A statistical UWB channel model based on physical analysis

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***Abstract*— UWB systems were presented as a promising radio technology. Because of their large bandwidth, these networks are supposed able to deliver high data rates at short ranges. This motivates the work presented in this paper where we analyze UWB channel behavior based on path model derived from physical approach. We will show then the impact of large bandwidth on path impulse response time dispersion due to physical phenomena like reflection and diffraction. Afterwards, we will propose a new UWB channel model based on previous physical analysis.**

I. INTRODUCTION

Ultra Wide Band (UWB) signalling techniques are being considered for indoor short-range high data rate radio links overlaying with other existing wireless systems. Scholtz in [1] [2] carried out initial work in this direction. Such techniques, as well as others are being considered in the standardization process of IEEE 802.15a Wireless Personal Area Networks (WPAN) proposal. FCC's "Report and Order" allows for a UWB system bandwidth that extends from 3.1-10.6 GHz . This large bandwidth represents a high potential regarding capacity and flexibility issues and makes UWB systems attractive for applications such as localization, security systems, emerging automotive and home based "location awareness" systems. Because of its large bandwidth, UWB channel model is different from classical narrow band approach and present specific propagation mechanisms that till now are not well understood. To design reliable and efficient systems, based on this new radio technology, we need to propose models that are enough close to the real channel behavior. Existing proposals on UWB channel modeling can be classified to statistical and deterministic models. The statistical models are based on observation and analysis of measurements campaigns made in different environments and scenarios. Their advantage that they are useful to study system performances and to design the transmitter-receiver chain. For UWB channel the report from 802.15 standardization group present an overview of the most interesting proposals. In general all these proposed models aim to reproduce measurement behavior and don't take into account the interactions between the physical phenomena like reflection, diffraction and the impact of large bandwidth on their combination and their consequence on time domain channel impulse response. Deterministic models aim to study physical characteristics of the channel but in general they are not easy to implement and not useful to design system performance because they don't reflect statistical behavior.

II. UWB PATH RESPONSE ANALYSIS BASED ON PHYSICAL MODEL

The motivation of our approach is to propose a more realistic statistical UWB channel model derived from physical approach in order to derive a generic path impulse response that can be parameterized (based on the analysis of physical path response for different materials, geometry...) to generate reflection or diffraction path. Using environement statistics (about dominant physical phenomena, materials, geometry...) derived from measurements analysis, this generic and parameterizable path impulse response will be easy to use in order to generate statistical UWB model. Many works studied physical models. Qiu [3] presented the impact of large bandwidth on time domain CIR due to diffraction. Based on heuristical approach, he propose a model to show the relationship between spread in time domain and large bandwidth . In this work, we will analyze both reflection and diffraction mechanisms for an UWB channel.

1) Reflected UWB path impulse response: Using the expression of the reflection coefficient verssus the frequency and the incident angle, $R(\psi, s)$ expressed as

$$R(\psi, s) = \pm \frac{\sqrt{s+2a} - \kappa\sqrt{s}}{\sqrt{s+2a} + \kappa\sqrt{s}} \tag{1}$$

with $\tau = \frac{\sigma}{\epsilon}$, $\beta = \frac{\sqrt{\epsilon_r - cos^2\psi}}{\epsilon_r sin\psi}$, $a = \tau/2$, $\kappa = \beta$ for vertical polarization and $a = \tau/2$, $\kappa = (\epsilon_r \beta)^{-1}$ for horizontal polarization. Barnes [5] derived the time domain expression of $r(t)$ as

$$r(t) = \left[K\delta(t) + \frac{4\kappa}{1-\kappa^2} \frac{\exp(-at)}{t} \sum (-1)^{n+1} n K^n I_n(at) \right] \tag{2}$$

Figures 1 and 2 derived for time resolution corresponding to frequency bandwidth equal to $1GHz$ give the reflection coefficient impulse response for different values of ϵ and σ. In addition, if we take into account the effect of frequency domain observation window, $r(t)$ will be convolved in time domain with $sinc(t)$ and thus the observed time domain impulse response will behaves as shown on figure 3.

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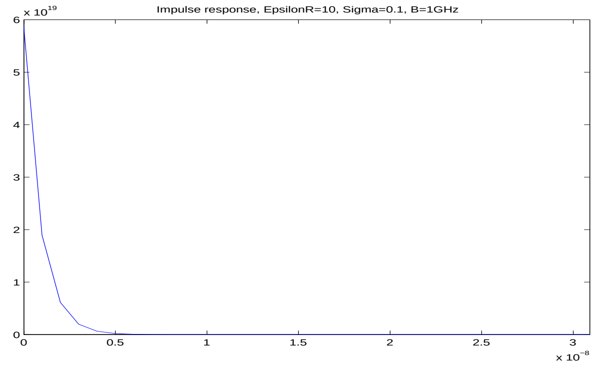

Fig. 1. Reflection Coefficient Impulse response with sigma = 0.1, epsilonr = 10 and Bandwidth = 1 GHz

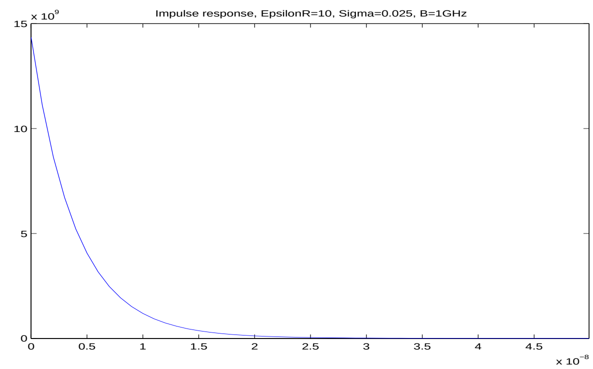

Fig. 2. Reflection Coefficient Impulse response with sigma = 0.025, epsilonr = 10 and Bandwidth = 1 GHz

2) Diffracted UWB path impulse response: Qiu in [4] derived the time domain impulse response due to diffraction for perfectly conducting half-plane as follow

$$h_d(\tau) = \frac{\sqrt{2r/c}}{2\pi}\left[\frac{cos\frac{1}{2}(\varphi-\varphi_0)}{\tau+\frac{r}{c}cos(\varphi-\varphi_0)}\right.$$
$$\left.-\frac{cos\frac{1}{2}(\varphi+\varphi_0)}{\tau+\frac{r}{c}cos(\varphi+\varphi_0)}\right]\frac{1}{\sqrt{\tau-r/c}}U(t-r/c) \quad (3)$$

c is the speed of light, τ is the path delay, φ and φ_0 are defined on figure 4. We plot on figure 5 the impulse response of eq. (3). diffraction for perfectly conducting half-plane As we can see from these figures, depending on materials parameters and the incidence angles, the impulse response can present a dramatical dispersion in time domain for both reflection and diffraction. These results are very important because they show clearly that the path response for UWB channel can have a dispersion in time domain about many nanosecondes. And if we recall that the rms delay spread for UWB channels ranges from $5ns$ to $20ns$, this dispersion can not be neglected. This means also, and contrary to what was adopted in the standardized IEEE 802.15.3a channel model [6] showed on 7, that the UWB path response could not be represented by a Dirac function. This large dispersion in time domain can also

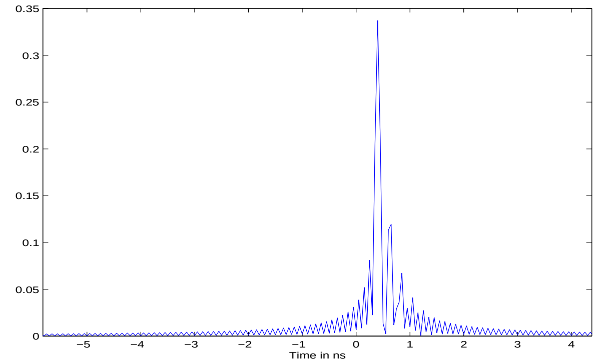

Fig. 3. Reflected path impulse response with windowing effect

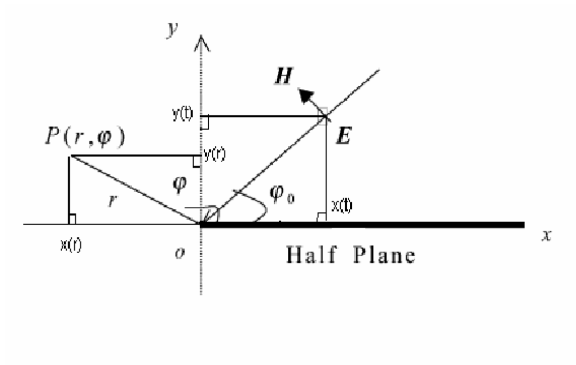

Fig. 4. diffraction at perfectly conducting half-plane

explain the clustered behavior of the APDP (Average Power Delay Profile) observed in many UWB channel measurements campaigns [8] [7] as shown on 6, and was modeled in IEEE 802.15.3a proposal using Saleh-Valenzuela approach, by a double sum as follow:

$$h(t) = \sum_{l=0}^{L-1}\sum_{k=0}^{K-1} exp(j\theta_{kl})\delta(t-T_l-\tau_{kl}), \quad (4)$$

where L is the number of clusters and K is the number of echoes in each cluster and the APDP (Average Power Delay Profile) is expressed as:

$$Ea_{kl}^2 = P(\tau_{kl}) = \Omega_0 exp\left(\frac{T_l}{\Gamma}\right) exp\left(\frac{\tau_{kl}}{\gamma}\right), \quad (5)$$

where Γ and γ are the decay constants of the clusters and of the echoes inside the clusters, respectively. This model states that all the paths are independent which is also different from what we can observe on figure 3 which shows that some observed paths can be correlated due to time domain disperssion. It states also that all the clusters have the same constant decay which is not true (see figure 6). This last remark was pointed out in many other works [9].

A. A new UWB channel model

Based on the physical analysis made in previous section, we can state that the path model can not be a Dirac function

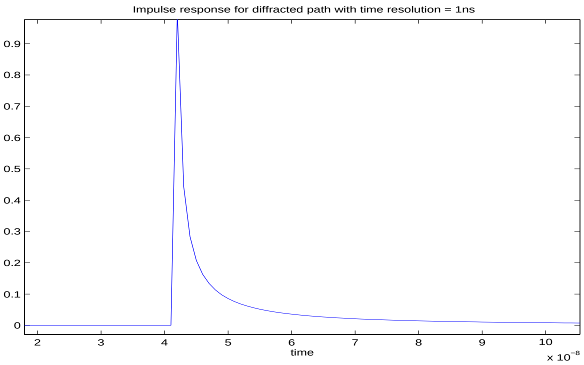

Fig. 5. Diffracted path Impulse response

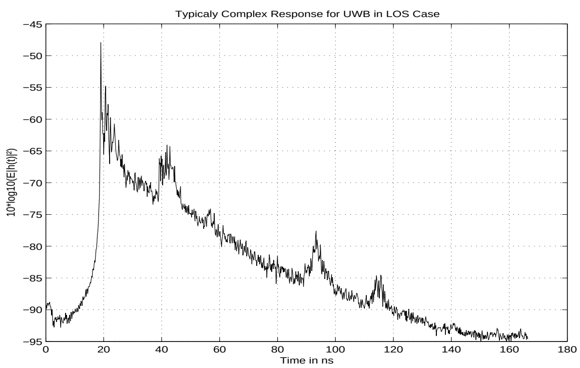

Fig. 6. APDP extracted from measurements campaign

as the model used for 802.15.3 but should be represented by a dispersed impulse response, $g(\tau, t)$. As we said before, this dispersion can explain the observed clustered behavior. Furthermore, the maximum rms delay spread for indoor channels is about 20ns, so the main important part of the impulse response corresponding to this small value is due to a few number of reflections. Thus we propose a more simplified and realistic UWB channel model using only one sum over all paths (dispersed or not) as follow:

$$h(t) = \sum_{l=0}^{L-1} g_l(\tau_l, t) U(t - \tau_l) \qquad (6)$$

where $U(t - \tau_l)$ is the Heavisides unit step function, $g_l(\tau_l, t)$ is the dispersed impulse response for the l^{th} path and L is the number of dominant paths. After analyzing UWB path impulse response for many scenario (different materials, incidence angles, distances,...), we propose as parametrizable path model next expression:

$$g_l(\tau_l, t) = g_l \exp\left(-\left(t - \tau_l\right)/\gamma_l\right) \qquad (7)$$

$\{g_l\}_{l=0}^{L-1}$ are assumed to be complex Gaussian variables. For the statistics of $\{\tau_l\}_{l=0}^{L-1}$, we chose to use a Poisson law which is generally used to model the delays Time of Arrival. The APDP of the modeled channel follows an exponential law as

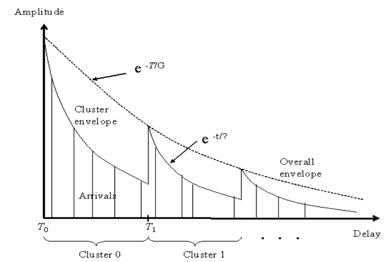

Fig. 7. Saleh Valenzuella model

usually for wireless channels. γ_l is a parameter that can be chosen randomly from a specific set representing the observed dispersion due to reflection or diffraction mechanisms for a path l. From the measurements [8], we observed that the time dispersion of the observed paths and clusters ranges from $1ns$ to $10ns$.

B. Results

For simulations we use the eq. (6) and (7) to reproduce the channel behavior observed from measurements campaign. We introduce in the model $L = 80$. Figure 8 shows the obtained simulated channel for a bandwidth $B = 2GHz$. As we can see this figure reproduces the observed APDP shape of UWB channel with its clustered behavior.

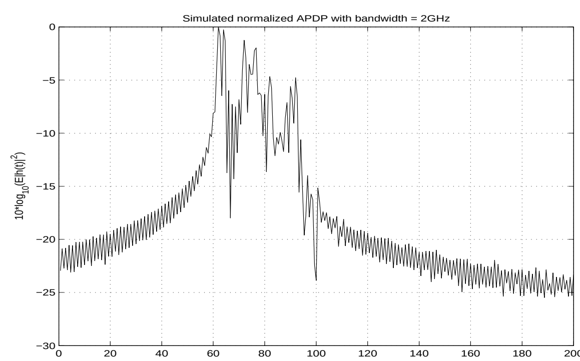

Fig. 8. Simulated channel with 80 paths

III. CONCLUSION

In this work, we analyzed the UWB path impulse response due to reflection and diffraction mechanisms. We have shown the experienced time dispersion and derived a more simplified and realistic UWB channel model compared to the standardized 802.15.3 channel model.

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