وأقل معدل خلال فترة النوم. اظهرت العلاقات بين كمية التعرض الشخصي خلال النشاطات المختلفة علاقة طردية بين استخدام الاجهزة المحمولة الشخصية وكمية التعرضة للإشعاعات الكهرومغناطيسية في النطاقات الترددية واي فاي 2 جيجاهيرتز و جي اس ام 900 و و جي اس ام 1800. أظهرت النتائج أن الأنشطة الشخصية المتعلقة بالتكنولوجيا اللاسلكية هي العامل الرئيسي الذي يؤثر على التعرض الشخصي للترددات الراديوية مما يجعل استخدام أجهزة قياس التعرض الشخصي هي الطريقة المثلى من أجل قياس هذه الإشعاعات.

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List of abbreviations

AM	Amplitude Modulation
DECT	Digital Enhanced Cordless Telecommunications
DL	Down Link
EMF	Electromagnetic Field
EMR	Electromagnetic Radiation
FM	Frequency Modulation
GSM	Global System for Mobile communications
Hz	Hertz
ICNIRP	International Commission on Non-Ionizing Radiation Protection
LTE	Long-Term Evolution
MTIT	Ministry of Telecom. & Information Technology
PCBS	Palestinian Central Bureau of Statistics
PEM	Personal Exposure Meter
RF	Radio frequency
RMS	Root Mean Square
ROS	Regression on Order Statistics
SIM	Subscriber Identity Module
TDMA	Time Division Multiple Access
TETRA	Terrestrial Trunked Radio
TV	Television
UL	Up Link
UMTS	Universal Mobile Telecommunications Service
V/m	Volt per meter
VHF	Very High Frequency
W/m^2	Watt per meter square
W-LAN	Wireless Local Area Network
WHO	World Health Organization
Wi-Fi	Wireless Fidelity

Chapter 1

Introduction

The exposure to radio frequency electromagnetic radiation (RF-EMR) from different man made sources is increasing every day, which is inevitable due to its importance in everyday life functions. In the last five years, the continuous development of wireless communication technologies increases its contribution to daily personal RF-EMF exposure. Mobile phones and portable devices that use radio waves as mean for sending and receiving data became irreplaceable and inseparable from individuals which increased the duration of daily exposure significantly.

Little is known about typical RF-EMF exposure levels and the spatial and temporal variability of RF-EMF in our environment (ICNIRP, 1998). As a result, the health effects of EM radiation have become a focus of attention for the researchers and a source of concern to the general public. Every year, more scientific researches suggested that biological effects are not limited to the process of heating of body tissues and there maybe adverse effects on neuron system and brain related to long-term exposure. While these researches are still under investigation, no non-thermal biological effects of electromagnetic fields in the radiofrequency range are proved (Anthony J. Swerdlow, 2011). The exposure to radio frequency electromagnetic radiation directly increase the temperature of internal organs and neuron system of human body which is known as microwave heating as contrary to exposure to heat source outside of the body. Microwave heating of body tissue differ in a way that it does not allow the heated body to adapt change in temperatures in the same way when body tissue is heated by an outside source, which is considered a hazard to unaware person who may expose to high energy source of RF-EMF.

In order to estimate the effects of exposure to RF-EMF on an individual, a method must be developed to measure these radiations during his daily life activities. The measurements in fixed locations does not reflect the amount of radiation exposed to due to the intervention of many factors such as electromagnetic waves interaction with matter as well as spatial and time varying electric field.

Therefore devices have been developed to measure RF-EMF; these devices are called personal exposure meter (PEM) or dosimeter. They are characterized by small size and weight to make them easier to carry for long period by the individual and designed to operate efficiently in different weather conditions. PEM can provide frequency selective exposure measurement, work for long measurement periods and store thousands of measurements.

However, there are some restrictions and problems concern the use of personal exposure meter in scientific researches. The high cost of development and manufacture is still an obstacle against using it in epidemiological studies which limit number of samples; cost also hinder technical capabilities of personal exposure meter such as frequencies range and detection limit where later it proved its importance due to the high proportion of measurements with very low electric field strength. Accuracy of RF-EMF measurements emitted from sources close to the device considered a major issue; this made measurement accuracy of RF-EMF emitted by personal mobile phone questionable. The inconsistency of batteries performance causes corruption of measurements (Mann, 2005) and other technical problem that might be encountered during scientific researches.

1.1 Electromagnetic radiation in the radio frequency range

Electromagnetic radiation (EMR) is a type of energy that travels as a stream of massless particles in wave form at the speed of light. These massless particles are called photons. The electromagnetic spectrum includes all types of EMR from radio waves to Gamma X-ray. All EMR regardless of origin are fundamentally the same, the difference between them is expressed energy, frequency or wavelength of the photons.

EMR can be divided into ionizing and non-ionizing radiation depending on the energy during interaction with targeted atoms. Ionizing radiation has enough energy to remove electron from atom orbit causing the atom to become charged. While non-ionizing radiation doesn’t have enough energy to break bond between molecules, it can be absorbed by human tissue and cause the molecules to vibrate in point motion which lead to energy being released in form of heat (ICNIRP, 1998), or it can induce electric current inside human body and stimulate nerves (World Health Organization, 2007). Radio waves are non-ionizing electromagnetic waves that lie between 100 KHz-300 GHz in the electromagnetic spectrum.

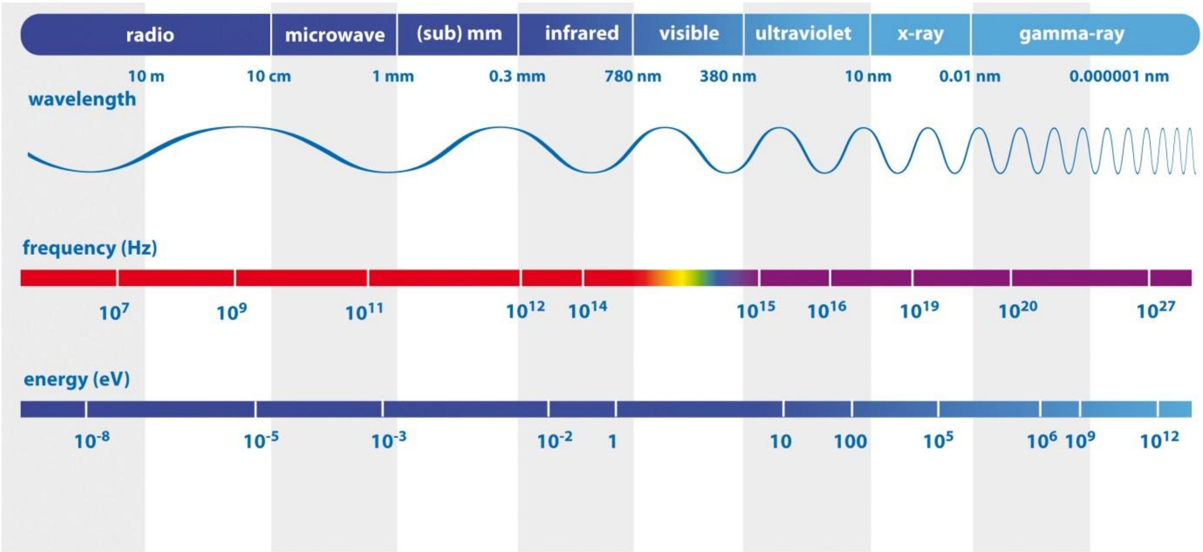

Fig. 1.1: Electromagnetic spectrum (Medialab, 2012).

Electromagnetic radiation comes from different natural man-made sources used for everyday life function and in medical applications and industry. These man-made sources differ in each country. The next sections will summaries the main RF sources in the West Bank-Palestine.

1.2 Main Radio frequency Sources in Palestine

In the last 20 years, there is steady increase in the spread of radio and television stations across Palestine, landline phones and the internet at homes and in number of Palestinian citizens who own smartphones. This section briefly reviews the main sources of RF-EMR in the West Bank-Palestine.

1.2.1. Audio-visual media RF sources (88 – 830 MHz)

Frequency modulation (FM) is used for radio broadcasting and two ways radio communications, mobile and stationary. FM broadcasting antennas operate on the VHF bands at frequencies from 88 to 108 MHz. TV broadcasting antennas operate at frequencies from 174 to 830 MHz depending on the TV band used for broadcasting.

There are 41 registered radio stations spread across Palestinian governorates (Palestinian Central Bureau of Statistics, 2015). All broadcasting is in the FM band and there is no radio stations broadcasting in AM band. The number of television stations is 15 (Ministry of Telecom. & Information Technology, 2015). Most of these stations are located in city centers and densely populated communities.

1.2.2. Mobile phones networks (GSM 900, GSM 1800 and UMTS 2100)

GSM (Global System for Mobile communications) is a global standard for digital mobile technology. GSM uses digital technology for second and third generation phones and TDMA transmission methods for voice communications and data services such as short messages and e-mails. GSM 900 and GSM 1800 are both considered second generation mobile technology and used by Palestinian mobile operators.

Practically, GSM service Provider Company operates GSM network which consist of necessary components for assisting and trafficking, sending and receiving voice calls and data services. GSM network user is exposed to its main components:

1- **Mobile station -** consists of two components; a terminal (mobile phone) and Subscriber Identity Module (SIM), a small smart card that is inserted into mobile phone to provide the user mobile access to subscribed services.
2- **Base transceiver station –** a macro cell that is responsible to handle the received and transmitted signal between mobile station and mobile network. Usually mounted on rooftops and covers 120 degree sector in range from 1 to 10 km.

GSM 900 uses frequencies from 880 – 915 MHz for transmitting digital information from mobile phones to base station (uplink) and 925 – 960 MHz for the opposite direction (downlink). GSM 1800 uses 1710 – 1785 MHz for uplink and 1805 – 1880 MHz for downlink.

Universal mobile telecommunications system (UMTS) is a 3rd generation mobile network that uses frequencies from 1920 – 1980 MHz for uplink and 2110 – 2170 MHz for downlink.

In recent years, many mobile network operators switched to 4th generation networks which include long term evolution (LTE) and worldwide interoperability for microwave access (WiMAX), provide faster data transfer rate allowing connection not only with mobile phones, but with laptop computers and tablets as well (Swiss Federal Office of Public Health, 2011).

One of the main features of GSM and newer technologies is their ability to utilize power when the GSM network is not in use reducing the output power emitted. However in the case of GSM mobile phones, when the mobile user is moving, a handover occur where the signal is handled from one base station to another closer to the new location of the mobile user. As a result, the phone transmits at peak power each time a handover happen which results in increase of average power (Bornkessel, 2011).

The number of mobile phone subscribers of the Palestinian mobile phone service providers is 3.3 millions, representing 74% of the Palestinian citizens in the year 2014 (Palestinian Central Bureau of Statistics, 2015).

There are two Palestinian mobile network providers in Palestine. The two providers offer the second generation of cellular mobile service to their users. One provider operates in the frequency band GSM 900 and the other uses GSM 900 and GSM 1800 frequency bands. The last statistics shows that 77.8% of the Palestinians subscribed to at least Palestinian mobile network provider and 93.4% of the population who are in their 20s own mobile phones (highest percentage among other age groups). Estimated Palestinian communities covered by the mobile phone service ratio of the population is 97% (Palestinian Central Bureau of Statistics, 2015).

There are five Israeli mobile network providers with the service of cellular phones, two network providers still uses the bandwidth of the radio GSM 900 and GSM 1800, two of the five providers offer 3rd generation (3G) mobile service and one provider offer fourth-generation (LTE) mobile service. Israeli mobile network providers' services represent 20%

of the Palestinian market size and the Internet (Ministry of Telecom. & Information Technology, 2015).

Lack of control by Palestinian Authority on some areas in the West Bank limits its ability to regulate the use and spread of technology that broadcasts unauthorized radio frequency bands and prevent selling non-local mobile service to Palestinian population.

1.2.3. Internet and Wi-Fi (2.4 GHz, 5.8 GHz)

Wireless Fidelity (Wi-Fi) is term that refers to IEEE802.11 standard for Wireless Local Networks (WLAN). WLAN operates at two frequency bands, 2.4–2.4835 GHz frequency band that referred as Wi-Fi 2G and 5.15–5.825 GHz band which is referred as Wi-Fi 5G. WiMAX considered an intermediate range WLAN.

Palestinian internet providers use landlines to distribute their services to general population. 51.4% of houses in the West Bank have access to internet (Palestinian Central Bureau of Statistics, 2015). Wi-Fi 2G frequency band is used by individuals to connect with the internet since laptops, mobile phones and other commercial devices are suited to use this band. Wi-Fi 5G band use is limited in some locations and institutes that need to transfer high amount of data between devices. The percentage of subscribers who have access to internet in the West Bank is 5% (Ministry of Telecom. & Information Technology, 2015). Download speed in homes can reach up to 16 Mbps.

1.2.4. Wireless phone (1920 – 1980 MHz)

Digital Enhanced Cordless Telecommunications (DECT) phones are cordless phones which consist of wireless handset and base station connected to telephone landline. The average output power increases with distance between handset and base station. Peak output power is 250mW and the average output power is 2mW. Base station maximum coverage distance is 50m. (Swiss Federal Office of Public Health, 2011) .

The proportion of the use of wireless phones in the home is not known. 403,118 Palestinians uses landline phones (Ministry of Telecom. & Information Technology, 2015).

1.2.5. Microwave ovens (2.45 GHz)

Microwave ovens work in the 2.4 GHz frequency band. The output power range from 500-2000 W. Age and physical damage of the microwave oven is the main factors that might cause leakage of RF radiation. Average leakage of 0.08 $mW.cm^{-2}$ (Alhekail, 2001).

1.2.6. Bluetooth devices (2.4 to 2.485 GHz)

Bluetooth devices work in 2.4 – 2.5 GHz band. It is used for voice and data transfer over short distance. Blue tooth devices transmit power only when transferring data resulting in RF emissions hundred times lower than mobile phones (Baan R, 2011).

1.3 Goals of this study

The main goal of this work is to evaluate and assess personal exposure to radio frequency electromagnetic radiation for a study sample that represents general population of the West Bank-Palestine.

Specific objectives

1- Measurements of personal exposure of an adult person to electromagnetic radiation during the exercise of daily life activities.
2- Calculation of time-averaged electric field for study volunteers.
3- Investigate the different factors and conditions that might affect the exposure to electromagnetic radiation.
4- Produce results that can be compared to similar previous studies and can set a baseline for future local studies.

1.4 Literature review

Many European countries began to measure both general and occupational personal RF exposure for their citizens. These researchers didn’t focus only on evaluating the exposure, but they were interested in improving methods and techniques used during measurements and the calculation of results in order to work out a protocol to be used in future studies.

Germany was the first country to perform personal RF exposure study for general public in south of Germany. Silke Thomas used ESM-140 personal exposure meter to measure the personal exposure for about 1500 adolescent and 1500 children for 24 hours; all were randomly chosen. Measurements of three mobile frequency ranged were obtained. Results expressed as the percentage of ICRINP reference levels where median of total RF-EMF of children and adolescents was 0.18% and 0.19% of the ICNIRP reference levels respectively. For statistical analysis of data below detection limits, he divided detection limit values by two (Thomas, 2008).

In Hungarian study, 47 university students participated for the measurement. Measurement period was 24 hours for commuter and metropolitans. Students from countryside carried PEMs for 27 hours. Also two personal exposure meters, DPS-90, ESM-140 and EME Spy 121 were carried by the volunteers in order to compare their performance and results (Thuróczy, et al., 2008) & (Finta et al, 2010).

In French study, the aim was to assess personal RF exposure for 377 randomly selected volunteers from two French cities including suburbs and rural surrounding (Viel et al, 2009). Personal exposure meter EME Spy 120 was carried by each volunteer for 24 hour measurements in weekdays. Performance of used PEMs was investigated and personal exposure was assessed and characterized in this study.

John Bolte measured temporal and spatial variation of personal RF exposure in selected micro-environments for participants living in or near Amsterdam and Purmerend in Netherlands. 98 volunteers participated in personal RF exposure study for 24 hour measurements. In addition to carried PEMs, GPS were used to log participants location during measurements in order to calculated geometric mean of electric field strength.

Various factors and variable affecting the personal exposure, especially at home, were investigated (Bolte & Eikelboom, 2012).

Exposure assessment, modeling and prediction of electromagnetic field in different indoor and outdoor environments were done in a Swiss study. EME spy 120 was used to measure personal exposure for 166 people each for one week. Diaries data were compared to GPS log to insure accuracy (Frei, et al., 2010).

Valič had done an exposure assessment study in Slovenia. Personal RF exposure was measured for 54 volunteers using EME Spy 120 personal exposure meter for 34 hours of measurement period. Data recorded were combined with diaries filled by volunteers and results in urban and rural locations were separated. Valič didn't use any statistical method to evaluate data below detection limit (Valič, 2009).

In all personal exposure studies, questionnaires were used to obtain information before and after the measurement process, while diaries were given to volunteers to obtain information during the measurement period. Large percentages of the results were below detection limit. Different statistical methods and models used to calculate the mean exposure. None of the studies' results exceeded safety limits.

Chapter 2

Measurement of Personal Radiofrequency Exposure

2.1 RF electromagnetic field parameters

Radio frequency electromagnetic waves propagate through free space at speed of light c. Frequency f (Hz) and wavelength λ (m) are related by:

$\lambda = c. f$

At any point in space, electric field strength vector is noted by **E** measured in V/m and magnetic field strength vector is noted by **H** measured in A/m. As a result of variation in the strength of a moving electric field, a magnetic field is generated which moves in the same direction of the electric field and perpendicular to it, this moving magnetic field generate electric field as well. Antenna is the main part of any wireless technology setup, its purpose is to transmit and receive electromagnetic waves. Measurement of RF electromagnetic fields depends on the relation between detected **E** and **H** which is dependent on the distance from transmitting antenna.

There are two main regions of electric field depending on transmission distance, near field and far field. In near field the spread and angle of dispersion of radio waves from the source or radio transmitter vary considerably with distance, as a result the relation between electric field and magnetic field is more complex and unpredictable with simple calculations.

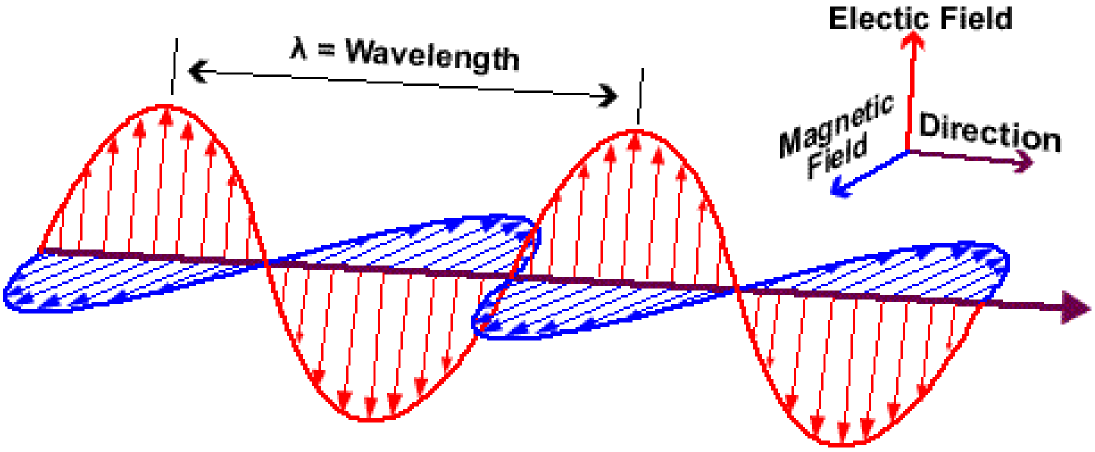

Fig. 2.1: Electromagnetic wave.

The ratio between **E** and **H** amplitudes called impedance of the air $\mathbf{Z_0}$ is constant and equals 377 ohms. Power density measurement can be applied in the far field region. The relationship between electric field strength **E** and power density **S** become as follow:

$$S = E^2/377$$

2.2 RF electromagnetic fields detection

To measure RF waves it must be detected, a receiver antenna is the main part of any detection setup and its purpose is to capture either electric field or magnetic field passing through the metal part of the antenna. In RF survey and personal meters, in addition to calibrated antenna, other electronic parts might be included depending on the properties and purpose of detection system. RF exposure meter characteristics vary in types depending on target RF range, RF application, wave type and source distance. RF exposure meters have different operating modes.

2.3 Personal exposure meters

Personal exposure meters (PEM) are used for instant individual RF exposure monitoring. The tri axial isotropic antenna detects the electromagnetic field strength emitted from all directions at the same moment without the need for moving parts. For low-intensity RF waves, amplifier is used to amplify the signal before sending it to the receiver. Other electronic boards to convert analog signals, calculate electric field strength, measure temperature, store data, and regulate battery usage.

In general, personal RF exposure meter must have the following characteristics:

1- Small in size, lightweight and can be worn easily.
2- Reasonable price/performance ratio.
3- RF Selective or spectrum analyzer.
4- Accurate measurements in different environmental conditions, such as high temperature and humidity.
5- Detection of low electric field strength and power density.
6- Can do both direct measurement and data recording.

2.4 Calculation of electric field strength

Using isotropic antenna allows the detection and measurement of incident electric field from three dimensions at once. For frequency band of interest, the electric field strength is the square root of all electric fields emitted from all directions and captured by three-axis of the antenna. The magnitude of the incident electric field is proportional to ($E \cos \theta$) where θ is the angle between the direction of electric field and antenna axis.

Personal exposure studies focus mainly on the average values, patterns and percentage of measurements above the safety limits because proven biological effect on human tissue depend on duration not on maximum exposure values. The time averaged electric field strength measurement is used when the exposure varies with time. The root mean square electric field strength E_{rms} can be calculated using the formulas:

$$\boldsymbol{E_{rms}} = \sqrt{\frac{\mathbf{1}}{\boldsymbol{n}}\sum_{\mathbf{1}}^{\boldsymbol{n}} \boldsymbol{E_i^2}} \quad (2.1)$$

Where:

E_i is the electric field measured in the nth time period.

n is the number of electric field values measured during a time interval.

2.5 Time-averaged electric field strength, magnetic field strength and power density

Time averaged RF exposure is measured when the exposure change with time. Using collected samples recorded by RF personal exposure meters time averaged values of E, H and S can be calculated using the following formulas

The time-averaged electric field E_{rms}, magnetic field H_{rms} and power density S_{rms} can be obtained using the following formulas:

$$E_{rms} = \sqrt{\frac{1}{T}\sum_{1}^{n} E_i^2 . \Delta t_i} \quad (2.2)$$

$$H_{rms} = \sqrt{\frac{1}{T}\sum_{1}^{n} H_i^2 . \Delta t_i} \quad (2.3)$$

$$S_{rms} = \frac{1}{T}\sum_{1}^{n} S_i . \Delta t_i \quad (2.4)$$

Where:

- Ei, Hi, and Si are electric field, magnetic field, and power density measurements, respectively at ith time interval.
- Δti the interval time, in minutes.

- T is the total measurement period.
- n the number of time intervals in total measurement time T

2.6 Guidelines for limiting RF-EMF exposure

Reference levels have been developed by many countries and organizations insure compliance with basic restrictions for exposure assessment. These basic restrictions are based on proven health effects caused by personal exposure to radiofrequency electromagnetic field. The International Commission on Non-ionizing Radiation Protection (ICNIRP) is an independent organization aims to provide risk assessment and protection from adverse effects from exposure to non-ionizing electromagnetic fields between 100 kHz and 300 GHz for both workers and general public (ICNIRP, 1998).

Basic restrictions are physically quantified using current density, power density and SAR. Many factors and variable were considered in the development of safety levels. In general, restrictions are provided to prevent individual exposure to high frequency electromagnetic fields with enough energy to increase the body tissue of 1 ^{o}C. The guidelines suggested that 6 minutes average is appropriate for whole body exposure, 30 minutes average for localized exposure and 1 minute average for medical implanted devices (ICNIRP, 2016). General public exposure limits are different from occupational because unlike workers, general public are unaware of their exposure to RF-EMF and thus cannot avoid exposure.

Table (2.1) present general public reference limits adopted by ICRINP in 1998 for personal exposure to time-varying electric field from various RF sources between 100 kHz and 300 GHz. Measured physical quantities in frequency range of interest get compared with basic restrictions in the same unit provided with ICNIRP guidelines for exposure to non-ionizing RF-EMF to insure that measured exposure levels do not exceed basic reference levels.

Table 2.1: Reference levels for general public exposure to time-varying electric and magnetic fields

Frequency Range	E-field strength (V/m)	H-field strength (A/m)	B-field (μT)	Power density (W/m^2)
3-150 kHz	87	5	6.25	--
0.15–1 MHz	87	0.73/ f	0.92/ f	--
1–10 MHz	$87/f^{1/2}$	0.73/ f	0.92/ f	--
10–400 MHz	28	0.073	0.092	2
400–2,000 MHz	$1.375\, f^{1/2}$	$0.0037\, f^{1/2}$	$0.0046\, f^{1/2}$	f /200
2–300 GHz	61	0.16	0.2	10

f is the frequency as indicated in the frequency range column

In order to evaluate measured exposure levels compliance with reference limits provided by ICNIRP guidelines. Compliance with reference limits is expressed as a dimensionless quantity called exposure quotient:

$$EQ = \left(\frac{E^{meas}}{E^{ref}}\right)^2 \qquad (2.4)$$

Where E^{meas} is the measured electric field strength, E^{ref} is the reference level for the measured frequency.

To measure the exposure quotient of total number N_i signals measured in a multi-frequency environment with their respective frequencies. The following formula is used to calculate total exposure quotient (TEQ):

$$TEQ = \sum_i^{N_i} \left(\frac{E_i^{meas}}{E_i^{ref}}\right)^2 < 1 \qquad (2.5)$$

Chapter 3
Methodology

3.1 Population sample

In this study, Bachelor and Master students from Al-Quds University were asked to carry the PEM for 24 hours. Recruiting volunteers from general population is not practical due to lack of interest, commitment to the task, and the risk of losing PEM. The volunteer recruitment process focuses on clarification of the study objectives, importance, measurement procedures and responsibilities.

Fortunately, information collected from the participating volunteers provided a wide variety regarding aspects of the individual life in the West Bank including: material status, living condition, occupation, travel time, mobile and internet providers and usage. Volunteers recruited from 7 northern and southern governorates in the West Bank.

An initial number of 65 students responded to the radiation center request. After contacting them, 31 students accepted and committed to carry the PEM for 24 hours. Carrying the personal exposure meter for longer period was rejected in most cases.

3.2 Instrumentation

For this study, two EME Spy 140 personal exposure meters designed and built by French company SATIMO were given to volunteers to monitor and record exposure to radio frequency electromagnetic strength for 14 predetermined selective frequency bands between 80 to 6000 MHz. Factory calibrations were done in 26 march 2015. Software was included with EME Spy 140 to import and graph the recorded data and to configure it. Other technical information is mentioned in device data sheet in appendix A.

EME Spy 140 is set to measure RF exposure for 24 hours (1440 minutes), interval between each two measurements was 10 seconds producing 8640 measurements per day for 14 frequency bands. Results are imported from the PEM to EME Spy software after each measurement period where results can be visualized and exported in electric field strength and Power density units.

During measurement period volunteers wore the PEM on their waist; some female carried it in small purse. During sleep they were asked to keep it near their head.

3.3 Data collection process

Data from volunteers were collected through three stages depending on their relevance to the collection process:

1. data collected before measurement period: using a questionnaire given to volunteers and included volunteers personal data regarding living conditions (location, type of apartment, number of occupied apartments in the building), number of RF emitting devices located in the volunteers home (network routers, DECT, microwaves, radios and TVs). Questionnaire and activity log kept simple and short in order to guarantee volunteer dedication and to prevent fatigue (Röösli M. , et al., 2010). Sample of questionnaire is included in appendix A.
2. Data collected during measurement period: the recording process conducted from Sep-21-2015 until July-15-2016. 8640 data point of personal RF exposure for every volunteer stored while carrying EME Spy 140 personal exposure meter for 24 hours. Diary (activity log) was given to every volunteer in order to keep track of activities done during measurement period. Daily activities were limited to five major activities: 1) Sleep (during bed time), 2) Home (volunteer living place), 3) Travel (outdoor travelling regardless of transportation and destination), 4) University (time spent in university including outdoor locations) and 5) other (any other activities). Transportation used for travelling was specified in the diary (public transport, private cars, on foot).

3. Seven volunteers' data were eliminated due to incomplete or inaccurate diary. Another six measurements where repeated because the PEM data were corrupted.

4. Data collected after measurement period: included number of mobile phones and Wi-Fi emitting devices used by the volunteers and their family members during measurement period, call logs stored in personal mobile phones during 24 hours (call start time, call duration, SIM operator) and mobile phone distance from head when they were sleeping (near, far).

Chapter 4
Results and Discussion

4.1 Data processing

This section discusses the process of data recording during the measurements period in addition to combining it with information collected from volunteers in order to display the results in a way it can be interpreted.

First, we extracted measurements recorded in EME Spy 140. For each frequency band, there are 8640 data point recorded every 10 seconds interval for total period of 1440 minutes (24 hours).

Then we categorized questionnaire information filled by volunteers. However, not all information can be used due to lack of number of samples in some categorize.

We synchronized information recorded by each volunteer in activity log forms given to them and call logs from their mobile phones with the data according to their time of occurrence. Note that no correction or shifting was made during this process. After separation of (TRAVEL) exposure measurements for each volunteer, we categorized it according to method used for travel.

For the frequency bands GSM 900 and GSM 1800 (uplink and downlink), measurements recorded during calls were separated only to remove it from the results. However, a comparison between exposure levels during idle status where no calls were made or received and Total dataset (Idle + Call) are made.

Chart below shows how the temporal variation in exposure was divided into categories to be summarized and visualized in order to interpret the results (Fig 4.1).

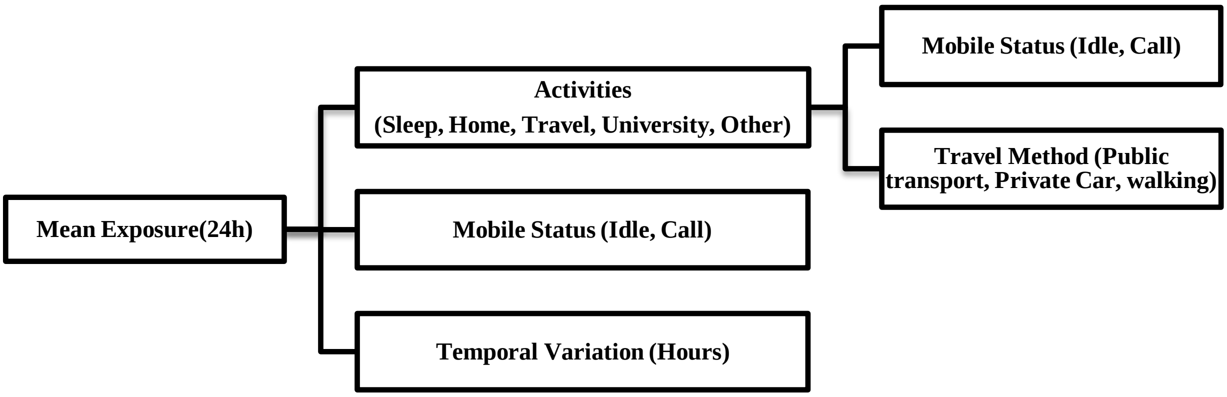

Fig. 4.1: Chart display the catigorization of 24 hours measurements dataset.

4.2 Statistical Analysis

For this study, time-averaged electric field is calculated to describe the personal RF exposure for summary and categorized exposure for each frequency band for every volunteer. Microsoft Excel and Minitab v17 statistical programs were used for calculation of time-averaged electric field strength, spearman correlation coefficient and for plotting the categorized results.

4.2.1. Temporal variation of personal RF exposure

For every study volunteer, measurements were divided into 24 groups by hour, each group contains measurements recorded from hh: 00 to hh: 59. For example, time-averaged electric field strength in 12:00 am period will include all measures from 12:00 am until 12:59 am. After calculation of time-averaged electric field strength for each hour period for all frequency bands, mean, median, maximum for all study volunteers was measured. Mean and median of time-averaged electric field strength time series is visualized.

4.2.2. Spatial variation of personal RF exposure

Categorized datasets are divided by activity location; time-averaged electric field is calculated for every activity location. 5 point Whisker plots are used to compare between activities measurements for the 24 volunteers. In addition to whisker plots, arithmetic mean is calculated for each activity groups' time-averaged electric field strength and visualized as crossed circle.

4.2.3. Robust regression on order statistics (ROS) method for estimation of non-detects

Due to technical limitation of EME Spy 140, large portion of the data was below detection limit. Percentage of non-detects varied between volunteers. Usually, it is accepted to calculate mean exposure by replacing data point below detection limit with detection limit value for respective frequency band. However, various methods are available for estimating measurements below detection limit and we used the most suitable method for our data, this method is called Robust regression on order statistics.

Robust ROS is a non-parametric method that is used to estimate mean for statistics with data below detection limit (censored) of the measurement method. Robust ROS assumes log-normal distribution of the data below detection limit (censored). In this study, Robust ROS was calculated in R version 3.2.2 statistical program using NADA package. Mean value of data sets with more than 99.9% of measurements below detection limits were substituted with detection limit value.

Although many of the measured frequencies had more than 90% of censored data as shown in Table (C.3), ROS method still applicable for our data because all datasets are very large (8640 data point) and has more than 10 detected measurements (Röösli M. , et al., 2008).

Robust ROS method was applied on each frequency band data set for all study volunteers. Results are summarized in Table (4.1) for normal and ROS time-averaged RF exposure.

Percentages of censored data (data below detection limit) are summarized in table C.3. Detailed results for every study volunteer are put in separate tables in the appendix C.

Mean exposure value calculated using robust ROS method used only in summary statistics for 24 hour exposure and weren't used in categorized data (Helsel, 2005). This method proven in many researches to provides more reliable estimations and more acceptable than omitting the non-detects from the results (Helsel, 2006).

4.3 Summary statistics of personal RF exposure

4.3.1. main results of total personal RF exposure

Time-averaged electric field strength is used as a measure of personal RF exposure during daily life for Al-Quds University volunteers. The mean total RF exposure of time-averaged electric field strength for 24 volunteers equal 0.45 V/m and the statistically modeled total RF exposure for 24 volunteers equal 0.45 V/m.

Table 4.1: Time-averaged Total RF exposures for 24 volunteers.

	Electric field (V/m)	
	Calculation Method	
	Normal	ROS
	Total	Total
Mean	0.452	0.451
Median	0.371	0.369
Minimum	0.189	0.185
Maximum	0.918	0.918
Sd.	52.16	52.18
Skewness	2.16	2.16

Comparison between the two calculation methods shows a 0.5 % difference in mean value of time-averaged electric field strength of the two methods. In Table (C.3), the percentage of data below detection limit in GSM 900 (DL) and Wi-Fi 2G datasets reduces the percentage of non-detects in total RF exposure nearly to 0 % for most volunteers.

4.3.2. Results of measured frequency bands time-averaged electric field strength

Time-averaged electric field strength for 24 volunteers was directly calculated using arithmetic mean of the whole dataset (8640 measurements) and then compared to arithmetic mean calculated from modeled dataset using Robust ROS method in order to quantify the difference caused by censored measurement. Comparison are made using whisker plot without including outliers as shown in Fig.(4.2).

Whisker plot comparison in Fig.(4.2) shows that there is a noticeable difference between normal and ROS mean exposure values for TV 3, TV 4& 5, TETRA and WiMAX datasets. The difference between normal and ROS mean exposure is only noticeable for data sets with more than 98% of data below detection limit. The reason for that because detection limits of EME Spy 140 is very low only large portion of non-detects will cause a difference in the mean exposure when replaced by estimated values.

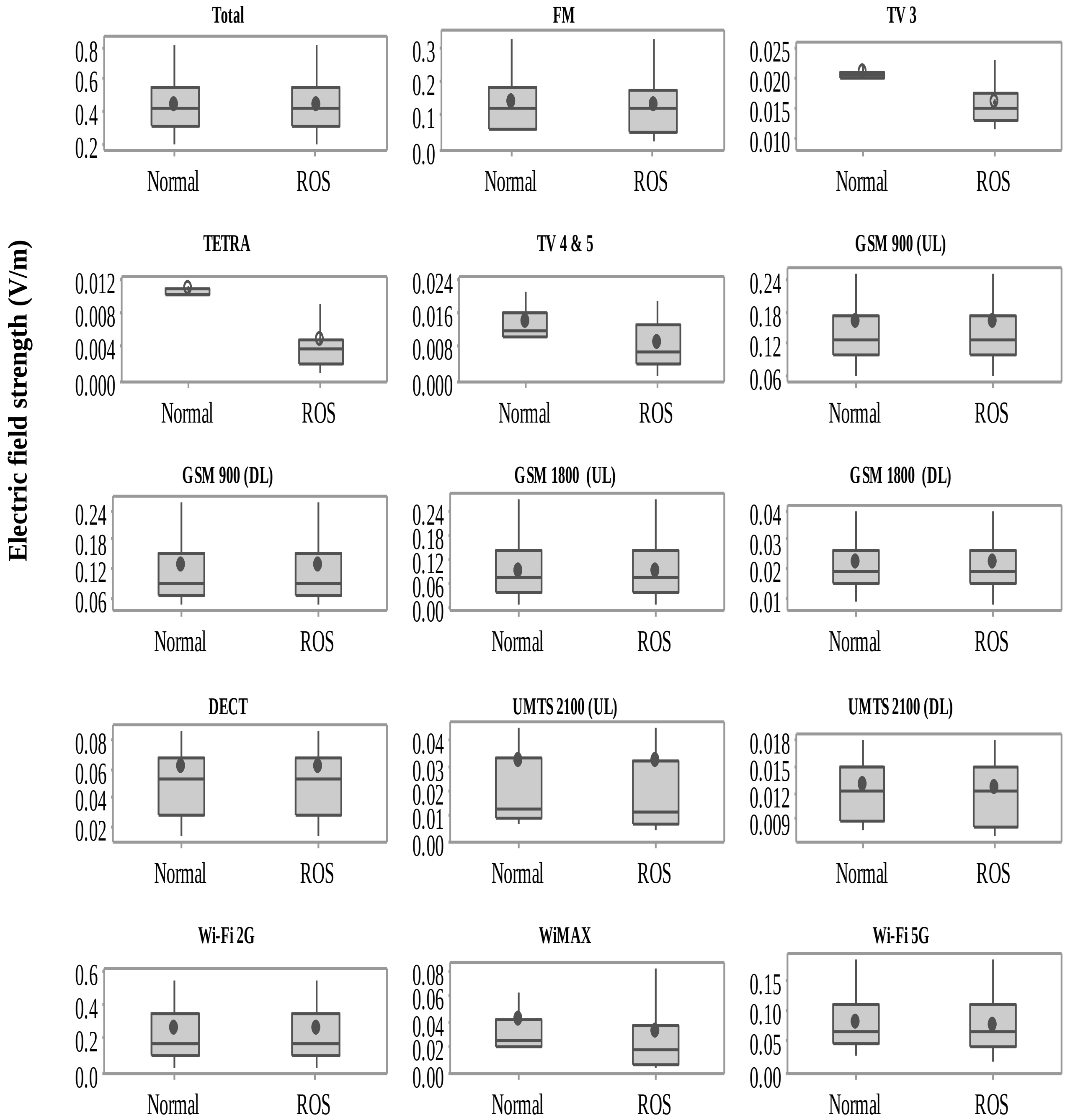

Fig. 4.2: Whisker plot inlcuding average (cricle) comparison between Normal and robust ROS method for calculation of time-averaged RF exposure for 24 volunteers.

4.3.3. Relative contribution to total RF exposure in 24 hours measurement period

Relative contribution of 14 frequency bands to total time-averaged electric field strength measured for 24 volunteers is illustrated in Fig.(4.3). personal exposure to RF sources carried by volunteers were the major contributors to total personal RF exposure during measurement period followed by exposure to FM transmitters and GSM 900 base stations. Others percentage includes all frequency bands with insignificant contribution.

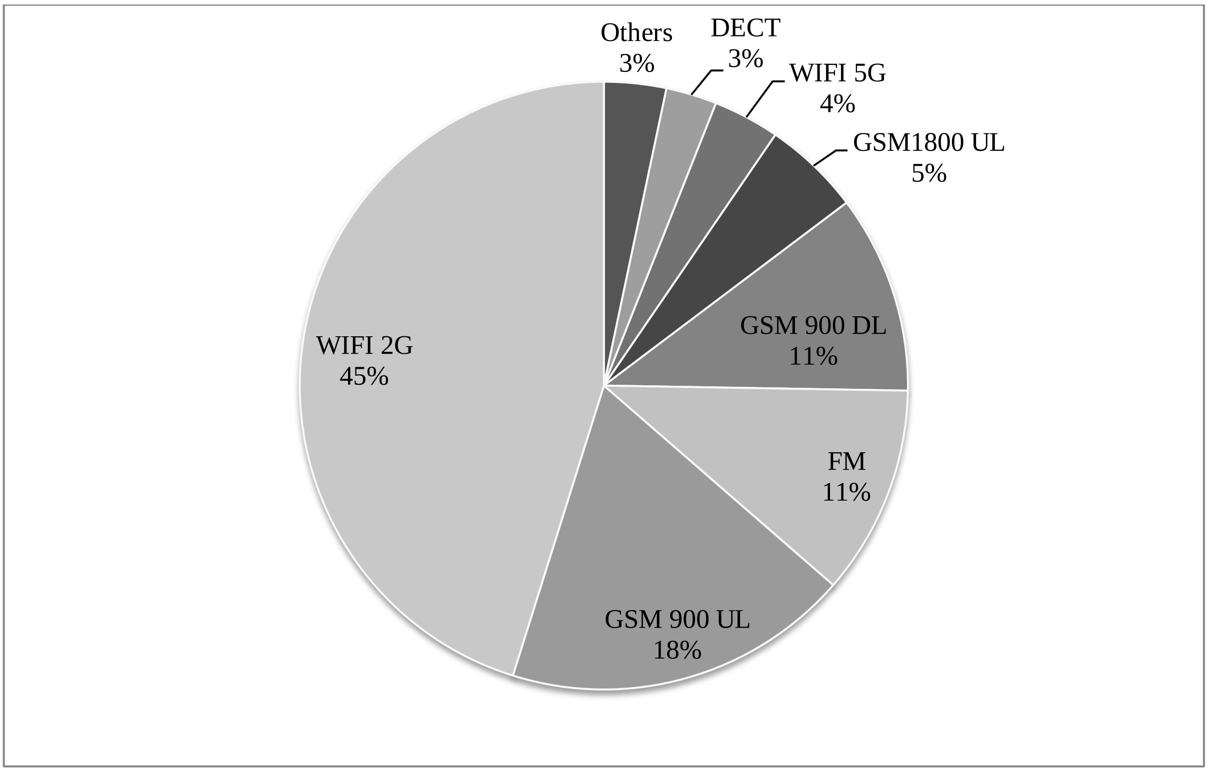

Fig. 4.3: Frequency bands relative contribution to total RF exposure for 24 volunteers.

4.3.4. Compliance with ICNIRP reference limits

Total exposure quotient was calculated for every frequency band measurement using EME Spy 140 analysis software for 24 volunteer. Mean ICNIRP percentage was calculated for every volunteer. Fig. (4.4) shows boxplot of 24 volunteers mean ICNIRP percentages for 14 frequency bands.

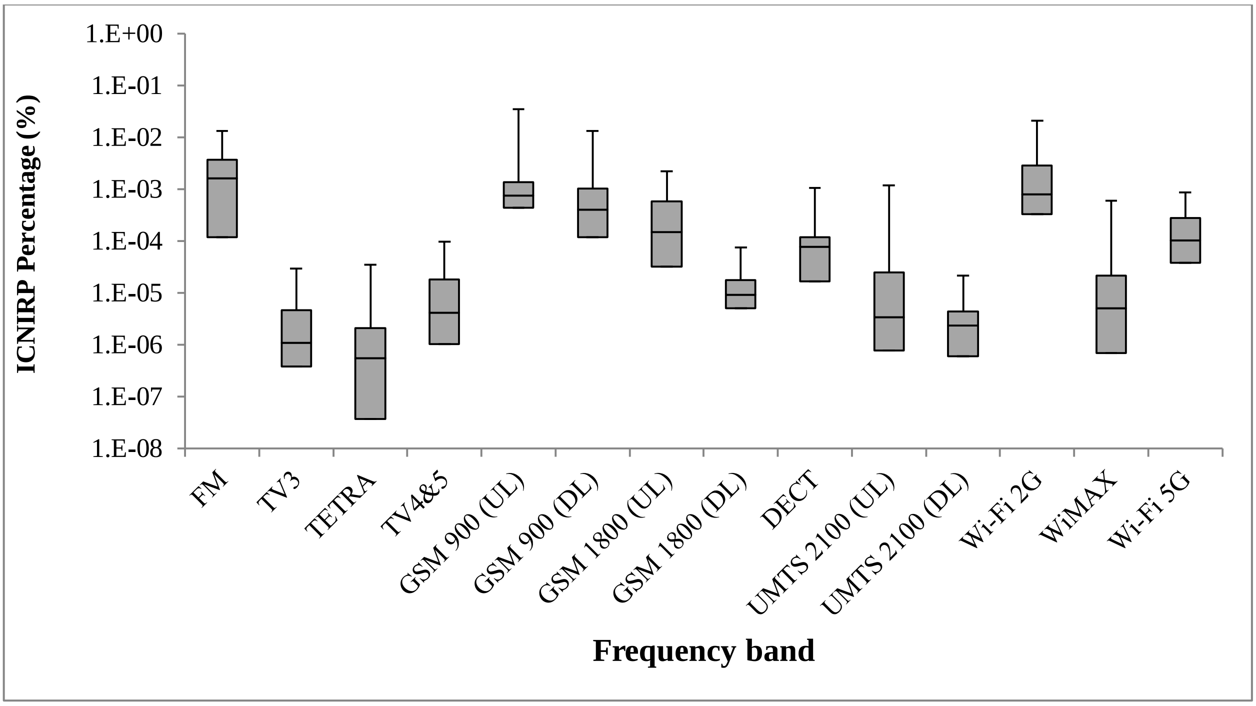

Fig. 4.4: boxplot of average ICNIRP percentage values for 24 volunteers

In average, none of the volunteers' measurements exceeded safety limits as the highest mean value of %ICNIRP was calculated in GSM 900 (UL) band and equal about 0.033%.

4.4 Temporal and spatial time-averaged RF exposure during daily activities

The measurements of electric field strength are categorized in hourly periods for each volunteer. Time-averaged electric field strength calculated for the duration of every hour of 24 hours measurements for 24 volunteers. Results are sorted by frequency band from small to large.

Spatial variation of time-averaged electric field was limited to 5 major locations or activities. Summary statistics are made for all study volunteers after dividing each dataset into 5 categories. 22 of 24 study volunteer spent time in (UNIVERSITY) activity while 15 study volunteers spend time in other activity during their 24 hours measurement period. Other activities for every frequency band are not interpreted due to lack of supporting information and in figures are not shown in whisker plot figures. Note that whisker plots do not include outliers.

Activity duration for each study volunteer is calculated according to their activity log entries. The activities happened during other activities are ignored because most of them are in different unique locations with no additional information about RF sources.

Time-averaged personal RF exposure levels categorized according to study volunteers SIM card service provider. For travel method, time-averaged electric field strength calculated is categorized by each type of travel method information provided in the activity log. Volunteers were asked to specify whether their mobile phone was near their bed during sleep activity. The results compared between it and those who kept their mobile phones away.

For GSM 900 and GSM 1800 frequency bands (uplink and downlink), each activity mean exposure is divided into two groups:

1-Idle: data points during calls are removed from the dataset.

2-Total: all data points are included.

4.4.1. Total temporal and spatial time-averaged RF exposure

Fig.(4.5) illustrates temporal variation of total personal RF exposure during measurement period. Maximum time-averaged exposure is calculated in the hour between 9 am -10 am and equal about 2.51 V/m. Total time-averaged electric field strength is mainly affected by personal activities and location of volunteer. Minimum personal RF exposure occurred at midnight, where volunteers are usually sleeping, and maximum occurred at evening.

In Fig.(4.5), mean and median RF exposure increases during travel periods when volunteers travelled in the morning and in the evening. The mean total time-averaged electric field strength during sleep was affected by inaccuracy in determination of the exact time when volunteers went to bed.

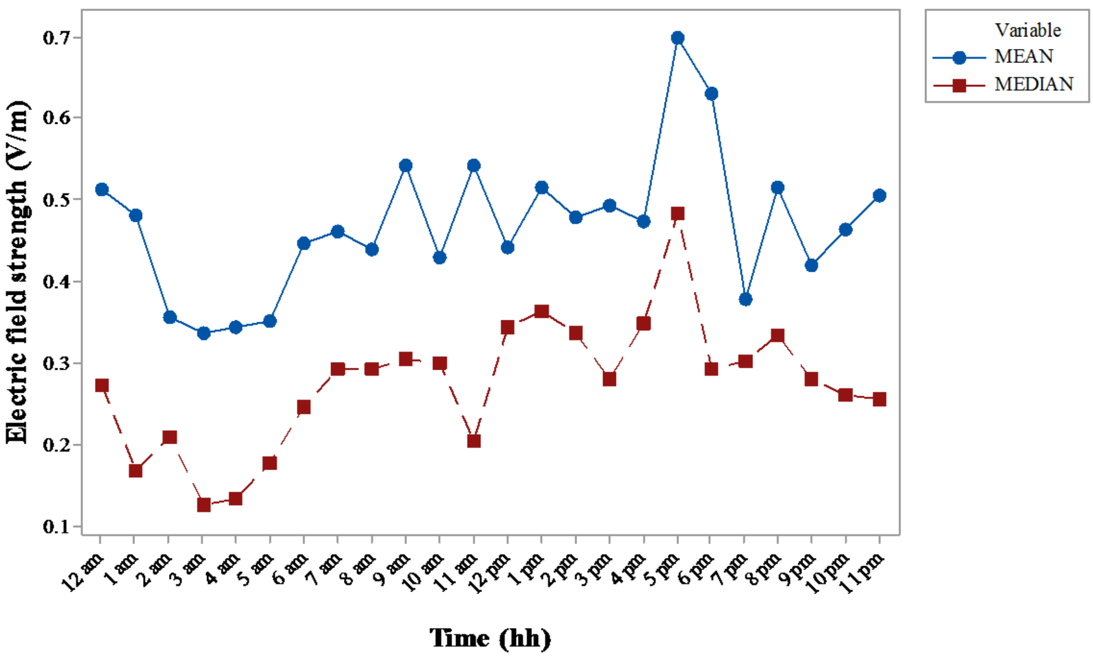

Fig. 4.5: Variation of Total time-averaged electric field strength during 24 hours.

Time-averaged electric field strength for measurements recorded in different activities is plotted in a whisker plot in Fig.(4.6) and similar plots for total RF exposure and each frequency band. Personal RF exposure levels are the highest during travel activity with mean value of 0.6 V/m and the lowest during sleep activity with mean value of 0.29 V/m. The mean is greater than the median in all activities which indicates that the distribution is skewed to the right caused by volunteer number 16 whose mean total RF exposure is higher than rest especially in home where.

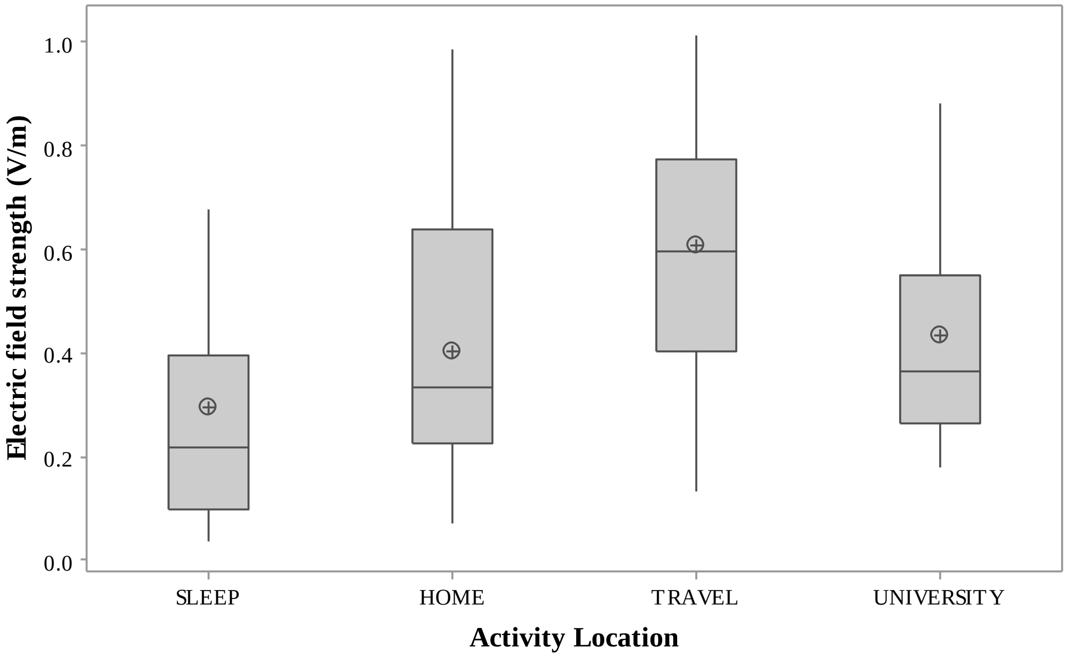

Fig. 4.6: boxplot of Total time-averaged electric field strength during daily activities.

A moderate positive correlation with R squared calculated around 0.5, is found during the investigation of relation between time spent in travel activity and volunteers' time-averaged electric field strength during travel activity periods as shown in Fig.(4.7). Similar travelling methods and routes increases the chance of being exposed to close amount of RF-EMF from outdoor sources, this resulted in the mean value to be close to the median of time-averaged electric field strength in travel activity compared to other activities as shown in Fig.(4.7).

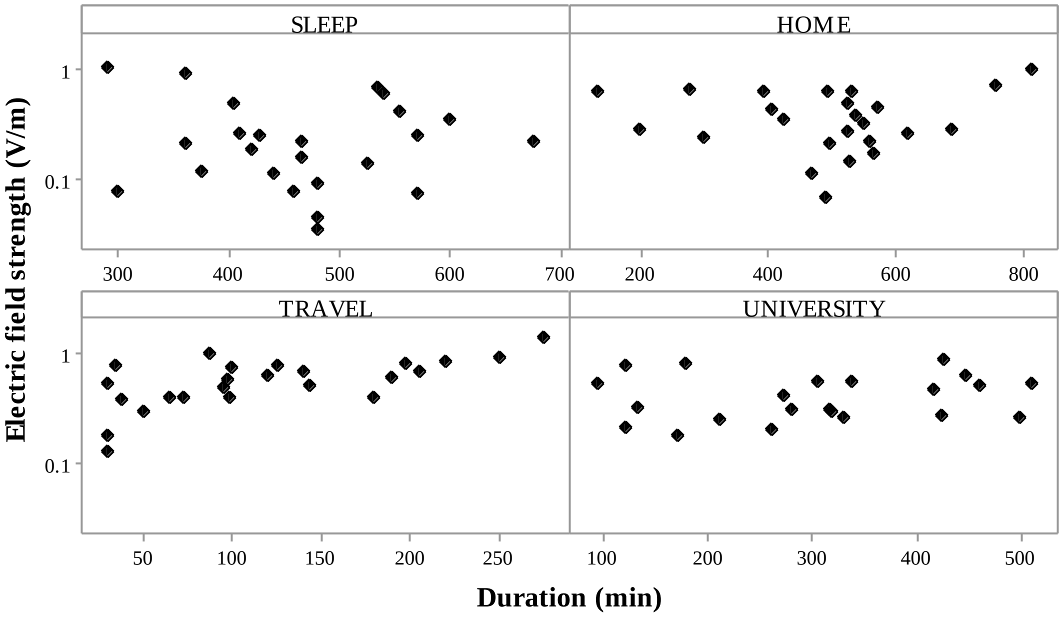

Fig. 4.7: Correlation between Total time-averaged electric field strength and duration.

4.4.2. FM band temporal and spatial time-averaged RF exposure

Median line in Fig.(4.8) shows that most volunteers exposed to an amount of RF electromagnetic radiation near the detection limit during the measurement period. Maximum time-averaged exposure is calculated in the hour between 10 am -11 am and equal about 1.5 V/m.

Variation between volunteers depends on the travel route, travelling speed and travelling method. The highest RF exposure occurs when volunteer travelled in the area around half kilometer from the location of transmitter tower because most of radio stations located in urban where building blocks most of the radiation. Exposure in other activities was as high as travel exposure for volunteers who spent their time in downtown areas.

Highest amount of RF exposure is calculated during travel with mean value of 0.29 V/m which is expected since FM is an outdoor source. Time-averaged electric field strength remained near detection limit during sleep, home and university activities. Mean value for time-averaged electric field strength in these activities is skewed to the right mainly due to inaccuracy of activity logs entries.

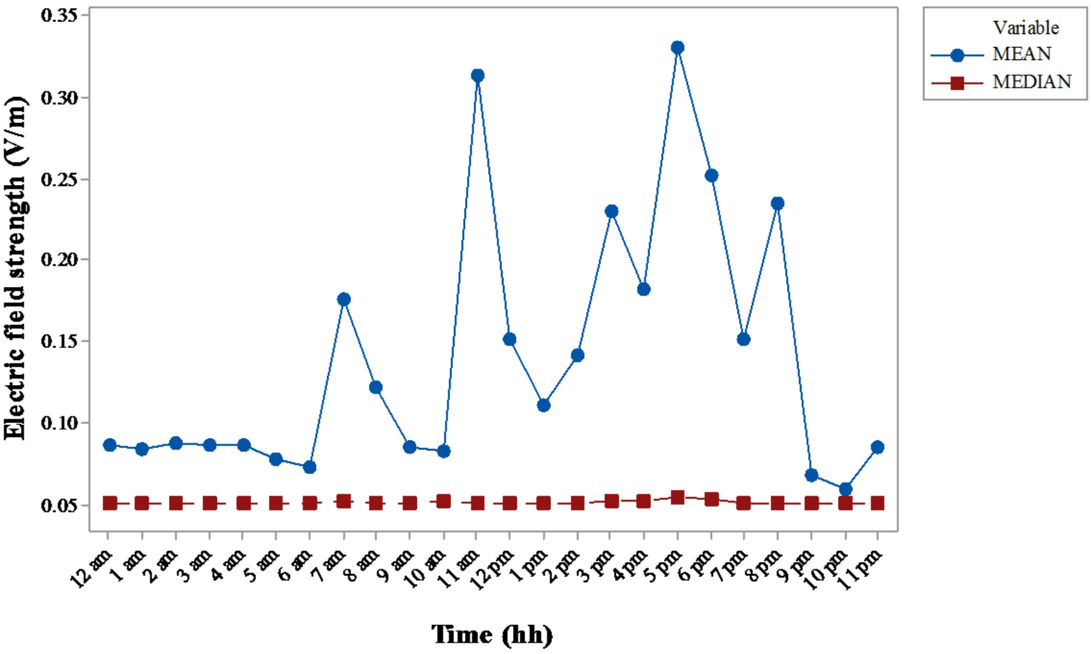

Fig. 4.8: Variation of FM time-averaged electric field strength during 24 hours.

While exposure from FM band depends on time spent during Travel activity as shown in Fig.(4.9), travel route can greatly affect the exposure for some volunteers. For example, volunteer number 3 and 16 labeled on individual points in Fig.(4.10) reported that they travelled in a street where a radio broadcasting tower is located, highly affecting their exposure due to low number of data points recorded in their personal exposer meters.

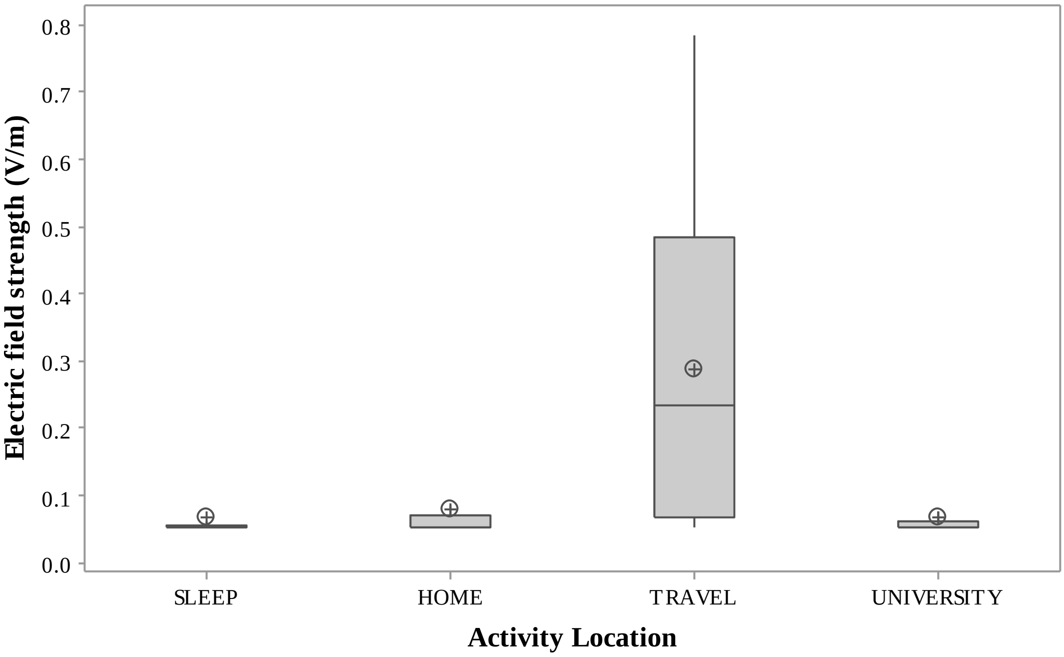

Fig. 4.9: boxplot of FM time-averaged electric field strength during daily activities.

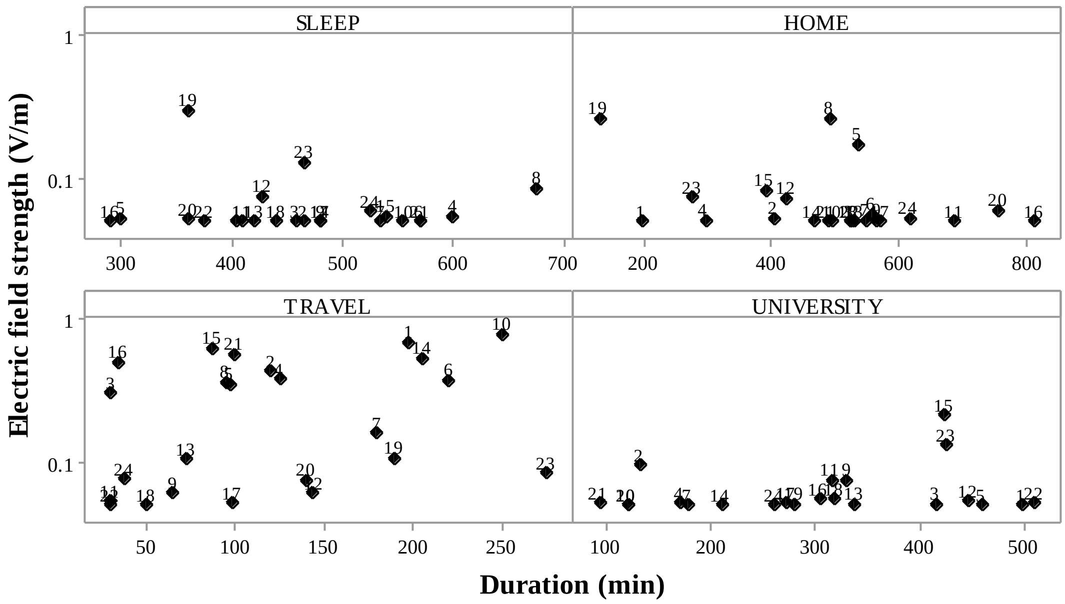

Fig. 4.10: Correlation between FM time-averaged electric field strength and duration.

It was reported that the home of volunteer number 19 is town located between two settlements which might be the source of consistent exposure during Sleep and Home activities. While high exposure average values during Home activity for volunteer number 5 and 8 during was probably affected by low accuracy of their diaries information.

4.4.3. TV 3 band temporal and spatial time-averaged RF exposure

Location and distance from TV3 transmitting sources is the main factor affecting the exposure. However, by looking at mean line in Fig.(4.11) there is no specific period where exposure in TV 3 frequency band might be higher because mean values at each hour was affected by maximum time-averaged electric field strength in the same period. Maximum time-averaged exposure is calculated in the hour between 6 pm -7 pm and equal about 0.04 V/m which is almost twice the mean in the same period. While median line indicates that increased RF exposure to TV 3 frequency band sources occurred in periods between 8 am – 11 am and 5 pm- 9 pm. In those two periods most of volunteers travelled locally and between governorates according to their activity log entries.

RF exposure to TV 3 band sources is very low for all volunteers even for volunteers with more than 50% of measurements above detection limit as shown in Table (C.3). Most of the exposure occurred during travel (Fig. 4.12).

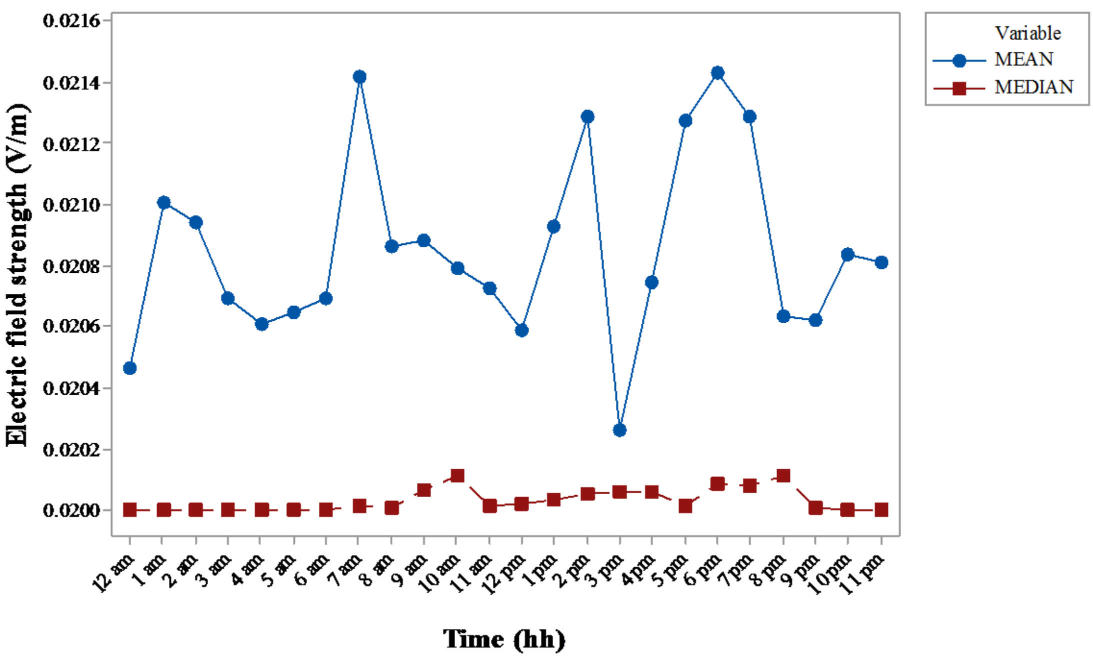

Fig. 4.11: Variation of TV 3 time-averaged electric field strength during 24 hours.

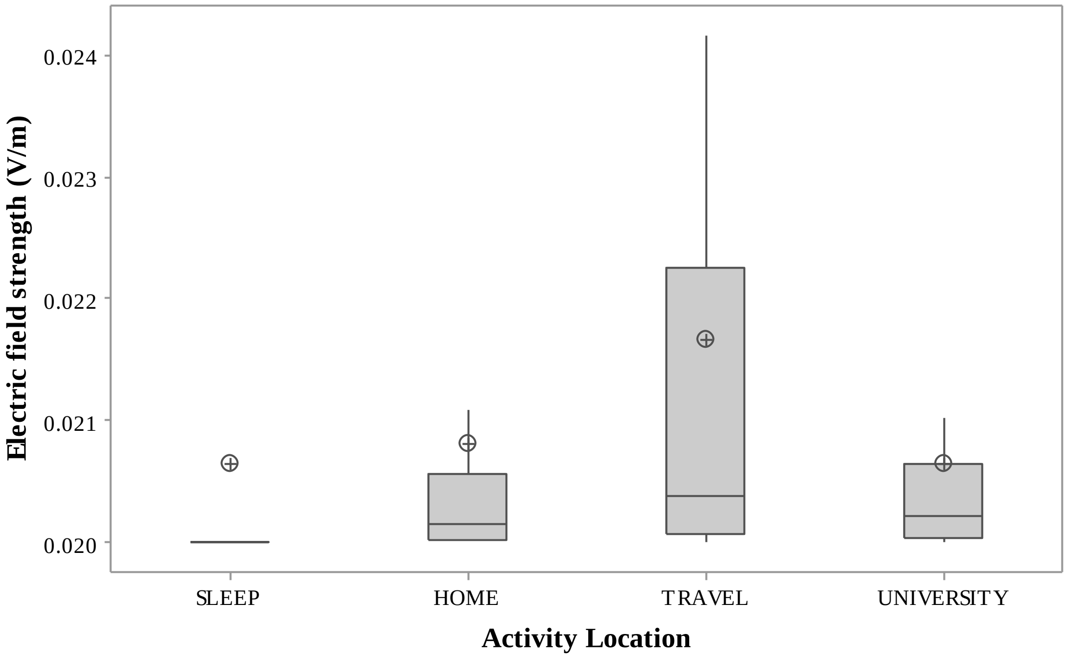

Fig. 4.12: boxplot of TV 3 time-averaged electric field strength during daily activities.

Relation between time-averaged electric field strength and activities duration couldn't be interpreted due to very high percentage of no detects greatly reducing the differences between volunteers' personal exposure levels regardless of conditions (Fig. 4.13).

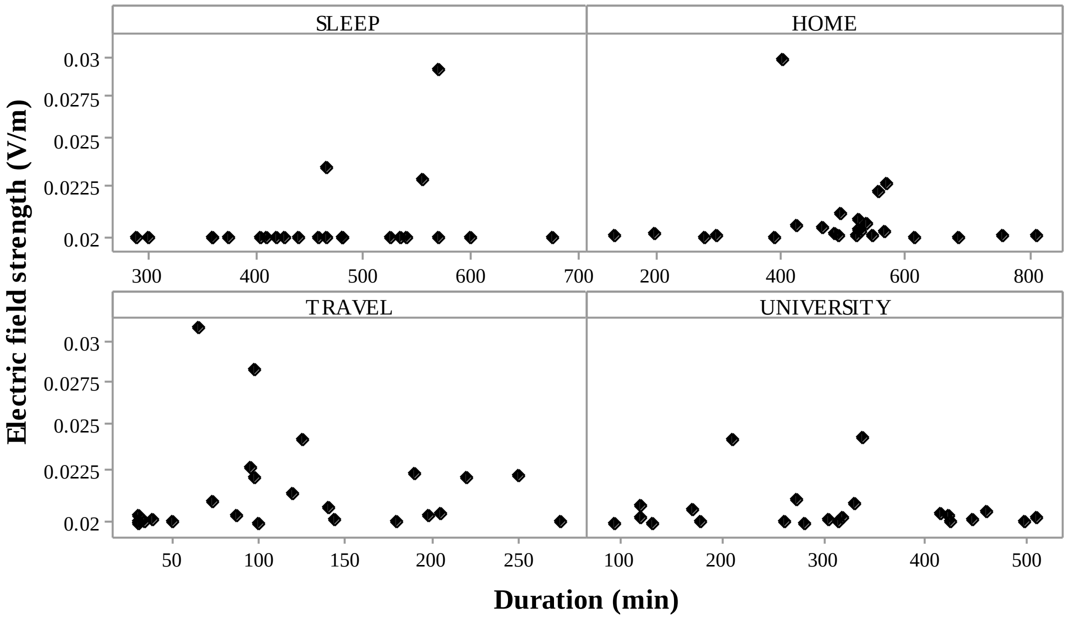

Fig. 4.13: Correlation between TV 3 time-averaged electric field strength and duration.

4.4.4. TV 4 & 5 band temporal and spatial time-averaged RF exposure

Same as TV 3 frequency band RF exposure, power density values from exposure in TV 4 & 5 frequency band is very low and depends mostly on the travel route and location of distance from TV 4 & 5 RF sources.

Exposure pattern in median line in Fig.(4.14) shows that measureable RF exposure mainly recorded in the period between 9 am and 2 pm. Maximum time-averaged exposure is calculated in the hour between 9 am -10 am and equal about 0.11 V/m.

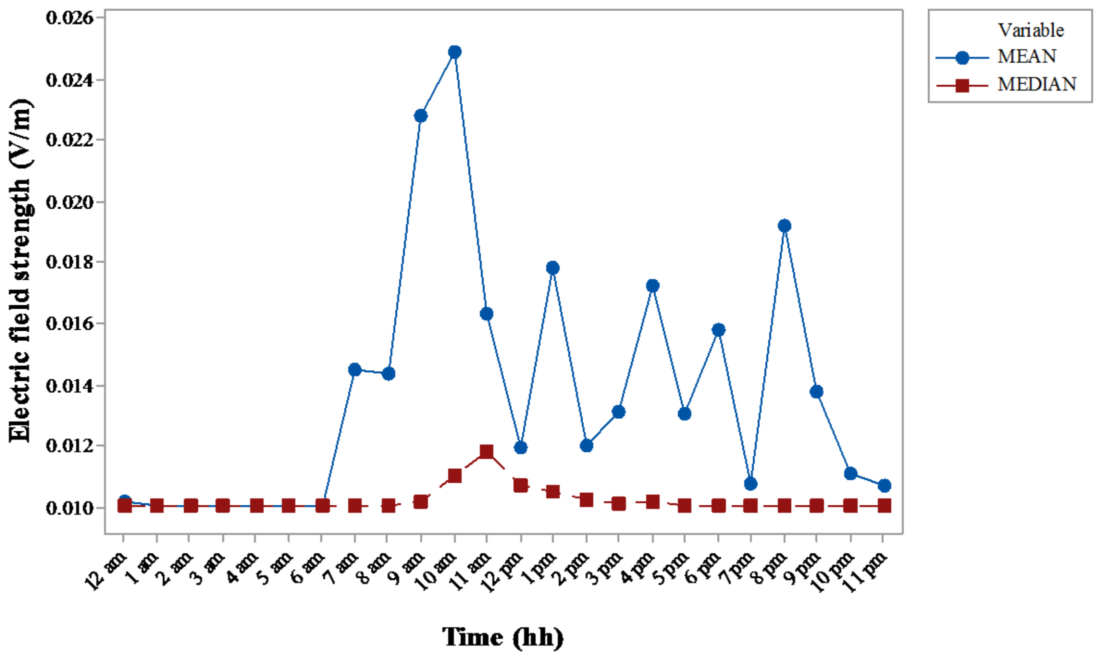

Fig. 4.14: Variation of TV 4&5 time-averaged electric field strength during 24 hours.

In Fig.(4.15), mean RF exposure in university is affected by outliers who were exposed to higher levels of RF radiation in the same frequency band. These levels are noticeable in Fig.(4.14) in period between 9 am and 2 pm where 22 out of 24 volunteers spent their time at university which indicates a nearby source to the location of the university. No additional information about nearby TV 4 & 5 RF sources near volunteers' homes were report as it was impossible to interpret the skewness of mean in home activity. No correlation was found between time-averaged electric field strength with activity duration in any of the categorized activities.

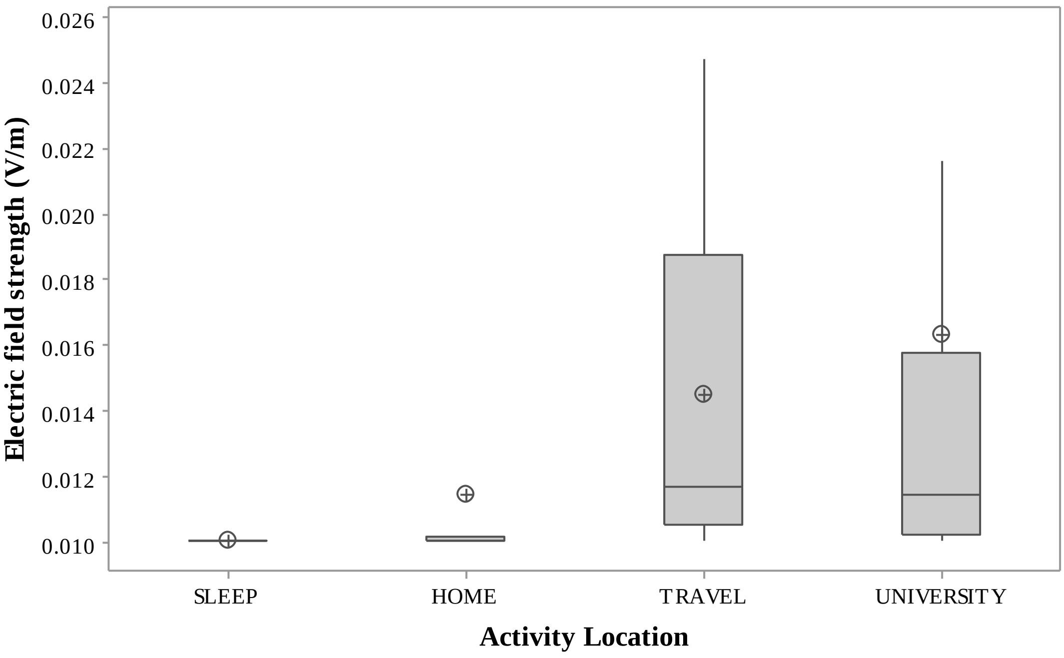

Fig. 4.15: boxplot of TV4 & 5 time-averaged electric field strength during daily activities.

4.4.5. TETRA band temporal and spatial time-averaged RF exposure

Most of the personal RF exposure to TETRA band occurred during daytime at rare occasions. Since there is a high percentage of data below detection limit (Table C.3), any measureable RF exposure readings will greatly increase the time-averaged exposure levels which make it difficult to interpret TETRA band. This applies on other bands with the same condition.

Fig.(4.16) illustrates time-averaged RF exposure during measurement period. Median line shows that exposure remained near detection limit, mean line indicate that volunteers' maximum time-averaged RF exposure spiked the mean in specific periods while the mean remained at minimum during most of the day. Maximum time-averaged exposure is calculated in the hour between 6 pm and 7 pm and equal about 0.07 V/m.

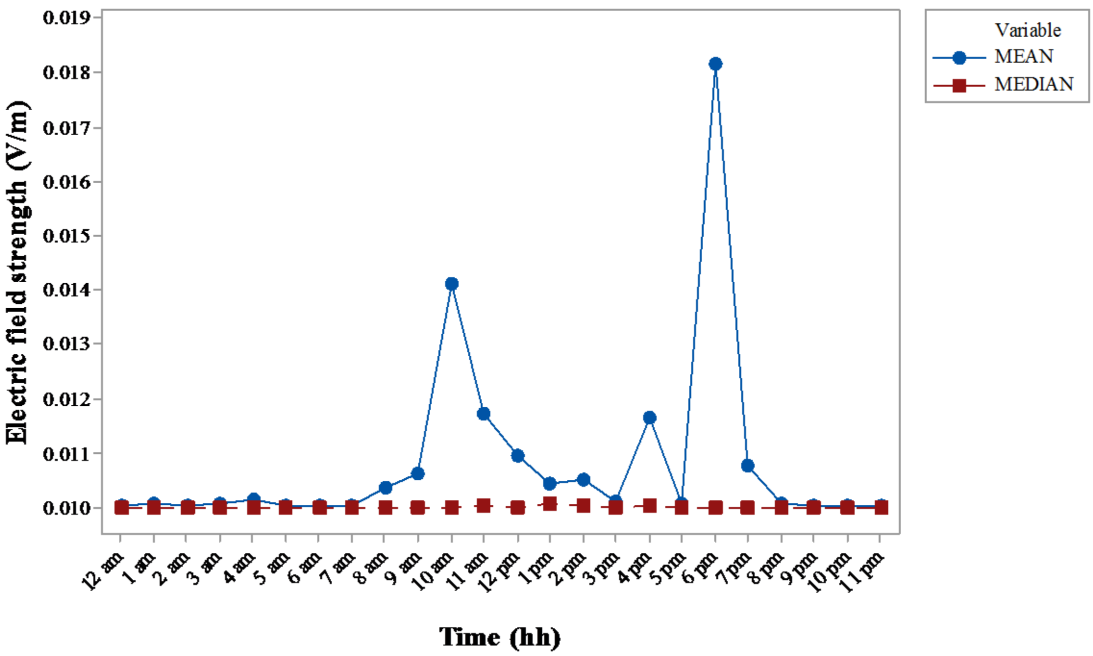

Fig. 4.16: Variation of TETRA time-averaged electric field strength during 24 hours.

In Fig.(4.17), the time-averaged electric field strength is found to be greater during time spent in university. Difference between mean and median indicates that mean is being affected by volunteer number 4 and 20.

The source for this frequency in the West Bank mainly comes from military bases spread across the country. Time-averaged RF exposure in the university is affected by rarely occurred high exposure readings. It's worth noting that an military base stationed on the opposite hill top of Al-Quds University which might be the source for TETRA band exposure since the exposure levels are low which means that TETRA source is not located in the compound. No correlation is found between time-averaged electric field strength with activity duration in any of the categorized activities.

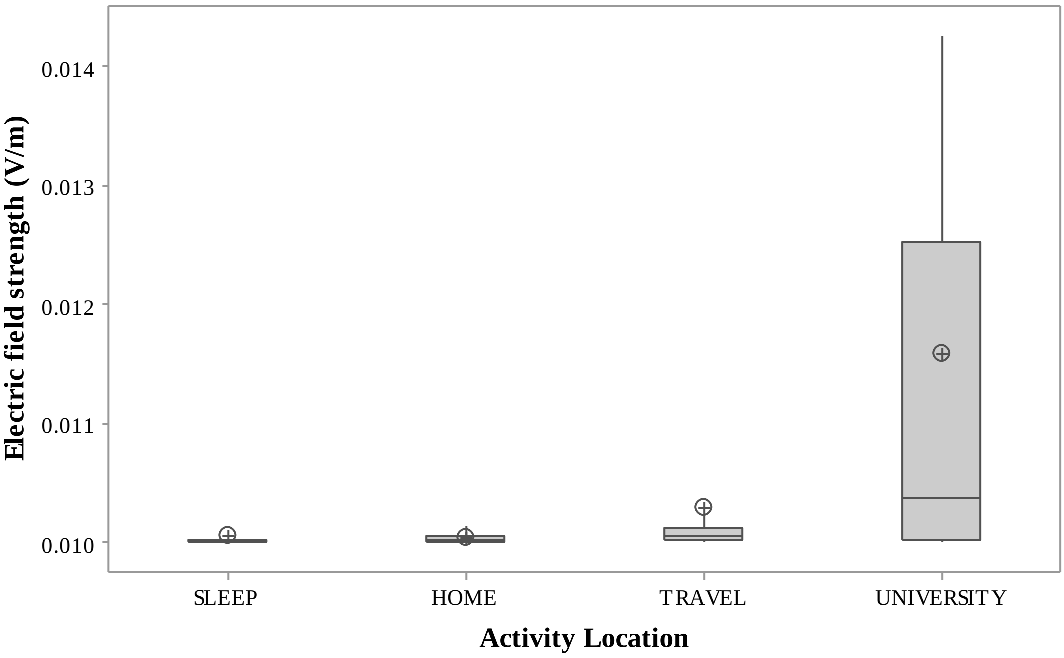

Fig. 4.17: boxplot of TETRA time-averaged electric field strength during daily activities.

4.4.6. GSM 900 (UL) band temporal and spatial time-averaged RF exposure

In Fig.(4.18), median line of time-averaged electric field strength indicates that the increase in RF exposure in GSM 900 (UL) frequency band was limited to periods where volunteers traveled to and from work or university or when they stayed in crowded areas. Maximum time-averaged RF exposure is calculated in the hour between 9 am and 10 am and equal about 1.98 V/m.

During travel, volunteers are expected to ride public transportation with GSM 900 network users which might increase exposure during travel when they set PEM carrier. Fig.(4.19) illustrate the difference between calculated time-averaged electric field strength with and without personal calls. The difference in exposure between Idle and Total status during travel compared to other daily activities is attributed to the low number of data points in the activity compared to the rest.

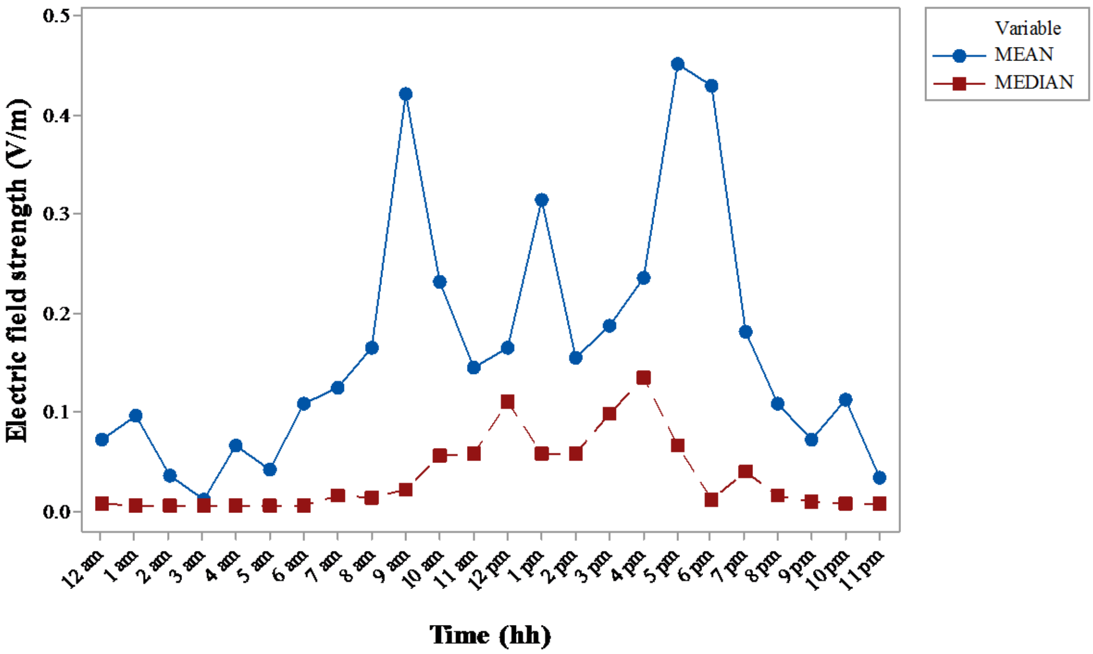

Fig. 4.18: Variation of GSM 900 (UL) time-averaged electric field strength during 24 hours.

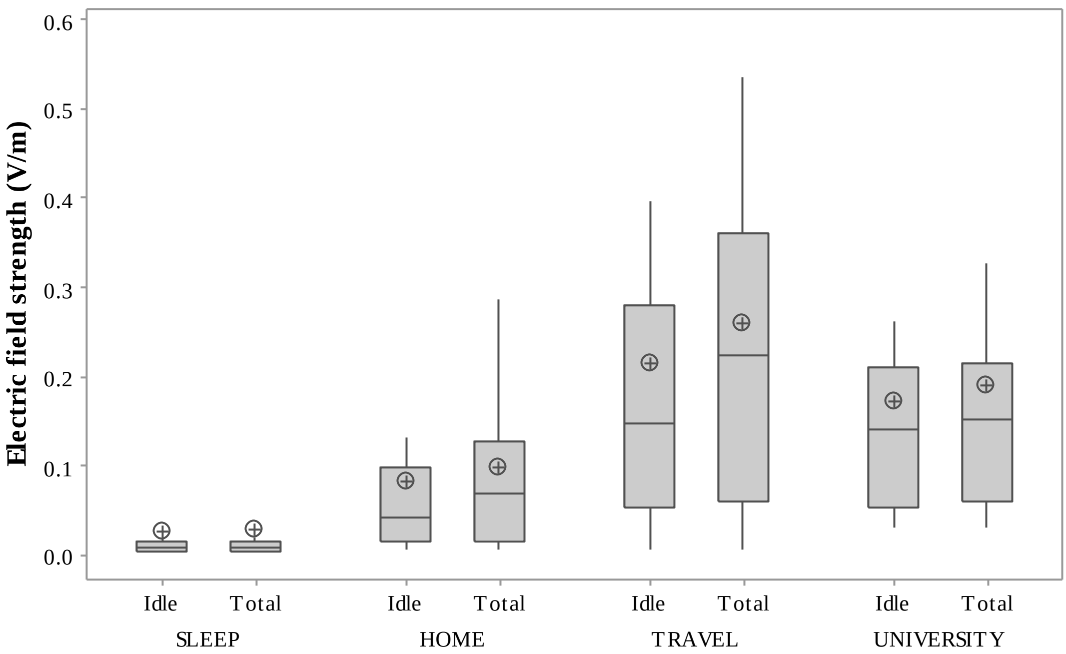

Fig. 4.19: boxplot of GSM 900 (UL) time-averaged electric field strength during daily activities for two data groups (Idle,Total).

Time-averaged electric field strength in GSM 900 (UL) (excluding personal calls data points) positively correlate with time spent in travel activity as shown in Fig.(4.20), this because most of the volunteer used public transportation where they were exposed to nearby RF-EMF emitted from nearby mobile phones operating in the same frequency band.

GSM 900 (UL) personal RF exposure in the other activities depends on various factors rather than duration of activity only (number of people near volunteer, ingoing and outgoing calls occurred near volunteer), Fig.(4.21) categorized time-averaged electric field strength according to volunteers active SIM card during measurement period. 4 volunteers didn't carry GSM 900 SIM card, 19 volunteers carried one and 1 volunteer carried two active SIM card during measurement period. Data points during calls are removed from datasets Mean value of tim-averaged electric field strength for volunteers' who didn't carry a SIM card is 0.08 V/m and for who carried an active SIM card is 0.15 V/m. In Fig.(4.20), weak positive correlation (R-sq =0.43) is found in the correlation between volunteers' time-averaged electric field strength and travel activity duration. Personal RF exposure depends mainly on travel duration more than personal call duration after investigation of personal mobile call during travel as there is no correlation between personal RF exposure in GSM 900 (UL) and call duration during travel period. Fig.(4.22) compares volunteers' time-averaged electric field strength during travel activity when they used different travel methods. In the same figure, time-averaged electric field strength calculated for 10, 18 and 11 periods where volunteers used private, public and on foot travel methods, respectively. Volunteers exposed to higher levels of RF-EMF when they used public transportation with maximum exposure of 1.33 V/m.

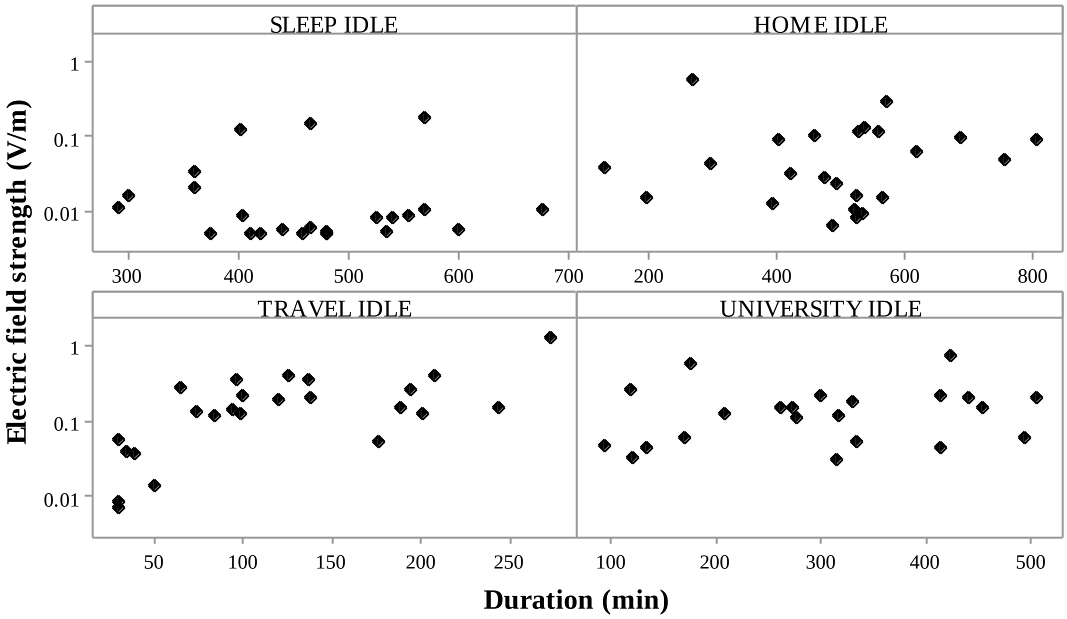

Fig. 4.20: Correlation between GSM 900 (UL) time-averaged electric field strength and duration.

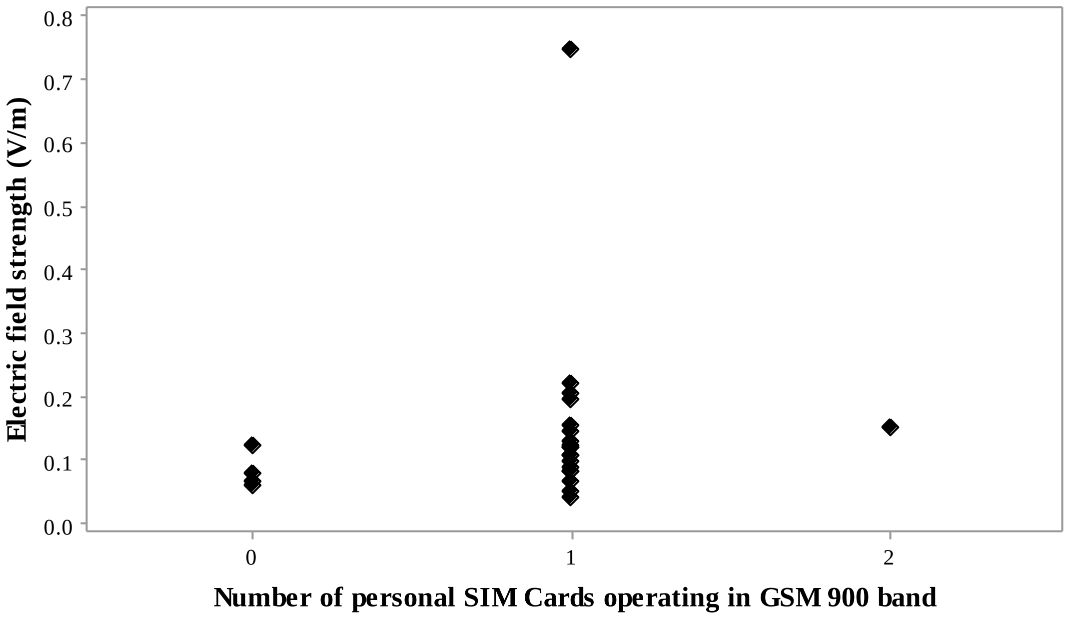

Fig. 4.21: GSM 900 (UL) personal RF exposure (idle) Vs. number of personal GSM 900 SIM cards.

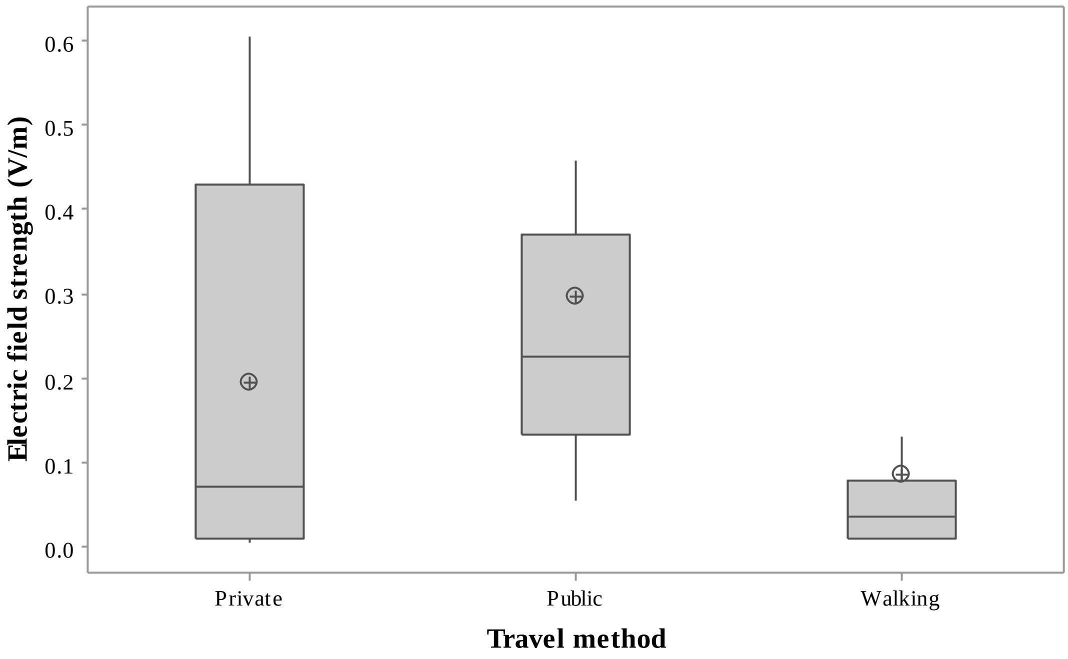

Fig. 4.22: boxplot of GSM 900 (UL) personal RF exposure categorized by travel method.

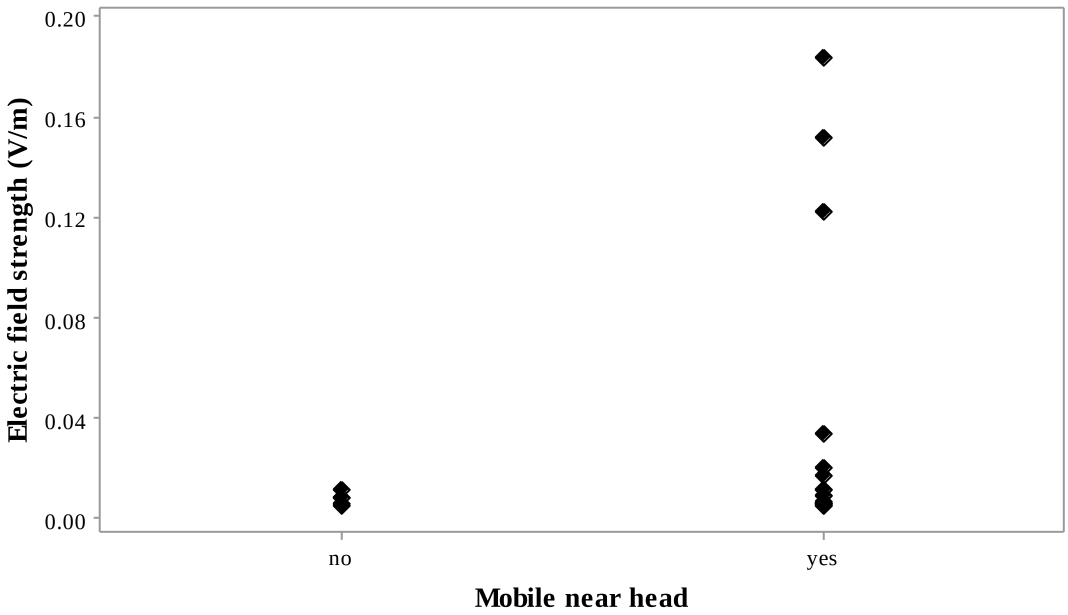

Fig. 4.23: GSM 900 (UL) personal RF exposure during sleep (idle) in the presence and absence of mobile phone near head.

In Fig.(4.23), personal RF exposure in GSM 900 (UL) band comparison between volunteers who put their personal mobile phones near their heads during sleep period showed that personal exposure levels in this band are higher in cases where mobile phone was near volunteers' heads with mean value of 0.032 V/m compared to 0.007 V/m in cases where volunteers put away their mobile phones during sleep.

4.4.7. GSM 900 (DL) band temporal and spatial time-averaged RF exposure

Fig.(4.24) shows that time-averaged electric field strength peaked at middle of the day where most of the volunteers either travelled or attended university where even the minimum time-averaged RF exposure levels between 12 am and 2 pm are three time higher than the rest of the day. Mobile base stations installed on university building's rooftops increased personal RF exposure. Maximum time-averaged RF exposure is calculated in the hour between 10 pm and 11 pm and equal about 1.04 V/m.

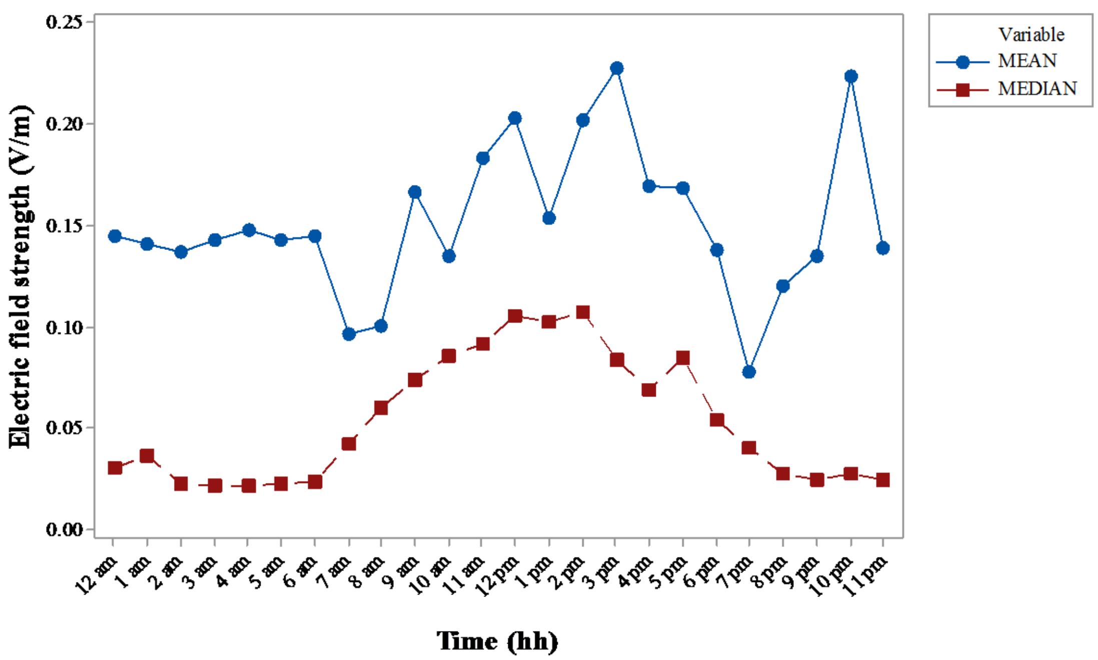

Fig. 4.24: Variation of GSM 900 (DL) time-averaged electric field strength during 24 hours.

Handover of signal between mobile base stations while moving also increase exposure in GSM 900 (DL) band. In university where it is expected for volunteers to attend lectures and stay in crowded areas, personal RF exposure is higher compared to exposure during time spent at home or sleep, this applies for GSM 900 (UL) frequency band as well.

By comparing time-averaged electric field strength with and without personal call periods in Fig.(4.25), personal RF exposure to GSM 900 (DL) frequency band does not depend on personal calls. GSM 900 (DL) personal RF exposure does not correlate with time spent in daily activities.

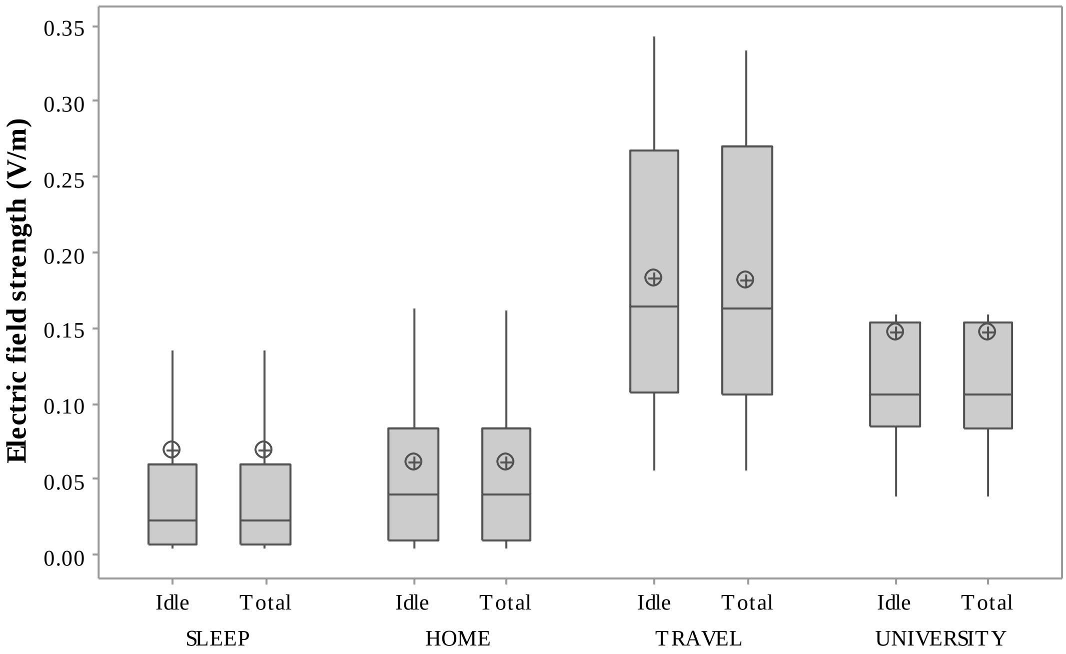

Fig. 4.25: boxplot of GSM 900 (DL) time-averaged RF exposure during daily activities for two data groups (Idle,Total).

Fig.(4.26) categorized time-averaged electric field strength according to volunteers' active GSM 900 SIM card during measurement period. Data points during calls were removed from datasets. Mean value of exposure levels for volunteers' who didn't carry a SIM card is 0.11 V/m and for who carried an active SIM card is 0.13V/m.

Fig.(4.27) compares volunteers' time-averaged electric field strength during travel activity when they used different travel methods. In the same figure, time-averaged electric field strength calculated for 10, 18 and 11 periods where volunteers used private, public and on foot travel methods, respectively. Median values indicate that volunteers exposed to higher levels of RF-EMF when they used public transportation. However, mean value of walking travel method and maximum time-averaged electric field strength equals about 0.5 V/m calculated when volunteer travelled on foot. Volunteers who walked travelled for shorter periods and might exposed directly to RF-EMF from base stations located on buildings' rooftops.

In Fig.(4.28), personal RF exposure in GSM 900 (UL) band comparison between volunteers who put their personal mobile phones near their heads during sleep, results showed that personal exposure levels in this band are higher in cases where mobile phone was near volunteers' heads with mean value of 0.08 V/m compared to 0.01 V/m in cases where volunteers put away their mobile phones during sleep.

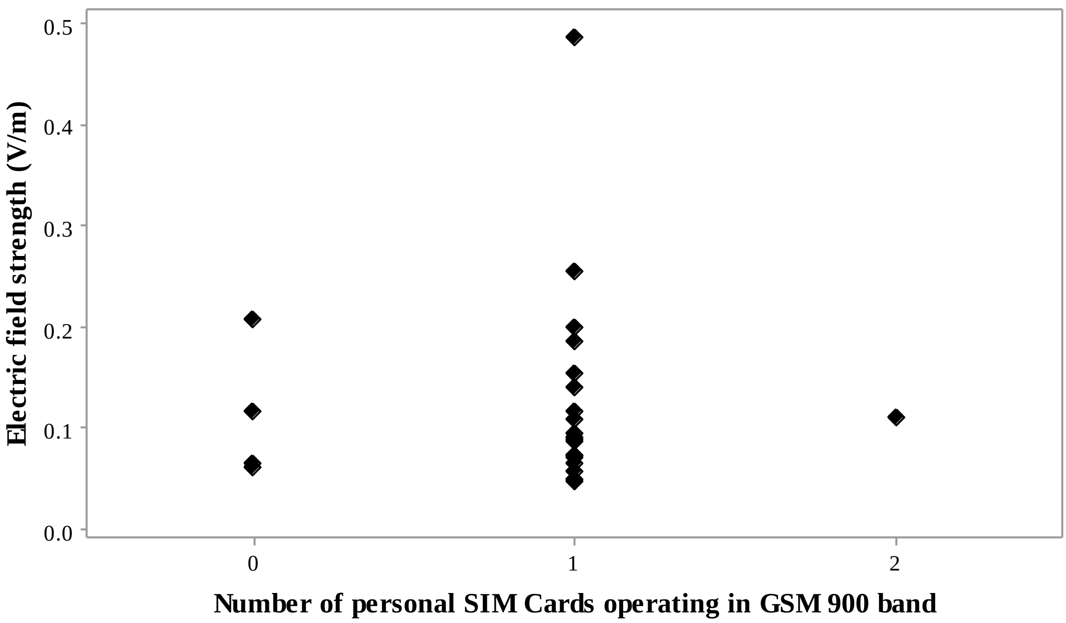

Fig. 4.26: GSM 900 (DL) personal RF exposure (idle) Vs. number of personal GSM 900 SIM cards.

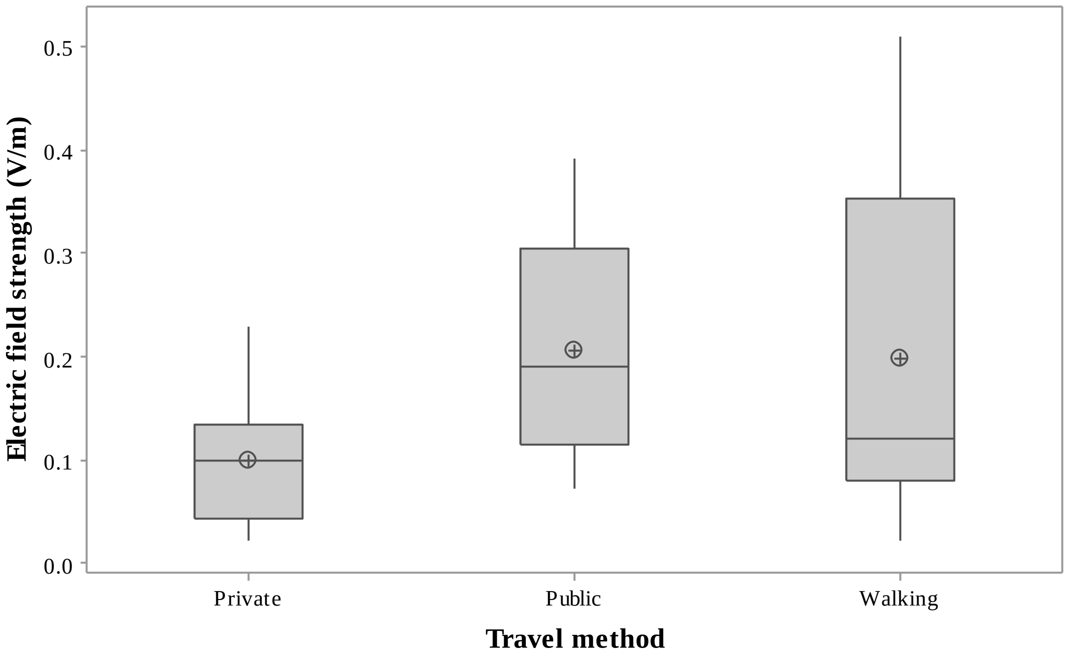

Fig. 4.27: boxplot of GSM 900 (DL) personal RF exposure categorized by travel method.

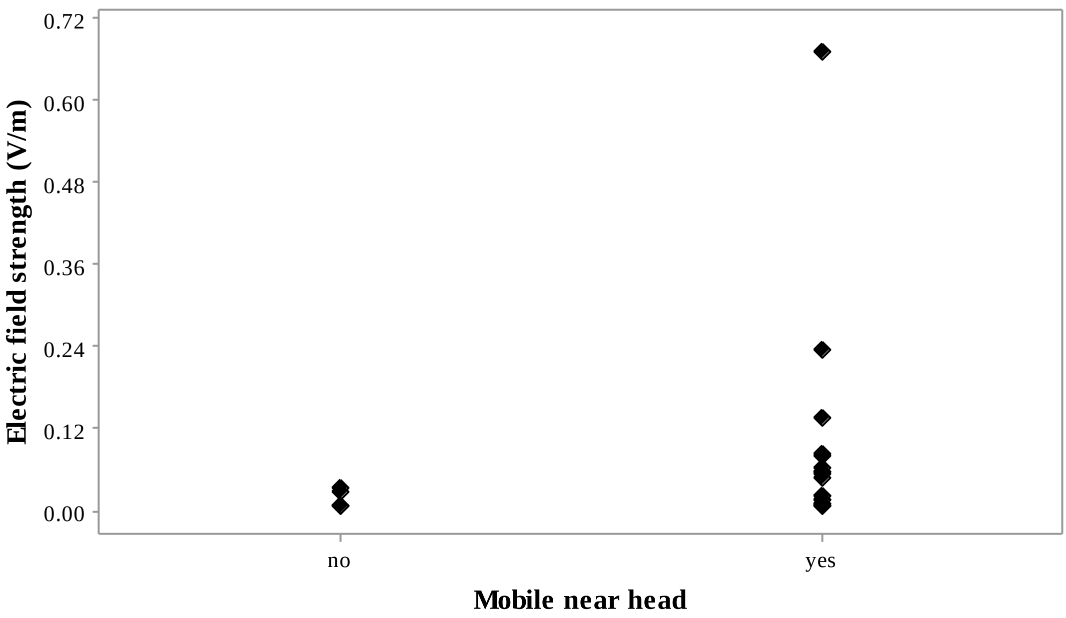

Fig. 4.28: GSM 900 (DL) personal RF exposure during sleep (idle) in the presence and absence of mobile phone near head.

4.4.8. GSM 1800 (UL) band temporal and spatial time-averaged RF exposure

Temporal pattern of time-averaged electric field strength median line for both GSM 1800 (UL) frequency bands in Fig.(4.29) shows increase of personal RF exposure to these frequency bands sources during daytime and decrease to near detection limit levels during evening and early morning hours. Maximum time-averaged RF exposure is calculated in the hour between 11 am and 12 am and equal about 0.63 V/m.

Time-averaged electric field strength for GSM 1800 (UL) is higher during travel and university as shown in figure 4.30. However, exposure levels are still much lower than GSM 900 band because there are more people who uses GSM 900 network than GSM 1800 and due to fewer numbers of GSM 1800 base stations in the West Bank cities compared to GSM 900 network. Only 9 volunteers carried operational GSM 1800 SIM card.

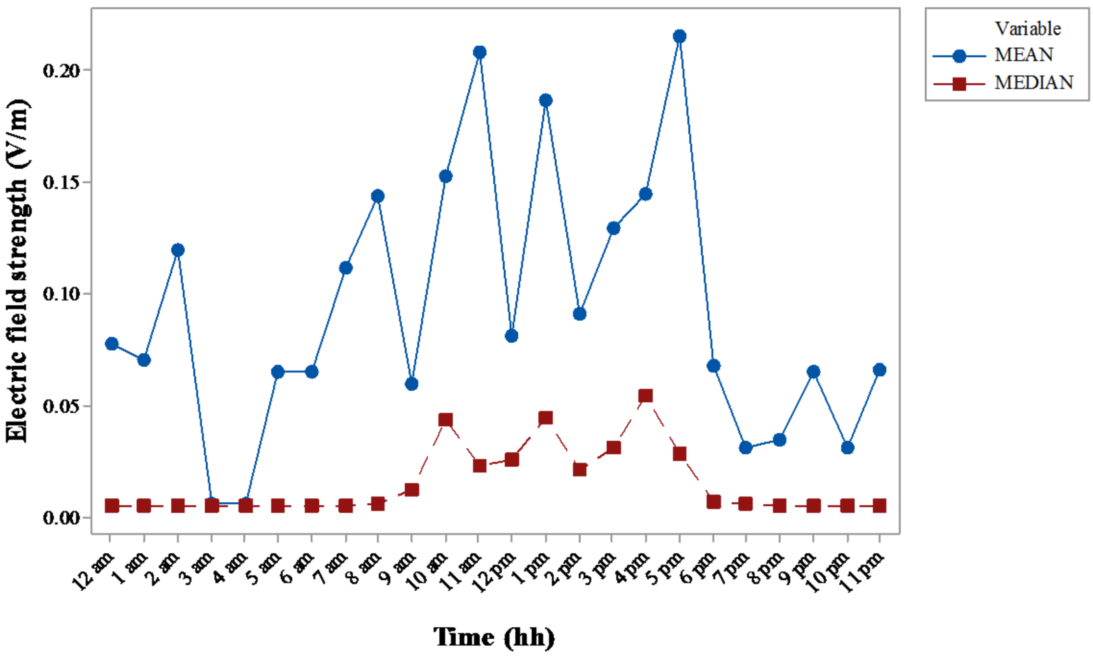

Fig. 4.29: Variation of GSM 1800 (UL) time-averaged electric field strength during 24 hours.

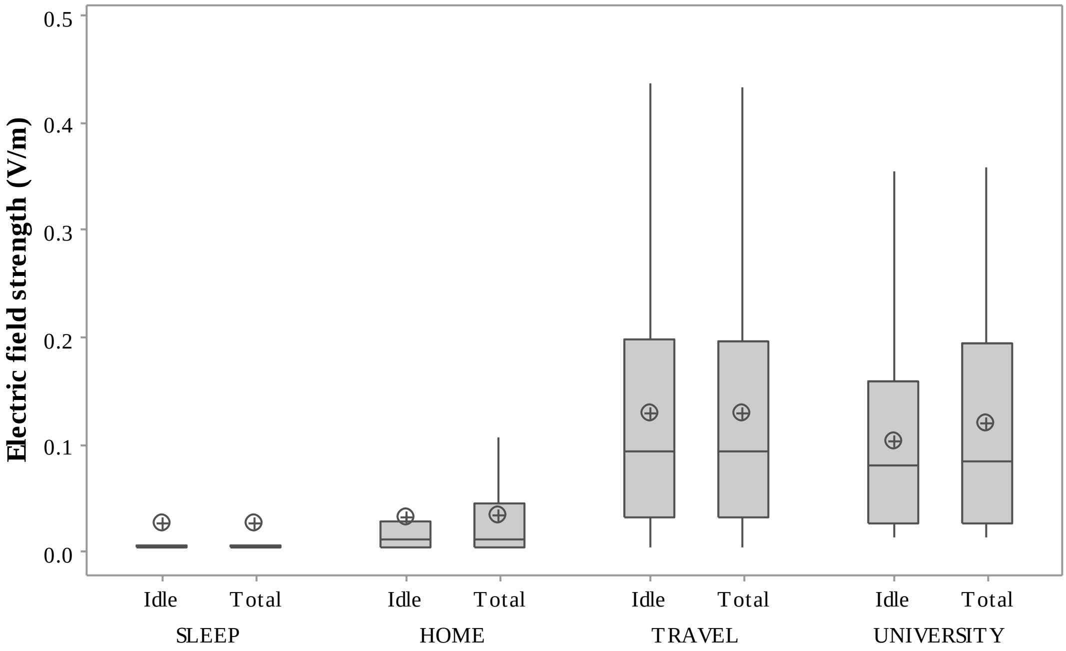

Fig. 4.30: boxplot of GSM 1800 (UL) time-averaged RF exposure during daily activities for two data groups (Idle,Total).

In Fig.(4.30), difference between idle and total time-averaged electric field strength mean value is noticeable only in university activity location.

Weak positive correlation (R-sq =0.29) is found in the correlation between volunteers' time-averaged electric field strength and activity duration and no correlation is found between personal RF exposure during travel and personal call duration as shown in Fig.(4.31).

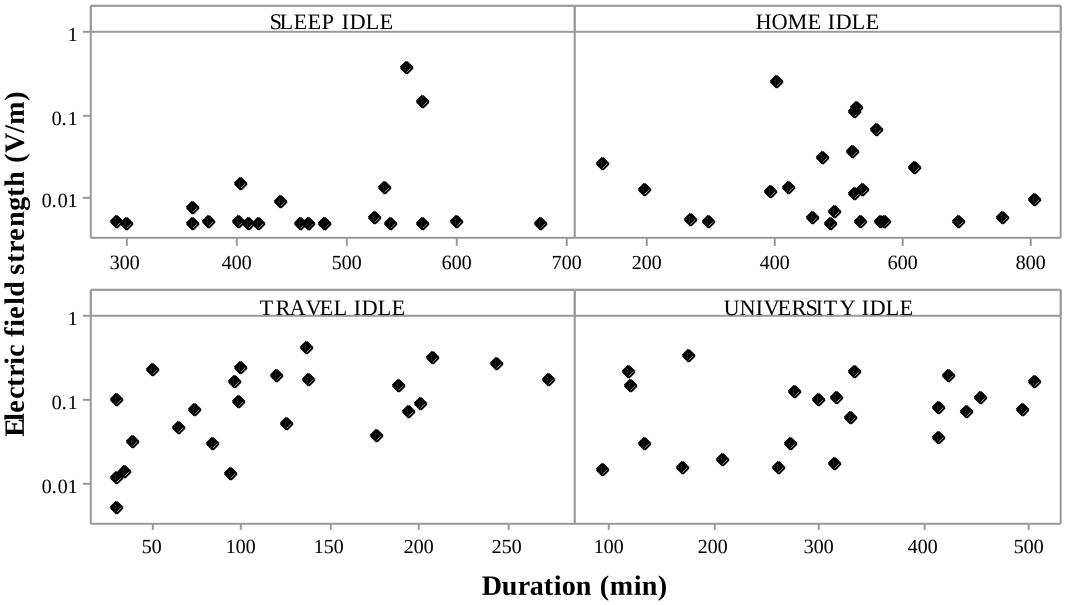

Fig. 4.31: Correlation between GSM 1800 (UL) time-averaged electric field strength and duration.

Fig.(4.32) categorized time-averaged electric field strength according to volunteers' active GSM 1800 SIM card during measurement period. 9 volunteers carried GSM 1800 SIM card. Data points during calls were removed from datasets. Mean value of exposure levels for volunteers' who didn't carry a SIM card is 0.07 V/m and for who carried an active SIM card is 0.1 V/m.

Fig.(4.33) compares volunteers' time-averaged electric field strength during travel activity when they used different travel methods. In the same figure, time-averaged electric field strength calculated for 10, 18 and 11 periods where volunteers used private, public and on foot travel methods, respectively. Volunteers exposed to higher levels of RF-EMF when they used public transportation with maximum exposure of 0.43 V/m.

In Fig.(4.34), personal RF exposure in GSM 1800 (UL) band comparison between volunteers who put their personal mobile phones near their heads during sleep, results showed that personal exposure levels in this band are higher in cases where mobile phone was near volunteers' heads with mean value of 0.03 V/m compared to 0.005 V/m in cases where volunteers put away their mobile phones during sleep, which is near detection limit of the personal exposure meter.

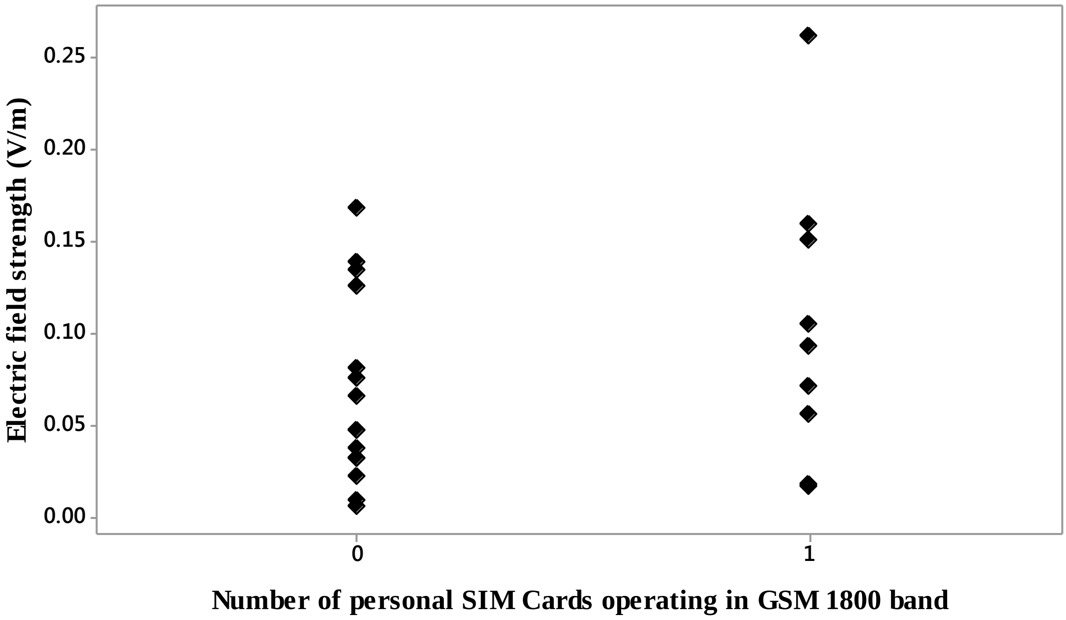

Fig. 4.32: GSM 1800 (UL) personal RF exposure (idle) Vs. number of personal GSM 1800 SIM cards.

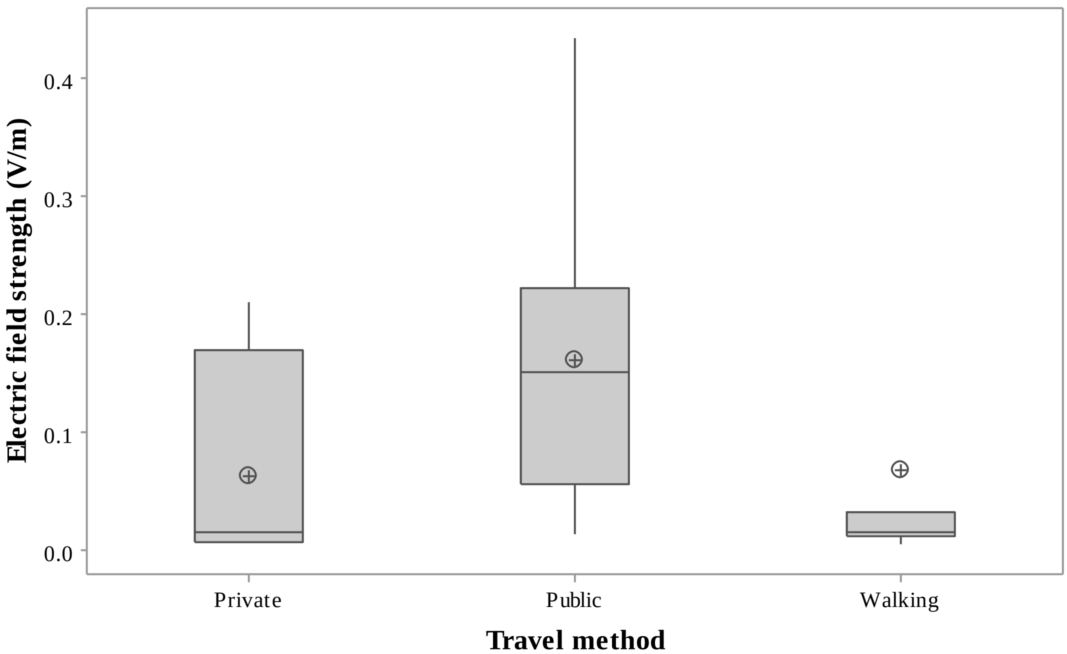

Fig. 4.33: boxplot of GSM 1800 (UL) personal RF exposure categorized by travel method.

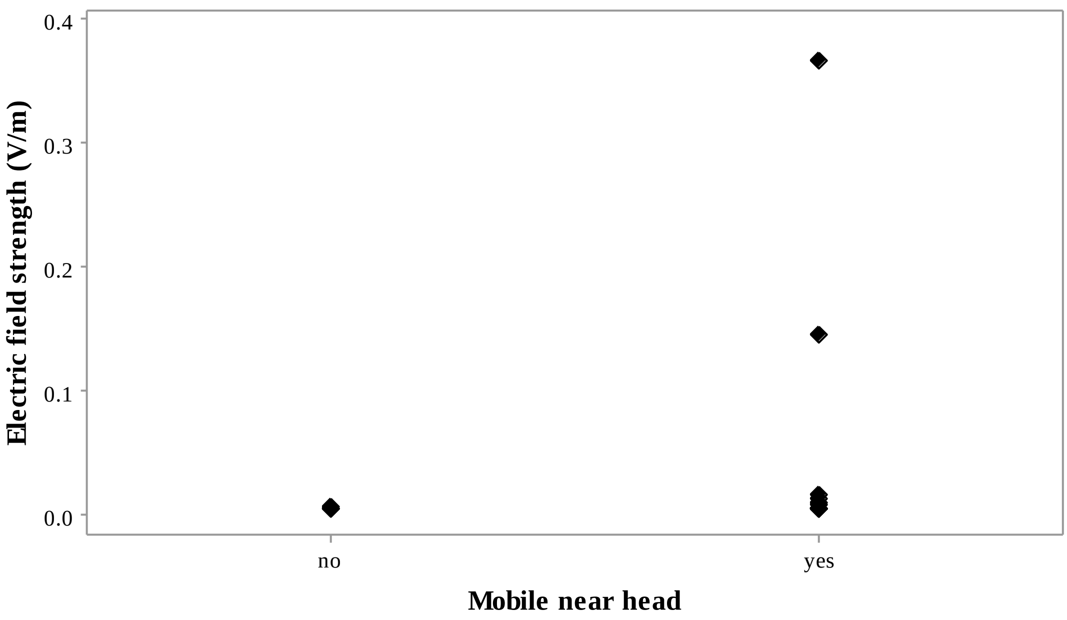

Fig. 4.34: GSM 1800 (UL) personal RF exposure during sleep (idle) in the presence and absence of mobile phone near head.

4.4.9. GSM 1800 (DL) band temporal and spatial time-averaged RF exposure

Temporal pattern of time-averaged electric field strength median line for GSM 1800 (DL) frequency bands in Fig.(4.35) shows increase of personal RF exposure to these frequency bands sources during daytime and decrease to near detection limit levels during evening and early morning hours. Fig.(4.36) shows temporal variation of time-averaged electric field strength during measurement period. Maximum time-averaged RF exposure is calculated in the hour between 6 pm and 7 pm and equal about 0.23 V/m. minimum exposure levels remains near detection limit of the personal exposure meter.

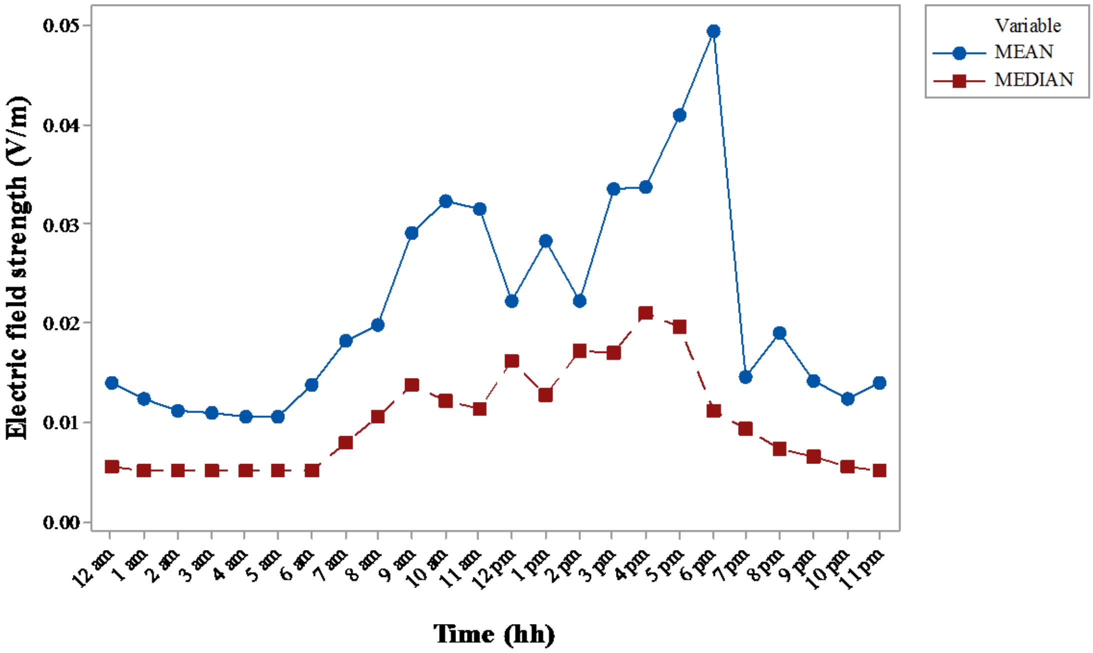

Fig. 4.35: Variation of GSM 1800 (DL) time-averaged electric field strength during 24 hours.

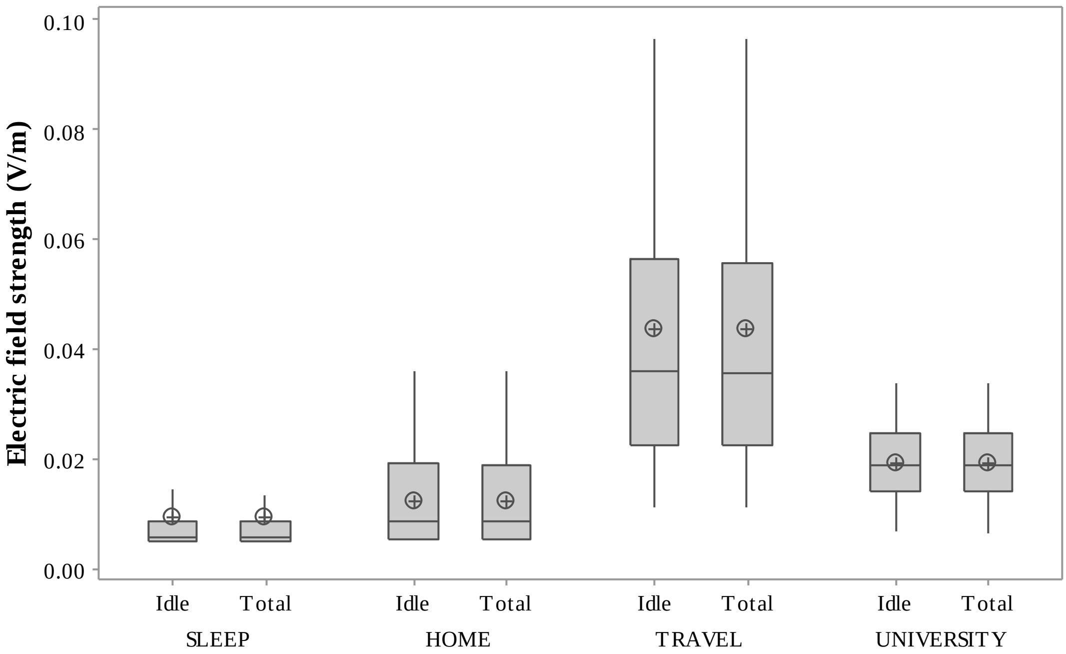

Fig. 4.36: boxplot of GSM 1800 (DL) time-averaged RF exposure during daily activities for two data groups (Idle,Total).

Same as GSM 900 (DL) band comparison between personal mobile phone status (idle and total) time-averaged electric field strength, marginal difference between idle and total status of mobile phone during measurement period. However, during travel, time-averaged electric field strength while mobile phone was idle is higher than total. This might be caused by time shift between personal exposure meter and volunteers' mobile phone clock, small number of data points during travel activity also increased the difference caused by this kind of inaccuracy. No correlation was found between time-averaged electric field strength and activity duration.

Fig.(4.37) categorized time-averaged electric field strength according to volunteers' active GSM 1800 SIM card during measurement period. Data points during calls were removed from datasets. Mean value of exposure levels for volunteers' who didn't carry a SIM card is 0.023 V/m and for who carried an active SIM card is 0.022 V/m.

Fig.(4.38) compares volunteers' time-averaged electric field strength during travel activity when they used different travel methods. In the same figure, time-averaged electric field strength calculated for 10, 18 and 11 periods where volunteers used private, public and on foot travel methods, respectively. Volunteers exposed to higher levels of RF-EMF when they used public transportation with maximum exposure of 0.13 V/m.

In Fig.(4.39), personal RF exposure in GSM 1800 (DL) band comparison between volunteers who put their personal mobile phones near their heads during sleep, results showed that personal exposure levels in this band are higher in cases where mobile phone was near volunteers' heads with mean value of 0.01 V/m compared to 0.008 V/m in cases where volunteers put away their mobile phones during sleep, which is near detection limit of the personal exposure meter.

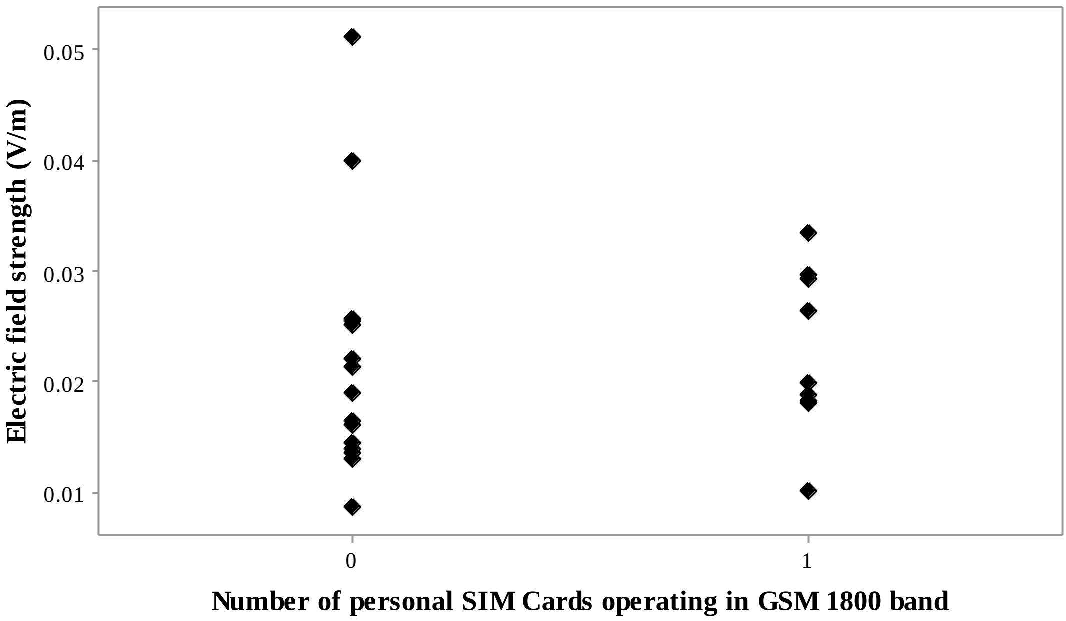

Fig. 4.37: GSM 1800 (DL) personal RF exposure (idle) Vs. number of personal GSM 1800 SIM cards.

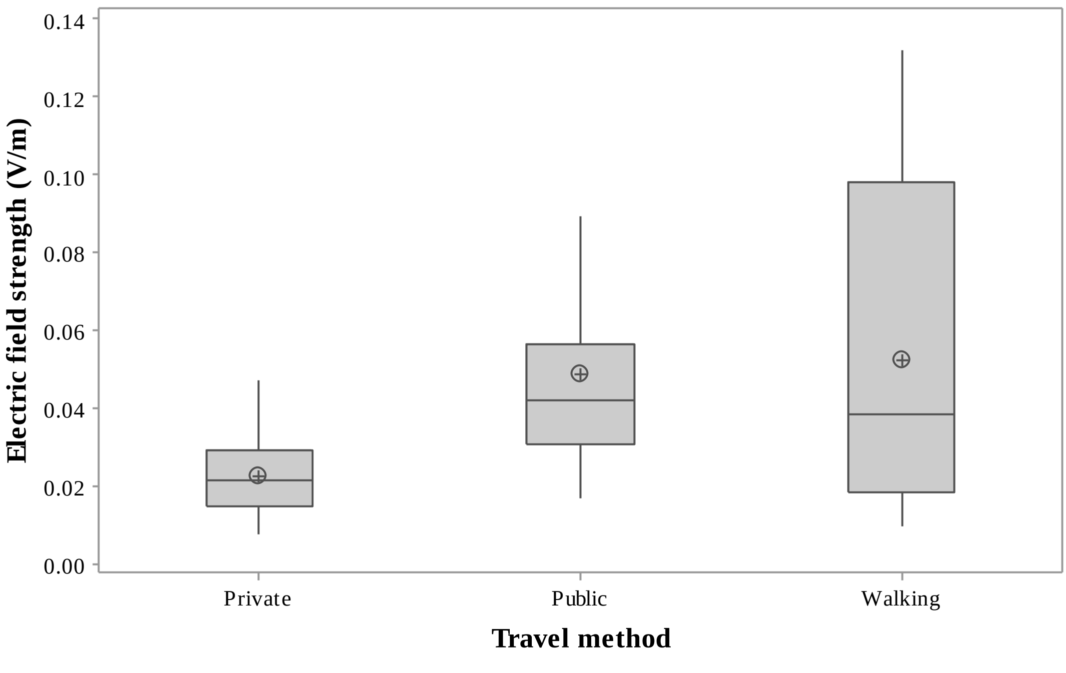

Fig. 4.38: boxplot of GSM 1800 (DL) personal RF exposure categorized by travel method.

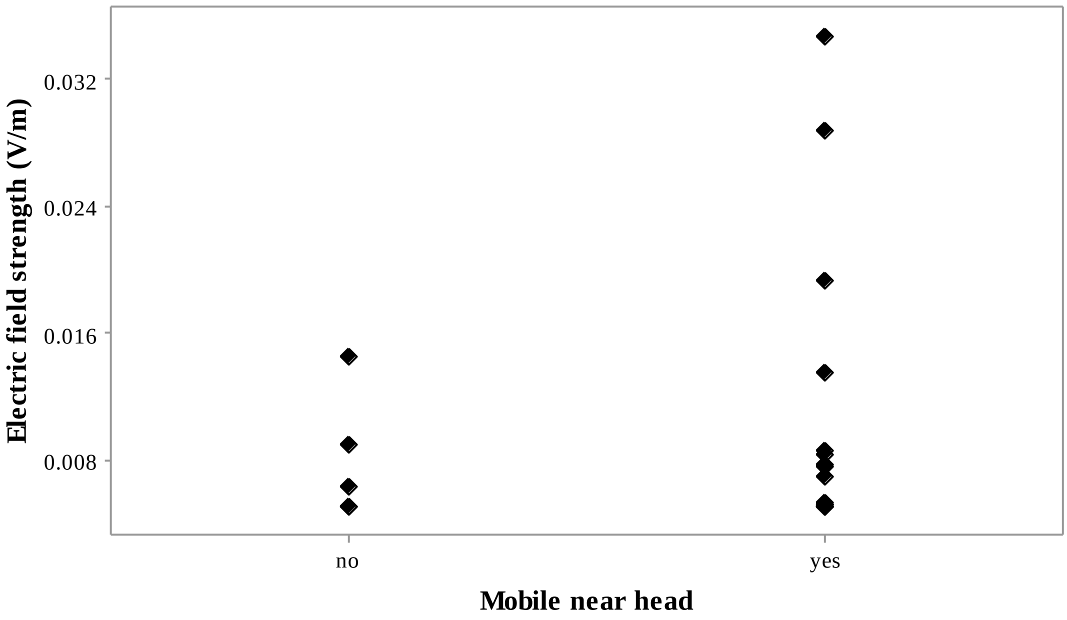

Fig. 4.39: GSM 1800 (DL) personal RF exposure during sleep (idle) in the presence and absence of mobile phone near head.

4.4.10. DECT band temporal and spatial time-averaged RF exposure

Personal RF exposure from DECT is the highest during travel (Fig. 4.40) which is abnormal since DECT is considered an indoor source of RF-EMF with short range (50 meter max). Maximum time-averaged RF exposure is calculated in the hour between 11 am and 12 pm and equal about 0.71 V/m. volunteers exposed to DECT sources in the evening during travel from university/work to their homes or to other locations such as coffee shops as shown in Fig. (4.41).

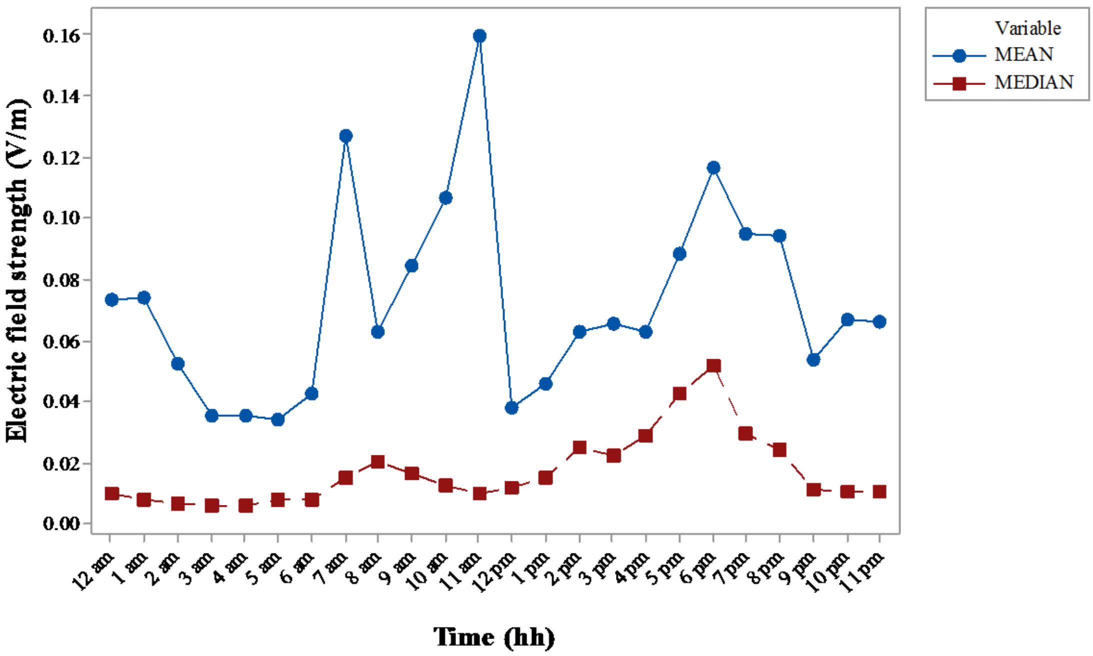

Fig. 4.40: Variation of DECT time-averaged electric field strength during 24 hours.

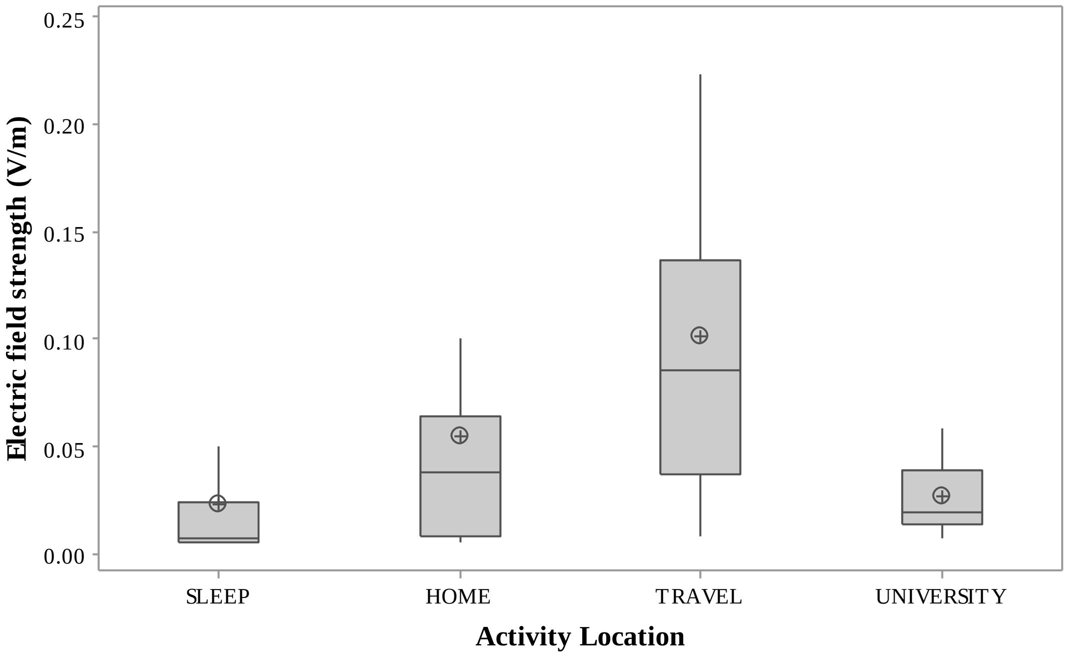

Fig. 4.41: boxplot of DECT time-averaged RF exposure during daily activities

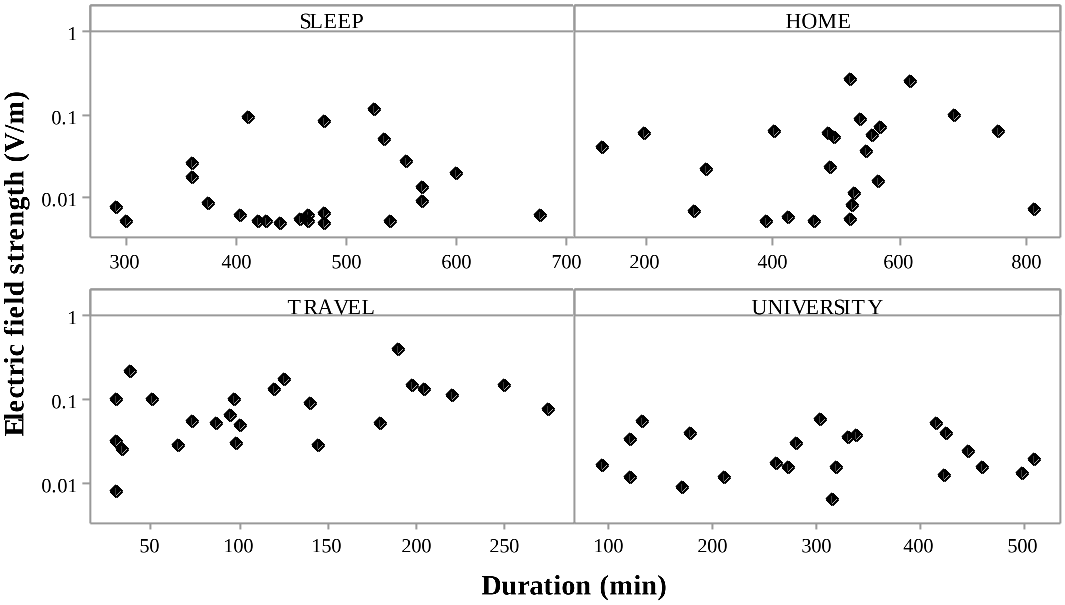

Fig. 4.42: Correlation between DECT time-averaged electric field strength and duration.

Due to rare volunteers' reported use of DECT phones during measurement period, exposure from DECT phones depended on volunteers distance from the phone base station in home and during bed time. During travel, there is a weak positive correlation between time-averaged electric field strength and travel duration as illustrated in Fig.(4.42).

Time-averaged RF exposure is calculated and categorized according to the presence of wireless DECT phones in study volunteers' homes. Unfortunately, it wasn't possible to record DECT call logs during measurement duration.

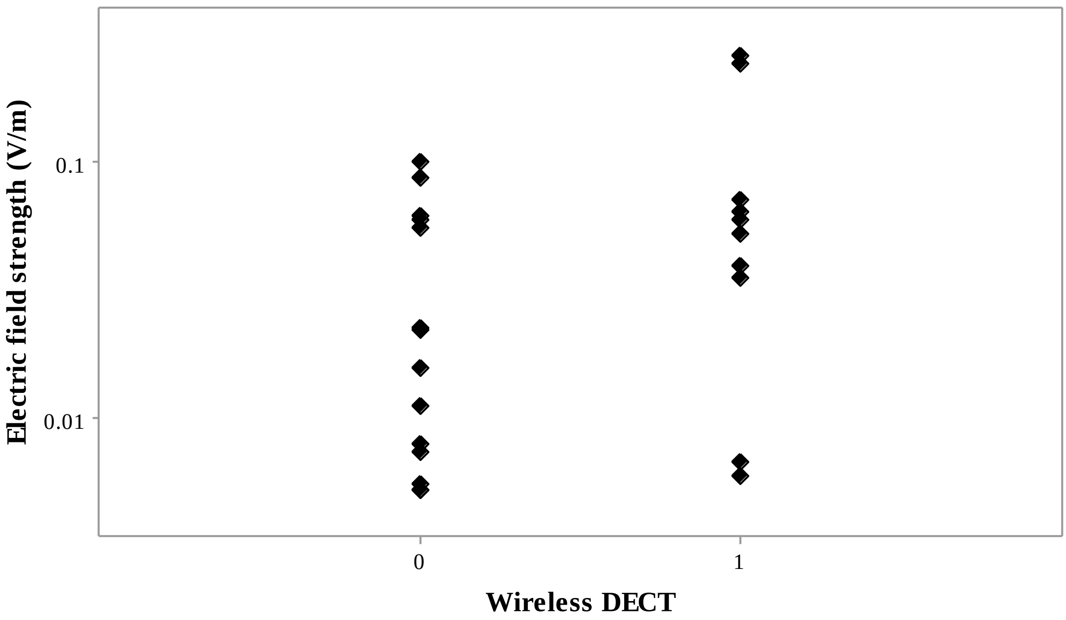

Fig. 4.43: DECT band time-averaged electric field strength (HOME) in the absence and presence of DECT phone.

Fig.(4.43) illustrate the comparison between time-averaged electric field strength in the presence and absence of DECT phones in volunteers' homes. The mean RF exposure level for volunteers without operational DECT phone in their homes equal 0.03 V/m and mean RF exposure level for volunteers with operational DECT phone in their homes equal 0.08 V/m, the maximum time-averaged electric field strength level in home location equal 0.27 V/m. it's worth noting that the two volunteers in the second group (with wireless DECT) whose time-averaged electric field strength levels higher than the others, spent their time at home near wireless DECT phone base station.

Most of study volunteers who owns DECT phones in their homes exposed to higher dose of EM radiation compared to those who doesn't own one. There is no clear explanation why there is variation in RF exposure levels between study volunteers who does not own a DECT phone.

In Fig.(4.44), scatter plot of DECT time-averaged electric field strength with time spent in home for every volunteer show no correlation between time spent in home and time-averaged electric field strength for the two groups of volunteers.

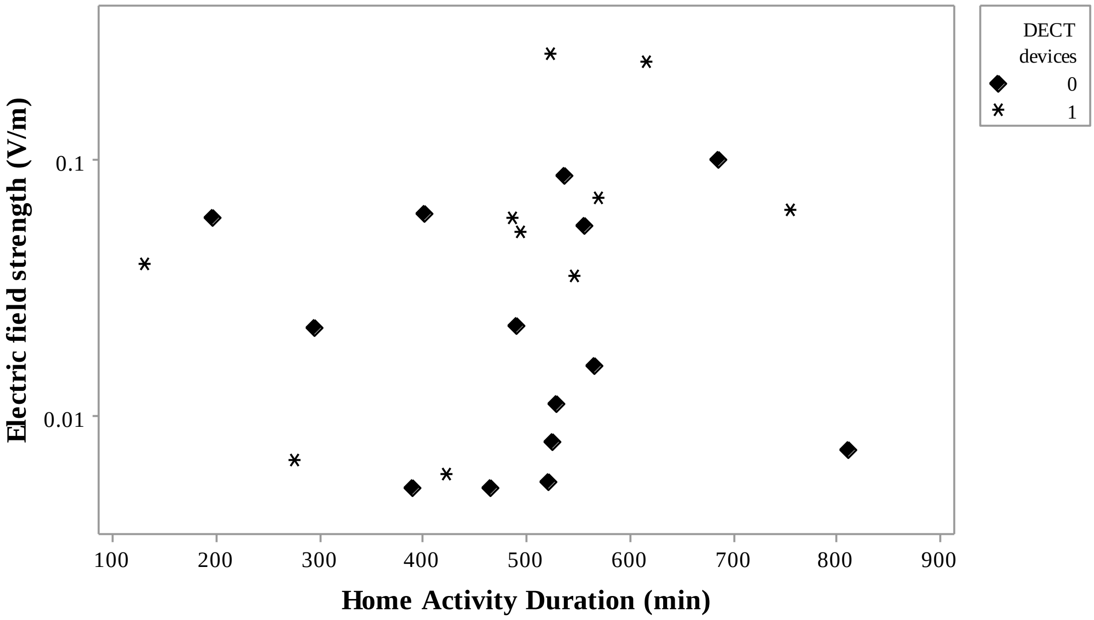

Fig. 4.44: DECT band time-averaged electric field strength in (HOME) versus activity duration (log base 10).

While there is a negative correlation between time-averaged electric field strength of indoor RF sources and time spent in travel activity as expected, indoor RF sources exposure pattern doesn't apply on DECT band time-averaged electric field strength correlation with travel duration. The mean value of time-averaged electric field strength is the highest in travel activity (Fig. 4.41), and there is a weak positive correlation between travel activity time-averaged RF exposure and activity duration (Fig. 4.45). Previous technical reports and scientific papers issued the problem of interference between DECT and GSM 1800 (DL) (Frei, 2009a), and (ERC, 2000) and interference between DECT and UMTS (UL) frequency band (European Telecommunications Standards Institute, 2013). The interference is most likely to occur during travel between any two Palestinian governorates since 2.5 G and 3G base stations are not located in Palestinian areas.

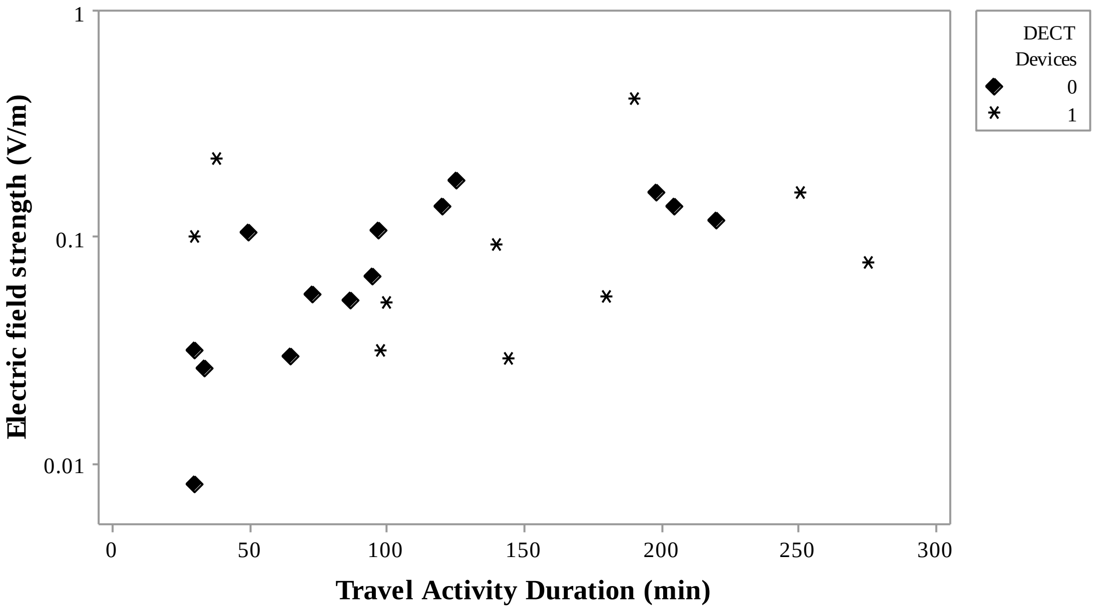

Fig. 4.45: Correlations between DECT time-averaged electric field strength (log base 10) and duration of (TRAVEL) activity.

4.4.11. UMTS 2100 (UL) bands temporal and spatial time-averaged RF exposure

The mean personal RF exposure remained at low levels during measurement period due to the absence of 3G base stations in the West Bank cities and the low number of 3G network users.

The mean value of volunteers' time-averaged electric field strength in UMTS 2100 (UL) band during different daily activities is affected by two volunteers (number 2 and 7) who carried and used 3G mobile phones during measurement period, their personal exposure to UMTS 2100 (UL) band is higher compared to other volunteers. In Fig.(4.46), mean line was affected by usage of 3G internet service during daytime. Maximum time-averaged RF exposure is calculated in the hour between 6 pm and 7 pm and equal about 0.65 V/m, and minimum time-averaged RF exposure remained near detection limit.

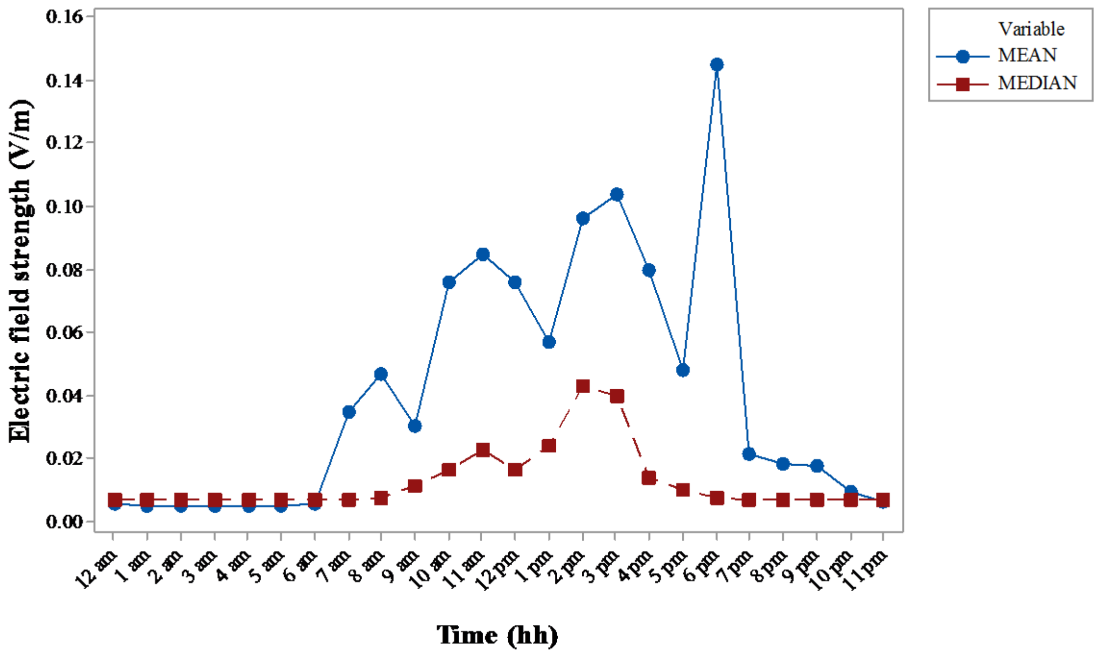

Fig. 4.46: Variation of UMTS 2100 (UL) time-averaged electric field strength during 24 hours.

Mean value of time-averaged electric field strength is affected by maximum exposure levels during travel where volunteers exposed to RF-EMF from people near them while riding transportation or when they remained in crowded areas in Al-Quds University different activities except during sleep (Fig. 4.47).

Fig.(4.48) shows that regardless of time spent in any activity location, personal phones operating in 3G network are the main source of RF-EMF in UMTS 2100 (UL) band. The difference between time-averaged power density for volunteers number 2 and 7 and other volunteers is more obvious due to their isolation from external factors affecting the personal exposure levels.

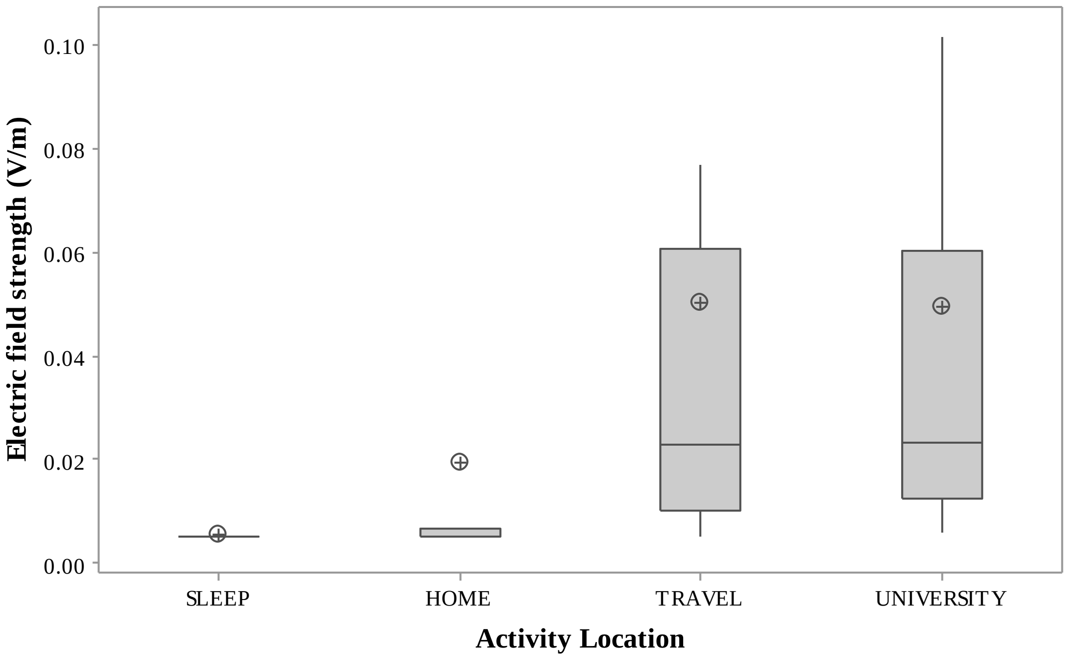

Fig. 4.47: boxplot of time-averaged UMTS 2100 (UL) RF exposure during daily activities.

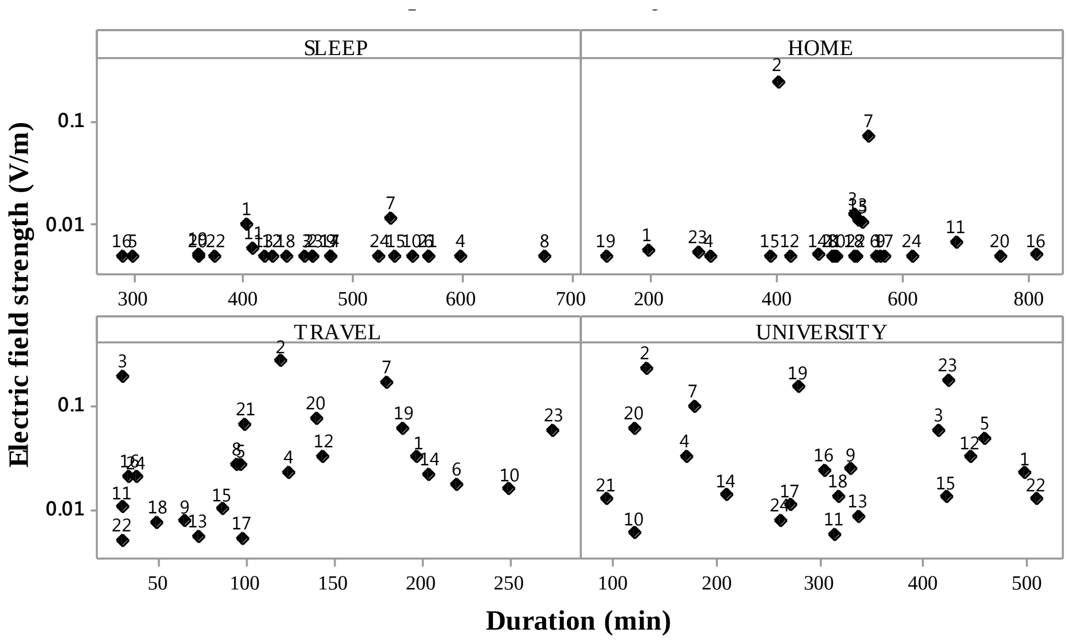

Fig. 4.48: Correlation between UMTS 2100 (UL) time-averaged electric field strength and duration.

4.4.12. UMTS 2100 (DL) bands temporal and spatial time-averaged RF exposure

In Fig.(4.49), median line of temporal variation indicates that most of the personal RF exposure to 3G base stations occurred in the afternoon. Maximum time-averaged RF exposure is calculated in the hour between 11 pm and 12 pm and equal about 0.06 V/m. Mean line of temporal variation is mainly skewed by time-averaged electric field strength of volunteer whose home is located near an Israeli settlement where 3G base stations are usually located in addition to their spread across the roads connecting Palestinian cities. Volunteers exposed to higher levels of personal RF exposure in UMTS 2100 (DL) during time spent during travel and at university. As personal exposure during travel is expected (Fig. 4.50), increased levels of exposure when volunteers attended university is attributed to the fact that Al-Quds University is located on hilltop which may cause a direct exposure to 3G base stations located in near Israeli territories.

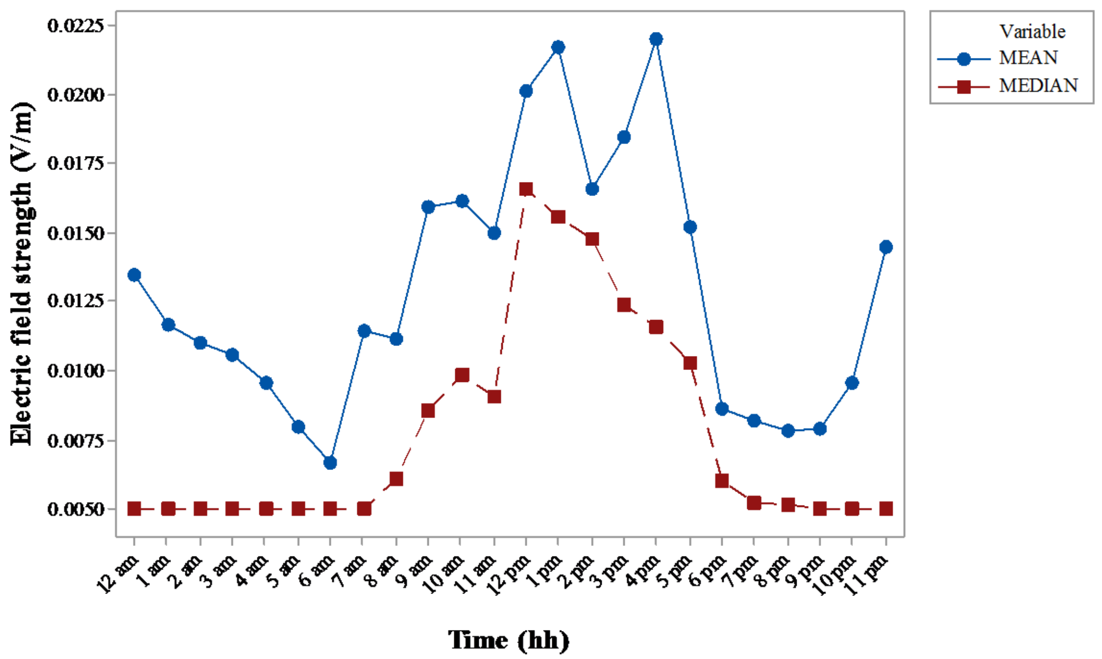

Fig. 4.49: Variation of UMTS 2100 (DL) time-averaged electric field strength during 24 hours.

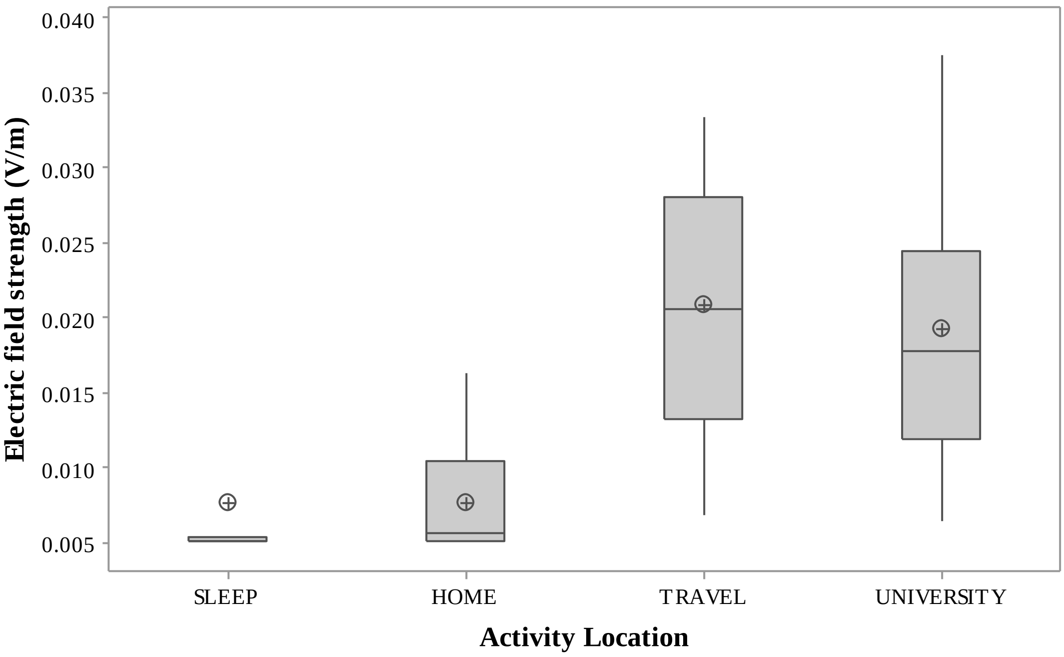

Fig. 4.50: boxplot of UMTS 2100 (DL) time-averaged RF exposure during daily activities.

4.4.13. Wi-Fi 2G band temporal and spatial time-averaged RF exposure

Temporal variation of personal RF exposure in Fig.(4.51) does not show any temporal pattern in daytime as both mean and median line show fluctuation of time-averaged electric field strength every hour period, the exposure decrease in general in late night and early morning hours when volunteers are usually in bed. Maximum time-averaged RF exposure is calculated in the hour between 8 am and 9 am and equal about 1.47 V/m.

Highest personal exposure levels in Wi-Fi 2G band detected during time spent at home where volunteers usually connected their devices to the internet via 2.4 GHz routers and when they attended to the university where 2.4 GHz routers installed across the campus (Fig. 4.52).

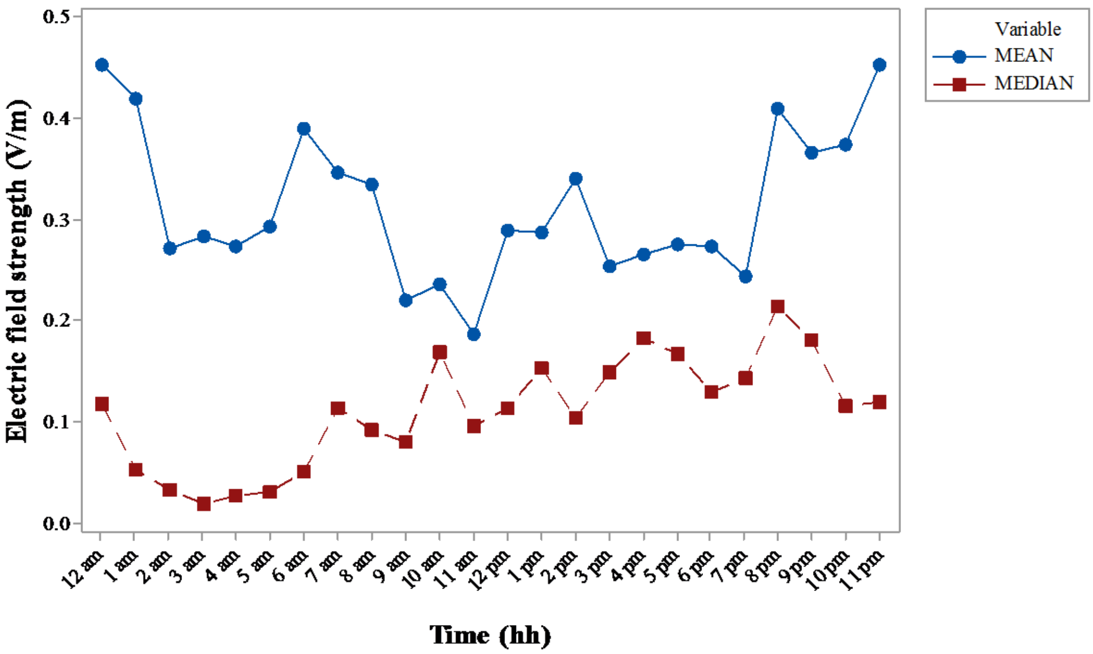

Fig. 4.51: Variation of WIFI 2G time-averaged electric field strength during 24 hours.

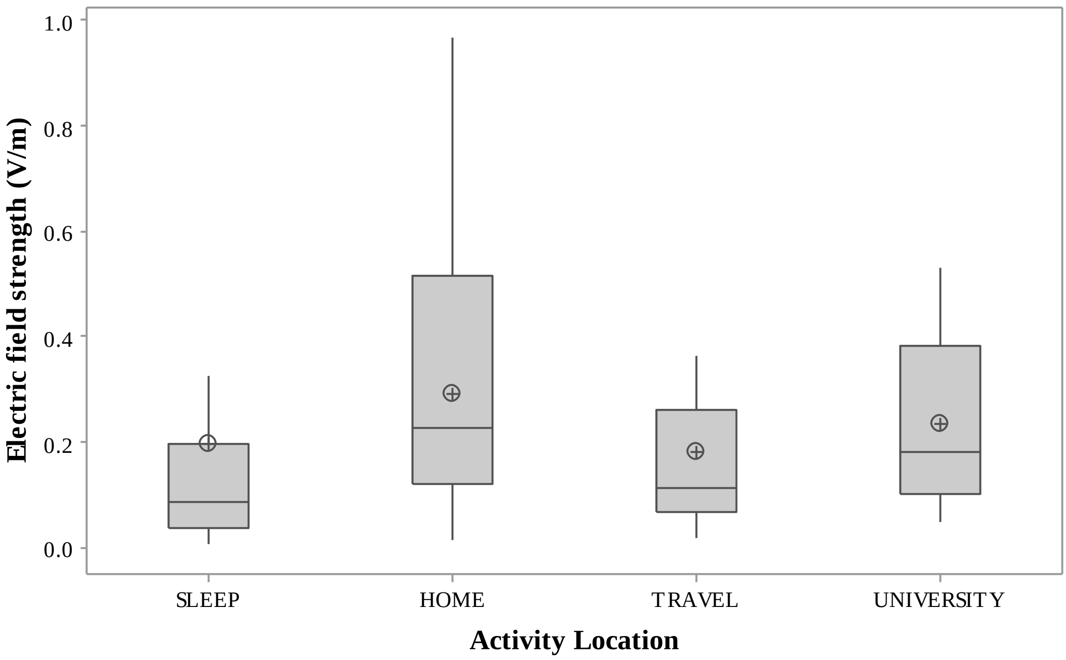

Fig. 4.52: boxplot of WIFI 2G time-averaged RF exposure during daily activities.

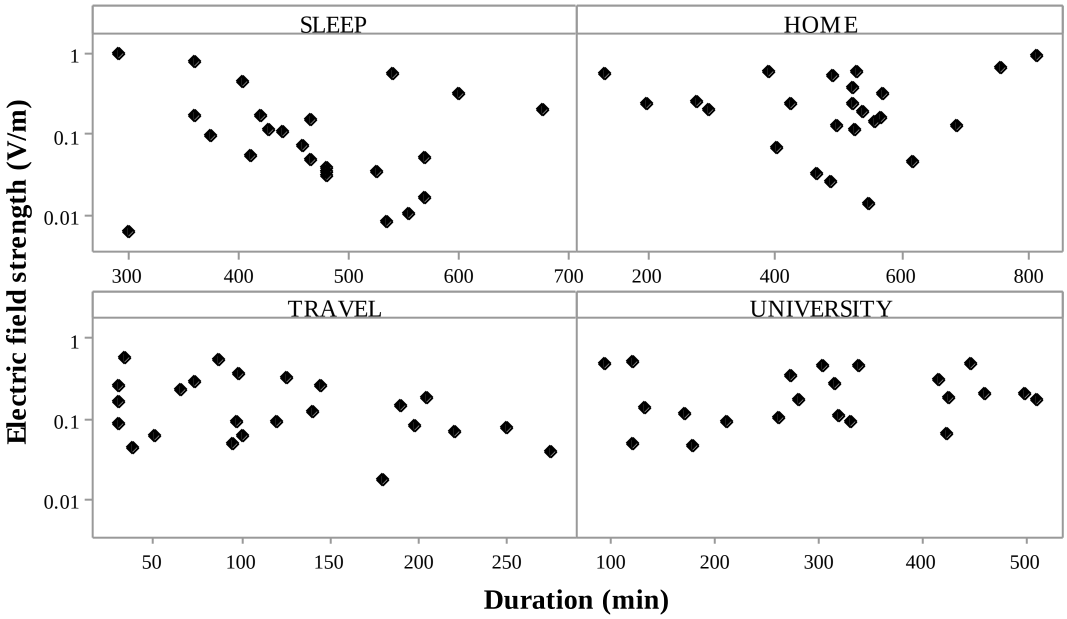

Fig. 4.53: Correlation between Wi-Fi 2G time-averaged electric field strength and duration.

No correlation was found between activity duration and personal RF exposure to Wi-Fi 2G sources was found as it depends on volunteer distance from radiation sources (routers, access points and WLAN adapters).

Number of factors and variables affecting personal RF exposure in WIFI 2G band were investigated, only information about home related Wi-Fi 2G band was collected. In Fig.(4.54) and Fig.(4.55), personal and family operational Wi-Fi devices operating in 2.4 GHz frequency were investigated.

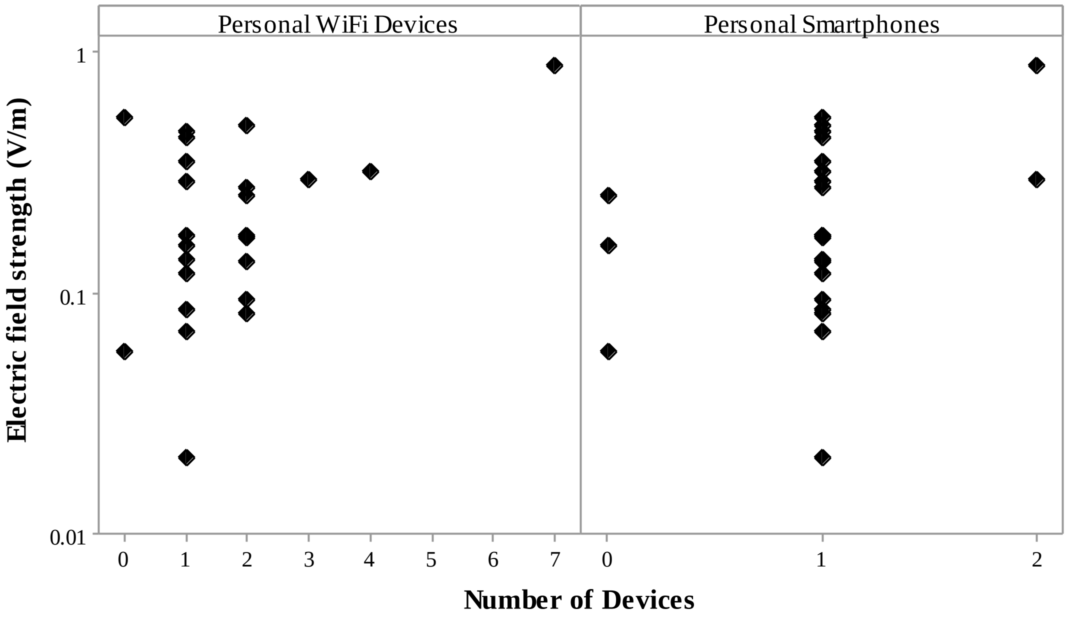

Fig. 4.54: Correlation between personal Wi-Fi devices and smartphones vs. time-averaged electric field strength.

There is a weak positive correlation between number of Wi-Fi devices including mobile phones owned and operated by volunteers during measurement period and time-averaged electric field strength when volunteers stayed at home (Fig. 4.54). On the other hand, no correlation is found between volunteers' family members' operational Wi-Fi devices and personal exposure (Fig. 4.55). Personal exposure from their devices is probably varied with time spent near family member. Also internet in personal devices plays major part in in increasing personal exposure levels. Note that Wi-Fi devices include smartphones in both figures.

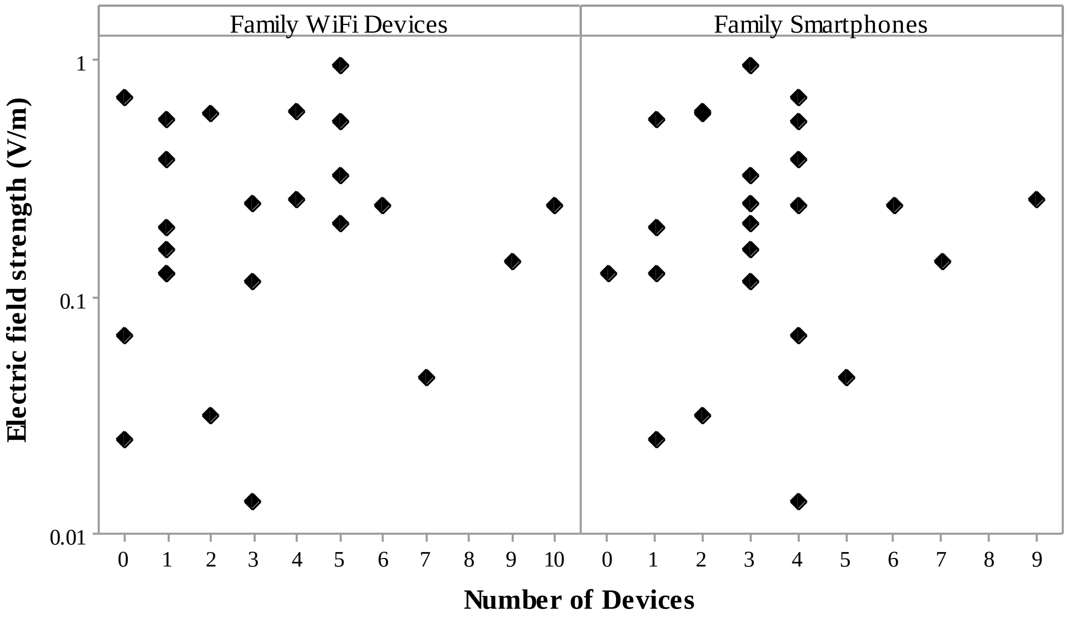

Fig. 4.55: Correlation between family Wi-Fi devices and smartphones vs. time-averaged electric field strength.

4.4.14. WiMAX band temporal and spatial time-averaged RF exposure

Temporal variation of time-averaged electric field strength every hour shows on particular pattern as the median line of time-averaged electric field strength remains near detection limit level and mean line is affected by exposure levels from volunteers with maximum personal exposure levels in every hour (Fig. 4.56). Maximum time-averaged RF exposure is calculated in the hour between 11 am and 12 pm and equal about 0.71 V/m.

Few volunteers exposed to measureable amounts of RF-EMF from WiMAX sources, Fig.(4.57) shows that most of the exposure occurred during travel. Mean value time-averaged electric field strength for each activity is affected by outliers.

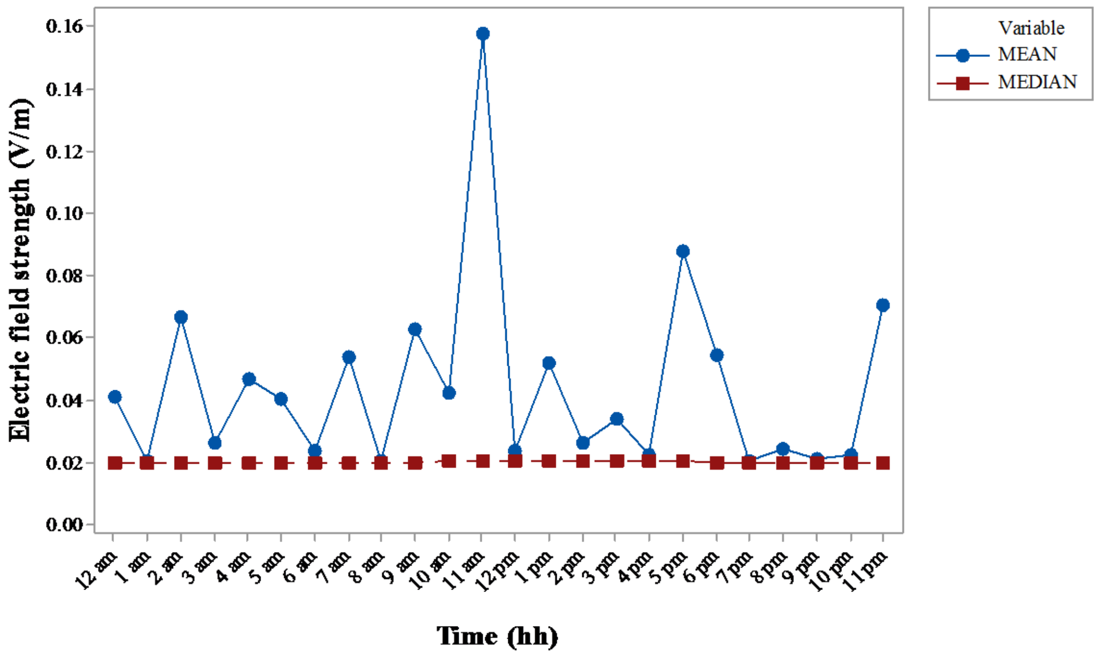

Fig. 4.56: Variation of WiMAX time-averaged electric field strength during 24 hours.

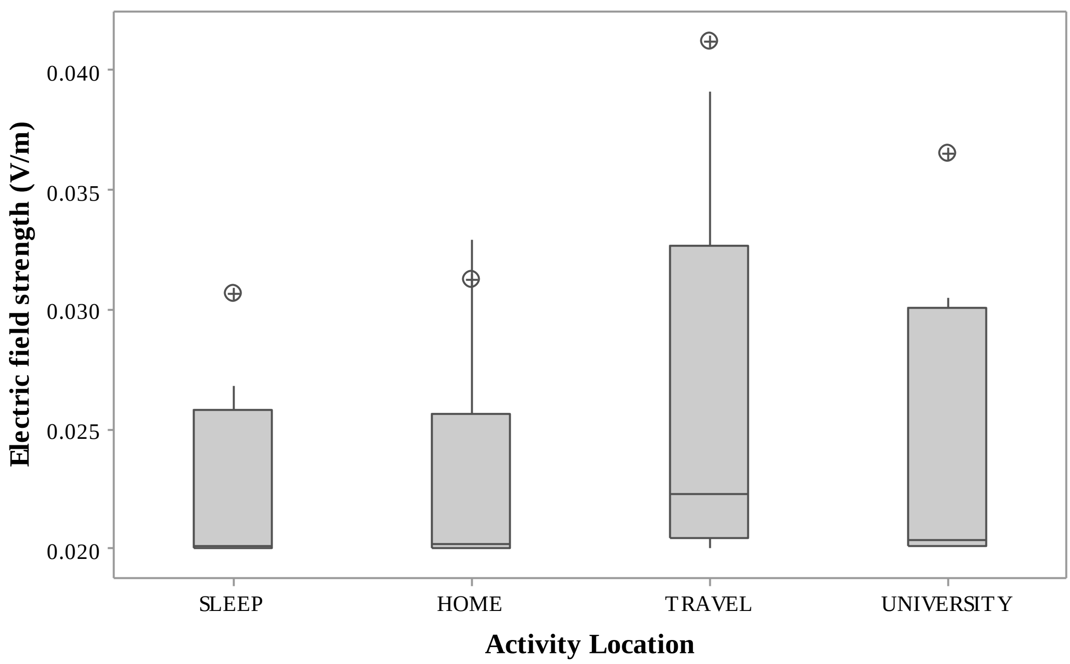

Fig. 4.57: boxplot of WiMAX time-averaged RF exposure during daily activities.

4.4.15. Wi-Fi 5G band temporal and spatial time-averaged RF exposure

Temporal variation of time-averaged electric field strength does not show any pattern as the fluctuation of the median line indicates that personal exposure levels during measurement period depend on individual conditions as shown in Fig.(4.58). Mean line is affected by volunteers who exposed to higher levels of RF-EMF in Wi-Fi 5G band. Maximum time-averaged RF exposure is calculated in the hour between 9 am and 10 am and equal about 0.61 V/m.

Routers operating in5.8 GHz band are the main source of personal exposure from Wi-Fi 5G band 5.8 GHz routers are rarely used in The West Bank. Fig.(4.59) shows that personal exposure was highest at home activity, only one volunteer used Wi-Fi 5G router at home. Routers in university also operate in 5.8 Ghz frequency band, volunteers personal exposure depended on volunteers location and distance from the sources. No correlation was found between time-averaged electric field strength and activities duration.

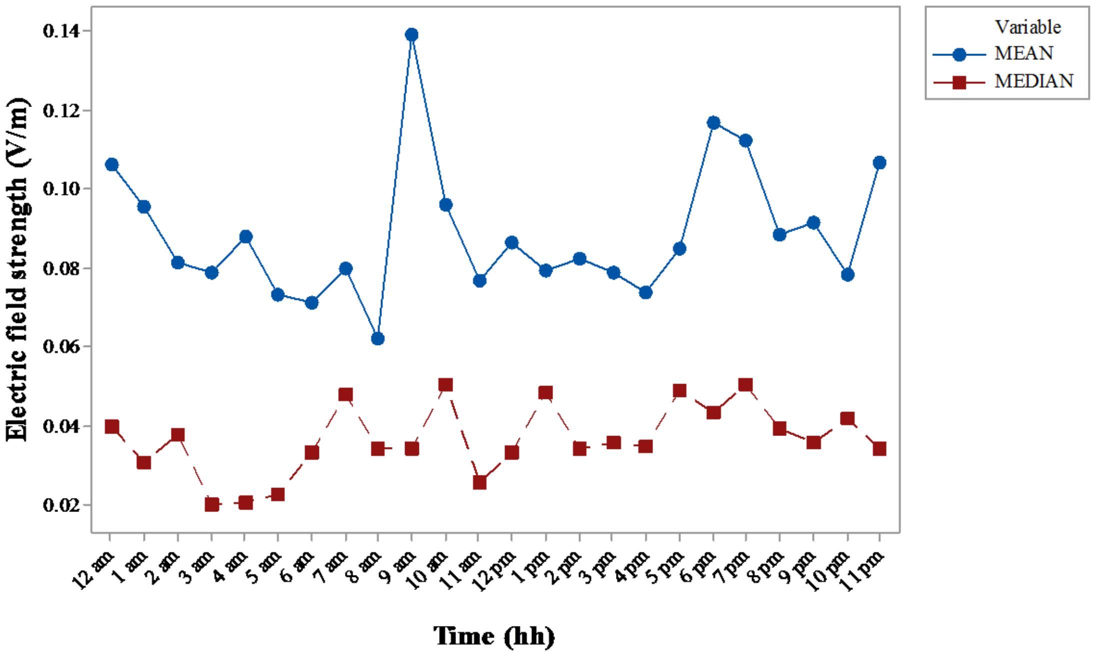

Fig. 4.58: Variation of WIFI 5G time-averaged electric field strength during 24 hours.

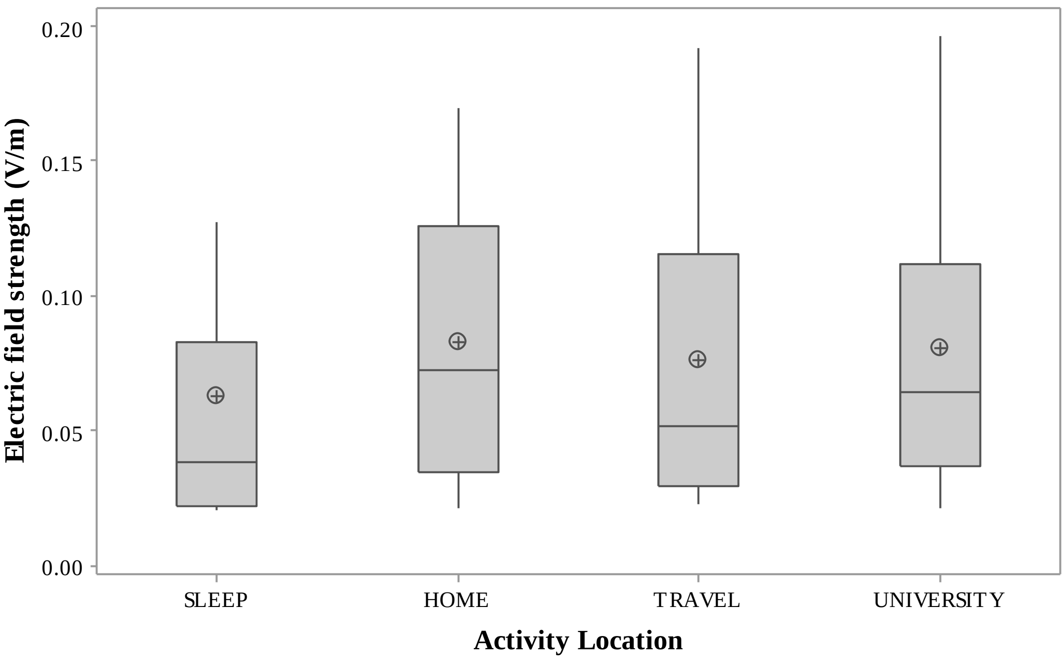

Fig. 4.59: boxplot of time-averaged WIFI 5G RF exposure during daily activities.

4.5 Uncertainties and difficulties in measurement of personal RF exposure

Several factors affected the accuracy of measurements and reliability of results during the measurement and calculation processes of RF-EMF exposure. The experiment has been designed to minimize the uncertainty or at least remove and separate abnormal and inaccurate results. In this section the main issues encountered will be discussed.

4.5.1. Data below detection limit

Most of the measurements of the electric field strength emitted from RF sources are low; the PEM couldn’t detect these measurements due to technical limitation. In result, datasets from TV3, TETRA, TV 4 & 5 and WiMAX with average percentage of data below detection limit percentages 88.2%, 99.4%, 95.3% and 99.3% respectively, shows a huge overestimation of personal RF exposure levels compared to ROS method results for summary statistics. This could underestimate the differences between time-averaged RF exposure for study volunteers in different activities and conditions, as seen in in the relations between time-averaged electric field strength and duration of the activities in TV3.

4.5.2. Body absorption of RF-EMR

Absorption of the RF radiations by the study volunteer body while carrying PEM was the most affecting factor which cause in reduction of the personal RF exposure measured by the PEM. Study volunteers usually carried PEM during their presence in the university, travel and any activities included under (OTHER) category, while some of them reported that they put the PEM near them while setting in fixed location in their homes.

4.5.3. Personal Wi-Fi devices usage

Results showed that total exposure mostly came from devices that transmit and receive data using Wi-Fi 2G frequency band. Unfortunately, personal devices internet usage couldn't be controlled or monitored as there is a no correlation between Wi-Fi 2G band exposure and number of operating personal devices during measurement period (Fig. 4.52).

4.5.4. Mobile call logs

When mobile call logs were extracted, call duration was recorded in minutes and seconds (mm:ss) while call start time was recorded in minutes (mm) only. Six measurements per second weren't good enough to pinpoint the intervals measured during calls and the whole minute had to be removed from the measurement when the data was divided into two categories (call, idle). This process ensured that in (Idle) category, there are no measurements affected by personal mobile call electromagnetic radiation.

4.5.5. Daily activity logs

Personal RF exposure results of each activity depend mainly on the study volunteer accuracy in recording the start time and duration of each activity. No correction or shifting of record diaries is made during data processing. The difference between real start time and the recorded one of the activity caused one of the following scenarios:

1- Indoor RF sources exposure data points being added to outdoor activity exposure dataset.

2- Outdoor RF sources exposure data points being added to an indoor activity exposure dataset.

Because travel activity is the only outdoor activity reported by study volunteers, interference between outdoor and indoor datasets occurred more than one time during total measurement period for every volunteer dataset as the travel activity always connect two indoor activities.

4.6 Conclusions

1- Personal exposure meter is an important tool to assess human exposure to electromagnetic radiation.

2- This is the first study of its kind in Palestine and the Middle East in general and it will set a baseline for future studies. Also it will be the final personal RF exposure study before the installation of 3G mobile network in The West Bank.

3- The use of statistical methods can be crucial to evaluate RF exposure for frequencies with high percentage of data below detection limit.

4- During daily life activities of Palestinian adults, RF-EMR exposure didn't exceed safety limits at any moment during measurement period.

5- Monitoring and quantifying personal use of technological devices especially smartphones and laptops proven to be important in interpretation of RF-EMR exposure.

6- It is important to perform micro environmental RF exposure studies in parallel with general population studies.

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Appendix A. EME Spy 140 data sheet (2 Pages)

EME Spy 140

A personal monitoring device to continuously measure human exposure to EMF on predefined frequency bands

- Operational frequency band up to 6 GHz
- Detection threshold down to 0.005 V/m
- Monitors in real time
- Light and portable

Main features

User profile

- Municipalities, governmental agencies, regulatory bodies, research laboratories, universities, broadcast, PMR, and mobile phone operators

Measurement capabilities

- Continuous monitoring of personal exposure to electromagnetic fields and identification of the contributors

Frequency bands

- 14 selected frequency bands from 88 MHz – 5850 MHz

Safety recommendations

- ICNIRP levels are used as a reference
- Other reference levels can be used

Real time visualization kit (optional)

- The field level for each frequency band is displayed as it is measured
- Export data to the EME Spy Analysis software for post processing and backup

Product Configuration

Equipment

- ■ EME Spy analysis software
- ■ User manual
- ■ USB cable
- ■ 4 rechargable batteries
- ■ Battery charger
- ■ Case
- □ Real time visualisation kit

Services

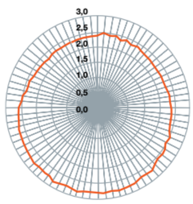
- ■ Initial calibration
- ■ Calibration report
- □ Installation
- □ Training
- □ Additional calibration
- □ Extended warranty

■ Included □ Optional

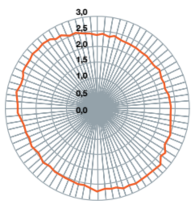
TECHNICAL CHARACTERISTICS

FREQUENCY RANGES	AXIAL ISOTROPY	
	Min - Max	Standard Deviation
FM (88 – 108 MHz)	± 2.6 dB	± 1.7 dB
TV3 (174 – 223 MHz)	± 2.2 dB	± 1.3 dB
TETRA (380 - 390 MHz)	± 2.5 dB	± 1.2 dB
TV4&5 (470 – 830 MHz)	± 0.8 dB	± 0.4 dB
GSM Tx (880 – 915 MHz)	± 2.6 dB	± 1.6 dB
GSM Rx (925 – 960 MHz)	± 2.4 dB	± 1.5 dB
DCS Tx (1710 – 1785 MHz)	± 2.3 dB	± 1.3 dB
DCS Rx (1805 – 1880 MHz)	± 2.2 dB	± 1.4 dB
DECT (1880 – 1900 MHz)	± 1.2 dB	± 0.8 dB
UMTS Tx (1920 – 1980 MHz)	± 0.9 dB	± 0.5 dB
UMTS Rx (2110 – 2170 MHz)	± 1.3 dB	± 0.6 dB
WiFi 2G (2400 – 2500 MHz)	± 1.5 dB	± 0.8 dB
WiMAX (3400 – 3800 MHz)	± 2.9 dB	± 1.5 dB
WiFi 5G (5150 – 5850 MHz)	± 3.9 dB	± 2.0 dB

Differentiating uplink[1] and downlink[2] is not only useful to assess the contribution of each transmitter, but also to avoid corruption of the results by phones emitting close to the dosimeter.



Vertical Polarization



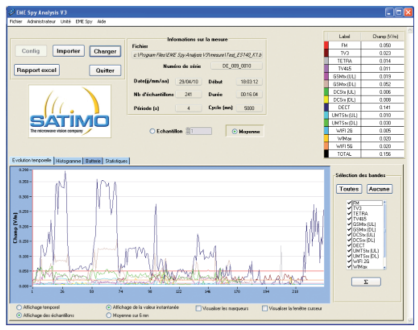
Horizontal Polarization

PROBE CHARACTERISTICS

Probe		Tri-axial E-field probe 80 MHz – 6 GHz
Sensitivity	FM	0.05 V/m
	TETRA, TV4 & 5	0.01 V/m
	GSM, DCS, DECT, UMTS, WiFi, 2G	0.005 V/m
	TV3, WiMAX, WiFi 5G	0.02 V/m
Dynamic		61.6 dB (up to 6 V/m)

MEASUREMENT CONFIGURATION

Number of data points	80 000 max
Logging intervals	4 - 255 s



EME Spy Analysis main window

OPERATING CONDITIONS

Temperature, humidity	-10 to 50°C, 85% of humidity
Battery life*	Recording mode: 42 hours with a recording period of 10 sec 19 hours with a recording period of 4 sec BlueTooth mode: 22 hours with a recording period of 10 seconds 13 hours with a recording period of 5 seconds

* 2 rechargeable batteries

MECHANICAL CHARACTERISTICS

Dimensions	168.5 x 79 x 49.7 mm (H x L x W)
Weight	440 g
Protection	IP 55

HARDWARE REQUIREMENTS

Processor	PC Pentium 500 MHz
Cable link	USB Port
Operating system	Windows 98/2000/XP
Free space on hard disc	200 MB

(1) Uplink: Sending of information from the mobile station to the BTS
(2) Downlink: Sending of information from the BTS to the mobile station

Appendix B. Questionnaire and activity log forms

استبيان

الهدف من هذا الاستبيان هو جمع معلومات عن اشخاص قد يتم اختيارهم للتطوع بحمل جهاز قياس موجات الراديو التي يتعرض لها الجسم

جهاز القياس يزن 440 جرام ويمكن وضعه على الخصر او الذراع . يتوجب على حامله ان لا يخلعه طوال فترة القياس الا في حالات سيتم تحديدها في التعليمات التي سيتم اعطاءها للمشارك قبيل بدء العملية

في حال وافقت على المشاركة في هذه الدراسة يرجي الاجابة على الاسئلة وملئ الفراغات التالية:

* سؤال مطلوب

*الاسم:...

*رقم الجوال:..

*البريد الالكتروني:..

العمر:.............

مكان السكن: ....

حدد عدد الأيام التي تتواجد بها في الجامعة: (ضع علامة X)

سبت	أحد	اثنين	ثلاثاء	أربعاء	خميس	جمعة

نوع السكن: (منزل مستقل / شقة) في حال كانت الاجابة شقة الرجاء تحديد عدد الشقق في البناء:.........

مكان العمل: .... نوع العمل: ميداني /مكتبي مدة العمل : (........-........)

وسيلة المواصلات : (عمومي / خصوصي / سير على الاقدام)

عدد الهواتف المحمولة التي تستخدمها(العدد الكلي):........

اذا كنت تستخدم الجيل الثالث حدد العدد:...........

هل تستخدم المايكرويف: (نعم / لا)

كم عدد الهواتف المحمولة في المنزل (بدونك):.........عدد الراوترات:..........

في حال وجود هاتف لاسلكي الرجاء تحديد العدد:.............

نوع نظام التشغيل على الهاتف المحمول الذي تستخدمه: (سيمبيان / اندرويد / ويندوز / آبل)

اين تحمل الهاتف النقال: (حقيبة / الجيب)

هل تضع الهاتف المحمول قريباً من رأسك وقت النوم؟ (نعم / لا)

Activity log

Volunteer name:

Starting time:

Starting date:

Main activity types: university, travel, home, sleep, other

Time of the activity	Activity type	comments

Appendix C. Study volunteers data

Table C.1: Normal arithmetic mean exposure for 24 hours

Volunteer number	Electric field (V/m)													
	FM	TV 3	TETRA	TV 4 & 5	GSM 900 + UMTS (UL)	GSM 900 + UMTS (DL)	GSM 1800 (UL)	GSM 1800 (DL)	DECT	UMTS 2100 (UL)	UMTS 2100 (DL)>	WIFI 2G	WIMax	WIFI 5G
1	0.301	0.020	0.019	0.018	0.133	0.109	0.060	0.033	0.065	0.019	0.029	0.297	0.030	0.070
2	0.153	0.024	0.010	0.016	0.117	0.094	0.169	0.040	0.062	0.219	0.009	0.069	0.104	0.048
3	0.066	0.020	0.010	0.021	0.119	0.090	0.048	0.013	0.163	0.045	0.016	0.290	0.064	0.103
4	0.133	0.021	0.013	0.016	0.128	0.116	0.017	0.019	0.055	0.015	0.014	0.254	0.029	0.087
5	0.181	0.021	0.010	0.012	0.179	0.257	0.078	0.025	0.063	0.030	0.015	0.173	0.026	0.083
6	0.155	0.025	0.011	0.014	0.236	0.139	0.159	0.020	0.059	0.008	0.008	0.093	0.152	0.056
7	0.074	0.020	0.010	0.012	0.211	0.485	0.125	0.025	0.044	0.084	0.011	0.021	0.026	0.034
8	0.294	0.020	0.010	0.010	0.077	0.086	0.006	0.014	0.026	0.009	0.009	0.357	0.020	0.086
9	0.057	0.021	0.010	0.010	0.106	0.071	0.032	0.013	0.021	0.013	0.018	0.122	0.020	0.037
10	0.330	0.022	0.010	0.014	0.109	0.119	0.264	0.030	0.074	0.008	0.013	0.083	0.106	0.056
11	0.057	0.020	0.010	0.012	0.066	0.200	0.009	0.026	0.086	0.006	0.011	0.158	0.020	0.038
12	0.067	0.020	0.010	0.011	0.248	0.110	0.071	0.018	0.017	0.021	0.014	0.318	0.027	0.143
13	0.175	0.021	0.010	0.011	0.091	0.047	0.135	0.014	0.030	0.012	0.008	0.444	0.022	0.120
14	0.207	0.021	0.010	0.010	0.138	0.090	0.038	0.051	0.052	0.012	0.011	0.086	0.021	0.025
15	0.200	0.020	0.010	0.010	0.152	0.056	0.022	0.019	0.015	0.009	0.012	0.503	0.021	0.112
16	0.092	0.020	0.011	0.030	0.128	0.073	0.048	0.016	0.028	0.012	0.014	0.888	0.020	0.167
17	0.051	0.022	0.011	0.010	0.196	0.049	0.033	0.009	0.067	0.007	0.008	0.277	0.022	0.065
18	0.051	0.020	0.010	0.016	0.059	0.065	0.119	0.018	0.027	0.008	0.012	0.171	0.046	0.057
19	0.177	0.020	0.010	0.011	0.080	0.154	0.082	0.016	0.194	0.072	0.009	0.475	0.021	0.121
20	0.060	0.020	0.011	0.017	0.143	0.189	0.171	0.029	0.062	0.033	0.018	0.538	0.031	0.094
21	0.174	0.020	0.010	0.010	0.111	0.065	0.067	0.022	0.049	0.019	0.009	0.136	0.022	0.051
22	0.051	0.020	0.011	0.011	0.121	0.208	0.174	0.010	0.013	0.008	0.015	0.139	0.021	0.044
23	0.113	0.020	0.011	0.012	0.749	0.073	0.138	0.021	0.041	0.102	0.015	0.176	0.085	0.182
24	0.055	0.020	0.010	0.010	0.078	0.061	0.018	0.026	0.180	0.007	0.012	0.058	0.023	0.029

Table C.2: Robust ROS arithmetic mean exposure for 24 hours

Volunteer number	Electric Field (V/m)													
	FM	TV 3	TETRA	TV 4 & 5	GSM 900 + UMTS (UL)	GSM 900 + UMTS (DL)	GSM 1800 (UL)	GSM 1800 (DL)	DECT	UMTS 2100 (UL)	UMTS 2100 (DL)	WIFI 2G	WIMax	WIFI 5G
1	0.300	0.018	0.017	0.015	0.133	0.109	0.060	0.034	0.065	0.018	0.029	0.297	0.022	0.068
2	0.147	0.023	0.002	0.014	0.117	0.094	0.169	0.040	0.062	0.219	0.008	0.069	0.102	0.044
3	0.044	0.015	0.003	0.019	0.119	0.090	0.048	0.012	0.163	0.045	0.016	0.290	0.061	0.102
4	0.127	0.015	0.009	0.016	0.128	0.116	0.017	0.018	0.055	0.014	0.013	0.254	0.021	0.085
5	0.177	0.014	0.002	0.007	0.179	0.257	0.078	0.025	0.063	0.029	0.015	0.173	0.017	0.081
6	0.148	0.026	0.004	0.013	0.236	0.139	0.159	0.020	0.059	0.007	0.007	0.093	0.150	0.053
7	0.055	0.015	0.010	0.008	0.211	0.485	0.125	0.025	0.044	0.084	0.011	0.020	0.017	0.028
8	0.293	0.013	0.002	0.001	0.077	0.086	0.004	0.014	0.026	0.007	0.008	0.357	0.005	0.084
9	0.047	0.014	0.003	0.004	0.106	0.071	0.032	0.013	0.021	0.012	0.018	0.122	0.005	0.032
10	0.327	0.022	0.002	0.010	0.109	0.119	0.264	0.030	0.074	0.006	0.013	0.083	0.105	0.053
11	0.050	0.012	0.001	0.010	0.066	0.200	0.008	0.025	0.086	0.005	0.012	0.158	0.003	0.033
12	0.064	0.012	0.004	0.006	0.248	0.110	0.071	0.018	0.017	0.020	0.014	0.318	0.018	0.142
13	0.168	0.017	0.002	0.004	0.091	0.047	0.135	0.014	0.030	0.011	0.007	0.444	0.010	0.118
14	0.202	0.017	0.001	0.004	0.138	0.090	0.037	0.051	0.052	0.011	0.010	0.086	0.005	0.015
15	0.196	0.014	0.010	0.002	0.152	0.056	0.022	0.019	0.014	0.007	0.011	0.503	0.007	0.113
16	0.077	0.015	0.004	0.029	0.128	0.073	0.048	0.016	0.028	0.011	0.014	0.888	0.004	0.167
17	0.021	0.017	0.004	0.003	0.196	0.049	0.032	0.007	0.067	0.004	0.007	0.277	0.009	0.062
18	0.026	0.016	0.010	0.012	0.058	0.065	0.119	0.018	0.027	0.006	0.012	0.171	0.041	0.054
19	0.178	0.011	0.005	0.006	0.080	0.154	0.082	0.016	0.194	0.072	0.008	0.475	0.006	0.120
20	0.052	0.012	0.004	0.013	0.143	0.189	0.171	0.029	0.062	0.033	0.017	0.538	0.023	0.092
21	0.167	0.014	0.001	0.001	0.111	0.065	0.067	0.022	0.049	0.018	0.008	0.136	0.008	0.047
22	0.017	0.017	0.004	0.005	0.121	0.208	0.174	0.010	0.013	0.007	0.015	0.139	0.006	0.039
23	0.120	0.011	0.005	0.007	0.749	0.073	0.138	0.021	0.041	0.102	0.015	0.176	0.083	0.181
24	0.042	0.016	0.002	0.003	0.078	0.061	0.018	0.026	0.180	0.004	0.012	0.058	0.020	0.021

Table C.3: Percentage of data below detection limit for 24 volunteers

Volunteer number	Percentage %													
	FM	TV 3	TETRA	TV 4 & 5	GSM 900 + UMTS (UL)	GSM 900 + UMTS (DL)	GSM 1800 (UL)	GSM 1800 (DL)	DECT	UMTS 2100 (UL)	UMTS 2100 (DL)	WIFI 2G	WIMax	WIFI 5G
1	85.5	95.0	97.9	95.4	51.9	1.0	49.5	33.5	63.7	86.3	33.3	23.9	97.1	89.7
2	78.5	50.3	99.7	90.5	77.6	29.0	83.9	63.6	71.7	75.0	77.6	81.6	99.6	93.7
3	98.6	91.0	99.5	95.8	84.3	45.8	80.2	80.1	52.9	90.9	81.7	55.3	99.6	94.5
4	73.6	93.3	99.2	82.7	78.2	0.5	87.5	64.7	38.0	92.1	85.2	55.6	99.5	86.9
5	75.1	90.5	99.7	98.5	89.4	1.3	85.0	57.3	73.4	93.6	66.7	54.7	99.2	96.5
6	89.7	45.8	99.4	60.4	76.4	2.1	81.8	64.1	63.2	97.3	82.1	66.2	99.1	96.7
7	96.9	99.0	100.0	99.2	85.1	0.6	95.6	3.8	5.8	77.6	12.2	50.5	99.8	98.5
8	11.6	96.7	99.7	99.9	33.7	0.3	95.4	20.3	48.5	98.1	84.1	40.3	99.3	94.8
9	90.1	90.8	99.9	98.2	87.5	0.2	85.7	66.3	40.2	94.7	74.1	62.7	99.3	96.1
10	94.4	43.5	99.6	96.6	89.1	74.0	89.8	79.4	73.2	96.3	85.4	61.8	99.4	98.5
11	85.8	99.4	99.9	85.8	92.3	0.1	91.9	38.9	25.9	87.8	77.1	48.6	99.7	98.3
12	61.0	95.5	98.9	98.1	79.4	1.5	79.7	21.1	85.0	92.1	62.2	20.5	98.5	93.7
13	97.7	88.0	99.6	99.7	85.9	11.7	93.3	79.5	82.3	97.0	77.9	40.2	99.6	93.2
14	95.3	85.6	99.9	98.9	81.7	36.3	89.1	80.8	89.2	97.2	85.6	64.1	99.8	98.5
15	75.5	97.7	99.9	99.8	61.8	20.3	94.0	56.0	93.4	99.1	90.8	30.3	99.7	74.9
16	98.5	98.4	99.8	97.2	69.8	0.8	83.5	83.6	70.8	91.9	25.9	0.8	99.6	81.4
17	96.8	80.8	99.8	99.7	89.5	72.0	93.6	89.7	25.6	97.9	91.2	49.4	99.8	94.9
18	96.5	97.5	100.0	98.3	89.4	9.5	81.8	62.8	85.8	96.8	72.7	51.3	99.9	92.4
19	57.8	95.2	98.0	97.6	53.6	9.7	53.6	33.5	33.9	90.6	67.3	46.8	99.1	92.6
20	58.6	97.1	99.4	99.4	84.7	0.7	87.7	31.0	16.3	96.1	84.5	47.2	99.5	96.1
21	97.8	95.6	99.8	99.8	40.3	10.3	95.9	28.6	23.1	97.2	89.1	88.4	99.6	98.4
22	99.1	91.0	99.0	97.9	82.1	0.2	88.5	11.7	54.2	95.9	5.7	10.1	99.4	96.4
23	61.7	99.7	98.5	97.5	78.7	3.0	84.7	66.5	65.6	96.0	70.7	54.2	98.3	93.6
24	76.6	99.2	99.6	99.2	30.9	0.0	55.6	17.1	24.2	98.3	33.9	36.6	100.0	97.5