Modeling of UWB Channels by Using an Efficient Ray Tracing Procedure

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I- Introduction

A fundamental step in Ultra Wide Band (UWB) communication systems involves the characterization of the indoor propagation channel. The frequency selectivity of the propagation process introduces fundamental differences between UWB channels and conventional (narrowband) channels. Various channel modeling techniques can be used to describe the UWB channel [1]: in particular, it is possible to resort to statistical modeling based on frequency or time domain measurement campaigns or to deterministic modeling based on simulations. To date, ray tracing (RT) based approaches have been widely used to characterize the indoor channel for both narrow-band and wide-band systems, while only limited attempts have been made to predict the UWB characteristics [2,3]. In this paper, we propose a novel and efficient procedure to extract the UWB propagation channel parameters, that employs a RT simulation[i] carried out at different frequencies and followed by a proper processing of the simulated data. A parallel ray approximation, usually adopted in array analysis, is successfully used to dramatically reduce the computational time of the procedure. An excellent agreement between simulation results and measured data is achieved, showing that the RT-based tool can be successfully used for accurate and reliable site-planning in UWB systems.

II- Measurement Procedure

Frequency-domain UWB channel measurements were conducted in an indoor environment that consisted of a 5 m×4.7 m×2.6 m laboratory of the Communications Research Group at the University of Oxford, with block walls, concrete floors and ceiling, a large glass window, and metallic and wooden furniture, as shown in Fig. 1a. A vector network analyzer (VNA) arrangement was used to sound the channel at $n_f = 1601$ discrete frequency in the UWB band $\left[f_l, f_h\right]$, where $f_l = 3.1$ GHz and $f_h = 10.6$ GHz [4]. The measurement bandwidth was thus *B*=7.5 GHz and the resolution of the measurement was $\Delta f = 4.6875$ MHz . The system was calibrated prior to the measurement to remove frequency-dependent attenuation and phase distortion.
Discone antennas, vertically polarized and omni-directional in the azimuth plane, were used to conduct the measurement [5]. The location of the transmitting antenna was

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fixed, while the receiver antenna was stationed atop a computer at a controlled horizontal position grid with dimensions 0.5 m×0.5 m and 1 cm×1 cm of resolution; the line of sight (LoS) case was considered. A careful adjustment was done for both antennas to be exactly at the same height and in vertical position to avoid any polarization mismatch. For each receiver location, the discrete complex frequency transfer function was recorded; it is worthwhile mentioning that the measured frequency transfer function represents the concatenation of the antennas with the channel.

III- RT setup

The scenario has been reconstructed in the RT simulator (Fig 1b); a spatial grid of 45×45 points is placed over the same 0.5 m×0.5 m area which was used for the measurements. For each point, the frequency response can be determined by employing the RT simulator [6], where the signal source is a set of dipoles transmitting continuous wave (CW) carriers at the same $n_f = 1601$ frequencies employed by the VNA . The RT tool "EMvironment 3.0" used in this study is an efficient fully three-dimensional (3-D) simulator based upon a combination of Binary Space Partition and Image Theory derived from Computer Graphics, and was developed at the Microwave and Radiation Laboratory of the University of Pisa, Italy. Firstly, the ray paths are identified; then complex vector electromagnetic field components are evaluated in terms of plane waves undergoing multiple phenomena of reflection, transmission and diffraction. More in details, the reflected field is evaluated through Geometrical Optics (GO), where the number of rays depends on the maximum order of the bouncing allowed, which is set a priori. Moreover, first-order diffractions from the edges are evaluated through heuristic Uniform Geometrical Theory of Diffraction (UTD) dyadic diffraction coefficients, valid for discontinuities in impedance surfaces. Transmissions through walls and objects are evaluated by resorting to a multilayered media description.

Apparently, the procedure described above can reveal rather CPU expensive, depending on the number n_f of frequency samples. However, it is worthwhile remarking that the time-consuming part in the RT algorithm is the determination of the rays reaching a given location, and this can be made only once at the beginning of the procedure. The low-complexity calculation of the received signal is then repeated n_f times. Moreover, to further reduce the computational cost, an approach based on the parallel ray approximation is used [6]: it allow us to obtain the frequency responses on the spatial grid of 45×45 points by employing the RT simulation on a coarser spatial grid, through the assumption that points located nearby are reached by the same number of rays having same amplitudes but different phases. In particular, the 45×45 frequency responses have been calculated by employing the RT simulation on a spatial grid of 9×9 points only.

IV- Comparisons between measurement and numerical results

The measured frequency responses have been processed in the following way: for each point of the measurement grid the impulse response has been derived through an Inverse Discrete Fourier Transform- IDFT; the propagation delay has been removed from it; a spatial average has been performed to obtain the measured power delay profile (PDP).

Regarding the RT simulation, for each point of the RT grid, the frequency response has been obtained by setting the number of bouncing to 4, omitting the diffracted rays (this assumption is due to the very low power level of the diffracted rays within the scenario) and by applying the frequency dependent radiation pattern of one discone antenna at both the transmitter and the receiver, individually [5]. Note that this can be easily done since in the RT simulation the angle of departure (AoD) and the angle of arrival (AoA) are known. Then, for each point the impulse response has been derived through an IDFT; the propagation delay has been removed, and a spatial average has been calculated to obtain the PDP.

In Fig. 2a, the measured normalized PDP (dotted line) and the normalized PDP calculated through the RT procedure (gray continuous line) are plotted: the two curves show a good agreement. Some differences can be observed in the 40 ns region: these differences are presumably due to a not perfect reconstruction of the scenario in terms of furniture and dielectric properties of the materials. Indeed, it can be shown that the RT derived PDP is sensitive to these scenario features, while it is robust towards the reconstruction of the scenario in terms of its dimensions. Finally, we should point out that, in order to compare the RT results with measurements, some Additive White Gaussian Noise (AWGN) has been added to the individual RT-generated impulse response before using them to get the PDP.

Fig 2b shows the Cumulative Distribution Function (CDF) of the *rms* delay spread. The dotted line has been obtained by constructing the CFD after calculating the *rms* delay spread for each of the measurement locations when using a -25 dB threshold for the impulse responses. The gray continuous line has been obtained by constructing the CFD after calculating the *rms* delay spread for each of the RT locations when using the same –25 dB threshold for the impulse responses. The two curves compare very well; in the same figure the mean *rms* delay spreads and the standard deviations obtained by using the measured data and by employing the RT procedure are also given.

These results show that RT simulators can be effectively employed to characterize the UWB channel with a good accuracy. The computational time for the RT simulation depends on the complexity of the reconstructed scenario, the number of bouncing included and the number of spatial points; for the RT simulation described in this paper the total computational time is approximately 12 hours (2.4 GHz Pentium IV with 1 GB RAM). Note that this computational time is obtained when the afore-mentioned parallel ray approximation is adopted, while it grows up to 32 hours for the conventional RT procedure. Finally, it is worthwhile pointing out that other approaches for modeling indoor propagation channels of wide-band communication systems are usually based on FDTD methods. However, despite they are rigorous and also applicable to complex inhomogeneous dielectric structures, they result to be very time and CPU consuming.

V- Conclusions

We presented an efficient procedure based on a RT method for predicting UWB indoor channel parameters. The RT simulations are carried out at different frequencies over the signal bandwidth B and the impulse response is then extracted by processing the data. An excellent agreement with measurements is achieved, demonstrating the effectiveness of such a method for accurate site-planning in realistic indoor environments. The proposed RT procedure can be used for investigating many aspects of the UWB channel, *i. e.* the impact of antenna effects on the channel, or the angle/multipath power properties. As an alternative, it can be employed for developing statistical propagation models.

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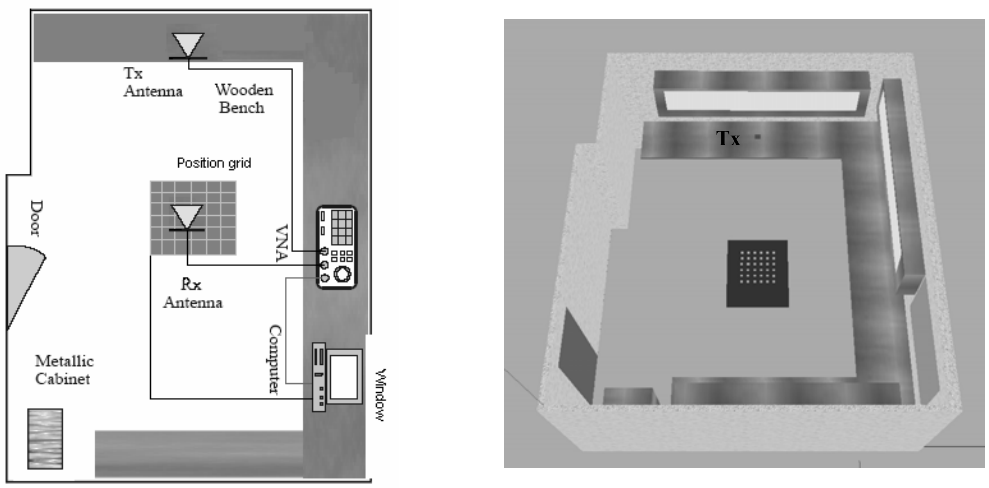
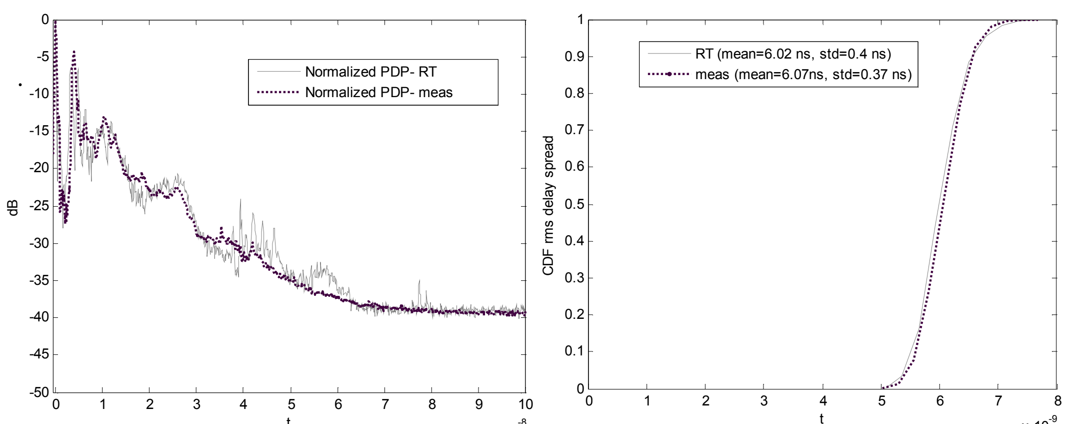


(a) (b)

Fig. 1 a)**-** A plan view of the measurement environment: the room is 5m×4.7m×2.6m, the transmitter (Tx) and the receivers are located at the same height of 1.35 m. b)- Pictorial view of the RT reconstructed scenario (ceiling not shown); the transmitter and the receivers (white dots grid) are also shown.



(a) (b)

Figs. 2 a)- Comparison of the PDPs (measured and simulated). The abscissa indicates the time exceeding that of the first arrived ray. b)- Cumulative Distribution Function (CDF) of the *rms* delay spread (measured and simulated).