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USING ULTRA WIDE BAND COMMUNICATION SYSTEM IN URBAN AREA TRANSPORT

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The propagation of UWB[3] signals in indoor and indoor-outdoor environments is the single most important issue, with significant impacts on the future direction, scope, and, generally, the extent of the success of UWB technology. If the channel is well characterized, the effect of disturbances and other sources of perturbations can be reduced by proper design of the transmitter and receiver. Detailed characterization of UWB radio propagation is, therefore, a major requirement for successful design of UWB communication systems.

This article sets out to characterize a UWB channel and also develops a comprehensive Matlab model of the channel. The developed Matlab models are thoroughly compared with IEEE approved measurement data through sets of specific characterizing parameters to ensure they closely resemble the actual channel impulse response and are valid. The model is intending to use for UWB transmission in subway stations.

Keywords: Ultra Wide Band (UWB), UWB propagation channel, model Saleh - Valenzuela, wireless networks, Matlab model of the channel UWB.

1. Introduction

A comprehensive overview on UWB technology is given in [1], [2], [3]. The history of UWB communication dates back to the very beginning of radio communication. Whereas we would consider this today as UWB communication, the early design choices were rather a result of limited hardware and technology. The further evolution of wireless communication was affected by carrier modulated narrowband communication, which may have originated from multiple accesses by frequency division.

UWB uses wide transmission bandwidths (in excess of 3 GHz), which results in desirable potentials such as accurate position location and ranging, lack of significant fading, high multiple access capability, secure communications, and possible easier material penetration. These advantages will result in more covert and faster wireless networks and also create new opportunities for the design of wireless positioning and ranging products. UWB channel models are very different compared to their conventional narrowband counterparts, because first

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[3] UWB - Ultra Wide Band

UWB is a carrier less communication scheme and secondly it uses a much wider bandwidth than the conventional wireless schemes. The channel impulse response to a UWB pulse is significantly different from the conventional narrowband systems due to the large bandwidth of the pulse, therefore making most previous research on the narrowband wireless channel models inapplicable.

2. Ultra Wide Band (UWB) channel modeling

UWB is a carrier less communication scheme which utilizes the bandwidth in the range of 3-7 GHz. The wide bandwidths used by UWB transmission allow a better support for multiple user communication, allocate faster communication links, and develop wireless ranging and positioning products. UWB will also relieve the communication spectrum congested by the narrow band wireless communications systems [4], [3]. The UWB system has low transmission power which allows working over a wide bandwidth without interfering with existing narrowband systems, but the lower power limits the range, thus mainly limiting UWB to indoor communication. The most widely used pulse in UWB communications is the Gaussian pulse [8]. The UWB antenna at the receiver and transmitter influence the UWB pulse due to their limited bandwidth and other factors [2], thus making the received pulse considerably different from what was transmitted. The UWB channel models are different compared to conventional narrowband communication systems, because UWB is a carrier less communication scheme and it uses a much wider bandwidth than the conventional wireless communication systems. In this paper is described a Matlab model to characterize an UWB channel using two different physical settings summarized under Non Line Of Sight (NLOS) 4 - 10 m and an extreme NLOS[4] multipath channel.

The major difference between Saleh-Valenzuela model [1] and 802.11 model is that Saleh-Valenzuela model doesn’t assume the arrival of paths on each sampling time interval. Instead, two Poisson models are employed in the modeling of the arrival time.

The simulation was realized using a slightly modified Saleh-Valenzuela model, recommended by IEEE 802.15 as multipath model.

$$h_i(t) = X_i \sum_{l=0}^{L} \sum_{k=0}^{K} \alpha_{k,l}^i \delta(t - T_l^i - \tau_{k,l}^i) \qquad (1)$$

Where $\{\alpha_{k,l}^i\}$ are the multipath gain coefficients, $\{T_l^i\}$ is the delay of the l^{th} cluster, $\{\tau_{k,l}^i\}$ is the delay of the k^{th} multipath component relative to the l^{th} cluster

[4] NLOS - Non Line Of Sight

arrival time (T_l^i),{ X_i } represents the log-normal shadowing, and *i* refers to the *i*-th realization.

Finally, the proposed model uses the following definitions:

T_l = the arrival time of the first path of the *l*-th cluster; $\tau_{k,l}$ = the delay of the *k*-the path within the *l*-th cluster relative to the first path arrival time, T_l; Λ = cluster arrival rate; λ = ray arrival rate, i.e., the arrival rate of path within each cluster.

By definition, we have $\tau_{0,l} = 0$. The distribution [7] of cluster arrival time and the ray arrival time are given by:

$$p\left(T_l \left| T_{l-1}\right.\right) = \Lambda \exp\left[-\Lambda\left(T_l - T_{l-1}\right)\right], \quad l > 0\mathbb{S}$$
$$p\left(\tau_{k,l} \left| \tau_{(k-1),l}\right.\right) = \lambda \exp\left[-\lambda\left(\tau_{k,l} - \tau_{(k-1),l}\right)\right], \quad k > 0 \qquad (2)$$

The channel coefficients are defined as follows: $\alpha_{k,l} = p_{k,l}\xi_l\beta_{k,l}$, $20\log 10(\xi_l\beta_{k,l}) \propto \text{Normal}(\mu_{k,l}, \sigma_1^2 + \sigma_2^2)$, or

$$\left|\xi_l\beta_{k,l}\right| = 10^{(\mu_{k,l}+n_1+n_2)/20} \qquad (3)$$

Where $n_1 \propto \text{Normal}(0,\sigma_1^2)$ and $n_2 \propto \text{Normal}(0,\sigma_2^2)$ are independent and correspond to the fading on each cluster and ray, respectively,

$$E\left[\left|\xi_l\beta_{k,l}\right|^2\right] = \Omega_0 e^{-T_l/\Gamma} e^{-\tau_{k,l}/\gamma} \qquad (4)$$

Where T_l is the excess delay of bin *l* and Ω_0 is the mean energy of the first path of the first cluster, and $p_{k,l}$ is equiprobable +/-1 to account for signal inversion due to reflections. The $\mu_{k,l}$ is given by:

$$\mu_{k,l} = \frac{10\ln(\Omega_0) - 10T_l/\Gamma - 10\tau_{k,l}/\gamma}{\ln(10)} - \frac{(\sigma_1^2+\sigma_2^2)\ln(10)}{20} \qquad (5)$$

In the above equations, ξ_l reflects the fading associated with the l^{th} cluster, and $\beta_{k,l}$ corresponds to the fading associated with the k^{th} ray of the l^{th} cluster. Note that, a complex tap model was not adopted here. The complex baseband model is a natural fit for narrowband systems to capture channel behavior independently of carrier frequency, but this motivation breaks down for UWB systems [7], [8], [9] where a real-valued simulation at RF[5] may be more natural. Finally, since the log-normal shadowing of the total multipath energy is captured by the term, X_i, the

[5] RF - Radio Frequency

total energy contained in the terms $\{\alpha_{k,l}^{i}\}$ is normalized to unity for each realization. This shadowing term is characterized by the following: $20\log10(X_i) \propto \text{Normal}(0,\sigma_x^2)$.

3. Simulations Ultra Wide Band (UWB) channel with Matlab

The developed Matlab models are in conformity with IEEE 802.15 task group. The developed Matlab model provides researchers and developers with the UWB channel impulse response, thus enabling them to:

- Develop the optimum UWB pulse shape;
- Develop and test the best UWB transmitters and receivers;
- Carry out performance analysis of UWB wireless systems under different indoor settings;
- Use the developed channel impulse response to explore new possibilities and products such as UWB ranging and positioning systems.

We simulated in MATLAB the impulse response (see fig. 1) and the frequency response (see fig. 2) for a 4-path Rayleigh channel. For the simulation, the transmission is done on 4 paths with the time delays 0, $1.5*10^{-5}$ s, $3.2*10^{-5}$ s, $2.1*10^{-5}$ s and the average path gains 0, -3, -3, -3, DPSK[6] modulation and random bit stream [7],[9].

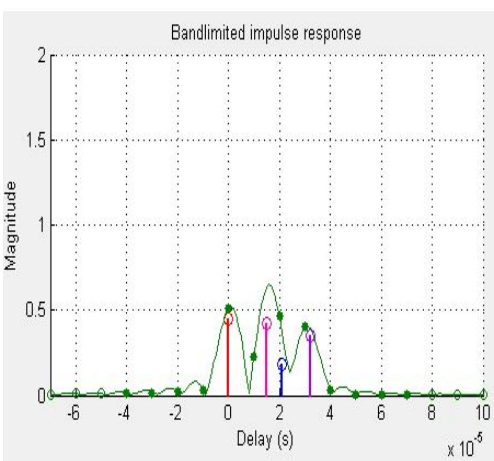

Fig. 1 Impulse response

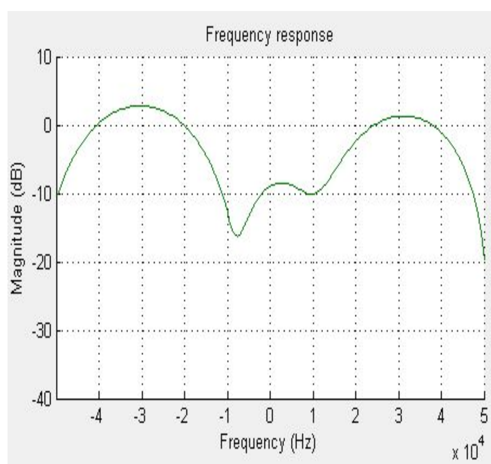

Fig 2.Frequency response

Channel characteristics desired to model

As shown above, there are 6 key parameters that define the model:

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[6] DPSK - Differential phase shift keying

Λ = cluster arrival rate;
λ = ray arrival rate, i.e., the arrival rate of path within each cluster;
Γ = cluster decay factor;
γ = ray decay factor;
σ_1 = standard deviation of cluster lognormal fading term (dB).
σ_2 = standard deviation of ray lognormal fading term (dB).
σ_x = standard deviation of lognormal shadowing term for total multipath realization (dB).

These parameters are found by trying to match important characteristics of the channel. Since it's difficult to match all possible channel characteristics, the main characteristics of the channel that are used to derive the above model parameters were chosen to be the following [7]:

- Mean excess delay;
- RMS[7] delay spread;
- Number of multipath components (defined as the number of multipath arrivals that are within 10 dB of the peak multipath arrival);
- Power decay profile.

We focus on the subway station conditions so we choose a model based on NLOS (4-10m) channel measurements corresponding to CM[8]3 (channel model number 3) (fig. 3 - 6), and a model generated to fit a 25nsec RMS delay spread to represent an extreme NLOS multipath channel, corresponding to CM4 (channel model number 4) (fig. 7 -10).

Table 1 Comparison between channel model CM3, CM4

CM3	**CM4**
Model Parameters Lam = 0.0667, lambda = 2.1000, Gam = 14.0000, gamma = 7.9000 std_ln_1 = 3.3941, std_ln_2 = 3.3941, NLOS flag = 1, std_shdw = 3.0000	Model Parameters Lam = 0.0667, lambda = 2.1000, Gam = 24.0000, gamma = 12.0000 std_ln_1 = 3.3941, std_ln_2 = 3.3941, NLOS flag = 1, std_shdw = 3.0000

[7] RMS - Root-Mean-Square
[8] CM - Channel Model

Model Characteristics	Model Characteristics
Mean delays: excess (tau_m) = 15.9 ns, RMS (tau_rms) = 15	Mean delays: excess (tau_m) = 30.1 ns, RMS (tau_rms) = 25
# paths: NP_10dB = 24.9, NP_85% = 64.7	# paths: NP_10dB = 41.2, NP_85% = 123.3
Channel energy: mean = 0.0 dB, std deviation = 3.1 dB	Channel energy: mean = 0.3 dB, std deviation = 2.7 dB

The model parameters are:
Lam - Cluster arrival rate (clusters per nsec)
lambda - Ray arrival rate (rays per nsec)
Gam - Cluster decay factor (time constant, nsec)
gamma - Ray decay factor (time constant, nsec)
std_ln_1 - Standard deviation of log-normal variable for cluster fading
std_ln_2 - Standard deviation of log-normal variable for ray fading
std_shdw - Standard deviation of log-normal shadowing of entire impulse response

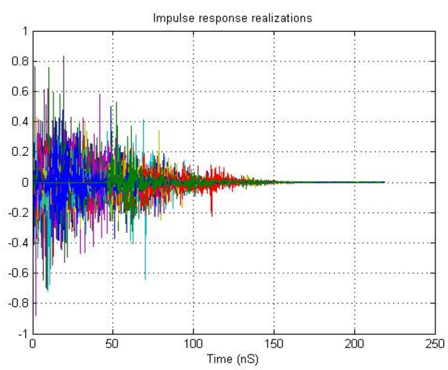

Fig.3 Impulse response CM3

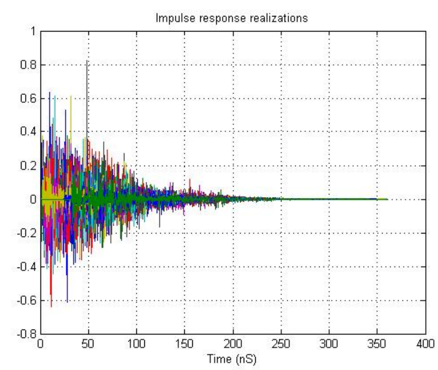

Fig.7 Impulse response CM4

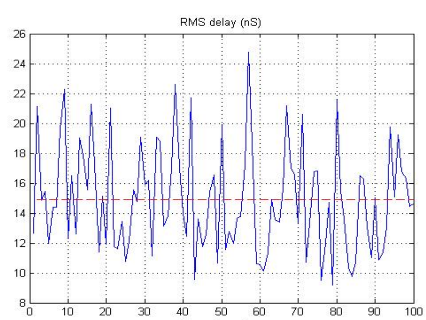

Fig.4. RMS delay CM3

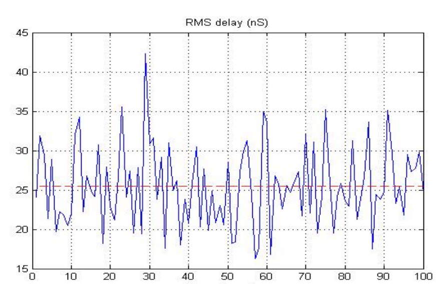

Fig.8. RMS delay CM4

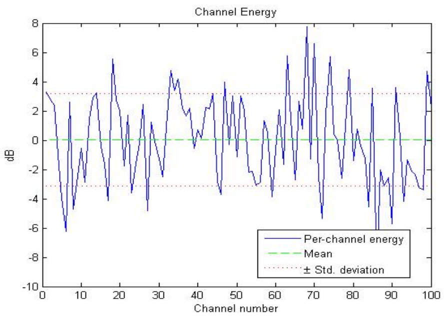

Fig.5. Channel energy CM3

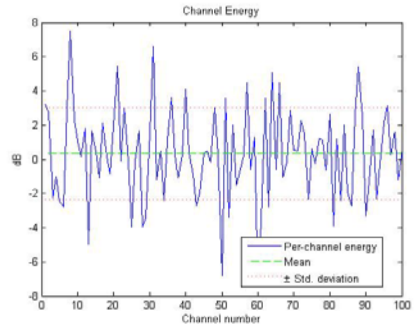

Fig.9. Channel energy CM4

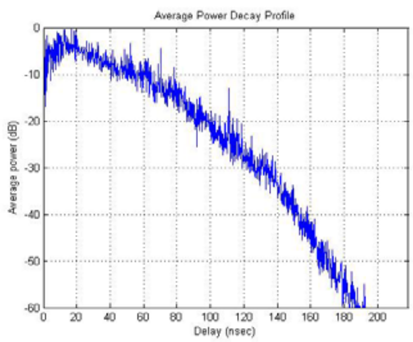

Fig. 6 Average power decay profile CM3

Fig. 10 Average power decay profile CM4

4. Conclusions

The Figs. 3 - 10 represents the graphs of the parameters of the CM3 and CM4, generated for 100 channels. A design of an UWB communication system based on this CM3 model use multiple transmitters, placed on a distance of maxim 20 meters, each other. In this case it is necessary to use a channel multiply access method. A design of an UWB communication system based on this CM4 model use only one transmitter, if the geometry of the enviroment allow that.

UWB technology is a promising candidate for the physical layer of future wireless sensor networks [5],[6]. The large bandwidth enables reliable short-range communication in harsh propagation environments as well as localization and imaging. In particular, non-coherent UWB communication is the method-of-choice for low complexity, low power and low cost systems. A smart implementation of non-coherent UWB is the generalized energy detection receiver. Its advantages are the robustness to channel variations and the low complexity analog implementation, which does not require high rate sampling of the receive signal [5],[8]. In this thesis, we contribute to communication, localization, and imaging for UWB sensor networks with generalized energy detection receivers.

The typical UWB propagation channel is a function which depends only weakly on the geometry of the environment. Rough knowledge about the surroundings is supposed to be sufficient for its characterization. Otherwise, no measurement campaign conducted in one environment could be a valid approximation of the channel in another, similar situation.

CM1 model is based on LOS[9] (0-4m) channel measurements reported in [3].

CM2 model is based on NLOS (0-4m) channel measurements reported in [3].

CM3 model is based on NLOS (4-10m) channel measurements reported in [3], and NLOS measurements reported in [9].

CM4 model was generated to fit a 25nsec RMS delay spread to represent an extreme NLOS multipath channel.

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R E F E R E N C E S

[1] *Andreas F. Molisch, Jeffrey R. Foerster, Marcus Pendergrass*, "Channel Models For Ultrawideband Personal Area Networks", 1536-1284, December 2003 IEEE.

[2] *Bo Hu and Norman C. Beaulieu*, "Accurate Evaluation of Multiple - Access Performance in TH-PPM and TH-BPSK UWB Systems", IEEE Transactions on communications, vol. 52, no. 10, October 2004.

[3] Digital Life Incorporation, "UWB signaling and the future of data communication", 2003, http://www.digit-life.com/articles2/uwb/;

[4] *D. Porcino and W. Hirt*, "Ultra-wideband radio technology: potential and challenges ahead," IEEE Commun. Mag., vol. 41, no. 7, pp. 66–74, July 2003.

[5] *H. Luecken, C. Steiner, and A. Wittneben*, "Location-aware UWB communication with generalized energy detection receivers," IEEE Trans. Wireless Commun., vol. 11, no. 9, pp. 3068–3078, Sept. 2012

[6] *J. Foerster and Q. Li*, "UWB Channel Modeling Contribution from Intel," IEEE P802.15-02/279-SG3a.

[7] *L. Yang and G. B. Giannakis*, "Ultra-wideband communications: an idea whose time has come," IEEE Signal Processing Mag., vol. 21, no. 6, pp. 26–54, Nov. 2004.

[8] *M. G. Di Benedetto, T. Kaiser, A. F. Molisch, I. Oppermann, C. Politano, and D. Porcino*, UWB Communication Systems–A Comprehensive Overview. Hindawi Publishing Corporation, 2006.

[9] *M. Pendergrass*, "Empirically Based Statistical Ultra-Wideband Channel Model," IEEE P802.15-02/240-SG3a.

[9] LOS - Line-Of-Sight