Environmental Research 161 (2018) 136–143

Contents lists available at ScienceDirect

Environmental Research

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

Assessment of long-term spatio-temporal radiofrequency electromagnetic field exposure

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A R T I C L E I N F O

Keywords:
Spatio-temporal exposure assessment
Telecommunications
Radiofrequency electromagnetic fields
Non-ionizing radiation

A B S T R A C T

As both the environment and telecommunications networks are inherently dynamic, our exposure to environmental radiofrequency (RF) electromagnetic fields (EMF) at an arbitrary location is not at all constant in time. In this study, more than a year's worth of measurement data collected in a fixed low-cost exposimeter network distributed over an urban environment was analysed and used to build, for the first time, a full spatio-temporal surrogate model of outdoor exposure to downlink Global System for Mobile Communications (GSM) and Universal Mobile Telecommunications System (UMTS) signals. Though no global trend was discovered over the measuring period, the difference in measured exposure between two instances could reach up to 42 dB (a factor 12,000 in power density). Furthermore, it was found that, taking into account the hour and day of the measurement, the accuracy of the surrogate model in the area under study was improved by up to 50% compared to models that neglect the daily temporal variability of the RF signals. However, further study is required to assess the extent to which the results obtained in the considered environment can be extrapolated to other geographic locations.

1. Introduction

Wireless telecommunications technologies have become an indispensable and ubiquitous part of our everyday life. As these technologies continue to grow more diverse and complex, in order to satisfy our evermore increasing desire for connectivity, so does the range of radiofrequency (RF) electromagnetic fields (EMF) used to carry the signals. Although ambient levels of RF-EMF generally encountered in everyday circumstances remain well below established scientific limits (ICNIRP, 1998), their relentless presence in our society raises concerns that long-term exposure at low levels may be associated with various non-specific physical symptoms (Baliatsas et al., 2015) and ecological effects on fauna and flora (Cucurachi et al., 2013).

Over the last decades, a number of studies have aimed at characterising the environmental RF-EMF exposure using either personal or spot measurements performed during the day. However, while our exposure to environmental RF-EMF is not at all constant in time due to environmental changes and variations in the number of active users (as well as the nature of their activity) in telecommunications networks (Joseph et al., 2009; Joseph and Verloock, 2010), these studies tend to neglect the temporal dimension (e.g., Frei et al., 2009; Aerts et al., 2013a, 2013b; Beekhuizen et al., 2013).

In spite of RF-EMF monitoring systems installed in various cities in Europe, such as in Greece (Gotsis et al., 2008), Italy (Troisi et al., 2008), and Portugal (Oliveira et al., 2007), published temporal analyses are scarce: the short-term variability of environmental RF-EMF – i.e., the variation between day and night-time as well as between the different days of the week – has been studied by e.g., Joseph et al. (2009), Joseph and Verloock (2010), Manassas et al. (2012), Mahfouz et al. (2012, 2013), Miclaus et al. (2013), Vermeeren et al. (2013), and Verloock et al. (2014), while long-term analyses have been performed by e.g., Rowley and Joyner (2012), Urbinello et al. (2014), and Tomitsch and Dechant (2015), using repeated measurements instead of monitoring networks. More importantly, detailed temporal information has yet to be included in RF-EMF surrogate modelling (Aerts et al., 2013a, 2013b).

In this paper, the impact of the temporal variability of telecommunications signals on outdoor RF-EMF exposure characterization is investigated. During more than a year, measurements of three downlink telecommunications signals – i.e., from base station to user device – were collected in a low-cost exposimeter network within an urban setting. First, the potential errors of using measurements at single instances were determined. Next, from this vast set of data, for the first time, a full spatio-temporal surrogate model could be built. And finally,

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https://doi.org/10.1016/j.envres.2017.11.003
Received 7 September 2017; Received in revised form 31 October 2017; Accepted 1 November 2017
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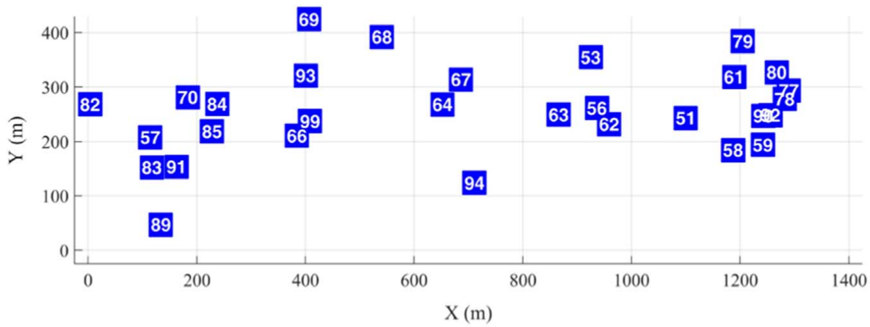

Fig. 1. The (X,Y)-locations and IDs of the exposimeters considered in this study (see Supplementary materials – Table 1 for a summary of the measurements).

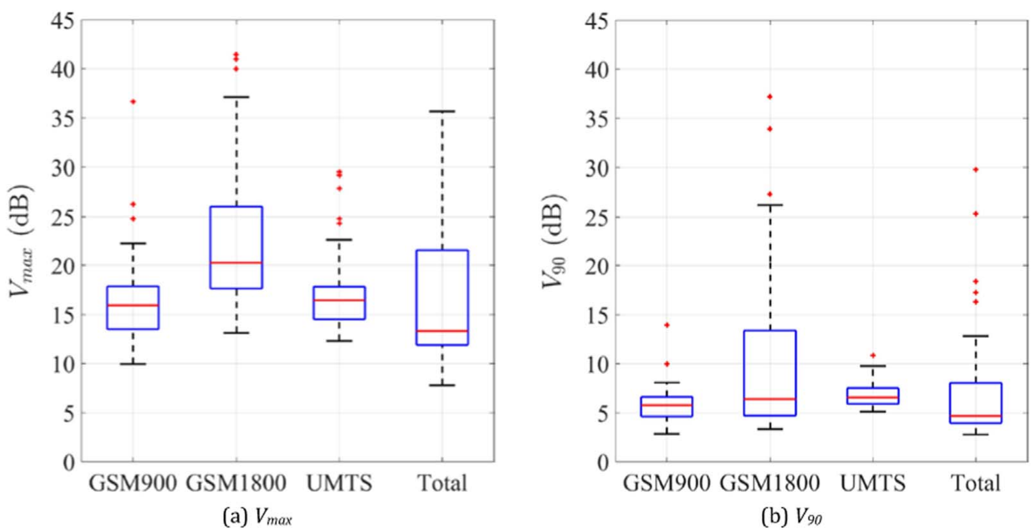

Fig. 2. (a) Maximum and (b) 90% temporal variability of the signals over the total assessment period (i.e., 09-12-2015–15-02-2017).

global profiles of the daily variation of the signals were composed, which were used to quantify the improvement of adding the temporal dimension to established RF-EMF surrogate modelling techniques.

2. Materials and methods

Long-term measurements of downlink telecommunications signals (i.e., the signals from base stations to personal devices) were gathered in a monitoring network comprising a number of fixed exposimeters. The analysis consisted in (a) calculating the variability of the signals over the entire measuring period in order to quantify the possible errors induced in surrogate models by assuming the downlink signal strength is constant in time; (b) determining the average variation of the signals during a single day (i.e., from 00:00 to 23:59); and (c) using this information to scale measurements taken at different times during the day (mimicking a real-life measurement campaign) to a single time instance in order to obtain an accurate surrogate model of the RF exposure at that single instance.

2.1. Monitoring network

In the city of Santander, Spain, an Internet-of-Things (IoT) platform (SmartSantander; http://smartsantander.eu/) has been deployed consisting of a network of IoT nodes which continuously measure various environmental parameters, such as temperature and CO_2. The area covered by the SmartSantander platform has a size of 0.4 km by 1.4 km. Recently, in the EU-FP7 LEXNET project, RF-EMF exposimeters have been added to this IoT platform (Diez et al., 2014), attached to masts at a height of 3 m. These devices were specifically designed to measure the environmental exposure (quantified by the electric field strength E, in V/m) induced by the three most-used telecommunications technologies (i.e., Global System for Mobile Communications (GSM) at 900 MHz (GSM900) and 1800 MHz (GSM1800), and Universal Mobile Telecommunications System (UMTS) at 2100 MHz). Moreover, they were developed for large-scale deployment, thus as cost-efficiently as possible. Frequency bands specifically used by fourth generation (4G) Long Term Evolution (LTE) were not included, as this technology was not yet in use when the exposimeters were installed in 2014 (Diez et al., 2014).

2.2. Exposimeter measurements

A measurement of a certain frequency band was performed by sampling the output voltage (0–3.3 V) and then calculating the median or maximum value of the acquired samples to obtain a single output value. The treatment and number of samples depended on the band, and was determined based on the calibration process (Diez et al., 2014). Then, this output value was converted to an electric-field strength within the range 5 mV/m to 5 V/m, using the exposimeter's antenna factor (AF) (Diez et al., 2014). Each of the considered frequency bands were alternately selected using an RF switch, and the nominal sample collection time (one value for each band) was either 5 or 10 min, depending on the specific exposimeter. This study focused on the telecommunications bands and also calculated the total electric-field strength as,

$$E_{total} = \sqrt{E_{GSM900}^2 + E_{GSM1800}^2 + E_{UMTS}^2}, \quad (1)$$

with E_i the electric-field strength measured in band i (GSM900, GSM1800, or UMTS – all downlink).

Finally, the data used in this study were collected during 14 months – between 9th of December, 2015, and the 15th of February, 2017.