Measurement 56 (2014) 50–57

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Temporal 24-hour assessment of radio frequency exposure in schools and homes

Leen Verloock [a], Wout Joseph [a,*], Francis Goeminne [a], Luc Martens [a], Mart Verlaek [b], Kim Constandt [b]

[a] Department of Information Technology, Ghent University/iMinds Gaston Crommenlaan 8, Box 201, B-9050 Ghent, Belgium
[b] Department of Environment, Nature and Energy (LNE), Flemish Government, Koning Albert II-laan 20, Box 8, B-1000 Brussels, Belgium

ARTICLE INFO

Article history:
Received 30 September 2013
Received in revised form 12 June 2014
Accepted 19 June 2014
Available online 27 June 2014

Keywords:
Temporal exposure
24 hours
School
Home
RF exposure of general public
Electromagnetic measurement

ABSTRACT

Temporal radio frequency (RF) exposure from present and emerging technologies in sensitive microenvironments such as schools and homes is important for evaluations of compliance to international limits. For the first time, temporal 24-hour measurements of all present RF signals, including LTE (Long term Evolution), are performed with accurate spectral narrowband equipment in these environments where children are present. The largest maximal variations are obtained for the cordless telephony (DECT) signals (10.6 dB) and for the WiFi 2.4 GHz signals (12.7 dB), while variations of broadcasting signals and telecommunication signals were much lower namely, 2.9 dB and 3.3 dB, respectively. Thus, indoor sources exhibit the largest variations indoor and are the most critical for practical exposure assessment and comparison with existing guidelines. It is recommended to perform exposure measurements during school days as highest field values were measured then. All field values measured over 24 hour satisfied the ICNIRP reference levels.

1. Introduction

Taking temporal variations of exposure to wireless networks into account when assessing exposure for compliance with existing exposure limits [1] is a must. Because of the rapid evolution of wireless technologies, it is important to permanently monitor exposure from radio-frequency electromagnetic fields (RF-EMF), as stated in the World Health Organization's (WHO) research agenda [2]. Up to now, data and assessment of temporal variations of RF-EMF exposure in sensitive places such as schools and homes are lacking. Measurements during time (days, weeks) are time-consuming, expensive, and difficult to execute in practice. Therefore compliance is often only evaluated by performing short-time spatial measurements [3–7].

Only limited data about temporal variations are available [8–13,15]. Existing literature and procedures are discussed in detail in [8,10] and a CENELEC standard has been proposed for the in-situ measurement of electromagnetic-field strength [16]. Manassas et al. [9] investigated diurnal variations of fields due to broadcasting and mobile telecommunication and provided median variations. In [10], Erlang data (representing average mobile phone traffic intensity during a period of time) is related to RF exposure using temporal measurements during a week. Reference [11] compared real exposure with the maximal estimated exposure to characterize the ratio between daily and maximum theoretical exposure values, while [12] compared various realistic extrapolation methods in two countries. The authors of [13] also stated that short-term exposure assessment is not reliable for evaluation of

* Corresponding author. Tel.: +32 93314918; fax: +32 9 33 14899.
E-mail address: wout.joseph@intec.UGent.be (W. Joseph).

http://dx.doi.org/10.1016/j.measurement.2014.06.012
0263-2241/

long-term exposure. Ref. [14] reported a variability of power density of the GSM900 downlink band of ±5.2 dB throughout the day as a result of traffic variation. The measurements of [14] were executed indoor at a single location. RF-EMF exposure assessment studies using exposimeters have also been reported, investigating spatial and temporal field aspects [17–20] but these assessments are difficult for accurate evaluation of temporal exposures due to limitations of the exposimeters (no settings per signal possible) and the use of exposimeters on the body can influence the results enormously. Finally Ref. [15] proposed a combination of temporal exposimeter measurements (standing alone) and spatial spectral narrowband measurements to assess exposure in indoor environments.

Currently, temporal RF-EMF exposure assessment in "sensitive" environments such as schools and homes, where children reside, is missing. The objective of this paper is to assess and characterize temporal exposures with accurate narrowband equipment (spectrum analyzers and measurement probes) during 24 hour in schools and homes where children are present. All present RF signals, including LTE (Long Term Evolution, recently being rolled-out in Belgium since the end of 2012) are considered. Moreover, we determine for which periods of the day (morning, school day, evening, night) higher variations of the exposure are possible in the different microenvironments. Finally, for WiFi, the duty cycle, which depends upon the type of wireless traffic and actual usage, is measured and characterized during 24 hour in these environments. Up to now, the assessment of the WiFi duty cycle was only performed at specific moments or for specific applications for WiFi. Authorities can use the recommendations and results of this paper to determine the time and moment of day when evaluating compliance to their guidelines. Moreover, the results are of importance for the WHO to build up knowledge about the temporal variations of emerging technologies.

This work was in authorization of the Flemish government. The Flemish government, Department of Environment, Nature and Energy (LNE) commissioned this study and no separate ethical approval was needed as the measurements did not occur with children but in their living environment. Approval from schools and Flemish government was obtained.

2. Materials and method

2.1. Selection of microenvironments

At 10 microenvironments, 5 schools and 5 homes, 24-hour temporal measurements were performed. All temporal measurements occurred indoor. The microenvironments are located in urban environments. The schools were selected based on the presence of internal RF sources and the use of wireless local area network (WLAN) devices. In every school, WiFi is used as WLAN technology and in a school tablets were used for educational purposes. Also five homes where children reside and WiFi was present were investigated. The homes are regular houses; no apartment buildings or flats were considered. The measurements were performed in the period of October 2012–April 2013.

2.2. Measurement equipment

Temporal exposure variations were assessed using frequency-selective narrowband measurements. The setup consisted of tri-axial Rhode and Schwarz R&S TS-EMF isotropic antennas (dynamic range of 1 mV/m–100 V/m for the frequency range of 80 MHz–3 GHz, and 2.5 mV/m–200 V/m for a frequency range of 2–6 GHz) in combination with a spectrum analyzer (SA) of type R&S FSL6 (frequency range of 9 kHz–6 GHz) (R&S, Munich, Germany). The measurement uncertainty was ±3 dB for the considered setup [6,16,21]. This uncertainty represents the expanded uncertainty evaluated using a confidence interval of 95%.

The location of the maximal total electric-field value at the site under consideration is identified through sweeping the area with the broadband probe [16]. A broadband probe of type Narda NBM-550 (measurement equipment) equipped with EF0391 (measurement probe with a dynamic range of 0.2–320 V/m and a frequency range of 100 kHz–3 GHz) or EF0691 (measurement probe with a dynamic range of 0.35–650 V/m and a frequency range of 100 kHz–6 GHz) was used for this purpose.

2.3. Measurement procedure to characterize the temporal variations

Firstly, at each school and home, 24-hour temporal measurements (during working days) were performed at a specific location. The location for this assessment was selected as follows. With a broadband probe the locations of maximal fields were searched for. At the location of the maximal total field value, the setup for the temporal assessment was positioned if practically possible. One has often to take into account that children and adults are not allowed to touch the equipment and be careful for vandalism or theft. If it was not possible to place the equipment at the maximum field location, the nearest "safe" location was chosen. We are here mainly interested in the temporal variations of the different present signals.

Secondly, with a spectrum analyser and tri-axial antenna, a spectral overview measurement in the frequency range of 80 MHz up to 3 GHz was performed to identify present RF signals.

Thirdly, narrowband measurements of the momentary field values of the significantly present signals (FM, T-DAB, DVB-T (digital TV), GSM900, GSM1800, UMTS/HSPA, LTE, WiMAX, DECT, WiFi, etc.) were performed during 24 hour [8,10]. All the abbreviations of these RF signals are explained below Table 1. The optimal settings of the SA for various RF signals were selected from [6]. This sequence of measurements was repeated an entire week - day (24 hour). The cycle time was about 3 min (setting of configuration of frequency band to be measured, sweeping of the SA, reading and transferring of the measurement traces, configuration of next frequency band, etc.). This duration also depends upon the number of frequency bands. If WiFi was measured the duration was prolonged