*Progress In Electromagnetics Research M, Vol. 50, 117–128, 2016*

# Comparative Analysis of Electromagnetic Field Exposure Levels and Determination of the Minimum Safe Distances from Mobile-Phone Base Stations in Urban Areas

**Enver Hamiti, Mimoza Ibrani*, Luan Ahma, Vlerar Shala, and Rreze Halili**

**Abstract**—Theoretical, software-computed and experimental evaluations of the exposure levels to electromagnetic fields generated by GSM 900, GSM 1800 and 3G base stations in urban areas, including determination of the minimum safe distances for population and occupational exposure, are presented. Using the software package SPECTRAemc with the P.1546 propagation wave model and a topographic digital map, the electromagnetic field levels were assessed considering the height of the receiving antenna to be at the height of human. At a few locations in the direction of maximum radiation intensity, in situ measurements of the electric field strength were performed. The base station power densities measured at a few exposure sites were in the range of 0.11 ($\mu$W/cm$^2$) to 6.73 ($\mu$W/cm$^2$). The results of Kosovo experimental survey are compared with surveys done in 21 countries in five continents. The power density values obtained in Kosovo are higher, but many times below the safety standard limits.

## 1. INTRODUCTION

The tremendous ongoing growth in the use of cellular communication services requires the installation of an increasing number of base station transmitters. The installation of base station transmitters is accompanied by concerns about possible adverse biological and health effects to both the population living near base stations and workers.

Wireless communication technologies have been shown to account more than 65% of exposure to radio frequency radiation, with mobile phones being identified as the dominant contributor [1].

The epidemiological evidence of health impacts from base station exposure has been reviewed [2], while a recent cross-sectional case control study has analysed possible genetic damage in individuals residing in the vicinity of base stations [3].

The widely used human exposure safety standards announced by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) for the general population and workers gives two types of exposure limitations that can be used in compliance assessment: basic restrictions that limit the specific absorption rates (SARs) for mobile-communication frequencies, and reference levels that limit the electric and/or magnetic field strength and power density [4].

Measurements of occupational exposure to electromagnetic fields generated by base stations and their comparison with ICNIRP guidelines for rooftop positions have been reported [5]. The results indicate that the reference levels for workers and the general public may be exceeded in front of a transmitting antenna at distances up to 1 and 2 m, respectively.

To prevent citizens from entering exposure zones where ICNIRP safety limits are exceeded, minimum safe distances to mobile-communication base stations should be determined.

The relationship between the base station antenna input power required to reach the ICNIRP SAR limit and that required to reach the ICNIRP power density limit has been given [6].

*Received 25 July 2016, Accepted 14 September 2016, Scheduled 23 September 2016*

* Corresponding author: Mimoza Ibrani (mimoza.ibrani@uni-pr.edu).
The authors are with the Faculty of Electrical and Computer Engineering, University of Prishtina, Prishtina 10000, Kosovo.

For a 900 MHz antenna of a base station, it was found that, at the input power of 10 W or higher, the minimum safe distance based on the SAR was less than that based on the electromagnetic field strength [7]. Thus, the calculation of the minimum safe distance can be based on the electromagnetic field strength, avoiding the high financial and computational costs of SAR-based calculations.

Another advanced method for computing the minimum safe distance for a base station antenna in the near-field region, based on source reconstruction, has been described [8].

Studies have reported the development of procedures, prediction formulas and instrumentation for assessing the SAR and radio frequency electromagnetic fields (RF-EMFs) of base station antennas, in terms of the antenna parameters, distance and time variations and amplitude probability of exposure levels [9–13].

The World Health Organization (WHO) also recommends working to investigate population radio frequency (RF) exposure, particularly useful for global exposure assessment and hopefully upcoming health risk from such exposure [14]. Comparative analysis of RF exposure survey of mobile communications presented in [15], gives data of national surveys in 21 countries across five continents since 2000. Surprisingly, regardless of country, the year and cellular technology, the measured values were a small fraction of human exposure standards. Also, no significant increase in exposure levels is observed since the widespread introduction of 3G mobile services, at ground level. They suggest extending the study to additional countries.

The main objective of the present paper is to assess the actual level of electromagnetic field exposure and to determine the minimum safe distance of public and occupational exposure for mobile-phone base station antennas, in a very dense urban environment in Kosovo. Our study considers the case of the highly populated neighborhood of Ulpiana in Prishtina, Kosovo. The chosen environment is characterized as one of the most exposed environments in Kosovo, where density of radiation sources is very high and the corresponding distance between humans and base stations antennas are worrisome. This conclusion is based on the research that we have done in different environments, including those that are considered to be more special, in terms of RF EMF exposure [16, 17].

We also aim to join international efforts to assess the experimental levels of RF-EMF exposure to areas that are very close to base stations of wireless communication systems. We present the results of a comparative analysis of data obtained from our measurements and RF-EMF exposure values resulted from surveys, which includes over 173,000 individual data points presented in [15].

Finally, we compare the results obtained by simulations with those obtained by in-situ measurements, in order to have a clear picture of the accuracy of the results obtained by simulations and perhaps to simplify the procedures for evaluating exposure of the population in the future. In a process of base transceiver station (BTS) sitting along with the signal coverage, also a safety distance should be calculated, resulting in multi parametric cellular network planning and optimization.

## 2. METHODOLOGY FOR EVALUATION OF EXPOSURE LEVELS AND DETERMINATION OF MINIMUM SAFE DISTANCES FROM MOBILE-COMMUNICATION BASE STATIONS

The first step was to scan RF sources in the chosen urban neighborhood. Eight base station antennas of GSM 900, GSM 1800 and 3G systems were identified in the study environment. The study area also contained a few private mobile radio transmitters operating on very high frequency and ultrahigh frequency ranges, two point-to-point sources operating on unlicensed bands of 2.4 and 5.5 GHz with low transmitting power, and a few short-distance microwave links with low transmitting power. Evaluation of the power balance of the identified RF sources reveals that the dominant contributors were the GSM 900, GSM 1800 and 3G base stations. Consequently, these contributions have become part of our study.

A map of the neighborhood and base station locations is presented in Fig. 1.

Base-station antennas operating in Ulpiana neighborhood are GSM 900, GSM 1800 and 3G antennas, characterized by 17, 17.8 respectively 18 dBi. Transmitting power/channel (W) was in the range between 1.99526 W and 6.30957 W for GSM 900 antennas, 6.30957 W for GSM 1800, while for 3G were used antennas of 19.95262 W and 15.84893 W. The data regarding the base stations technical parameters are obtained from service provider.

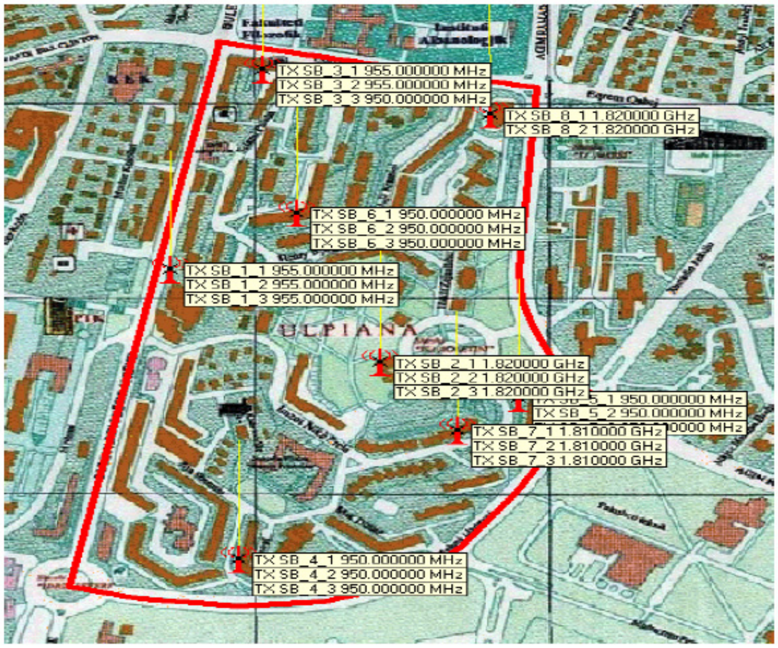



**Figure 1.** The map of Ulpiana neighborhood.

### 2.1. Theoretical Evaluation of the Peak Power Density and Minimum Safe Distance Calculation

The power density of a plane wave, when a person is exposed to a single antenna of a base station, can be calculated as [18–20]

$$S = \frac{1}{4\pi}\frac{P_t}{R^2}10^{\frac{G}{10}} \tag{1}$$

where $P_t$ is the total power of the channels per sector radiated by the antenna and $G$ the gain of the antenna (in dB) in the direction of the person from the antenna.

In the case of the simultaneous action of $N$ antennas, the total power density is obtained as the sum of individual power densities of the different antennas.

At a distance $\rho_0$ from the antenna, the form of the electric field changes from a cylindrical shape in the near field to a spherical field. For a sector antenna, this distance is determined as [18–20].

$$\rho_o = \frac{\phi_{3\,\mathrm{dB}}}{6}G_A L \tag{2}$$

where $\phi_{3\,\mathrm{dB}}$ is the horizontal half-power (or $-3\,\mathrm{dB}$) beam width, $G_A$ the antenna broadside directivity and $L$ the antenna height.

For sector base-station antennas, the peak value of the power density of near-field (cylindrical) radiation, in the horizontal direction of propagation, at distance $\rho$ from the antenna centre and at azimuth $\Phi$, is calculated as [18–20]

$$S_\rho^{peak}(\rho,\phi) = \frac{P_t 2^{-\left(\frac{\phi}{\phi_{3\,\mathrm{dB}}}\right)^2}}{\phi_{3\,\mathrm{dB}}\rho L\sqrt{1+\left(2\frac{\rho}{\rho_0}\right)^2}} \tag{3}$$

where $P_t$ is the total power of the channels per sector radiated from the antenna and $\Phi$ the azimuth angle.

Taking the azimuth value $\Phi = 0$ in the expression and considering the peak power density to be equal to the ICNIRP reference level, the minimum safe distance $\rho$ can be calculated as

$$\rho = \rho_0 \sqrt{\frac{\sqrt{\left(\frac{P_t}{\phi L S \rho_0}\right)^2 + \frac{1}{16}} - \frac{1}{4}}{2}} \tag{4}$$

Relations in Eqs. (3) and (4) can be used to simply and accurately calculate the level of exposure and minimum safe distance from a base station antenna.

### 2.2. Calculated Results

The density of radiated power and the minimum safe distance are calculated using technical parameters of the base station antennas under investigation, in the direction of the maximum radiation intensity (angle $\Phi = 0$) [19, 21, 22].

In Table 1 are presented the minimum safe distances for GSM 900, GSM 1800 and 3G base stations, in terms of public and occupational exposure.

**Table 1.** Evaluated minimum safe distances for mobile-communication base stations.

| No. | System | Frequency [MHz] | Antenna type | Antenna directivity $G_A$ [dBi] | Total power of the channels per sector [W] | Antenna length L [m] | Value of $\Phi_{3dB}$ [rad] | ICNIRP standard for public [μW/cm$^2$] | ICNIRP standard for occupational [μW/cm$^2$] | The value of the $\rho_o$ [m] | The minimum safe distance for public exposure ρ [m] | The minimum safe distance for occupational exposure ρ [m] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | GSM 900 | 955 | K 742 266 | 17 | 3x5 | 2.51 | 0.57 | 450 | 2250 | 11.90 | 2.19 | 0.47 |
| 2 | GSM 900 | 950 | APX | 17 | 3x7 | 2.00 | 0.57 | 450 | 2250 | 9.52 | 3.35 | 0.81 |
| 3 | GSM 1800 | 1810 | K 742 266 | 17.8 | 3x6.3 | 2.51 | 0.58 | 900 | 4500 | 14.56 | 1.42 | 0.29 |
| 4 | UMTS | 1820 | K 742 215 | 18 | 20 | 1.30 | 0.57 | 900 | 4500 | 7.79 | 2.52 | 0.59 |

Figure 2 illustrates the dependence of the peak power density (W/m$^2$) as a function of distance $\rho$ (m) from the antenna. The graphs also show the reference exposure levels of the ICNIRP for the general population and occupational exposure. The results for the minimum safe distances varied from 1.42 m to 3.35 m for the exposure of the general population.

The results are valid for specific antennas having certain parameters and maximum transmission power. Additionally, the results are obtained for ideal conditions of wave propagation, since no consideration is given to possible reflections and other effects that may occur in reality.

For the far-field region, calculated power densities of the base station at different exposure positions are given in Table 2. The calculated base station power densities for given exposure sites ranged from 0.1 to 7.6 μW/cm$^2$.

## 3. EVALUATION AND MAPPING OF ELECTROMAGNETIC FIELD LEVELS AND IN SITU MEASUREMENTS

### 3.1. Software Mapping of Electromagnetic Field Levels

The methodologies of determining RF exposure and coverage, as well as electromagnetic field mapping via different software packages, are elaborated [23–27].

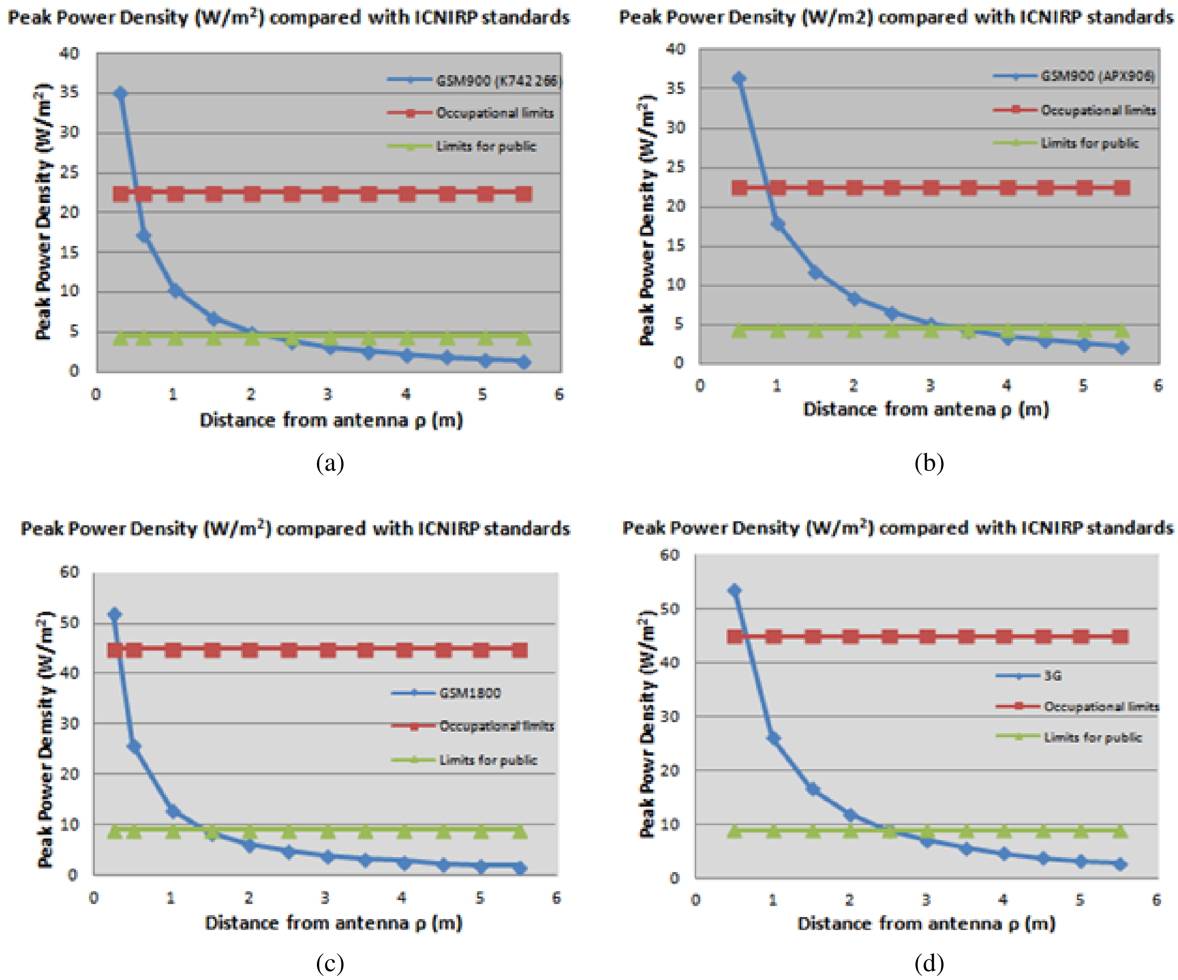
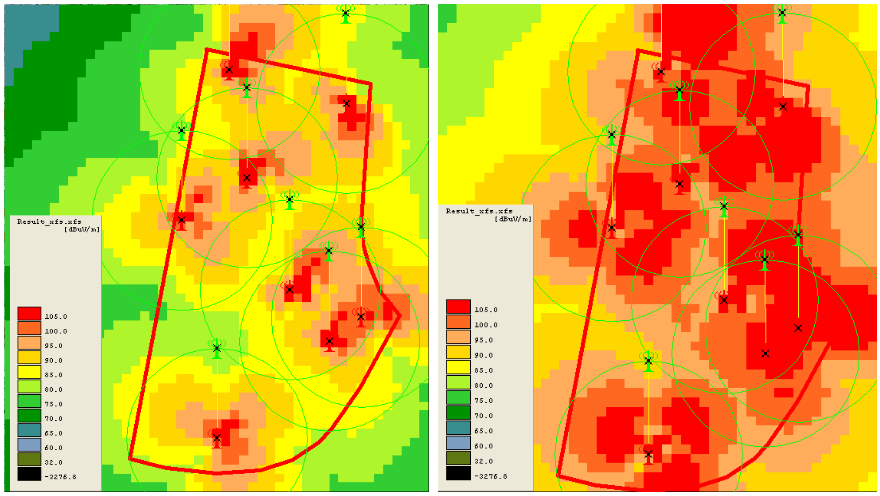



**Figure 2.** Peak power density (W/m$^2$) as a function of distance $\rho$ (m), compared with ICNIRP standards for (a) GSM 900 with antenna K742266; (b) GSM 900 with antenna APX906515L; (c) GSM 1800 with antenna K742266; and (d) 3G with antenna K742215.

**Table 2.** Calculated base station power densities in the far-field region.

| Mobile system | Base station power density in the far-field region | | | | |
|---|---|---|---|---|---|
| GSM 900 (K742 266) | $\rho$ [m] | 38.36 | 40 | 45 | 50 |
| | S (μW/cm$^2$) | 1.1 | 0.1 | 0.8 | 0.6 |
| GSM 900 (APX906 215L) | $\rho$ [m] | 24.24 | 30 | 35 | 40 |
| | S (μW/cm$^2$) | 5.00 | 4.00 | 3.00 | 3.00 |
| GSM 1800 | $\rho$ [m] | 74.26 | 80 | 85 | 90 |
| | S (μW/cm$^2$) | 0.6 | 0.47 | 0.42 | 0.37 |
| UMTS | $\rho$ [m] | 20.35 | 25 | 30 | 35 |
| | S (μW/cm$^2$) | 7.6 | 5.1 | 3.5 | 2.6 |

SPECTRAemc software, the ITU-R P.1546 wave propagation model, and digital topographic maps, digital terrain models, with resolution of 20 m are used to evaluate and map the RF-EMF levels. The electromagnetic field levels are assessed at two positions from the ground, considering the height of a receiving antenna to be 1.5 or 5 m. The signal coverage zones for electric field levels ranging from 60




(a) (b)

**Figure 3.** Electromagnetic field levels in the Ulpiana neighborhood for receiving antenna heights of (a) $h = 1.5\,\mathrm{m}$ and (b) $h = 5\,\mathrm{m}$.

to 105 dBμV/m are mapped and illustrated. Fig. 3 presents the signal coverage zones for base-station electric field levels ranging from 60 to 105 dBμV/m and for a height of the receiving antenna of 1.5 or 5 m in the urban neighborhood under investigation.

In the human exposure scenario in the urban neighborhood of Ulpiana, for the case that the height of the receiving antenna is 1.5 m, the electric field strength calculated with SPECTRAemc ranges from 65.4 dBμV/m (0.001862 V/m) to 157.5 dBμV/m (76.73 V/m). The maximum value of 157.5 dBμV/m is found close to the antenna having the highest transmission power. This is also seen in Fig. 3.

In the case that the height of the receiving antenna is 5 m, the electric field strength within the area of Ulpiana ranges from 76.9 dBμV/m (0.006998 V/m) to 157.5 dBμV/m (76.73 V/m).

The results reveal that the electromagnetic field is stronger at greater heights. This is to be expected because the antennas are located at altitudes above 20 m, and in their horizontal plane, the radiated level is higher.

Table 3 gives the minimum and maximum of the electric field strength $E$ and power density $S$, in the urban neighborhood calculated with SPECTRAemc. These values of electric field strength ($E$) and power density ($S$) show the determined level in certain points using the SPECTRAemc software.

**Table 3.** The minimum and maximum value of the electric field $E$ (V/m) and power density $S$ (μW/cm$^2$) in the Ulpiana neighborhood, expressed also in dBμ.

| Antenna height (m) | The minimum value | | | | The maximum value | | | |
|---|---|---|---|---|---|---|---|---|
| | $E$ [dBμV/m] | $E$ [V/m] | $S$ [μW/cm$^2$] | $S$ [dBμW/cm$^2$] | $E$ [dBμV/m] | $E$ [V/m] | $S$ [μW/cm$^2$] | $S$ [dBμW/cm$^2$] |
| 1.5 | 65.4 | 0.001862 | $9.19 \times 10^{-7}$ | $-60.36$ | 157.7 | 76.73 | 1561.91 | 31.93 |
| 5 | 76.9 | 0.006998 | $1.29 \times 10^{-5}$ | $-48.86$ | 157.7 | 76.73 | 1561.91 | 31.93 |

Given the total surface area of the Ulpiana neighborhood, which is 0.39 km$^2$, Table 4 presents the percentages of the neighborhood having different levels of exposure of the electromagnetic field.

### 3.2. Experimental Evaluation of the Electromagnetic Field Levels

An *in situ* experimental evaluation of base-station electromagnetic field levels was performed with a Narda EMR-300 radiation meter. Measurement points were chosen near antennas, in the far-field region, and in the direction of the maximum antenna radiation intensity, for all sectors of base stations.

**Table 4.** Zones of exposure levels to the electromagnetic field, shown by values of the electric field $E$ (V/m) and power density $S$ (μW/cm$^2$), expressed also in dBμ.

| $E$ [dBμV/m] | $E$ [V/m] | $S$ [μW/cm$^2$] | $S$ [dBμW/cm$^2$] | Area coverage of the respective electric field strength | | | |
|---|---|---|---|---|---|---|---|
| | | | | $h = 1.5$ m | | $h = 5$ m | |
| | | | | Area covered [km$^2$] | Area covered [%] | Area covered [km$^2$] | Area covered [%] |
| $\geq 105$ | 0.177 | 0.00838 | −20.76 | 0.02 | 5.12 | 0.13 | 33.33 |
| $\geq 100$ | 0.1 | 0.0026 | −25.76 | 0.05 | 12.82 | 0.28 | 71.79 |
| $\geq 95$ | 0.056 | $8.31 \times 10^{-4}$ | −30.76 | 0.12 | 30.76 | 0.37 | 94.87 |
| $\geq 90$ | 0.031 | $2.54 \times 10^{-4}$ | −35.76 | 0.24 | 61.53 | 0.39 | 100 |
| $\geq 85$ | 0.017 | $8.38 \times 10^{-5}$ | −40.76 | 0.35 | 89.74 | - | - |
| $\geq 80$ | 0.01 | $2.65 \times 10^{-5}$ | −45.76 | 0.39 | 100 | - | - |

Maximum and average values were obtained for the electric field strength and power density, measured for a period of 6 minutes at a height 1.5 m from the ground. The maximum value obtained for the average electric field strength was 5.04 V/m.

The measurements were conducted in time period 11–12 a.m. The measurements were repeated at other time intervals during the same day and in the same time period on other days. The obtained results were in the range of $+-15\%$ of the ones presented.

Comparison of the obtained results with the ICNIRP reference values reveals that the exposure levels of the base-station electromagnetic field are well below the ICNIRP exposure limits.

The results of comparative analysis conducted between exposure levels obtained via measurements and exposure levels estimated with software are given in Table 5. The measured exposure levels are lower, but the differences are small and within acceptable confidence intervals.

Besides a comparison of the electric field strength, Table 5 presents measured power density values for base stations at certain exposure positions. The measured power densities range between 0.11 (μW/cm$^2$) to 6.73 (μW/cm$^2$).

Measured values of electric field in 900 MHz band are 1.5%–9.47% of ICNIRP reference levels, while measured values for 1800 MHz band vary from 1.3%–8.6% of respective ICNIRP limits.

There is ongoing research debate about children sensitivity to radio-frequency electromagnetic fields, in comparison with sensitivity in other age groups, and the exposure of children to base-station electromagnetic fields thus needs investigation. Table 6 presents measurements of the electromagnetic field strength in the playgrounds of a primary school and kindergarten located in the neighborhood under study, as a tentative evaluation of base-station exposure levels in environments specific to children. Results for mobile-phone use by children and the exposure of children to different radio-frequency sources in indoor environments have been published [28] while a method of modelling base station indoor exposure according to outdoor measurements has been proposed [29], triggering new research in this direction. Furthermore, to clarify the effects of RF-EMF energy absorption by biological tissues, a method for measuring the absorbed radiation from cell phone antennae into ex vivo brain tissue is elaborated on [30], confirming that magnitude of temperature rise as a result of RF-EMF energy absorption in the brain tissue was a function of irradiation power and time.

The obtained values of electric field measured in playground of school and kindergarten are at 2.11% and 1.22% of ICNIRP limit, respectively.

## 4. A COMPARATIVE ANALYSIS OF MOBILE COMMUNICATION BASE STATIONS RF EXPOSURE LEVELS BETWEEN KOSOVO AND OTHER WORLD COUNTRIES

In order to present results of a comparative research done between the exposures levels obtained from measurements in Kosovo with different world countries, we have based our comparative analyses on results published in [15]. This publication includes summarized information of the surveys for 23

**Table 5.** Measured vs. software-estimated values of the electric field $E$ (V/m) and power density $S$ ($\mu W/cm^2$), expressed also in dBμ.

| Base station | Sector no. | Azimuth [°] | Distance from base-station [m] | Measured vales | | | | Evaluation with SPECTRAemc | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | $E$ [dBμV/m] | $E$ [V/m] | $S$ [$\mu W/cm^2$] | $E$ [dBμV/m] | $E$ [V/m] | $S$ [$\mu W/cm^2$] |
| SB_8 | 1 | 190 | 15 | 128 | 2.51 | 1.67 | 129 | 2.81 | 2.09 |
| | 2 | 290 | 7 | 134 | 5.04 | 6.73 | 136 | 6.31 | 10.55 |
| SB_6 | 1 | 60 | 30 | 122 | 1.25 | 0.41 | 125 | 1.77 | 0.83 |
| | 2 | 215 | 30 | 121 | 1.12 | 0.33 | 132 | 3.98 | 4.20 |
| | 3 | 345 | 30 | 132 | 3.98 | 4.20 | 133 | 4.46 | 5.29 |
| SB_1 | 1 | 30 | 55 | 124 | 1.58 | 0.66 | 126 | 1.99 | 1.05 |
| | 2 | 150 | 40 | 127 | 2.23 | 1.32 | 129 | 2.81 | 2.09 |
| | 3 | 270 | 30 | 128 | 2.51 | 1.67 | 130 | 3.16 | 2.65 |
| SB_4 | 1 | 60 | 40 | 116 | 0.63 | 0.11 | 118 | 0.79 | 0.16 |
| | 2 | 165 | 20 | 128 | 2.51 | 1.67 | 130 | 3.16 | 2.65 |
| | 3 | 295 | 35 | 120 | 1.00 | 0.26 | 124 | 1.58 | 0.66 |
| SB _7 | 1 | 50 | 20 | 130 | 3.16 | 2.65 | 130 | 3.16 | 2.65 |
| | 2 | 170 | 25 | 128 | 2.51 | 1.67 | 129 | 2.81 | 2.09 |
| | 3 | 270 | 15 | 131 | 3.54 | 3.34 | 132 | 3.98 | 4.20 |
| SB_5 | 1 | 80 | 12 | 126 | 1.99 | 1.05 | 127 | 2.23 | 1.33 |
| | 2 | 240 | 20 | 124 | 1.58 | 0.66 | 125 | 1.77 | 0.83 |
| | 3 | 350 | 35 | 126 | 1.99 | 1.05 | 127 | 2.23 | 1.32 |
| SB_2 | 1 | 40 | 65 | 120 | 1.00 | 0.26 | 122 | 1.25 | 0.41 |
| | 2 | 150 | 55 | 131 | 3.54 | 3.34 | 132 | 3.98 | 4.20 |
| | 3 | 260 | 45 | 118 | 0.79 | 0.16 | 120 | 1.00 | 0.26 |

**Table 6.** Electromagnetic field base-station exposure levels (values of the electric field $E$ (V/m) and power density $S$ ($\mu W/cm^2$), expressed also in dBμ)) in the playgrounds of a kindergarten and primary school.

| Location of measurement | Measurements with Narda EMR 300 | | | Evaluation with SPECTRAemc | | |
|---|---|---|---|---|---|---|
| | $E$ [dBμV/m] | $E$ [V/m] | $S$ [$\mu W/cm^2$] | $E$ [dBμV/m] | $E$ [V/m] | $S$ [$\mu W/cm^2$] |
| Kindergarten playground | 117 | 0.71 | 0.13 | 118 | 0.79 | 0.16 |
| Primary school playground | 119 | 0.89 | 0.21 | 120 | 1 | 0.26 |

countries in five continents with 173,323 measurement points, with the main characteristics and expands of the abbreviated names of the mobile technologies presented at Table 7.

Since all measurement surveys were done independently there was lack of a standardized measurement protocol in the participating countries, different methodology in use, different instruments, different frequency bands and resolution bandwidths and measurement modes, different criteria for selecting measurement locations etc. All these facts are considered to have caused a discrepancy between obtained results. In Table 7 are presented the results by country and by mobile technology in use, for

**Table 7.** Summary of the results from measurement surveys by country and mobile technologies[‡].

| COUNTRY ABBREVIATIONS | Power density S (μW/cm$^2$)/ Technology | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | GSM 900 | GSM 1800 | CDMA | WCDMA | AMPS | GSM 900/1800 | GSM 1800/WCDMA | ALL MOBILE REQUENCIES | GSM900/GSM1800/ WCDMA | ETACS | UMTS | PCS1900 |
| AU | 0.0189 | 0.0179 | | 0.0062 | | | | | | | | |
| AT | 0.0043 | 0.0046 | | 0.0005 | | | | | | | | |
| BE | 0.2270 | 0.0366 | | 0.0083 | | | | | | | | |
| CA | | | | | 0.0018 | | | | | | | 0.0008 |
| EG | | | | | | 0.4120 | | | | | | |
| FR | 0.1120 | 0.0468 | | 0.0140 | | | | | | | | |
| DE | | | | 0.3590 | | 0.7330 | | | | | | |
| GR | 0.1430 | | | | | | 0.1590 | | | | | |
| HU | 0.1370 | 0.0419 | | | | | | | | | | |
| IE | 0.0629 | 0.0317 | | 0.0620 | | | | | | | | |
| JP | | | 0.0003 | 0.0002 | | | | | | | | |
| MY | | | | | | | | 0.4880 | | | | |
| NZ | | | | | | | | 0.6780 | | | | |
| PE | 0.5560 | | | | | | | | | | | 1.0100 |
| KR | | 0.3430 | 0.5590 | 0.3070 | | | | | | | | |
| ES | 0.5370 | | | | | | | | | | | |
| SE | 0.1910 | 0.1260 | | 0.1060 | | | | | | | | |
| CH | | | | | | | | | 0.1370 | | | |
| TH | 0.0047 | 0.0142 | | | | | | | | | | |
| UK | 0.0009 | 0.0014 | | 0.0001 | | | | | | 0.0000 | | |
| USA | | | | | | | | 1.3600 | | | | |
| KOS | 1.1158 | 2.5533 | | | | | | | | | 3.000 | |

comparative reasons. In the first column are presented all country abbreviated names[†], while in others are respective measured power density $S$ (μW/cm$^2$) values by different mobile technologies. Measured results for the Kosovo case are worrisome and need to be adressed by respective authorities, even that are taken in mentioned particular location. The extensive research in this regard is preferable, in order to have complete view of power density values for Kosovo case.

A graphical representation of obtained power density data in Kosovo in comparison with power density data of other countries, for different cellular technologies, is given in Fig. 4.

As a conclusion, USA and Kosovo have measured the highest exposure levels, due to the use of broadband measurements instruments, which are considered to yield higher values than narrowband measurements instruments.

The below detection limit of narrowband instruments is typically 4–5 orders of magnitude below broadband instruments, but this is very dependent on the amount of amplification and the signal processing involved in the setup [15].

[†] Australia AU, Austria AT, Belgium BE, Canada CA, Egypt EG, France FR, Germany DE, Ghana GH, Greece GR, Hungary HU, Ireland IE, Japan JP, Malaysia MY, Netherlands NL, New Zealand NZ, Peru PE, South Korea KR, Spain ES, Sweden SE, Switzerland CH, Thailand TH, United Kingdom UK, United States of America USA, Kosovo KOS.

[‡] Abbreviations: AMPS, Advanced Mobile Phone System; CDMA, Code Division Multiple Access; ETACS, Extended Total Access Communications System; GSM, Global System For Mobile; NMT, Nordic Mobile Telephone; PCS, Personal Communications Services; WCDMA, Wideband CDMA; a Broadcast (FM radio and television).

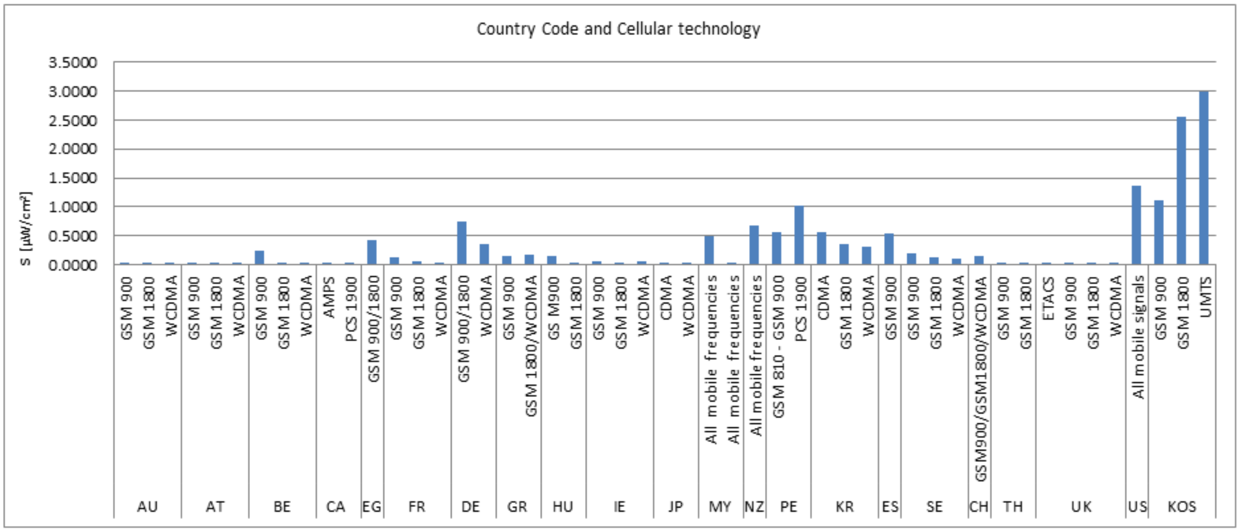



**Figure 4.** Comparison of power density $S$ ($\mu$W/cm$^2$) for each country and for different cellular technology.

Another reason for the high levels of exposure in the USA is that the measurements were taken in a large number of rooftops very close to base stations, same as in Kosovo, where the measurements were taken considering the direction of maximum radiation intensity. This fact has resulted in significantly higher exposures levels in comparison with other countries.

In Kosovo, it is observed that due to irregular urban planning levels of exposures tend to be higher.

## 5. CONCLUSIONS

The continuous deployment of emerging wireless-communication base stations in densely populated areas is triggering research on the assessment of human exposure to radio-frequency electromagnetic fields and possible health and environmental impacts, including the determination of safe exposure zones. The present study scanned electromagnetic sources in an urban environment and evaluated the power balance. The main contributors to electromagnetic exposure levels were thus found to be GSM 900-MHz, GSM 1800-MHz and 3G base stations. A comparative analysis of exposure levels obtained employing a theoretical approach, in situ measurements and exposure levels estimated with software shows that the measured exposure levels are lower, however the differences are small and within acceptable confidence intervals. Furthermore, comparing results of the power density values obtained in Kosovo with other countries have resulted to be higher. This due to some differences in measurement equipment, measurement location criteria, settings of measurements, survey methodology, urban planning and years of survey analyses.

Comparing the obtained results of electric field levels with ICNIRP reference levels reveals that the exposure levels are many times below the safety standard limits at positions from the ground to the height of a person.

## REFERENCES

1. Gajšek, P., P. Ravazzani, J. Wiart, J. Gresllier, T. Samaras, and G. Thuróczy, "Electromagnetic field exposure assessment in Europe radiofrequency fields (10 MHz–6 GHz)," *Journal of Exposure Science and Environmental Epidemiology*, Vol. 25, No. 1, 37–44, 2015.
2. Khurana, V. G., L. Hardell, J. Everaert, A. Bortkiewicz, M. Carlberg, and M. Ahonen, "Epidemiological evidence for a health risk from mobile phone base stations," *International Journal of Occupational and Environmental Health*, Vol. 16, No. 3, 263–267, 2010.

3. Gandhi, G., G. Kaur, and U. Nisar, "A cross-sectional case control study on genetic damage in individuals residing in the vicinity of a mobile phone base station," *Electromagnetic Biology and Medicine*, 344–354, 2014.
4. International Commission on Non-Ionizing Radiation Protection, "Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)," *Health Physics*, Vol. 74, No. 4, 494–522, 1998.
5. Alanko, T., M. Hietanen, and P. von Nandelstadh, "Occupational exposure to RF fields from base station antennas on rooftops," *Annals of Telecommunications — Annales des Télécommunications*, Vol. 63, Nos. 1–2, 125–132, 2008.
6. Lacroux, F., E. Conil, A. C. Carrasco, A. Gati, M. F. Wong, and J. Wiart, "Specific absorption rate assessment near a base station antenna (2,140 MHz): Some key points," *Annals of Telecommunications — Annales des Télécommunications*, Vol. 63, Nos. 1–2, 55–64, 2008.
7. Joseph, W. and L. Martens, "Comparison of safety distances based on the electromagnetic field and based on the SAR for occupational exposure of a 900-MHz base station antenna," *IEEE Transactions on Electromagnetic Compatibility*, Vol. 47, No. 4, 2005.
8. Laviada, J., Y. Alvarez-Lopez, and F. Las-Heras, "Efficient determination of the near-field in vicinity of an antenna for the estimation of its safety perimeter," *Progress In Electromagnetic Research*, Vol. 103, 371–391, 2010.
9. Gosselin, M.-C., G. Vermeeren, S. Kuhn, V. Kellerman, S. Benkler, T. M. I. Uusitupa, W. Joseph, A. Gati, J. Wiart, F. J. C. Meyer, L. Martens, T. Nojima, T. Hikage, Q. Balzano, A. Christ, and N. Kuster, "Estimation formulas for the specific absorption rate in humans exposed to base station antennas," *IEEE Transactions on Electromagnetic Compatibility*, Vol. 53, No. 4, 2011.
10. Gosselin, M.-C., A. Christ, S. Kuhn, and N. Kuster, "Dependence of the occupational exposure to mobile phone base stations on the properties of the antenna and the human body," *IEEE Transactions on Electromagnetic Compatibility*, Vol. 51, No. 2, 2009.
11. Wang, J., T. Tayamachi, and O. Fujiwara, "Amplitude probability distribution measurement for electric field intensity assessment of cellular-phone-base stations," *IEEE Transactions on Electromagnetic Compatibility*, Vol. 50, No. 3, 2008.
12. Ozdemir, A. R., M. Alkan, and M. Gulsen, "Time dependence of environmental electric field measurements and analysis of cellular base stations," *IEEE Electromagnetic Compatibility Magazine*, Vol. 3, No. 3, 2014.
13. Higashiyama, J. and Y. Tarusawa, "Design of electric field meter to assess human exposure in environment with mobile base station," *2014 International Symposium on Electromagnetic Compatibility, Tokyo (EMC'14/Tokyo)* 650–653, IEEE, 2014.
14. World Health Organization, WHO research agenda for radiofrequency fields, http://www.who.int/peh-emf/research/agenda/en/index.html (accessed December 19, 2010), 2010.
15. Rowley, J. T. and K. H. Joyner, "Comparative international analysis of radiofrequency exposure surveys of mobile communication radio base stations," *Journal of Exposure Science and Environmental Epidemiology*, Vol. 22, No. 3, 304–315, 2012.
16. Ibrani, M., E. Hamiti, L. Ahma, R. Halili, V. Shala, and D. Berisha, "Narrowband frequency-selective up-link and down-link evaluation of daily personal-exposure induced by wireless operating networks," *Wireless Networks*, 1–10, 2016.
17. Ibrani, M., E. Hamiti, L. Ahma, and B. Shala, "Assessment of personal radio frequency electromagnetic field exposure in specific indoor workplaces and possible worst-case scenarios," *AEU-International Journal of Electronics and Communications*, Vol. 70, No. 6, 808–813, 2016.
18. Miclaus, S. and P. Bechet, "Estimated and measured values of the radiofrequency radiation power density around cellular base stations," *Romanian Journal of Physics*, Vol. 52, Nos. 3/4, 429, 2007.
19. Cicchetti, R. and A. Faraone, "Estimation of the peak power density in the vicinity of cellular and radio base station antennas," *IEEE Transactions on Electromagnetic Compatibility*, Vol. 46, No. 2, 275–290, 2004.

20. Kamo, B., R. M. Mitrushi, V. Kolici, O. Shurdi, and A. Lala, "Estimated peak power density in the vicinity of cellular base stations in Albanian territory," *2010 International Conference on Software, Telecommunications and Computer Networks (SoftCOM)*, 117–120, IEEE, 2010.
21. Gajšek, P. and D. Simunic, "Occupational exposure to base stations — compliance with EU Directive 2004/40/EC," *International Journal of Occupational Safety and Ergonomics*, Vol. 12, No. 2, 187–194, 2006.
22. Baldauf, M. A., S. Knorzer, J. A. Pontes, and W. Wiesbeck, "Safety distances underneath vertically polarized base station antennas," *18th International Zurich Symposium on Electromagnetic Compatibility, EMC Zurich 2007*, 191–194, IEEE, 2007.
23. Beekhuizen, J., R. Vermeulen, H. Kromhout, A. Bürgi, and A. Huss, "Geospatial modelling of electromagnetic fields from mobile phone base stations," *Science of the Total Environment*, Vol. 445, 202–209, 2013.
24. Hasenfratz, D., S. Sturzenegger, O. Saukh, and L. Thiele, "Spatially resolved monitoring of radio-frequency electromagnetic fields," *Proceedings of First International Workshop on Sensing and Big Data Mining*, 1–6, ACM, 2013.
25. Agbinya, J., Z. Chaczko, and K. Aboura, "Radio frequency pollution mapping," *Proc. of the Fourth International Conference on Broadband Communication Information Technology and Biomedical Applications*, 2009.
26. Genc, O., M. Bayrak, and E. Yaldiz, "Analysis of the effects of GSM bands to the electromagnetic pollution in the RF spectrum," *Progress In Electromagnetics Research*, Vol. 101, 17–32, 2010.
27. Paniagua, J. M., M. Rufo, A. Jimenez, and A. Antolin, "The spatial statistics formalism applied to mapping electromagnetic radiation in urban areas," *Environmental Monitoring and Assessment*, Vol. 185, No. 1, 311–322, 2013.
28. Ibrani, M., L. Ahma, and E. Hamiti, "Assessment of the exposure of children to electromagnetic fields from wireless communication devices in home environments," *IET Communications*, Vol. 8, No. 12, 2222–2228, 2014.
29. Beekhuizen, J., R. Vermeulen, M. van Eijsden, R. van Strien, A. Bürgi, E. Loomans, and A. Huss, "Modelling indoor electromagnetic fields (EMF) from mobile phone base stations for epidemiological studies," *Environment International*, Vol. 67, 22–26, 2014.
30. Gultekin, D. H. and L. Moeller, "NMR imaging of cell phone radiation absorption in brain tissue," *Proceedings of the National Academy of Sciences*, Vol. 110, No. 1, 58–63, 2013.