Combined Monte Carlo Simulation and Ray Tracing Method of Indoor Radio Propagation Channel

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1 Abstract

This paper presents a simulation tool based on a combined Monte Carlo and Ray Tracing method for the prediction of power delay profiles within an indoor environment. The simulation tool and results for the CW–fading, time delay spread and low pass channel impulse response are discussed.

2 Introduction

Understanding of multipath fading in an indoor environment is important to design optimized mobile communication systems. Fading is caused by signal propagation over several paths and the superposition at the receiver. The paths arise through many reflections and transmissions of the electromagnetical wave at the walls. A 3–dimensional simulation tool to predict this multipath fading was designed. The complexity of the buildings complicates the determination of the paths. Hence at the beginning a fast Monte Carlo simulation predicts the dominant paths. Because the Monte Carlo method cannot describe the exact path to the receiver, in a second step the Ray Tracing model is used to determine the correct path. Results of the combined methods are discussed.

3 Monte Carlo-Simulation

The Monte Carlo method generates an empirical dispersion of rays, which are emitted from the transmitter location. Assuming equal power for all rays the probability density function of the ray direction is determined by the antenna pattern. Consider

$$G(\phi,\theta) = \left(\frac{\cos(\pi/2\cos(\theta))}{\sin(\theta)}\right)^2 \quad (1)$$

as the pattern of a half wave dipole, the spatial dependency probability density function of the ray is proportional to the square of the pattern

$$f(\phi,\theta) = c_\phi c_\theta G^2(\phi,\theta) \quad (2)$$

$G(\phi,\theta)$ and $f(\phi,\theta)$ are separable to $G(\phi,\theta) = G_\phi(\phi)G_\theta(\theta)$ and $f(\phi,\theta) = f_\phi(\phi)f_\theta(\theta)$. The integral of the density function yields the cumulative distribution function.

$$F_\phi(\phi) = \int_{\phi'=0}^{\phi} f_\phi(\phi')d\phi = c_\phi \phi \quad (3)$$

and

$$F_\theta(\theta) = \int_{\theta'=0}^{\theta} f_\theta(\theta')\sin(\theta')d\theta' \quad (4)$$

The coefficients c_ϕ and c_θ are determined by $F_\phi(\phi = 2\pi) = 1$ and $F_\theta(\theta = \pi) = 1$. Consider u and v as two statistically independent random numbers with a constant density function in $[0,1)$, the ray distribution is calculated from the inverse cumulative distribution function.

$$\phi = {F_\phi}^{-1}(u) = 2\pi u \quad \text{and} \quad \theta = {F_\theta}^{-1}(v) \quad (5)$$

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${F_\theta}^{-1}$ is solved numerically. Figure 1 presents the distribution of 10000 rays of the half wave dipole. The ray is emitted from the transmitter and traced inside the building by a propagation algorithm until the power of the ray falls short of a limit (Figure 2). The ray can be reflected, transmitted and absorbed by the walls. If a ray is partly reflected and transmitted by the same wall, then the ray is split into two rays. In the simulation the receiver is surrounded by a sphere

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and every ray hitting the sphere is registered and contributes to the received signal.

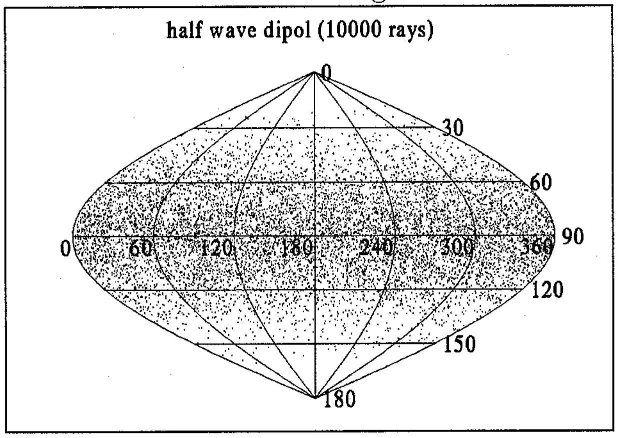

Fig. 1. Mapping of the unit sphere in a plain with azimuth and elevation angle. Directions of the rays determined by the half wave dipole.

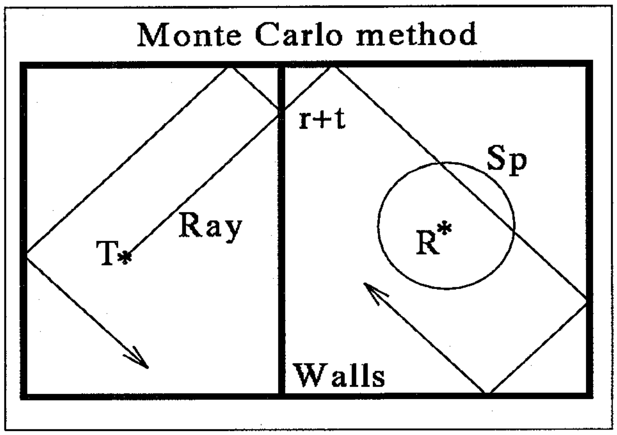

Fig. 2. Ray traced from the transmitter T to the receiver R in a simplified building (Sp: Sphere, r+t: Reflection and Transmission)

4 Ray Tracing

The Monte Carlo simulation generates lots of rays (Figure 3), which are intercepted by the receiver sphere. From those a filter algorithm selects all rays reflected from a specific wall or combination of walls. This is the basis for the Ray Tracing method [5] to calculate the exact path to the receiver from the information on the intercepted walls as given by the Monte Carlo simulation. The transmitter T is mirrored on the reflection wall to the mirror source S. The ray is traced back from the receiver R to the reflection point P towards the mirror source S. After a change of the path direction the ray is traced back to the transmitter T. Now the exact received amplitude a_i, phase shift ϕ_i and time delay τ_i of every received ray depending on frequency, polarization, wall material and antenna pattern is obtained. The index i is the number of the received ray.

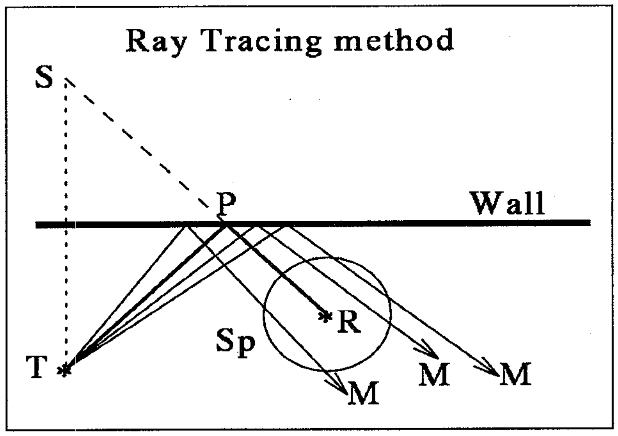

Fig. 3. Ray Tracing method (T: Transmitter, R: Receiver, P: Reflection Point, Sp: Sphere, S: Mirror Source, M: Rays determined by Monte Carlo method).

5 Channel impulse response

The multipath channel is described as a linear filter with a discrete complex low pass channel impulse response for one receiver location (x_0, y_0, z_0) given by

$$h_0(t) = \sum_i a_i e^{-j\phi_i} \delta(t - \tau_i) \qquad (6)$$

The coefficients are determined by the received rays as given by the simulation.
The figures 5, 6 and 7 illustrate simulation results with the building presented in Figure 4. The building consist of 108 different walls described by different thicknesses d_n and complex dielectrics $\underline{\epsilon}_{r,n}$. Any orientation of the walls in the three dimensional space is allowed. The transmitter T is located in the corridor 1.705 m above ground and the receiver is moved along the dashed track. The transmitter and the receiver antennas are

half wave dipoles with horizontal polarization working at a frequency of 1.89 GHz.

Figure 5 presents five low pass channel impulse response with the receiver moved over a 4 m track in obstructed Line–of–Sight (OLOS) topography.

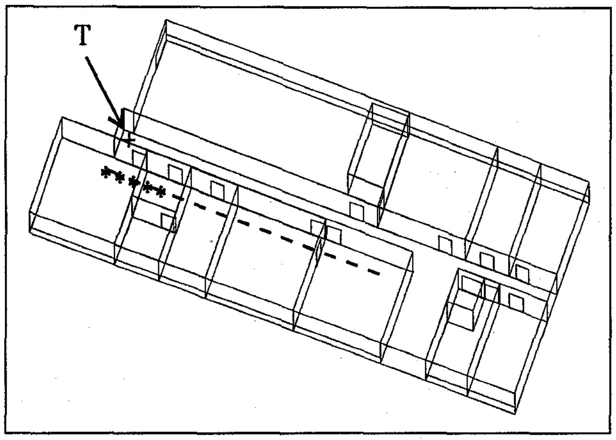

Fig.4. 3D-building. Overall dimensions are 36.03m × 15.3m × 3.0m. The cross marks the location of the transmitter T. The stars mark the locations of the receiver in Figure 5 and the dashed line marks the receiver position in Figure 6 and 7.

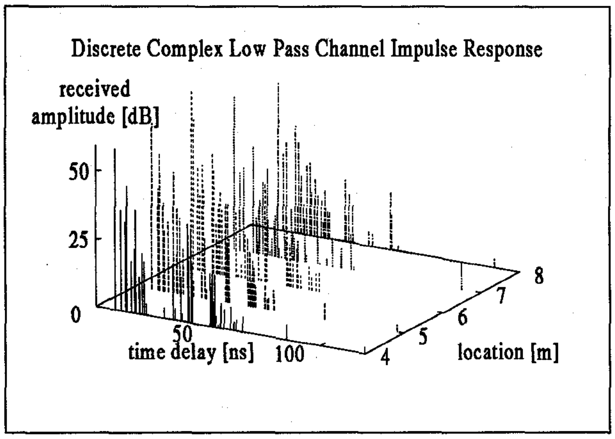

Fig.5. Low Pass Channel Impulse Response given by the simulation. The receiver position are marked in the building (Figure 4).

6 Characteristic Parameters

The superposition of the detected rays gives the received amplitude. The amplitude depends extremely on the position of the receiver. Figure 6 shows a simulated CW–fading signal as the receiver is moved along a 20 m track. The fast fluctuation of the received power over a short track is called multipath fading and is caused by the phase differences in the arriving paths. In addition to the multipath fading the amplitude of the received signal has a large scale fading which is caused by shadowing.

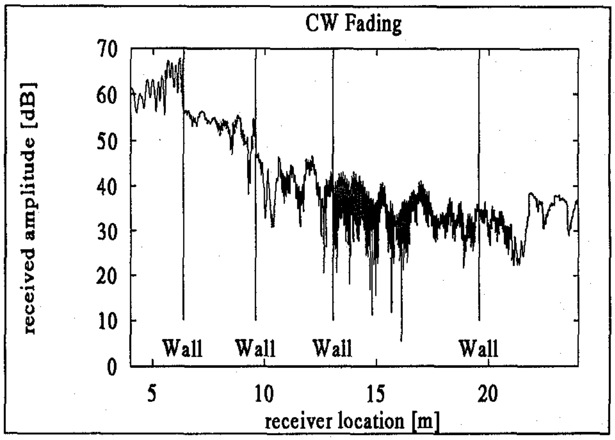

Fig.6. CW Fading given by the simulation. The receiver is moved along five rooms presented in the building (Figure 4).

Characteristic parameters for the radio propagation are the mean excess delay $\overline{\tau}$ and the rms multipath delay spread τ_{rms} given by

$$\overline{\tau} = \frac{\sum_i {a_i}^2 \tau_i}{P_r} \quad \text{where} \quad P_r = \sum_i {a_i}^2. \qquad (7)$$

P_r is the average received power. The square root of the second central moment of the delay power spectrum function is defined to be the multipath delay spread.

$$\tau_{rms} = \sqrt{\overline{\tau^2} - (\overline{\tau})^2} \quad \text{where} \quad \overline{\tau^2} = \frac{\sum_i {a_i}^2 {\tau_i}^2}{P_r} \qquad (8)$$

Figure 7 shows the cumulative distribution function of the rms multipath spread of the simulated 20 m track.

7 Conclusion

The combined Monte Carlo and Ray Tracing method simulating three dimensional standing wave pattern in buildings, predicts the low pass channel impulse response. Due to the combination of the methods the simulation works much faster than a single method. From the channel impulse response the spatial density of the receiver amplitude or the root mean square (rms) delay spread are determined. The influence of antenna patterns, the wall material, the CW–frequency or the transmitter location can be studied without expensive measurements.

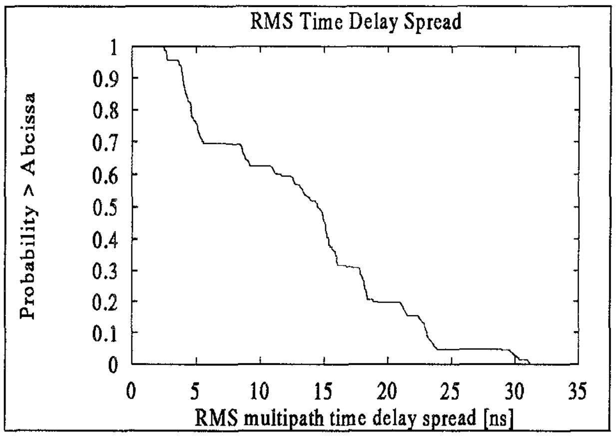

Fig. 7. Cumulative distribution function of the rms multipath time delay spread simulated along the 20 m track in the building (Figure 4).

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