Ultra-Wideband Interference Modelling for Indoor Wireless Channels using the FDTD Method

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***Abstract*—The propagation of an ultra-wideband (UWB) pulse is simulated in a simplified model of a two-dimensional office environment using the FDTD method. The power delay profile (PDP) is calculated for nine locations. It is found that the PDPs can be characterized using a clustered-exponential decay model. Randomly sized and positioned metal clutter alter the PDPs to follow a single-exponential decay model, with an average decay of -0.50 dB/ns.**

I. INTRODUCTION

Ultra-wideband (UWB) technology and systems have been the focus of considerable attention, particularly for wireless communications [1]. UWB signals are defined as having an instantaneous bandwidth greater than 500 MHz, or fractional bandwidth greater than 20% [1], [2]; and offer many potential advantages, including high spectral efficiency, low power consumption and high data rates [1]. As UWB systems operate over a broad frequency range, which often includes licensed spectrum, transmissions must comply with a spectral mask to limit interference to other users; the FCC mask is widely used: -41.3 dB/MHz over 3.1–10.6 GHz [3].

The impact of UWB systems on existing 'narrowband' systems (e.g. wireless LANs and cellular networks) has been a major focus in establishing these standards. Consequently, in many cases, interference from compliant UWB systems is not significant and can largely be treated as contributing toward the noise floor [4]. The impact of interfering 'narrowband' systems on UWB systems is less well understood, as are the impacts of other UWB systems operating in close physical proximity. UWB technology is still in the development-phase, and efforts currently focus on formulating efficient and reliable communication schemes, and transmitter and receiver architectures. Central to this effort, however, is an understanding of the UWB propagation channel and the development of reliable models to predict key parameters needed to assess the performance of the various communication schemes.

The power-delay-profile (PDP) is frequently used to assess system performance, and [5] has identified three main classes of models currently used to characterize the indoor UWB PDP: (a) clustered exponential decay [6] (similar to the impulse-response models proposed by Saleh and Valenzuela [7]); (b) single exponential decay [2]; and (c) single exponential decay with a superimposed log-normal variation in excess delay [8]. It should be noted that all three models are based on experimental measurements in a number of different residential and commercial buildings. Time-domain electromagnetic techniques (such as the FDTD method) inherently capture the impulse response of the channel [3], [9], and present an alternative to empirical models. The aim of this work is to use the FDTD method to examine the UWB indoor radio channel, formulate suitable models for the PDP, and assess the impact of interference to and from UWB communication systems.

II. UWB CHANNEL MODELLING USING THE FDTD METHOD

The high computational costs of time-domain methods generally limits their application to two-dimensional representations of the indoor radio channel, particularly at UWB frequencies [3], [9]. A floor plan of the two-dimensional office environment considered is shown in Fig. 1; the 4×6 m problem space is terminated in a 12-cell thick CPML. The mesh size is 1 mm, ensuring a mesh density of 15 cells/λ at the highest frequency of interest. The walls of the office are modelled as 1 cm thick drywall sheets ($\epsilon_r = 3.0$, $\sigma = 2.0$ mS/m) attached to a timber frame ($\epsilon_r = 4.0$, $\sigma = 10.0$ mS/m); the resulting 6 cm space between the drywall sheets is hollow. The glass windows ($\epsilon_r = 3.0$, $\sigma = 2.0$ mS/m) are 4 mm thick, and the two-dimensional representations of furniture are timber and metal ($\sigma = 10^7$). At this stage frequency-dependent material properties have not been taken into account.

A single E_z field component is used to excite the lattice with a Gaussian monocycle, given by $p(t) = \left(-3 + \frac{24\pi t^2}{\tau^2} - \frac{16\pi^2 t^4}{\tau^4}\right)\exp\left(-2\pi\left(\frac{t}{\tau}\right)^2\right)$, where $\tau = 0.168$ ns. This pulse complies with the UWB spectral mask [3]. The small-scale averaged PDP is calculated at nine locations across both offices, as indicated in Fig. 1. At each location, the time-history of the E_z field is recorded at 25 points on a 5×5 grid with a 50 mm separation. The PDP is calculated by temporally aligning and averaging the $|E_z|^2$ field across the 25 points and normalizing to the strongest component.

Fig. 2(a) and (b) show the PDP for locations 1 and 7. At location 7 it is observed the strongest pulse arrives with an excess delay of approximately 7.5 ns; while at location 1, the first pulse is strongest. In general, when the direct path is shadowed by objects in the environment (e.g. at locations 5 and 7) reflected/scattered components can dominate the PDP. For the nine locations considered, the PDP tends to follow a clustered exponential decay with excess delay, i.e. each

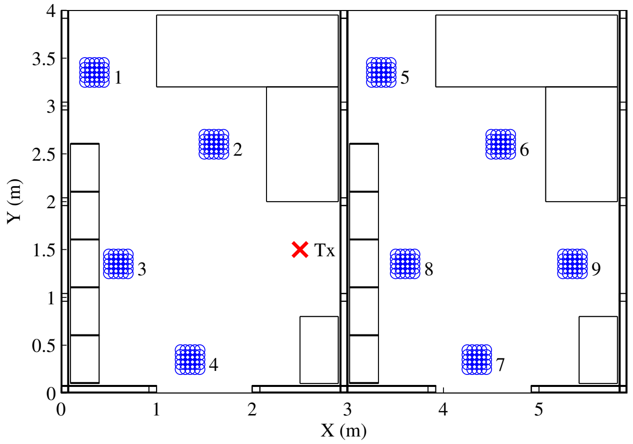

Fig. 1. Floor plan of the simplified two-dimensional office environment considered; transmitter and receiver locations are identified.

cluster of components can be individually characterized by an exponential decay. (For the problem examined, there is insufficient data to fit the full Saleh-Valenzuela model.)

III. IMAPCT OF ENVIRONMENTAL CLUTTER

Many of the clusters in the PDPs can be attributed with reflections from walls and other large objects in the propagation domain. However, in reality environments tend to be considerably more cluttered, which may limit the effects of specular reflection. An approximation of the propagation behaviour in a cluttered environment can be obtained by placing a number of randomly positioned and sized scattering objects in the environment. Fig. 2(a) and (b) show the PDP recorded at locations 1 and 7 when 75 metal objects (with dimensions between 3–15 cm) are distributed randomly throughout the problem space. It is observed that the PDPs follow a single exponential decay with excess delay, and the effects of multiple clusters tends to be averaged out. For all nine locations examined, the decay rate is approximately -0.50 dB/ns.

Similar to [3], the PDPs from a specific wireless channel can used to assess the performance of an UWB communications system. Furthermore, by using appropriate system and circuit models, the impact of interfering UWB transmitters on narrowband and other UWB systems can be analyzed from the perspective of the physical environment.

Future work will focus on calculating system performance, examining larger domains, determining the convergence of the PDP with different realizations of clutter and comparisons with experimental measurements.

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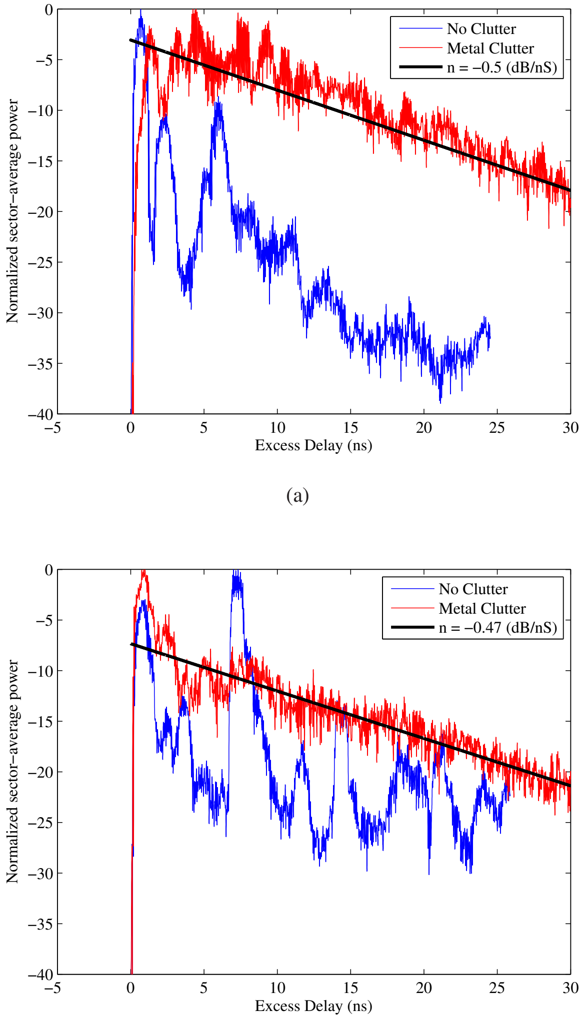

(a)

(b)

Fig. 2. Power delay profiles for (a) location 1; and (b) location 7 in Fig. 1, when cluttered and non-cluttered office environments are considered.

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