An Electromagnetic Characterization of Indoor Radio Environment in Microwave WLAN Systems

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***Abstract* — An accurate electromagnetic characterization of a typical indoor environment in which a microwave *WLAN* system operates is presented. The characterization has been performed by means of a heuristic *UTD* diffraction coefficient suitable to take into account not only the effects of building walls, floors, and corners, but also the presence of penetrable furniture. The numerical results show that the electromagnetic field distribution and the channel performances are significantly influenced by the diffraction processes arising from the presence of furniture.**

I. Introduction

The performances of modern wireless local area network (*WLAN*) strongly depend on the electromagnetic characteristics of the environment in which they operate. In these environments the field propagation is dominated by many scattering processes due to obstacles (walls, openings, furniture, etc.) [1]-[8]. Therefore, to satisfy system requirements directly during design phase, it is necessary to evaluate preliminarily the field coverage and the performances of the radio channel.

In the last few years, prediction models suitable to analyze the indoor radio environments when metallic furniture are present have been developed [4]-[7]. These models do not take into account the diffraction processes arising from penetrable objects.

In this paper, a model based on the Uniform Theory of Diffraction (*UTD*) has been adopted to analyze the characteristics of a realistic indoor environment in which a *WLAN* system can operate. The model employs a suitable heuristic diffraction coefficient [8], [9] to analyze the electromagnetic scattering from penetrable objects. The results show the influence of the position and the diffractive properties of the objects on the field distribution and the performance of the radio channel.

II. High-Frequency Field Model

The model adopted to predict the high-frequency field is based on the Uniform Theory of Diffraction (*UTD*). The electromagnetic field is given in terms of diffracted and ray-optical fields. The Geometric Optics (*GO*) field has been computed by means of reflection and transmission dyadics, while the diffracted field by means of a suitable *UTD* heuristic diffraction coefficient for penetrable objects [8], [9]. The objects present in the environment have been modeled as junctions of thin flat multistrate structures [7] and the radio source using its radiation pattern.

III. Channel Modeling Description

Since multipath phenomena and time dispersion significantly influence the performances of *WLAN* communication systems, an accurate description of the indoor radio channel is necessary. Therefore, to model the channel behavior, the Turin's model based on finite-duration pulses [2], [3], [7] has been adopted.

Assuming that each echo has a Gaussian pulse shape, the impulse response of the radio channel is

$$h(t) = \sum_{i}^{N} \beta_i \, f(t-\tau_i) e^{j\theta_i} \quad (1)$$

with

$$f(t) = \frac{1}{\sqrt{\sqrt{2\pi}\sigma_t}} e^{-\frac{t^2}{4\sigma_t^2}} \quad (2)$$

where N is the number of ray paths that contribute to the signal, β_i , θ_i and τ_i are magnitude, phase and time delay of the $i-th$ contribution, respectively, and σ_t is the time variance of the Gaussian pulse. The excess mean delay, $\bar{\tau}$, and the rms multipath delay spread, τ_{rms}, are expressed by:

$$\bar{\tau} = \frac{\int_0^\infty t \left| \sum_i^N \beta_i \, f(t-\tau_i) e^{j\theta_i} \right|^2 dt}{\int_0^\infty \left| \sum_i^N \beta_i \, f(t-\tau_i) e^{j\theta_i} \right|^2 dt} \quad (3)$$

$$\tau_{rms} = \sqrt{\frac{\int_0^{\infty} (t-\bar{\tau})^2 \left| \sum_i^N \beta_i \, f(t-\tau_i) e^{j\theta_i} \right|^2 dt}{\int_0^{\infty} \left| \sum_i^N \beta_i \, f(t-\tau_i) e^{j\theta_i} \right|^2 dt}} \quad (4)$$

III. The Broadcast Beam Tracing Algorithm

The computation of the electromagnetic field and the performance of the radio channel have been carried out by means of the beam-tracing method employing the broadcast technique [4], [5], [8]. This technique has a computational burden no strongly dependent on the number of surfaces describing the environment and it is particularly efficient when the number of the field computation points is large.

Two parts form the numerical algorithm. The first determines the ray optical paths, while the second evaluates the electromagnetic field distribution. The field propagation is described by means of electromagnetic ray beams. In the computational model, each beam is formed by three rays belonging to the edges of a ray tube having a triangular cross section. The field radiated from the antenna is modeled by means of beams shooting from the antenna towards all space directions independently of the observation points (see Fig. 1).

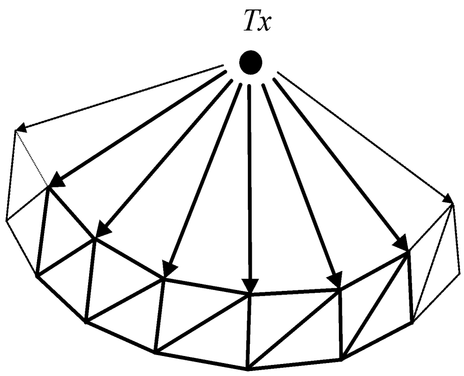

Fig. 1. Beams shooting from a *Tx* antenna. Each beam is formed by three rays.

In the numerical procedure, only the edge diffraction processes excited by the *GO* field have been taken into account. Each edge is considered as a secondary source that radiates an electromagnetic field in the spatial directions predicted by the Keller's cone.

IV. Numerical Results

To validate the procedure described in section III, various structures have been considered. For brevity sake's only a numerical example is given here.

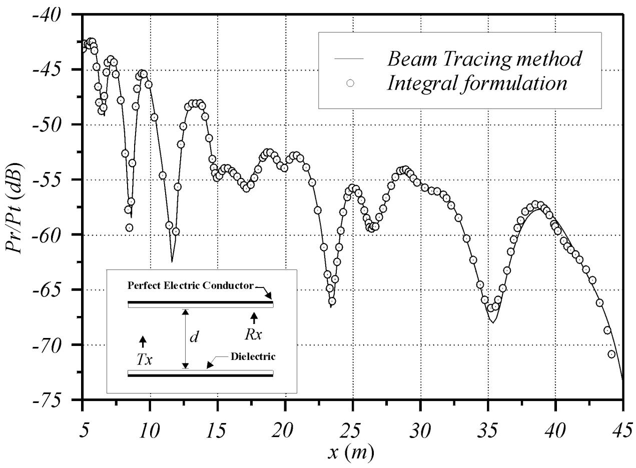

Fig. 2. Normalized received power versus distance from *Tx* in a two parallel-coated corridor computed by means of the Spectral Domain Approach [10], and the beam tracing method. Corridor height $d = 3m$. Coated dielectric characteristics: thickness $t = 13cm$, $\varepsilon_r = 4$, and $\sigma = 0.02 S/m$. *Tx* and *Rx* are vertical electric dipoles located at $(0, 1.8m)$, $(x, 2.85m)$, respectively. Frequency $1GHz$.

In the structure shown in Fig. 2 a short vertical electric dipole *Tx* excites an electromagnetic field in a corridor formed by two parallel metallic plates coated with a dielectric slab of finite conductivity. In the figure, the normalized power received from a short electric dipole *Rx*, obtained by means of an integral formulation [5], [10], and by the proposed beam tracing method, is shown. As it can be observed, a good agreement with the integral solution is achieved.

The proposed procedure has been applied to analyze the field distribution and the radio channel performances of a *WLAN* system working inside the room shown in Fig. 3. This room is provided with a wooden table and door, two wooden cabinets, and a glass window. The material characteristics used in the numerical computations are given in Tab. 1. The radiating system, located at the *Tx* point $(3.48m, 0.05m, 2.50m)$, consists of a vertically polarized $\lambda/2$ dipole reflector antenna, operating at $1.8GHz$ and radiating $250mW$. The field computation zone is the shadowed horizontal plane at $1m$ from the floor. The power received from a vertically oriented $\lambda/2$ dipole antenna (Rx) has been evaluated along a y-oriented line crossing the center of the table (see Fig. 3). The communication system has been assumed to have $\sigma_t = 1ns$. Such σ_t value can represent that of a good measurement system suitable to determine the channel impulse response.

The numerical computations have been performed taking into account the *GO* field contributions up to four reflections/transmissions. The diffracted field arising from any scattering object is considered excited both by the line of sight *GO* field and by the *GO* contributions that have experienced up to two reflections/transmissions. Finally, the diffracted field contribution is taken into account if it reaches the observation point directly or after one reflection/transmission process.

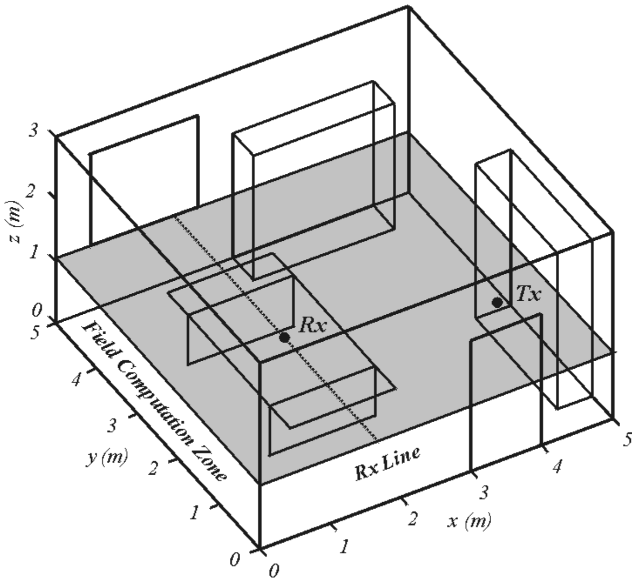

Fig. 3. *Tx* indicates the location of the half-wave reflector antenna working at *1.8 GHz*. The shadow region, which includes the *Rx* line, indicates the field computation zone. The external wall is at $y = 5\,m$. The internal walls are at $x = 0$, $x = 5\,m$, and $y = 0$, respectively.

TABLE I

MATERIAL CHARACTERISTICS. FREQUENCY 1.8 *GHZ* [5]

	ε_r	σ (m*S/m*)	***Thickness* (*cm*)**
Ceiling/Floor	7.9	89	25.0
External brick wall	5.2	28	22.0
Internal brick wall	5.2	28	12.0
Wooden door/cabinet/table	3.0	0.0	4.0
Glass window	3.0	0.0	0.5

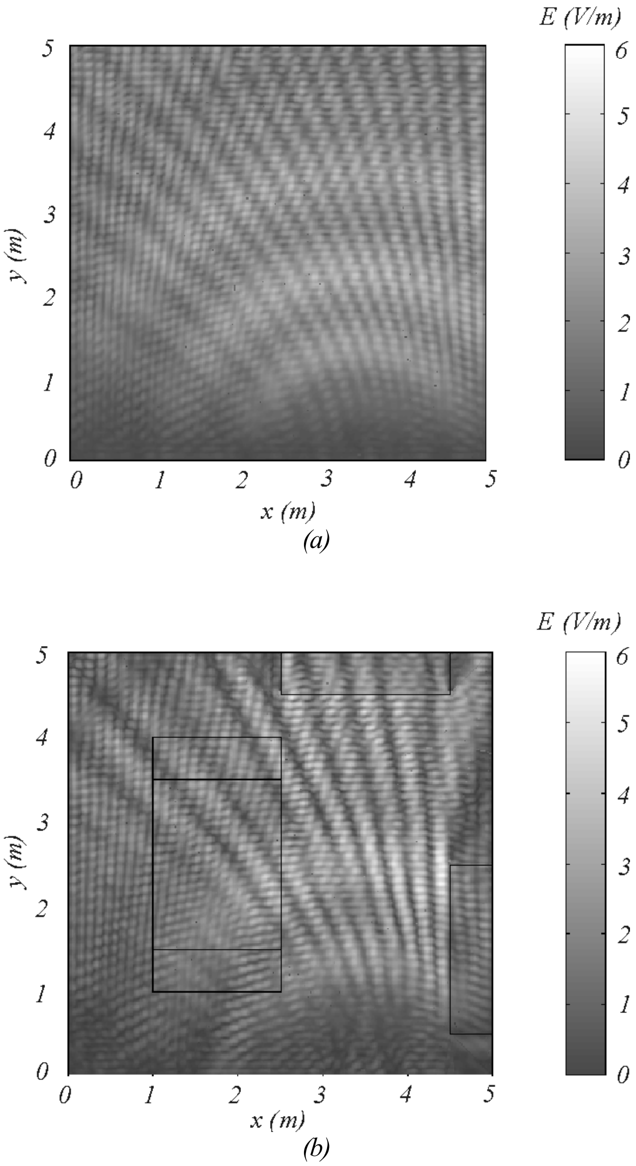

Fig. 4. Electric field magnitude. (a) Empty room, (b) furnished room. Frequency *1.8 GHz*.

The amplitude of the electric field distribution in the room of Fig. 3 is shown in Fig. 4a (empty room) and 4b (furnished room), while the normalized power, received from the *Rx* antenna, is shown in Fig. 5. In both cases, fast and slow multipath fading due to the multiple reflection and diffraction processes is particularly evident (see Fig. 4). These effects, as it appears also from the normalized received power (see Fig. 5), are significantly emphasized by the presence of furniture.

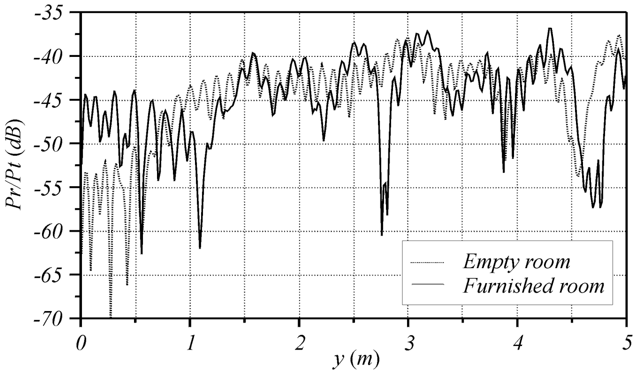

Fig. 5. Normalized power received versus y. Antenna characteristics: $Tx = (3.48\,m, 0.05\,m, 2.50\,m)$ half-wave reflector antenna, $Rx = (1.76\,m, y, 1.00\,m)$ half-wave antenna. Frequency $1.8\,GHz$.

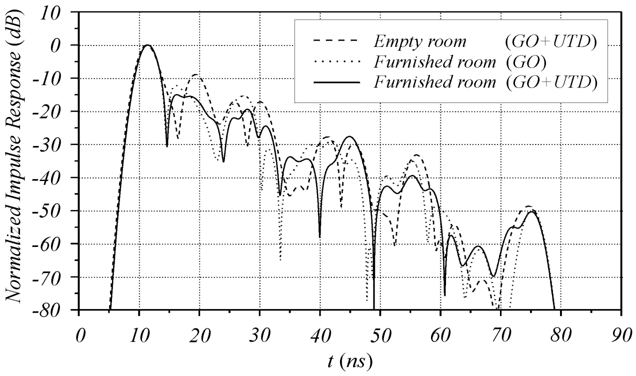

Fig. 6. Normalized Turin's impulse response based on Gaussian pulses having $\sigma_t = 1\,ns$. Antenna characteristics: $Tx = (3.48\,m, 0.05\,m, 2.50\,m)$ half-wave reflector antenna, $Rx = (1.76\,m, 2.49\,m, 1.00\,m)$ half-wave antenna. Frequency $1.8\,GHz$.

In Fig. 6, the normalized impulse response at $Rx = (1.76\,m, 2.49\,m, 1.00\,m)$ is shown. Two situations which refer to empty and furnished room have been considered. In the empty room the impulse response has been computed by means of the total electromagnetic field (optical and diffracted field), while in the furnished case it has been evaluated using either the *GO* or the total field. In the above mentioned situations, the *RMS* multipath delay spread assumes the value $4.24\,ns$, $3.70\,ns$, and $3.19\,ns$, respectively. As it can be observed, the presence of furniture, giving rise to a greater field diffusion, introduces an additional attenuation of the echoes of the *RF* received signal with respect to the empty room case. This effect is confirmed from measurements reported in literature [3].

V. Conclusion

The performances of microwave wireless communication systems operating in realistic indoor environments have been analyzed. The analysis model employs a three-dimensional beam-tracing algorithm to compute the field distribution and the channel performances with an adequate degree of accuracy. The diffraction phenomena have been modeled by means of a suitable *UTD* heuristic diffraction coefficient for penetrable objects. The numerical results show that the electromagnetic field distribution and the characteristics of the radio channel are significantly influenced by the diffraction phenomena due to the presence of furniture. In particular, it has been observed that the diffraction phenomena are responsible for the reduction of the spreading of the impulse response.

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