Experimental Assessment of Influence Factors of Body Shadow Effect in Dosimetry Measurements in Indoor Enclosures

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Abstract— This study proposed a methodology of measurement to avoid the underestimation due to the presence of the wearer in the exposure data logged by bodyworn dosimeters. This uncertainty is defined as body shadow effect (BSE). The designed protocol isolates the treatment of the BSE from the uncertainty of the discontinuous transmission that is quantified by the duty factor. Simulations have been performed means of a software prediction tool in order to estimate the measured E-field levels with the designed experimental method. The validity of the proposed methodology has been checked through the comparison between the experimental and simulated results in terms of the cumulative distributions function (CDF).

1. INTRODUCTION

The use of wireless systems, such as WLAN spreading to a wide range of sectors, ranging from domestic households, to administrative as well as industrial and healthcare environments, with a broad and transverse application scope [1–3]. The number of personal devices that operate in the frequency band of 2.4 GHz is spreading in enclosed environments. Presently smartphones, tablets and laptops are equipped with a Wi-Fi interface that provides ubiquitous connectivity. Despite the benefits of this useful way of connection, some concern exists about the assessment of electromagnetic field (EMF) exposure of humans that use the emitting devices [4, 5].

Personal exposure meters (PEMs) are bodyworn devices for measuring exposure to EMF. The immediate proximity of the user underestimates EMF exposure levels in the registered data. This alteration is known as body shadow effect (BSE).

Regulations about the protection of human exposure to non-ionizing radiation provide thresholds to assure the health and protection of the human beings. These thresholds have been fixed taking into account unperturbed data provided by scientific studies, so these thresholds must be compared with objective and undisturbed data. The BSE has been studied by several authors, in some cases correction factors have been recommended to compensate the underestimation in the logged data by PEMs [6], but it is possible to avoid this effect, without a further treatment of data, through the design of a strict protocol of measure to avoid the influence of the wearer in the logged results.

This study describes the procedure of design of an experimental protocol of measurement of the E-field levels in indoor enclosures and dynamic conditions to avoid the influence of the BSE.

2. METHODS AND MATERIALS

In order to avoid the influence of the BSE it is necessary to know the position where the user has to wear the dosimeter in the realization of the experiment. Initial tests were required in order to know the position of the measuring device to avoid the influence of the wearer during the realization of the experiment. These preliminary measurements were performed in an indoor enclosure, in dynamic conditions with a real access point. The test was to measure the E-field levels with a dosimeter in different positions: completely non-line of sight (NLoS), and in line of sight (LoS) with the PEM situated one meter away from the user, and not in contact with the body.

The results obtained in this preliminary stage are summarized in Figure 1.

The obtained results match with similar works performed in outdoor and indoor conditions [6]: the position of the PEM situated 1 m away from the user is optimal to log reliable levels of exposure to E-field that are not affected by the underestimation caused by the influence of the human body.

After the analysis of the results shown in Figure 1, it is deducible the extreme low values logged by the PEMs under test. Between the 40% and the 60% of data are under the minimum value of the range of sensitivity of the dosimeter. Real Wi-Fi devices in general, and in particular the APs, do not transmit information continuously; it is depend on the traffic demand, the data rate, the

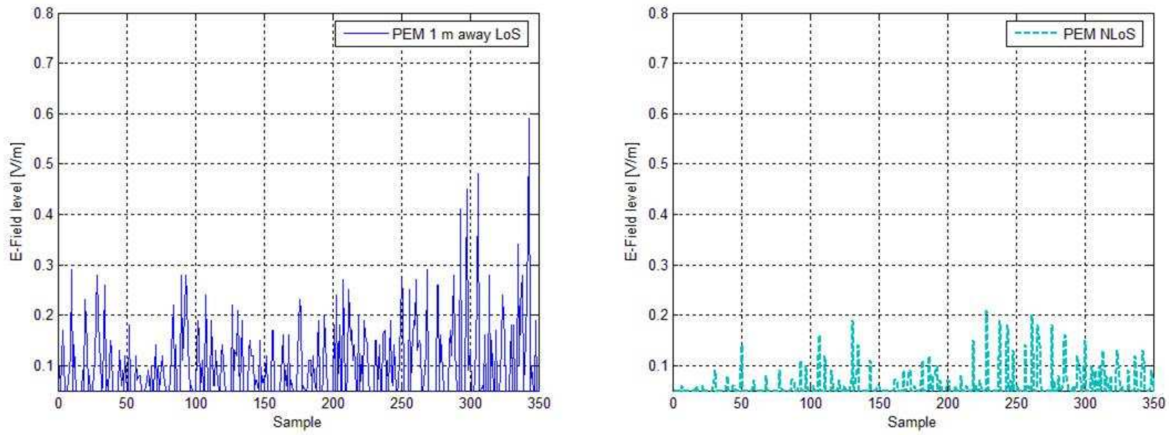


Figure 1: Results of PEMs worn in different positions: 1 m away in front of the body (LoS) and in the back (NLoS).

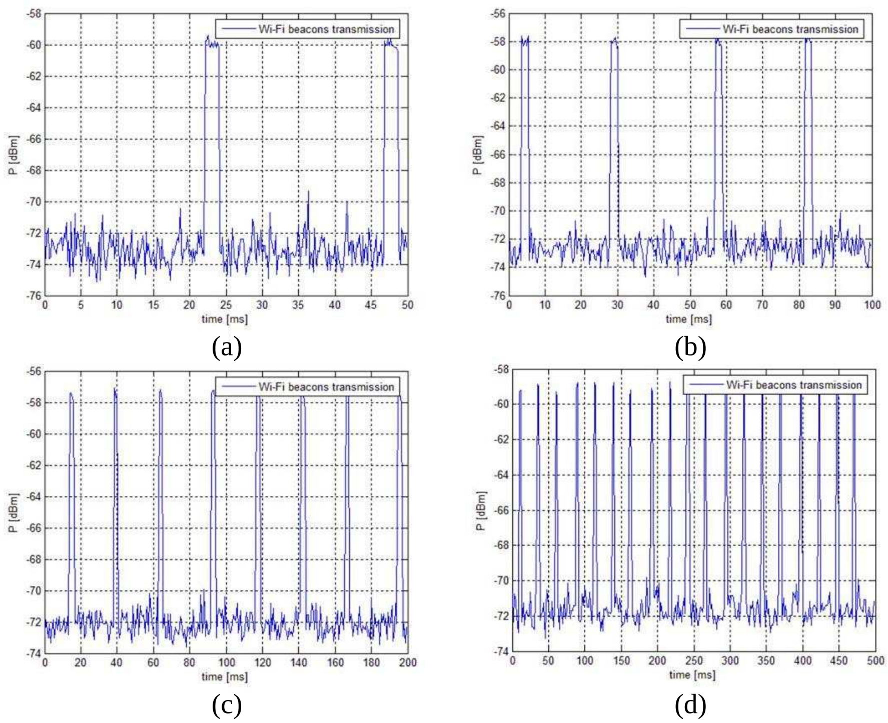


Figure 2: Single sweeps of beacon signal measured with a SA in zero span mode and different values of SWT: (a) 50 ms, (b) 100 ms, (c) 200 ms, (d) 500 ms.

quality of services (QoS), the protocol, the number of connected devices, etc.. When no devices are connected, the AP only transmits beacons, being the levels of E-field generated quite low.

It is possible to characterize the beacon transmission from the AP. Figure 2 illustrates singles sweeps taken with an spectrum analyzer (SA) in zero span mode, 1 MHz of resolution bandwith (RBW), and a sweep time (SWT) from 50 ms to 500 ms. The period of the beacon transmission is 25 ms, and the value of the duty factor, or duty cycle (DC), is calculated following two procedures published in previous works. One of the methods proposes to calculate the duty factor in function of the number of samples above a mid-level called set point. In this case the duty factor is calculated with the following formula [7]:

$$DC = \frac{number\ of\ samples > setpoint}{total\ number\ of\ samples} \tag{1}$$

The second method calculates the DC with the theoretical definition: the ratio of active duration

t_{active} to total duration t_{total} of the WLAN transmission [8]:

$$T = 100 \times \frac{t_{active}}{t_{total}} \tag{2}$$

t_{active} is defined as the time that the signal is 5 dB above the signal noise equal to −72 dBm for the configuration settings. Figure 2 illustrates the transmission of the beacons with different SWT, the period of transmission of the beacons is 25 ms and the mean of t_{active} is about 3 ms.

The values of DC are estimated with both methods, and are shown in Table 1 in function of the SWT. For small values of SWT the values of DC are different. As the value of the sweep time increases the DC values obtained with both methods tend to converge.

Table 1: Results of the duty factor in function of the applied method and the sweep time.

	Sweep time (ms)			
Methods	**50**	**100**	**200**	**500**
Number of samples	0.1833	0.1400	0.1167	0.1400
Definition of duty factor	0.0800	0.0833	0.0967	0.1368

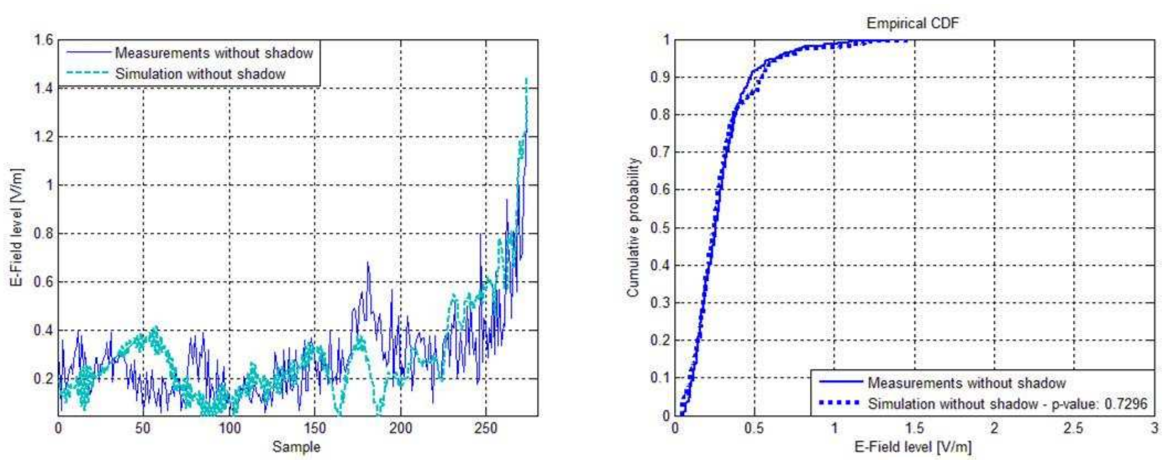
The DC obtained with both methods tends to converge when the number of samples is high. Approximating the results obtained for a sweep of 500 ms, the DC of the AP under test is about 14%, which justifies the high percent of non-detects in the results. To address the shadow effect in an isolated way, it is necessary to prevent the high number of non-detects by increasing the value of the DC. Therefore, it is intended to isolate the treatment of the shadow effect avoiding other uncertainties associated with using of PEMs. To achieve this purpose, experimental measurements have to be performed with a signal generator that transmits continuously and a biconical antenna.

The designed experimental protocol consists of the implementation of the measurements with a signal generator as radiation source, and with the measuring device situated 1 m away from the user to avoid the BSE. The designed protocol isolates the treatment of the BSE from the uncertainty of the discontinuous transmission. Simulations have been performed means of a software prediction tool in order to estimate the measured E-field levels obtained with the designed experimental method.

3. RESULTS

Figure 3(a) shows the experimental and simulated results. Both types of data vary in the same way in function of the distance from the radiation source.

In order to provide more exhaustive conclusions about the validity of the proposed methodology, the results have been compared in function of the p-value obtained with the Kolmogorov Smirnov



(a) (b)

Figure 3: Comparison between experimental and simulated results, (a) in terms of E-field levels in V/m, (b) in terms of the CDFs.

test. The p-value is an indicator of the similarity between the cumulative distribution function (CDF) of the compared data. In this particular case the p-value is 0.7296, being a very acceptable result as it is shown in Figure 3(b) where the CDFs of the experimental and simulated results are compared.

4. CONCLUSION

This study has presented a methodology to evaluate the impact of Wi-Fi technology in terms of exposure to EMFs in indoor enclosures. The use of PEMs as measuring devices presents uncertainties that are necessary to avoid in order to obtain objective conclusions about exposure conditions. With this purpose requirements in the implementation of the experimental measurements have been fixed: the PEM has to be situated 1 m from the user to avoid the shadow effect, and in order to isolate the treatment of the BSE the radiation source must transmit continuously to avoid the non-detects. Taking into account these rules, evaluations of E-field levels have been made in an indoor enclosure by means of simulations and measurements. After comparing both types of data in terms of the variation of the E-field levels and in terms of the p-value, it is concluded that the designed experimental method avoids the non-detects and the underestimation by the shadow effect in the logged data, providing real, objective and non-disturbed data and conclusions about EMF exposure.

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