Statistical UWB channel model parameters estimation based on SAGE algorithm

Rachid Saadane
GSCM_LRIT Laboratory
Faculty of Sciences Rabat
University Mohammed V
B.P. 1014 Morocco
rachid.saadane@gmail.com

Aawatif Menouni Hayar
Mobile communications
Department
Eurecom Institute
BP 193, France
menouni@eurecom.fr

Helmut Hofstetter
Mobile communications
Department
Eurecom Institute
BP 193, France
Hofstetter@eurecom.fr

Driss Aboutajdine
GSCM_LRIT Laboratory
Faculty of Sciences Rabat
University Mohammed V
B.P. 1014 Morocco
aboutaj@fsr.ac.ma

***Abstract*—This work presents a simple and realistic UWB channel model based on physical propagation effects and UWB channel measurements conducted at Eurecom. A mathematical description of the model is discussed and the corresponding parameters extraction is presented. This model is described entirely by a set of four parameters, namely the number of MPCs, the MPC amplitude, the MPC delay and the MPC decay constant. These parameters are extracted using SAGE algorithm. It presents a good fit to measurement data and is easy to implement.**

I. Introduction

Recently, wireless personal area networks (WPANs) have attracted considerable attention due to their ability to provide ad-hoc networking with low cost and low power consumption devices. The Commission on February 14, 2002 adopted a First Report and Order in ET Docket No. 98-153 to amend Part 15 of the FCC Rules to permit the marketing and operation of certain types of new products incorporating ultra-wide band technology [1].

The ultra–wideband (UWB) radio channel is affected by various propagation mechanisms, namely reflection, transmission, scattering and diffraction. It can therefore be described by a set of multi–path components (MPCs), each having a specific delay, angle of arrival, and angle of departure.

Several models are available that characterize the behavior of both, the indoor and the outdoor wireless multi-path channel. However most of them focus on applications to narrowband and wideband wireless systems [2], [3]. With the emergence of UWB technology as a serious support for high data rate transmission for short–range indoor applications, new sets of indoor propagation measurements have been performed by many researchers e.g. [4]–[7]. In this work the data collected from channel measurements conducted at Eurecom [8] are used. These measurements contain several line-of-sight (LOS) and non-LOS (NLOS) environments. In [11] an overview on UWB channel models is given. They all model the UWB channel as a sum of independent Dirac functions. The correlation between taps the distortion of the path profile due to diffraction and to the effect of large bandwidth are not taken into account. In [12] the distortion of the MPCs at frequency bands relevant for UWB channels is studied for a physical model but no statistical parameters were derived.

In this paper we propose a novel simplified statistical UWB channel model which takes the distortion and the correlation of the MPCs into account.

The validation of the proposed model is based on the estimation of its parameters using Space Alternating Generalized Expectation maximization (SAGE) algorithm. The validation process is made in two steps. First, we evaluate the estimation process using an analytical channel based on the diffraction and reflection mechanisms. In second time, we apply the same algorithm on a generated channel based on our proposed statistical model.

The paper is organized as follows: Section II presents an UWB MPC response analysis based on physical model. Section III describes the proposed statistical channel model and parameters estimation.In section IV, we show the main results obtained in this work. Finally, we conclude and we give an an outlook on future work in Section V.

II. Analysis of the UWB Impulse Response

The UWB impulse response is the result of the superposition of several MPCs. As a first step towards our new statistical channel model we investigate the properties of a single MPC. Qiu [12] has presented the impact of large bandwidth on the impulse response due to diffraction. Based on a heuristic approach he proposes a physical model showing the relationship between path dispersion in time domain and large bandwidth.

Using the expression of the reflection coefficient versus the frequency, Barnes [15] derived in time domain an analytical expression for channel impulse response (TD-CIR). The expression of the reflection coefficient versus the frequency and the incident angle, $R(\psi, s)$ expressed as

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

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

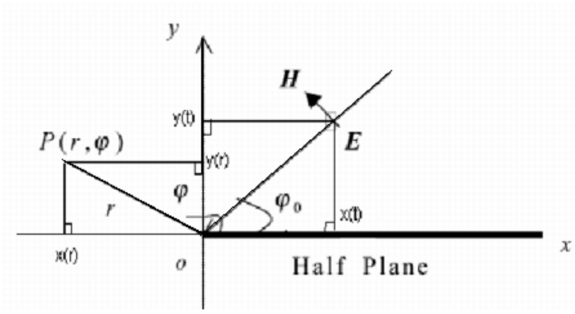

Fig. 1. Diffraction at perfectly conducting half-plane.

polarization.

Barnes [15] derived the time domain expression of reflected path $h_r(t)$ as

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

Qiu in [12] derived the time domain impulse response of diffracted path for perfectly conducting half-plane as follow

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

c is the speed of light, τ is the path delay, φ and φ_0 are defined on Fig. 1.
Figs. 2 and 3 show the distortion of of Dirac and pulse signal due to reflection phenomenon respectively for different bandwidths. We plot on Fig. 4 the response of diffracted pulse for different displacement types using the equation in (3).

Fig. 5 shows the effect of the material constitutive parameters (ϵ: permittivity and σ: conductivity) on TD-CIR for a bandwidth equal to 1 GHz.

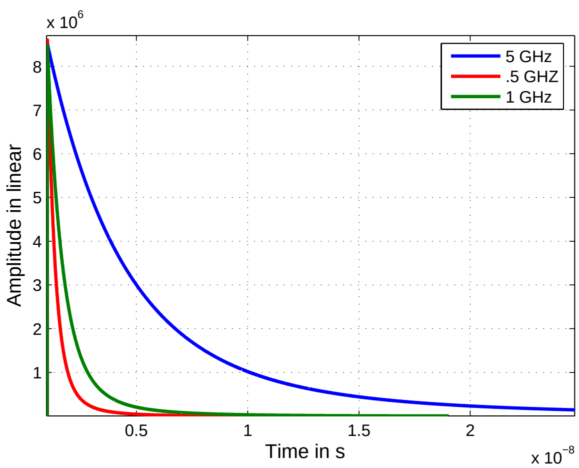

Fig. 2. Reflection of Dirac versus channel bandwidth for a horizontal polarization with arc displacement, σ_r = 0.001 ϵ_r = 6

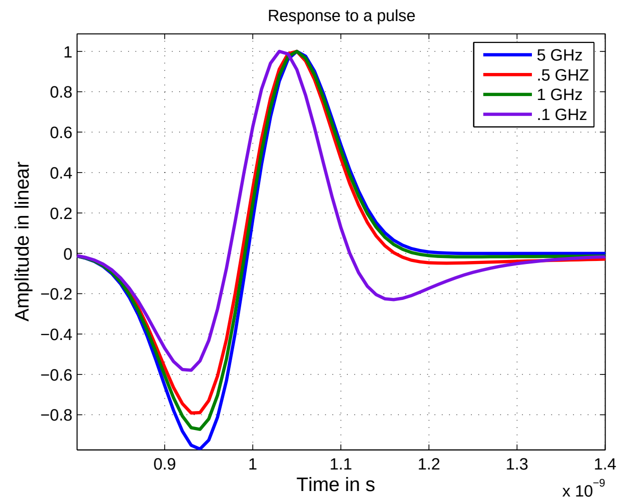

Fig. 3. Reflection of pulse versus channel bandwidth for a horizontal polarization with arc displacement, σ_r = 0.001 ϵ_r = 6

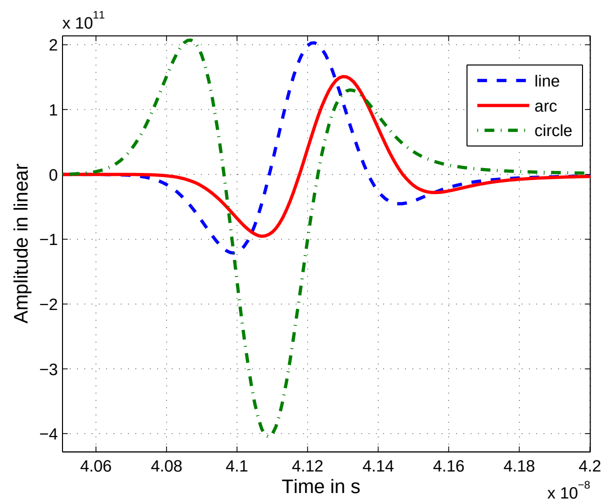

Fig. 4. Diffracted pulse for the same frequency bandwidth and different displacement types.

As we can see from these figures, the impulse response of a single MPC may show significant dispersion in time domain due to propagation phenomena and large bandwidths. These results demonstrate also that a single path of an UWB channel can experience a dramatically dispersion effect in time domain in the range of several nanoseconds. If we further recall that the RMS delay spread τ_{rms} for UWB channels ranges from 5 ns to 25 ns for indoor CM1-CM4 environments [7], this dispersion should be taken into account to model UWB path response.

This implies that, the UWB impulse response should not be represented by a set of Dirac functions. The large dispersion in time domain may also explain parts of inter-paths correlation and the clustered behavior of the Power Delay Profile (PDP)

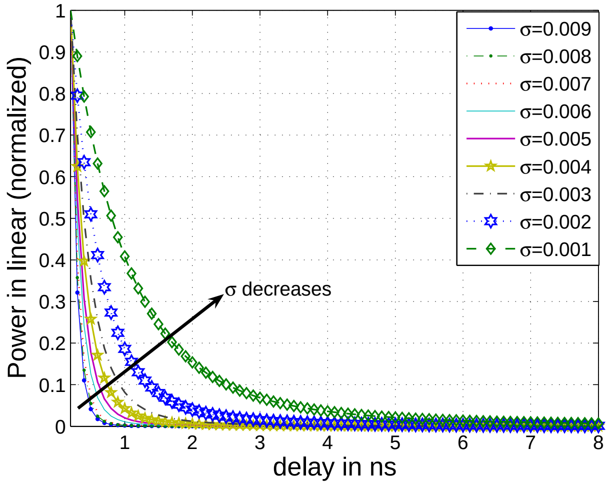

Fig. 5. The path dispersion time versus σ with $W = 1GHz$, $\epsilon = 6$.

observed in many UWB channel measurement campaigns [7], [8]. This statement does not mean that we argue against clusters. It was shown several times that clusters exist. But our idea influences the way clusters are built out of sets of MPCs. If each MPC has a certain time dispersion, the PDP of a single reflection looks like the PDP of a cluster.

In the proposal IEEE 802.15.3a the channel impulse response is modeled using Saleh–Valenzuela approach, by a double sum of independent Dirac functions, as follows:

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

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:

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

where Γ and γ are the constants decay 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 Fig. 5 which shows that some resolved paths, thanks to large bandwidth, can be correlated due to time domain dispersion.

III. Channel Model and Parameter Estimation

A. Channel Model Description

Based on the measurement and the physical analysis performed above, we propose a new simple channel model. The proposed model is given by:

$$h(t) = \sum_{l=1}^{L} g_l e^{-(t-\tau_l)/\gamma_l} u(t - \tau_l), \tag{6}$$

where $g_l e^{-(t-\tau_l)/\gamma_l}$ is used to present the path dispersion in time domain and $u(t)$ is the Heaviside function. To simplify the channel model in (6) we make $\alpha_l = g_l e^{\tau_l/\gamma_l}$,

$$h(t) = \sum_{l=1}^{L} \alpha_l e^{-t/\gamma_l} u(t - \tau_l). \tag{7}$$

The signal parameters of the l^{th} MPC are the time delay τ_l, α_l is the complex amplitude, and γ_l denotes the decay constant.

B. Parameter Estimation

The received signal is given by

$$y(t) = h(t) * \delta(t) + n(t) = \sum_{l=1}^{L} \alpha_l e^{-t/\gamma_l} u(t - \tau_l) + n(t) \tag{8}$$

At first we estimate γ_l by using a method based on the approximation by regression (we can see the γ_l as the slope of each MPC). Second, we estimate the parameters α_l and τ_l using the SAGE algorithm [16], [17].
The number of MPCs L in the observed UWB signal $y(t)$ is derived using the Akaike Information Criterion (AIC) [19].

IV. Results

A. UWB Channel measured Data

In this section, we present and analyze the results obtained from the UWB channel measurement conducted at Eurecom Institute [8]. The measurements were performed in the frequency domain using a Vector Network Analyzer (Rohde and Schwarz, ZVM family). From these measurements we determine the complex channel transfer function $H(f)$. the measured frequency range was 3.1 to 9 GHz, this leads to a delay resolution of approximately 0.166 ns. The spectrum was divided into 6003 points *i.e.* 1 MHz frequency sampling step. The antennas separation was 6 meters.

B. UWB Channel Model Implementation

The channel model is implemented, using Matlab Tool, based on equations derived in [12] and [15]. The nature of the environment (dense, large number of reflecting/diffracting scatterers, geometry, etc...) is fully parameterizable.

For the statistical model, we propose as a first approach to model γ_l using normal distribution. α_l and τ_l are generated respectively using lognormal and exponential distributions respectively.

Fig. 6 shows the power delay profile for simulated channel with $L = 100$, $\bar{\gamma} = 1.5$ (estimated from measured channel [8]) and time resolution 0.1667 ns corresponding to $W = 6\ GHz$. We can see from this figure that the simulated channel exhibits the same clustered behavior as what was observed from UWB channel measurements [8]. The Power Delay Profile is given by

$$PDP(\tau) = \frac{1}{N} \sum_{t_n=1}^{t_n=N} |h(t_n; \tau)|^2. \tag{9}$$

The PDP is generally characterized by the first central moment (mean excess delay) τ_m and the square root of the

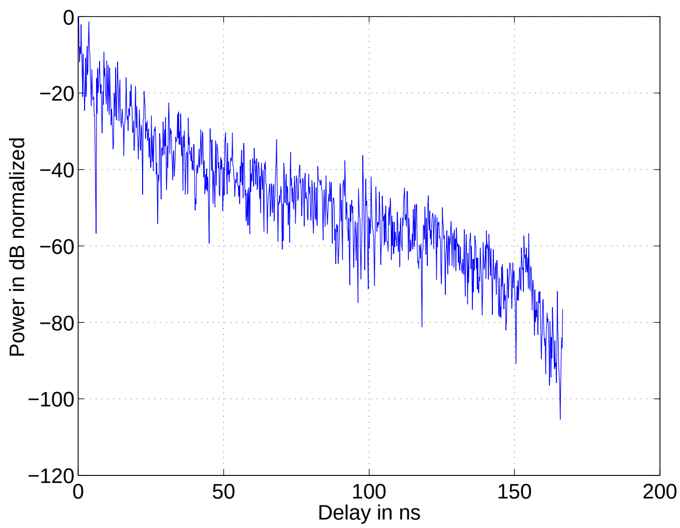

Fig. 6. The power delay profile for simulated channel

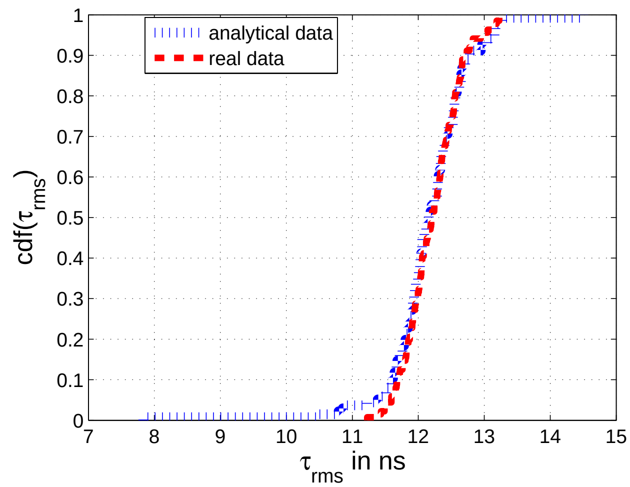

Fig. 8. Comparison between τ_{rms} from simulated and real channel for (6 GH).

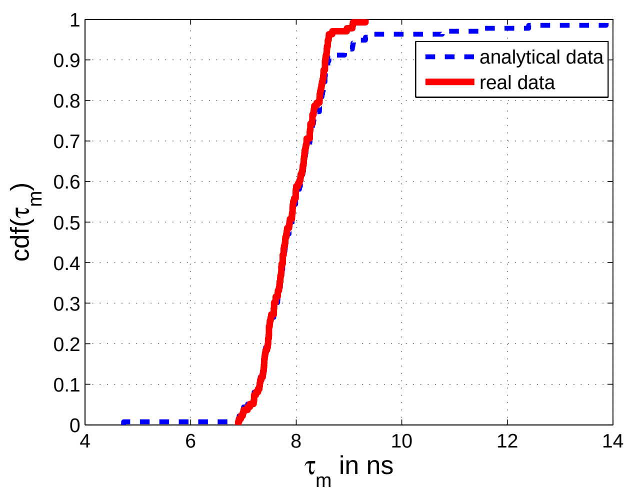

Fig. 7. Comparison between τ_m from simulated and real channel for (6 GH).

second moment (root mean square delay spread), τ_{rms}.
Figs. 7 and 8 show the cumulative distribution function of τ_m and τ_{rms} respectively for the simulated channel compared with real one.
These results show that the statistics of the simulated model are in agreement with those published in the literature.

C. Channel Parameters Estimation

In this part, we will focus on the estimation of the channel parameters using the model presented in equation (6). In Figs. 9 and 11, we show single realizations of the impulse responses of the analytical[1] channel and the measured channel [8] and compare them with channel built based on our parameter estimates.

In Fig. 10, we show single realizations of the impulse responses of the simulated based on the model in equation (7) and compare them with one based on our parameters estimates. The Figure shows the good agreement with original and estimated channels.

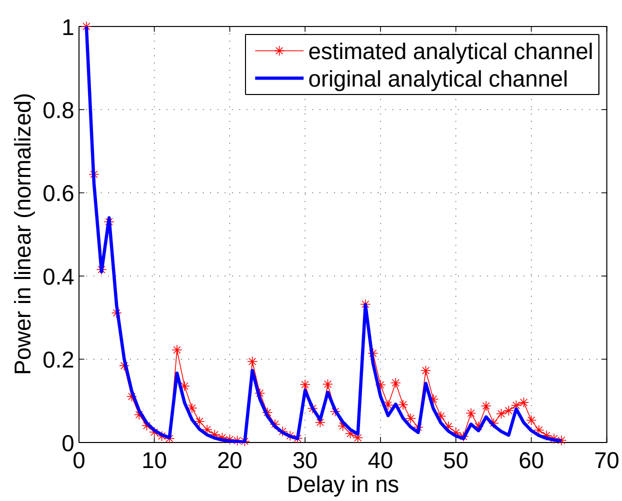

Fig. 9. The estimated channel for analytical (synthetic) channel 1 GHz of bandwidth, the distance between analytical channel and estimated one is 0.0789.

V. Conclusion and Future Work

We present a novel UWB statistical channel model based on physical analysis and real UWB channel measurements. A mathematical description of the model is discussed and the corresponding parameters estimation presented. The parameter extraction is based on the SAGE algorithm and first results

[1]The analytical channel is constructed using a sum of reflected or diffracted paths generated following equations 2 and 3 .

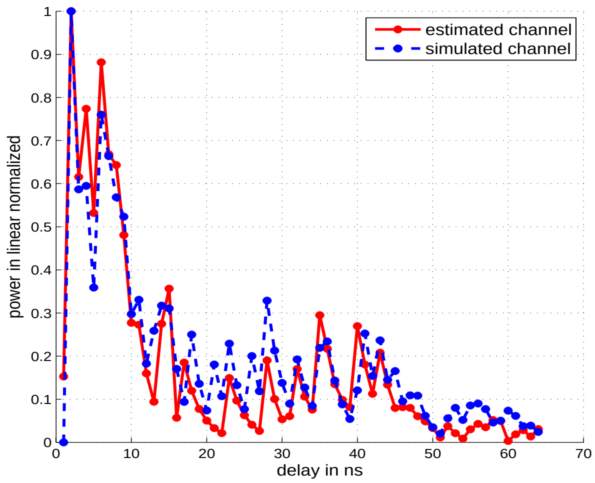

Fig. 10. Estimated impulse response of the simulated channel $\bar{\gamma} = 1.5$, $L = 40$.

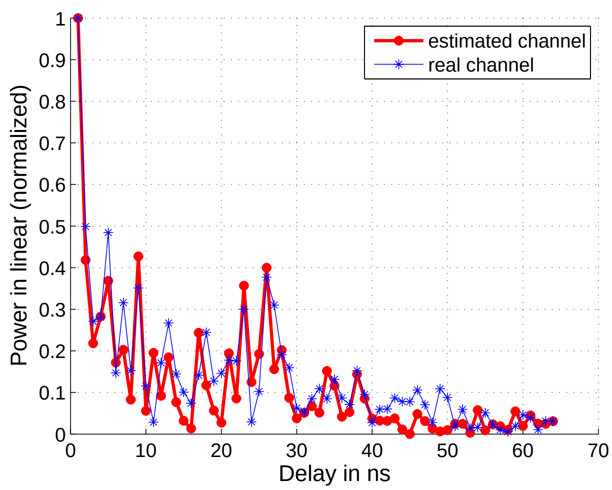

Fig. 11. The estimated channel for real channel for 1 GHz of bandwidth, the distance between real channel and estimated one is 0.0048.

are provided. The proposed model presents a good fit to measurement data and is easy to implement. A set of four parameters, namely the number of MPCs, the MPC amplitude, the MPC delay and the MPC decay constant, describes the whole model. As a next step we will study the bandwidth dependency of our channel model parameters.

REFERENCES

[1] "First report and order, revision of part 15 of the commission's rules regarding ultra-wideband transmission systems," FCC, ET Docket 98-153, Feb. 14, 2002.

[2] Scholtz, R. A. , "Multiple Access with Time-hopping Impulse Modulation," *IEEE Military Communications Conference*, Vol. 2, 11-14 Oct. 1993, pp:447-450.

[3] Win, M. Z. , Scholtz, R. A. , "Impulse radio: how it worksTransactions on Communications," *IEEE Communications Letters*, Vol. 2 Issue: 2, Feb. 1998,pp.36-38.

[4] S.S. Ghassemzadeh, R. Jana, C.W. Rice W. Turin, and V. Tarokh. "Measurement and modeling of an indoor UWB channel", *IEEE* , vol. 52, N. 10,October 2004.

[5] J. Kunisch and J. Pamp, "Measurement results and modeling aspects for UWB radio channel", *IEEE Conference Ultra Wideband Systems and Technologies*, 21-23 May 2002, pp. 19-23.

[6] D. Cassioli, M. Z. Win, and A. F. Molish," The ultra-wide bandwidth indoor channel-from statistical model to simulation," *IEEE Journal on Selected Areas Communications*, vol. 20, 2002 pp. 1247-1257.

[7] A.F. Molisch, J.R. Foerster, M. Pendergrass, "Channel models for ultra-wideband personal area networks, "*IEEE Wireless Communications*, Vol. 10, Issue 6, Dec. 2003 pp. 14 – 21.

[8] A. Menouni Hayar, R. Knopp, R. Saadane, "Subspace analysis of indoor UWB channels " *EURASIP Journal on applied signal processing, special issue on UWB - State of the art,* vol 2005 Issue 3 , pp 287–295.

[9] R. J.-M. Cramer and R. A. Scholtz, and M. Z. Win, "Evaluation of an ultraultrawideband propagation channel," *IEEE Trans. Antennas Propagation,* vol. 5, No. 5, pp. 561-570, May, 2002.

[10] A. F. Molisch, K. Balakrishnan, D. Cassioli, C. C. Chong, S. Emami, A. Fort, J.Karedal, J. Kunisch, H. Schantz, U. Schuster, K. Siwiak, "IEEE 802.15.4a channel model - final report", *http://www.ieee802.org/15/pub/04/15-04-0662-01-004a-channel-model-final-report-r1.pdf*.

[11] A. F. Molisch, " Ultrawideband propagation channels - theory, measurement,and models, " (invited paper) *IEEE Trans. Vehicular Techn.,special issue on UWB,* in press, 2005.

[12] R. C. Qiu, "A Study of the Ultra-Wideband Wireless Propagation Channel and Optimum UWB Receiver Design," *IEEE Journal on Selected Area in Communications,* vol. 20, No: 9, December 2002.

[13] K. Haneda, J. Takada, "An Application of SAGE Algorithm for UWB Propagation Channel Estimation," *UWBST'2003 Virginia, USA,* pp. 483–487.

[14] K. Haneda, J. Takada and T. Kobayashi"Experimental Evaluation of a SAGE Algorithm for Ultra Wideband Channel Sounding in an Anechoic Chamber," *IEEE IWUWBS&UWBST'2004 Kyoto, Japan,* pp. 66–70.

[15] P. R. Barnes, "On the Direct Calculation of a Transient Plane Wave Reflected from a Finitely Conducting Half Plane," *IEEE Trans. on Electromagnetic Compatibility,* Vol.:33, No: 2, MAy 1991.

[16] J. A. Fessler and A. O. Hero, "Complete-data spaces and generalized EM algorithms," in Plac. IEEE Conf. Acoust., Speech, Signal Processing, 1993, Vol. 4, pp. 1-4.

[17] B.H. Fleury and M. Tschudin and R. Heddergott and D. Dahlhaus and K.L. Pedersen, "Channel parameter estimation in mobile radio environments using the SAGE algorithm," *IEEE-Journal Selected Area Ccommunications*, Oct 1999, Vol. 17, No. 3, pp. 434–450.

[18] M. Wax and T. Kailath, "Detection of Signals by Information Theoretic Criteria," *IEEE Trans. on Acoustics,Speech, and Signal Processing*, vol. ASSP-33, No. 2, pp. 387-392, April, 1985.

[19] R. Saadane, D. Aboutajdine, A. Menouni Hayar, R. Knopp, "UWB Channel And Degrees Of Freedom Evaluations," *International Journal on Wireless and Optical Communications Special Issus in Ultra Wide*, April 2007, Vol. 4, No. 2 pp. 1-13.