Statistical Approach for Exposure Assessment to IEEE 802.11 Base Stations in Indoor Environments

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Abstract

The paper presents a methodology developed and implemented for the assessment of human exposure to Indoor Base Stations compliant with the IEEE 802.11 Standards. An efficient procedure that combines simulations and measurements has been introduced and verified in a selected and controlled environment. The procedure is based on a precise simulation of the electromagnetic ambience where the access points are deployed, by means of a combination of physical and ray optics. A statistical description of the obstacles is implemented to sped up the computational time. Data have been statistically analyzed and compared to measurements, to identify conservative exposure coefficients that minimize the number of measuring points, without introducing an excessive overestimate.

1. Introduction

The exponential increase of wireless services has generated a great interest in monitoring the radio frequency (RF) emissions from any kind of radio-telecommunication network. RF monitoring is carried out not only to verify the spectrum occupancy (avoiding mutual interference among different transmitters), but also to assess the human exposure in leaving and working environments. Several standards have been published and a complete set of exposure limits, as well as measurement techniques, is available in the literature. Site surveys in the radiofrequency and microwave bandwidths are very well standardized and easy to apply in outdoor situations, where the electromagnetic field distribution is relatively complex and can be easily predicted by means of propagation tools based on geometrical optics. On the contrary, in indoor environments, the electromagnetic field map is exponentially complicated by the presence of several obstacles, several of them being movable ones. All together, those obstacles generate an almost random field distribution whose prediction would require a huge amount of simulation time or even a longer measurement time.

To overcome the listed problems and speed up the assessment process, a procedure based on a combination of statistical simulations and measurements has been introduced. Among the several modeling possibilities listed by the literature, a physical optics (PO) analysis of the propagation has been chosen. The procedure is conservative and may speed up significantly the indoor assessment.

2. Indoor Propagation Model

The task of modeling the electromagnetic field propagation within or though indoor environments has been extensively treated by the technical literature and several comprehensive reviews are available [1], [2], [3], [4], [5]. Either deterministic or heuristic methods can be implemented for different purposes. The formers are preferable for a precise assessment of human exposure to indoor wireless access points and base stations. The latters are more suitable for network design, and outdoor-to-indoor coverage calculations. Deterministic models can be chosen among a large set of solutions, either using ray tracers (RT) combined with geometrical theory of diffraction (GTD) techniques, or full wave (FW) solutions. Precise results can be obtained, even if they rely on the possibility to accurately model the walls with their geometrical and electromagnetic properties. And, with even more complications, the inner obstacles and furniture should be accounted with their intrinsic dielectric, magnetic and conductivity constants.

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When the frequency increases, the application of FW methods becomes more critical, while GTD techniques are normally preferable. On the contrary, if the number of obstacles is large, FW methods are normally faster than GTD ones. To accelerate the electromagnetic characterization of a complex indoor environment several methodologies have been proposed in the literature, either by significantly reducing the number of rays in GTD techniques or simplifying the geometrical description in FW methods [5]. An example is represented by [6].

In the case of Wi-Fi Access Point systems, the transmitter works at relatively higher frequencies, in the upper UHF bandwidth, [2.4-2.5] GHz and/or the lower SHF bandwidth, [5.15 – 5.35] GHz. Moreover, it is typically deployed in a fully furnished room, with borders with different characteristics (wooden doors, glassed or plastic windows, plasterboard, concrete or metallic walls). Under these conditions, both FW and GTD may require additional improvements to achieve fast resolution times.

Recently, some authors [7] have presented indoor penetration simulation comparisons based on GTD and PO techniques, showing that PO provides better results with an acceptable increase of computational time. Results have been confirmed by measurements.

Following the results shown by publication [7], in this paper, the PO technique is used to simulate a complex indoor environment, where the walls are characterized by materials with different electromagnetic behavior and furniture is modeled as well.

According to the PO theory applied to a generic plane scattering object, the scattered field can be expressed as a function of the electric and magnetic fields on the object by means of an integral formulation. For the implementation, the dyadic Green function has been selected, according to (1) and (2) and the formulation reported by [8]:

$$\underline{E}^{s}(\underline{r}) = \int_{\Sigma} \left[j\omega\mu \underline{\underline{G}}(\underline{r}-\underline{r}') \cdot \left(\hat{n} \times \underline{H}^{\Sigma}(\underline{r}')\right) - \nabla \times \underline{\underline{G}}(\underline{r}-\underline{r}') \cdot \left(\underline{E}^{\Sigma}(\underline{r}') \times \hat{n}\right) \right] d\Sigma \tag{1}$$

$$\underline{H}^{s}(\underline{r}) = \int_{\Sigma} \left[j\omega\varepsilon \underline{\underline{G}}(\underline{r}-\underline{r}') \cdot \left(\hat{n} \times \underline{E}^{\Sigma}(\underline{r}')\right) + \nabla \times \underline{\underline{G}}(\underline{r}-\underline{r}') \cdot \left(\underline{H}^{\Sigma}(\underline{r}') \times \hat{n}\right) \right] d\Sigma \tag{2}$$

The surface fields have been calculated by applying standard plane wave boundary conditions derived by the knowledge of the electromagnetic properties of the material, according to a standard plane wave description [8].

Taking into account that the walls may be constructed with different materials, on each wall surface a list of sub-surfaces is identified and the field calculation is applied. In case the sub-surface size is comparable to the wavelength, a statistical description is introduced, identifying a macro-sub-surface having equivalent electromagnetic properties, calculated from a geometrical weighted mean of the single properties of each sub-surface.

A complementary component of the PO model is given by the identification of the illuminated surfaces. To this purpose, an accelerated RT has been developed, based on the concepts published by [9]. An extended analysis of the proposed implementation and comparisons with the state of the art will be reported in further publications.

Finally, an iterative algorithm is necessary in order to take into account the field generated by further reflections [10]. For the specific application, the selection of surfaces has been integrated with a characterization of the surface reflection coefficient, discarding any component that may contribute below 2% of the direct ray, 10% of the first reflected ray, 25% of the second reflected ray.

3. Combination with Measurements

Most of the times, the exact characteristics of the materials that form the walls are not known. Concrete reflectivity my vary 7 to 10 dB, depending on its thickness and the presence of metal inside. Glass reflectivity may exhibit similar variations, and wood even worst ones. To improve the quality and reliability of the simulation, one should have measured the dielectric constant and (when necessary) the conductivity of all materials of the walls of the room. In many cases, this is not feasible; in many others it is not economically sustainable.

To overcome this problem, we have developed an adaptive procedure that makes use of controlling points, where simulations are matched to measurements, in order to modify iteratively the wall characteristics.

The variation of the reflection coefficients has been managed by means of a least square minimization, thanks to the extremely fast run times and a one-time calculation of all radiation integrals towards the controlling points. The functional has been calculated as the sum of the absolute values of the logarithmic differences between simulated and measured data.

It is evident that the choice of the number of controlling points represents a relevant parameter for the application of the proposed procedure. For this reason, it has been deduced from a real case of application, as shown in the next section.

4. Methodology Application

The procedure has been applied to a room having walls made out of five different materials. The room map is shown in Fig.1. All reported dimensions are in centimeters. The room has an extended octagonal shape. Glass, plasterboard, wooden, concrete, metallic walls are present. One wooden table has been deployed in the room, as shown by the dashed lines (balloon C). The floor is made of carpet-lined concrete, while the ceiling is pure reinforced concrete. Only two walls are homogenous: all the others mix different materials, as in the case of the wooden doors and the glass-metallic windows. To give the experiment more generality, the door at the bottom left has been kept open, realizing a free space boundary condition, as it was giving access from outdoor.

The access points (APs) have been placed in three deferent positions, as indicated by the bullets A, B and C in Fig.1. Position A refers to an IEEE 802.11g AP installed on the wall at 2 meters above the floor, fixed on concrete, right over a wooden door. Position B refers to an IEEE 802.11n AP installed below the ceiling, at 3.85 meters above the floor. Position C refers to an AP installed on a wooden table, at 85 cm above the floor. The controlling points have been deployed on four grids of eight points, indicated with brown color in Fig.1. The grids were parallel to the ground, at three different heights above the floor: 90 cm, 110 cm, 150 cm.

The total amount of controlling points is equal to 24. Data are available for Aps deployed in three different positions, which means that the same method can be applied three times, and the same results in terms of walls properties, together with the same variations between analyses and measurements should be obtained. Results reported in Tab.1 show the average variation between simulation and measurement and its standard deviation, using a different number of controlling points. As one can see, starting from 8 controlling points, it is possible to obtain an acceptable datum. Results reported in Tab.2 show the estimated walls properties using 8 controlling points. It is possible to appreciate the consistency of the results, independently on the position of the AP. Only the conductivity of metal, wood and glass varies significantly, but (as obvious) that parameter does not affect the reliability of the results.

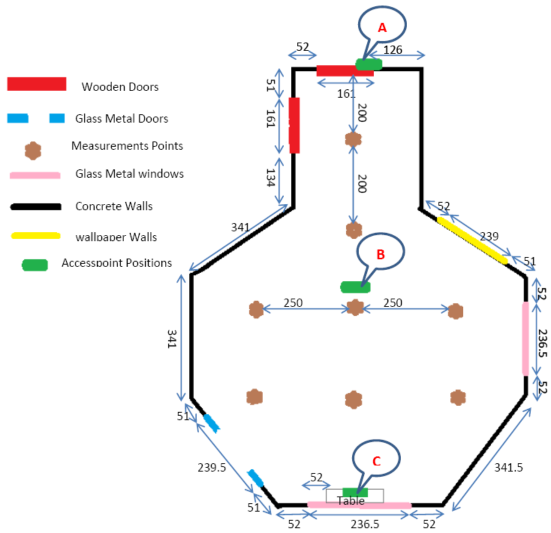

Fig.1 Map of the room used to perform the method verifications

Ptn No.	AP A		AP B		AP C	
	Avg Err	Std Dev	Avg Err	Std Dev	Avg Err	Std Dev
2	3.0	1.2	2.5	1.3	3.3	1.1
4	1.0	0.8	1.4	1.1	1.6	1.0
6	0.6	0.3	0.6	0.2	0.8	0.3
8	0.4	0.1	0.3	0.2	0.4	0.1
10	0.3	0.1	0.3	0.1	0.3	0.1
12	0.3	0.1	0.1	0.1	0.2	0.1
14	0.2	0.1	0.2	0.1	0.2	0.1
16	0.3	0.1	0.1	0.1	0.3	0.1
20	0.1	0.1	0.2	0.1	0.2	0.1
24	0.2	0.1	0.3	0.1	0.1	0.1

Tab.1 Average Error and Deviation Standard [dB] as a function of the number of controlling points

Material	Elm Prop	AP A	AP B	AP C
Concrete	ε_r	2.8	2.5	2.6
	σ [mS/m]	3.3	6	1.2
Wood	ε_r	2.3	2.2	2.3
	σ [nS/m]	3	0.01	30
Glass	ε_r	6.2	6.1	6.2
	σ [nS/m]	0.1	0.001	4
Metal	ε_r	-	-	-
	σ [MS/m]	22	0.5	1
Plaster-board	ε_r	2.3	2.2	2.3
	σ [S/m]	0.03	0.01	0.05

Tab.2 Materials characteristics as a result of optimization in the three scenarios

5. Conclusion

The paper presents a procedure for the characterization of the exposure assessment to Wi-Fi Access Points installed within complex indoor scenarios. The procedure is based on PO electromagnetic field calculations, and it makes use of standard acceleration techniques for a fast computation of the ray tracer. A new statistical approach has been introduced to simplify the description of complex boundary conditions, and new thresholds have been dimensioned to minimize the number of reflections. The integration with measurements offers the possibility to adapt the statistical parameters, improving the precision of the calculation and the definition of the field map. The results obtained during a preliminary application of the method are promising and suggest a further exploitation of the method to more general cases.

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