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Radiofrequency Electromagnetic Field Exposure in Everyday Microenvironments

Rachel Nkem Olatunji
Adekunle Ajasin University Akungba-Akoko

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ABSTRACT: A measuring campaign for the assessment of electromagnetic radiation near base stations in the city center of Leuven, Belgium, has been carried out.The aim is to evaluate the current exposure levels and characterize the general public exposure to radiofrequency electromagnetic fields. The measurements were performed in public areas in different locations in Leuven. The study was also carried out as a function of location and time using highly precise measurement equipment. Measurement values were analyzed based on data extracted from raw measurements within 700MHz to 4000 MHz frequency band for telecommunication services. The result presentation includes electric field strength referring to broadband measurements at the highest exposure measurement point. In general, measurement results show that all exposure values are in compliance with the reference levels defined for Flanders and considerably below the limits recommended by ICNIRP.

KEYWORDS: radiofrequency; electromagnetic field; exposure; base station

I. INTRODUCTION

With the rapid increase and development of emerging wireless technologies, concerns about exposure to radiofrequency electromagnetic fields (RF-EMF)in everyday environment has made World Health Organization (WHO) [1] to place a high priority on research involving real-life exposure to electromagnetic fields (EMF) and its determinants.Thus, environmental EMF exposure has become both a scientific topic and a social issue as there is keen attention of the public to RF-EMF exposure near wireless telecommunication base stations. The dense deployment of base stations in residential areas is also an important factor that could cause conflicts between residents and wireless network service providers. In a way of solving this problem, WHO proposed EMF risk communication andrisk perception as major aspects of the EMF issues [2-3], thus giving rise to EMF measurement campaigns which play an important role in the risk communication activities since it can directly identify whether the risk exist or not. Although exposure quantification is complex due to high variability of RF-EMF levels in the environment, several studies have presented and analyze variations in RF-EMF exposure levels near telecommunication base stations for the general public. This is based on a number of exposure measurements in various microenvironmentsin different parts of the world such as Serbia [4]; Korea [5], China [6]; and in 23 countries across five continents [7].

Exposures of the general public to electromagnetic fields generated by wireless systems is mostly within the radio frequency range (3 kHz to 300 GHz). These frequencies are used in broadcasting stations (radio and television), mobile phone base stations (GSM - Global System for Mobile Communications, UMTS -Universal Mobile Telecommunications System,and LTE - Long-TermEvolution), Digital Enhanced Cordless Telecommunications (DECT) base stations, and wireless communication applications such as wireless fidelity (WiFi) systems and worldwide interoperability for microwave access (WiMax). Microenvironmental exposure measurements can also include hotspots of wireless local area network (WLAN) and uplink from other people's mobile phones.

In order to evaluate the possible impact of exposure to electromagnetic radiation from mobile communication systems, recent studies have been conducted in the area of exposure field measurements by collecting dataeither by walking [8-12] or on a bicycle [13-14] or a mixture of walking the pedestrian way and driving [15].There are exposure studies which involved volunteers wherein they are informed on how to use the measurement device [16-17]. This could be disadvantageous as the volunteers may not adhere strictly to the measurement protocol thereby yielding inaccurate data. Larger geographical areas have been covered in [18-20] during mobile monitoring compared to spot measurements in whichhigh reproducibility of exposure measurements have been obtained. [21-22].

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Different techniquesusing basic standards in [23] andmeasurement devices for exposure measurements in the immediate environment of mobile communication systems have been developed. For example, some personal exposure meters in [24] were demonstrated to overestimate signals with bursts, such as signals from WiFi appliances and mobile phones. Thus,portable devicesespecially the ones worn on the body for exposure measurements have challenges such as sensitivity range, body shielding and out-of-band response [24-25].But exposure assessments with spectrum analyzer device for either mobile phone exposure such as [26] or base station exposures [27-29] is known to be accurate. Previous studies such as [29] analyzed exposure for both indoor and outdoor microenvironments with spectral equipment but only one study in [27] has shown the correlation between outdoor and indoor study in the same city.

The conclusions reached from previous measurement campaigns about exposure assessments are quickly outdated because of rapidly evolving mobile technologies. For this reason, all existing mobile communication systems were investigated in this study for only outdoor locations. This is in line with the fact that mobile phone base station emissions are dominant exposure source when being outdoors than indoors [27]. In exposure measurements, uplink fields are typically attributed to other people's mobile phones possibly far from the measurement setup. Although this is not the case with measurement instruments worn by volunteers as the uplink field is a mixture of the emissions from the volunteer's mobile phone and other people's. The uplink fields recorded in this study are emanating from other people's mobile phones within the measurement location during active base station transmission. This is achieved bydistributing 3 different smartphones (set on different network modes) to people within the base station environment to make calls for free.The goals were 1) to study the exposure as a function of location in the city center and as a function of time during the day and at night with 2) professional highly precise measurement equipmentand3) to check whether there is increase or decrease in exposure levels in comparison with the fields obtained in year 2015 and 2017.RF-EMF measurements have been carried out across the globe but only a few studies have conducted research on time trends in exposure levels. To the best knowledge of the authors a study combining all these different aspects has not been performed beforein Belgium.

II. METHODOLOGY

The measurements discussed and analysed in this work were carried out between August and September 2019during working days. All measurements were performed at 9.00 am, 12.00 noon, 14.00 pm, 17.00 pm, 19.00 pm, 21.00 pm, and at midnight. The measured frequency band ranges from 700 MHz to 4000 MHz. Most widely used radio communication bands, used for cellular transmission, are located in this band (GSM, UMTS and LTE). The measurements consisted of a broadband measurement, in order to characterize the environment in terms of total radiation levels contributed by cellular communication systems in the area. Comparative measurements were carried out with two spectrum analyzers in order to obtain good results. The detection limit of these spectrum analyzers is about -90 dBm and the power levels measured were sufficiently high. Power levels below the noise floor (-65 dBm) of the measurement settings were neglected.

Measurements were performed with alogarithmic periodic antenna mounted on a tripod and connected to one of the two spectrum analyzers. The person operating the measurement equipment was at least 2.5 m away from the tripod. The influence of body proximity on measured fields was also avoided for the public. This was done by a visible notice displayed at the measurement sites indicating that people should not walk close to the equipment as a measurement was going on. At first, test measurements were carried out at three heights (1.1, 1.5 and 1.7 m) above the floor. The maximum value was always obtained at 1.5m. As a result this height was used for all measurements, according to CENELEC [30].Measurements were carried out for the two orthogonal polarizations (vertical and horizontal polarization) shown in Figure 1. During the exposure measurement, the maximum-hold setting was kept during a time interval of 6 minutes until the spectrum analyzer reading stabilized. The used equipment consisted of the following:

•hyperLOG 7040 antenna(gain 4 dBi in the frequency band 700 MHz - 4 GHz),
• two portable spectrum analyzers: Anritsu MS2721A and Keysight N9344C,
• RF coaxial cable with SMA - SMA connectors,
• atripod.

The settings of the spectrum analyzers were:
• Trace mode: MaxHold and RMS detection,
• Duration of each measurement: 6 minutes.

All electric field strengths were calculated with a resolution of 0.01 V/m.

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2.2 Measurement Locations

The choice of the measurement locations was driven by the concentration of the base stations installed in the city center of Leuven, Belgium. The base stations seen in the course of this measurement, were building mounted and rooftop ones. Figure 3A shows the map of the base stations in Leuven. The ones which were operational within the period of the measurement campaign are in red, see [31]. The measurements were performed in thirty (30) outdoor locations spread out over the city center. This means that all base stations in the city center were covered in the measurement campaign. A permit was obtained from the city council in order to have official access to all public areas.

The choice of the exact measurement position was based on the proximity to a selected base station, as the intensity of the radiation decreases rapidly with distance from the emitting source. The horizontal component of the distance between a measurement spot and the closest base station was determined for all the measurements. The exact measurement position in the immediate neighborhood of a specific base station was chosen in such a way that it corresponds to the position with the highest level of radiation exposure to which a person might be subjected,in conformity with [32]. This was achieved by performing measurements in a zone of about 10 m diameter at a certain distance from the base station location, thereby selecting the spot with the highest exposure. Since buildings, trees and other solid objects may significantly absorb, reflect or scatter the RF signals, the outdoor locations were based on the line-of-sight criterion and further specified in detail by checking the levels using the measuring equipment in the neighborhood of the base stations. The measurement spot coordinates were recorded by using the Global Positioning System (GPS),see Figure 3 (right).The selected microenvironments are publicly accessible places where people spend part of their time.

Figure 2: Building mounted base station (left), rooftop base station (middle), and mast installed on building (right)

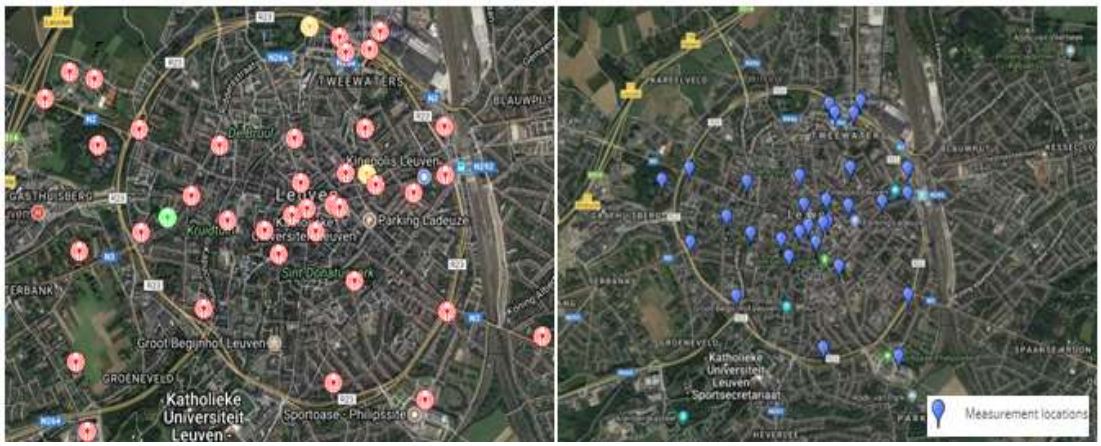

Figure 3: Map of base stations in Leuven [31] (left) &measurement locations considered in Leuven city center (right).

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2.3 Measurements

During the processing of the data, in order to obtain the received power at the position of the antenna (P_{ant}), the cable losses (P_{cab}) have to be considered:

$$P_{ant} = P_{dBm} + P_{cab} \cdot l \quad (1)$$

where l is the cable length and P_{cab} the losses, normally known in dB/m.

The cable losses are easily measured with a vector network analyzer (VNA). The incident field at the position of the antenna was obtained by taking into account the gain of the antenna in the expression (4) below. The raw data as measured by the SA (Spectrum Analyzer) were extracted for the uplink and downlink frequency bands of: LTE 800, GSM 900, GSM 1800, UMTS 2100, LTE 2600 and DECT system.

To determine the electric field strength values, expressions 2 are substituted into expression 3:

$$S = \frac{e^2}{120\pi} \text{ and } G = \frac{4\pi}{\lambda^2} A_{eff} \quad (2)$$

$$P_r = S. A_{eff} \quad (3)$$

For a plane wave which is incident on the antenna, the relationship between field strength and received power can be written as

$$e = \sqrt{\frac{480\pi^2}{\lambda^2}\frac{P_r}{G}} = \sqrt{K \cdot P_r} \quad (4)$$

with $K = \frac{480\pi^2}{\lambda^2}\frac{1}{G}$

where

e = field strength (V/m)

λ = wavelength in free space (m)

P_r = received power (W)

G = antenna gain

A_{eff} = antenna effective area (m^2)

S = power density (W/m^2)

In order to obtain the total field, in principle 3 polarizations have to be combined. To this goal, in principle three measurements with the SA are necessary. The total field can then be calculated by summing in a ‘‘root sum square’’ way.

$$E = \sqrt{\sum_i^3 e_i^2} \quad (5)$$

where i refers to the actually measured 3 components (x,y,z) of the electric field.

The total fields in all the considered bands were obtained also by summing over the discrete measurement points in the corresponding band in a root sum square way.

The electric field strength at each specific time for the 30 measurement locations was computed and the spread over time was calculated by subtracting the lowest electric field from the highest.

The main characteristic of this measurement protocol is that it involves computing the averages of maximum exposure around base stations, both over time (6 minutes measurement interval, processed data even over a day), over space (many different locations), and frequency (several bands together). This means that it does not give any information on a specific exposure on a specific time in a specific spot for a specific base station. However, this averaging is exactly the point of the paper. Instead of being viewed as a weak point, this can thus actually be seen as the strong point, since it gives a very good general view on exposure.

III. RESULTS AND DISCUSSION

3.1 Daily exposures in different microenvironments

Exposure to radiofrequency electromagnetic fields from mobile phone base station antennas changes within the time of the day.in order to quantify the daily variations, we performed measurements during peak and off hours in the day and at night. Mobile communications systems like GSM, UMTS and LTE were investigated and the exposure metric used is electric field strength. The average values (over time) for all 30 outdoor locations are depicted in Figure 4. Each plot on the base station locations represents the average values of electric field strength over 7 different measurement times for the highest exposure point in each outdoor microenvironment.Exposure levels spread across the locations show spatial variability. From all the locations considered the highest average field value measured is 2.30 V/m andgenerated by the GSM 900 signal. It can be deduced from the graph (Figures 4) that GSM 900 exposure mostly dominates over GSM 1800, UMTS and LTE. For 26locations out of 30, which is 86%, the level of GSM 900 is higher than the level of LTE 800, GSM 1800, UMTSand LTE 2600.These results are in line with our previous study [27] which showed that for 76% of measurement locations, exposure in GSM 900 band was higher than UMTS.

Within the bands considered, UMTS and LTE 2600 exposures were considerably lower than

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GSM 900, GSM 1800 and LTE 800.The highest outdoor values measured represent36.6% of the legal limit for LTE 800, 76.6%for GSM 900, 42.8% for GSM 1800, 21.5% for UMTS and 4.4% for LTE 2600.Similarly, the lowest outdoor exposure (in percentage of legal limit for Flanders) is in the order of 2.7% for LTE 800, 13.3%for GSM 900, 4.3% for GSM 1800, 2.4% for UMTS and 3.1% for LTE 2600. In terms of average, the field intensities outdoors vary over the measurement time as this is much dependent on the number of mobile phone calls and data transmission.

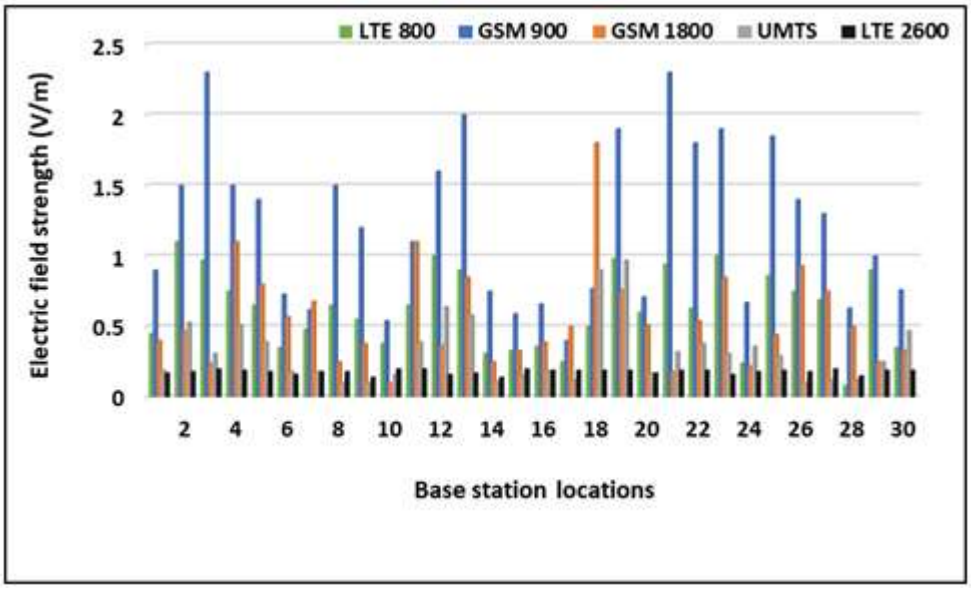

Figure 4: average (over time) of electric field strength measured in different outdoor locations near individual base stations

3.2 Analysis of data variability

We analyzed exposures by activity, for the different source constituents: downlink (radiation emitted from mobile phone base stations), uplink (transmission from phone to base station), others which include DECT and WiFi. At the time this measurement was carried out, most of the locations had only WiFi 2G in the city center which suggest that WiFi 5G had not been fully deployed.In total, 420 base station measurements were collected in the locations considered. Exposure to mobile phone base stations consisting all downlink frequencies (of GSM, UMTS and LTE) combined gives values ranging from 0.71 to 2.53 V/m. While the uplink exposure values ranges from 0.18 to 1.02 V/m.The specific averages of exposure from all frequency bands (including downlink, uplink, DECT and WiFi) in each location combined correspond to total RF-EMF. The total exposure varied widely across the locations and ranges from 0.76 V/m to 2.68 V/m. The plot in Figure 5 shows that the highest contributor is the downlink signal while the lowest are observed in DECT and Wi-Finamed as others. Overall, measurements above 2 V/m were infrequent in the downlink bands and as a consequence seen in eleven different locations out of 30 in total RF-EMF.

The uplink exposure was considerably lower than the downlink values in all locations. The proportion of uplink total average values above 0.5 V/m in all thirty locations is 43.3%. In the GSM band, no uplink measurements above 1.0 V/m occurred in all locations. In a way of comparing the different exposure constituents, it is evident from the graph that downlink exposure is the main contributor to total RF-EMF.

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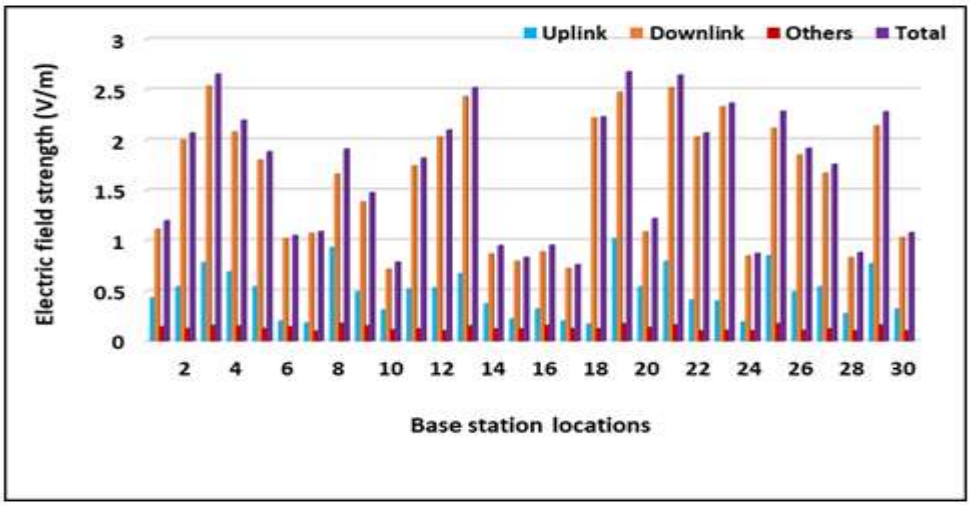

Figure 5: Exposure for uplink, downlink, others (DECT and Wi-Fi) and total RF-EMF for different base station locations

Measurement data which includes telecommunication services and their corresponding frequency bands, minimum E field, maximum E field and exposure ratio are summarized in Table 1. The exposure ratio, which is defined as the maximal field over the ICNIRP reference field level, is given for all the services. From the table, GSM 900 contributed the most in the exposure ratio calculation. The relatively high value of the spread (of electromagnetic exposure) seen in GSM 900 system depicts the wide sample distribution.

LTE: Long-Term evolution, GSM: global system for mobile communication, DECT: digital enhanced cordless telecommunications, UMTS: universal mobile telecommunications system, Wi-Fi: wireless fidelity 802.11, E_{min}: minimum electric field strength, E_{max}: maximum electric field strength and ER: exposure ratio.

Services band (MHz)	Frequency	E_{min} [V/m]	E_{max} [V/m]	Exposure ratio ER [%]
LTE 800	791-821	0.35	1.00	2.57
GSM 900	925-960	0.54	2.30	5.61
GSM 1800	1805-1880	0.22	1.10	1.89
DECT	1880-1900	0.03	0.09	0.15
UMTS	2110-2170	0.12	0.64	1.05
Wi-Fi	2400-2400	0.05	0.15	0.24
LTE 2600	2620-2690	0.14	0.20	0.33
Total signal				

Table 1: Measure frequency bands, exposure values and exposure ratio

IV. CONCLUSION

A representative outdoor scenario for the exposure within a city is investigated and the field levels assessed were further processed to obtain the real exposure. Measurements were conducted for an antenna in line-of sight with the transmitting base station for mobile communication systems and emerging wireless network. The result of the measurements revealed that all the exposure values were below reference levels for Flanders and considerably below the ICNIRP exposure limits. The major exposure contributor being GSM 900 signal. The present measurement also considered exposure from emerging technologies such as LTE in which the exposure levels of LTE 800 are slightly higher than UMTS. While considering exposure from other wireless systems we found out that downlink exposure from mobile phone base stations is the most relevant contributor to exposure in most microenvironments.

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