World Academy of Science, Engineering and Technology
International Journal of Electrical and Computer Engineering
Vol:6, No:6, 2012

On the Perfomance of Multiband OFDM under Log-normal Channel Fading

N.M. Anas, S.K.S. Yusoff, R. Mohamad

***Abstract*—**A modified Saleh-Valenzuela channel model has been adapted for Ultra Wideband (UWB) system. The suggested realistic channel is assessed by its distribution of fading amplitude and time of arrivals. Furthermore, the propagation characteristic has been distinct into four channel models, namely CM 1 to 4. Each are differentiate in terms of cluster arrival rates, rays arrival rate within each cluster and its respective constant decay rates. This paper described the multiband OFDM system performance simulates under these multipath conditions. Simulation work described in this paper is based on WiMedia ECMA-368 standard, which has been deployed for practical implementation of low cost and low power UWB devices.

***Keywords*—**Log-Normal, Multiband OFDM, Saleh-Valenzuela

I. Introduction

FEDERAL Communications Commission (FCC) defined Ultra Wideband (UWB) system in terms of the emitted signal bandwidth is more than 20% of its center frequency, or more than 500MHz. In 1998, FCC mandated that UWB radio transmission can legally operate in the range from 3.1 to 10.6 GHz on an unlicensed basis [1]. The First Report and Order that appeared on 14 February 2002 authorized the operation of UWB devices under stringent power spectral density emission at -41.3dBm/MHz [2]. There were two proposals to exploit the 7.5GHz unlicensed bandwidth, namely direct-sequence (DS-UWB) supported by UWB Forum and multiband OFDM supported by MB-OFDM Alliance [3]. However, multiband OFDM has more favors as an effective solutions providing high-speed data transmission over short-range wireless link. March 2005, has seen the merging of MB-OFDM Alliance and WiMedia into technology transfer agreements of UWB specifications. On December 2005, European Computer Manufacturers Association (ECMA) released ECMA-368 standard for UWB high-rate physical and MAC layers based on WiMedia multiband OFDM technique. Since then, this technology becomes prominent as compelling solution and being adopted by the USB-IF for Wireless USB and by the Bluetooth Special Interest Group (SIG) for high speed Bluetooth.

N. M. Anas is with the Faculty of Electrical Engineering, Universiti Teknologi Malaysia, Skudai, 81310 Malaysia (e-mail: nuzli.anas@ieee.org)
S. K. S. Yusof is with the Faculty of Electrical Engineering, Universiti Teknologi Malaysia, Skudai, 81310 Malaysia (e-mail: kamilah@fke.utm.my)
R. Mohamad is with the Faculty of Electrical Engineering, Universiti Teknologi Mara, Shah Alam, 40450 Malaysia (e-mail: roslina780@salam.uitm.edu.my)

The paper is organized as follows: Section II present the multiband OFDM technique for UWB system. Section III discussed the UWB channel based on modified Saleh-Valenzuela proposed model. Section IV explained baseband system implementation based on WiMedia ECMA-368 standard and its error-rate analysis simulated under the UWB channel. While Section V concluded the paper and proposed the future works.

II. UWB System Model: ECMA-368 Standard

Since FCC allocated 7500 MHz spectrum for unlicensed used, one of the proposed approach is to use multiband techniques in which the UWB frequency band is divided into several sub bands. Each sub band occupies a bandwidth of at least 500 MHz in compliance with the FCC regulations as shown in Fig. 1. The advantage of the multiband approach allows the information to be processed over a much smaller bandwidth [2], thus reduce the design complexity and lowering the power consumption. Six band groups are defined in which Band Group 1 to 4 consists of 3 sub bands, spanning from band 1 to 12. Band Group 5 contains two bands 13 and 14 while Band Group 6 contains bands 9, 10 and 11 as depicted in Fig. 1. Relationship between the center frequency and its band number, n_b is given below, in which provides the definition of unique numbering of all channels that are spaced 528 MHz apart where f_c and n_b is the center frequency and the respective sub band number.

$$f_c(n_b) = 2904 + (528 n_b), n_b = 1,2,...,14 \quad (1)$$

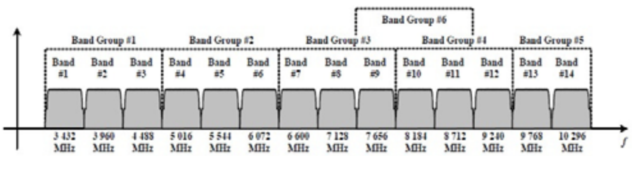


Fig 1. UWB Frequency Band Planning

However, only three-band is used in the initial deployment of multiband OFDM systems. UWB system occupies bandwidths of 528 MHz on each sub band are combined with OFDM techniques [4] in which support of Band Group 1 is mandatory. This system employs 128-point Fast Fourier Transform (FFT) indicates the number of subcarriers on each OFDM symbol. The system parameters on the OFDM scheme used 122-subcarriers carry energy out of 128 FFT point. Of the 122-subcarrier, 100 being used to carry data, 12 are assigned for pilot tones and the remaining ten are guard tones. Thus, the

OFDM symbols duration is 242.42 ns, where the subcarrier bandwidth is 4.125MHz. The discrete-time signal is created by taking the inverse Discrete Fourier Transform (IDFT) of the low-rate complex stream as follows

$$s_n[k] = \frac{1}{\sqrt{N_{FFT}}}\left[\sum_{l=0}^{N_D} C_{D,n}[l]e^{\frac{j2\pi M_D[l]k}{N_{FFT}}} + \sum_{l=0}^{N_G} C_{G,n}[l]e^{\frac{j2\pi M_G[l]k}{N_{FFT}}} + \sum_{l=0}^{N_P} C_{P,n}[l]e^{\frac{j2\pi M_P[l]k}{N_{FFT}}}\right] \quad (2)$$

where $k\in[0, N_{FFT}-1]$, $n\in[N_{sync}, N_{packet}-1]$, N_D is the number of data subcarriers, N_G is the number of guard subcarriers, N_P is the number of pilot subcarriers, N_{FFT} is the number of total subcarriers and $C_{D,n}[l]$, $C_{G,n}[l]$, $C_{P,n}[l]$ are the complex numbers representing on the l^{th} data, guard and pilot subcarriers of the n^{th} OFDM symbol respectively. The function $M_D[l]$, $M_G[l]$ and $M_P[l]$ define a mapping from the indices $[0, N_D-1]$, $[0, N_G-1]$ and $[0, N_P-1]$ to the logical subcarriers $[-N_{T/2}, N_{T/2}]$ excluding 0, respectively. The exact definition for the mapping functions can be found in [5].

Each symbol is appended with zero-padded (ZP) suffix in time domain instead of cyclic prefix as usually being done in conventional OFDM system. The same multipath robustness still can be achieved by this approach while providing ripples-free in the power spectral density as dictates in Fig. 2. The advantage is that power back-off circuitry is not needed at the transmitter. The ZP suffix is also used to provide a time windowing to allow the transmitter and receiver sufficient time to switch between different frequencies [6]. Each of OFDM symbol has 37 ZP appended at the end of symbols as guard interval giving a total interval time of 312.5 ns.

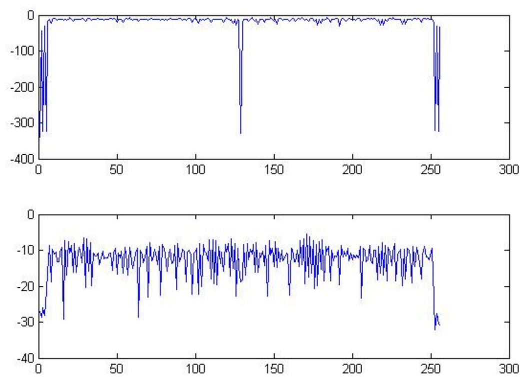


Fig. 2. Power Spectral Density for ZP (top) and CP (bottom)

In UWB system, each of OFDM symbols are then coded across all sub bands by time-frequency code as to exploit frequency diversities and provide robustness against interference. As the matter of fact, multiband OFDM symbol are not continually sent on one frequency band; instead, they are interleaved over the different sub band across both time and frequency as shown in Fig. 3. By interleaving the symbols across sub-bands, UWB systems can still maintain the same transmit power as if they were using the entire bandwidth [6]. Multiple access of UWB system is advantage by the used of frequency-hopping sequences over the set of sub bands.

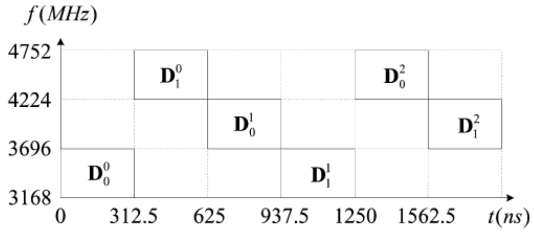


Fig. 3. Time-frequency Coding for Multiband OFDM System

Convolutional encoder is used for error controlling in which a redundancy being introduced. ECMA employs industrial standard convolutional encoder with the rate, R of 1/3 with generator polynomial $[133, 145, 175]_8$ where $[.]_8$ refer to octal number representation, while other code rates of 1/2, 5/8 or 3/4 are supported by puncturing. The system capable to support data rates up to 480 Mbps. Viterbi algorithms is used at the receiver as the maximum-likelihood decoding.

The coded stream is interleaved prior to modulation to provide robustness against burst errors. It is performed in three distinct operations, first stage involved permutation of six consecutive OFDM symbols to exploit frequency diversity within sub-band group. In addition, data subcarriers within an OFDM symbol are permuted to provide robustness against narrow-band interferers. Lastly, cyclically shift operated on the bits in successive OFDM symbols by deterministic amounts, enables the time-domain spreading. The binary data is then mapped using quadrature phase-shift keying (QPSK) for data rates 200 Mbit/s and lower while dual-carrier modulation (DCM) used for data rates 320 Mbit/s and higher.

III. UWB Channel Modeling

UWB is a radio technology for short-range communications utilizing high spectrum bandwidth. Much likely that this system is exposed to highly dispersive channel in which a large multipath energy arrives at the receiver. Saleh and Valenzuela [7] have proposed a new model that modeled the arrivals of multipath delay as a Poisson process. This model also associated the multipath components arrived with multiple clusters, each consist a set of arrays as shown in Fig. 4.

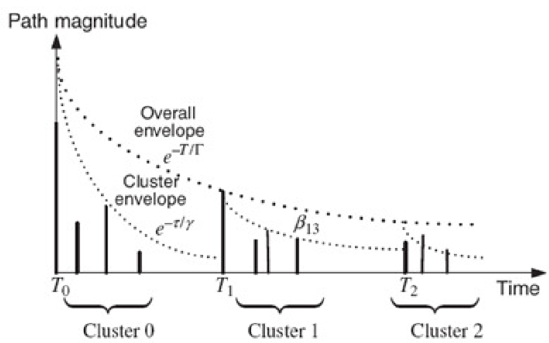


Fig. 4. Saleh-Valenzuela Channel Model

The arrival times of each cluster as well as rays within each cluster follow an individual Poisson distribution. It is shown that a distribution of cluster arrival times and a distribution of ray arrival times are given by the following exponential distribution, respectively,

$$p(T_m | T_{m-1}) = \Lambda \exp[-\Lambda(T_m - T_{m-1})], m = 0,1,.... \quad (3)$$

and

$$p(\tau_{r,m} | \tau_{(r-1),m}) = \lambda \exp[-\lambda(\tau_{r,m} - \tau_{(r-1),m})], r = 0,1,.... \quad (4)$$

where T_m is the arrival time of the first ray in the m^{th} cluster and $\tau_{r,m}$ denotes the arrival time of the r^{th} ray in the m^{th} cluster. Each cluster and ray arrival rated is modeled by Poisson process with cluster arrival rate of Λ and ray arrival rate of λ. Noted that, the arrival time of first array in m^{th} cluster, $\tau_{1,m}$ defined the arrival time of the m^{th} cluster, i.e., $\tau_{1,m} = T_m$. Say $\beta_{r,m}$ and $\theta_{r,m}$ denote amplitude and phase of the r^{th} ray and m^{th} cluster respectively. Then the channel impulse response is given as

$$h(t) = X \sum_{m=0}^{M} \sum_{r=0}^{R} \beta_{r,m} e^{j\theta_{r,m}} \delta(t - T_m - \tau_{r,m}) \quad (5)$$

where $\beta_{r,m}$ is an independent random variable with Rayleigh distribution and $\theta_{r,m}$ refers to a random variable distributed over [0, 2π]. In practice, the number of rays and clusters are limit to M and R, respectively even if there are infinite numbers of arrived multipath. Meanwhile, a log-normal random variable X is introduced so as to reflect the shadowing,

$$20\log_{10} X \sim Normal(0, \sigma_x^2) \quad (6)$$

Central limit theorem is commonly invoked to profile the signal envelops using Rayleigh distribution when the multipath received is large [8]. Though Saleh-Valenzuela channel model described the indoor propagation characteristic, it has been found later that amplitudes of multipath fading do not follow the Rayleigh distribution. Due to extremely large UWB bandwidth, the received signals are no longer can be quantified as Rayleigh as only few multipath components overlap within the short duration of impulse. Based on intense measurements of indoor environment, [9] report has suggested modifying Saleh-Valenzuela model in such a way that multi cluster and its rays component are subject to independent log-normal distribution rather than Rayleigh distribution. Then, the UWB discrete-time impulse response can be re-written as follows

$$h_i(t) = X_i \sum_{m=0}^{M} \sum_{r=0}^{R} \alpha_{r,m}^{(i)} \delta(t - T_m^{(i)} - \tau_{r,m}^{(i)}) \quad (7)$$

where i represent the i^{th} generated impulse response realization. For simplicity, the index i in this equation will be ignored in the following discussion. Noticed that the channel coefficient, $\alpha_{r,m}$, is given by

$$\alpha_{r,m} = p_{r,m} \xi_m \beta_{r,m} \quad (8)$$

where ξ_m represents the log-normal fading of the m^{th} cluster while $\beta_{r,m}$ reflects the log-normal fading of the r^{th} ray in the m^{th} cluster. $P_{r,m}$ is a binary random integer ±1 to account for signal inversion due to reflection as compared to uniformly distributed phase over [0, 2π] of channel coefficient in Saleh-Valenzuela channel modeling. Since the multiplication result of ξ_m and $\beta_{r,m}$ are also independent log-normal random variable, then the distribution also follows a log-normal distribution, that is

$$20\log_{10}(\xi_m \beta_{r,m}) \sim Normal(\mu_{r,m}, \sigma_1^2 + \sigma_2^2) \quad (9)$$

where σ_1^2 and σ_2^2 are the variance of m^{th} cluster and r^{th} ray respectively. It is known that mean of the channel amplitude for r^{th} ray in the m^{th} cluster is given by

$$\mu_{r,m} = \frac{10\ln(\Omega_0) - 10^{T_m}/\Gamma - 10^{\tau_{r,m}}/\gamma}{\ln(10)} - \frac{(\sigma_1^2 + \sigma_2^2)\ln(10)}{20} \quad (10)$$

where Γ and γ denotes the ray and cluster decay constant respectively. Ω_0 represents the average power, E of the first ray in the first cluster is associated with its average power as follow

$$E\left[|\xi_m \beta_{r,m}|^2\right] = \Omega_0 e^{-T_m/\Gamma} e^{-\tau_{r,m}/\gamma} \quad (11)$$

The UWB channel parameters for four different types of channel models is summarized in I, denoted as CM1, CM2, CM3 and CM4, based on modified Saleh-Valenzuela channel modeling. CM1 and CM2 are based on measurement of line-of-sight (LOS) and Non-LOS environment respectively for distance between 0-4 meters. CM3 is based on measurement for a Non-LOS environment over the distance 4-10 meters while CM4 represent extreme Non-LOS with long delay spread constituted a worst-case environment. These parameters are derived from IEEE SG3a Channel Modeling Sub-Committee report.

TABLE I
UWB CHANNEL MODEL PARAMETERS

Parameter	*CM 1*	*CM 2*	*CM 3*	*CM 4*
Λ (1/ns)	0.0233	0.4	0.0667	0.0667
λ (1/ns)	2.5	0.5	2.1	2.1
Γ (ns)	7.1	5.5	14.0	24.0
γ (ns)	4.3	6.7	7.9	12.0
σ_1 (dB)	3.3941	3.3941	3.3941	3.3941
σ_2 (dB)	3.3941	3.3941	3.3941	3.3941

IV. System Performance of UWB System

UWB system occupies bandwidths of 528 MHz on each sub band are combined with OFDM techniques in which support of Band Group 1 is mandatory. Fig. 5 shows typical multiband OFDM UWB system of transmitter and receiver where the time-frequency kernel is uses to specify the centre frequency for the transmission of each OFDM symbol. A pre-select filter is implemented at the receiver to retrieved single sub-band assuming perfect timing and symbol synchronization. Considered, both phase and frequency offset during the transmission does not occurred, comparative analysis of multiband OFDM system based on the ECMA-368 standard is carried under realistic UWB channel. Four distinctive channels modeling namely CM 1-4, based on modified Saleh-Valenzuela are characterized by cluster arrival rates, ray arrival rate within clusters, cluster decay factors, and ray decay factors as specified in I. The analysis used multipath Rayleigh fading to provide comparison in terms of bit-error rate (BER).

Fig. 5 and 6 shows the performance result of UWB system of un-coded QPSK and coded 1/3 QPSK simulates under Rayleigh and modified Saleh-Valenzuela channel impulse response. It can be seen that the system performance for signal-to-noise ratio exceed 15 dB, CM 1 and CM 2 have shown a similar performance with Raleigh but not to CM 3 and CM 4 in which substantiate the severe condition of multipath effects of 15 ns and 25 ns delay spread respectively [10]. The propagation analyses substantiate comparable performance between Saleh-Valenzuela and Rayleigh channel for both CM1 and CM2. This indicates less number of cluster and smaller ray arrival rate characteristic for these both impulse responses.

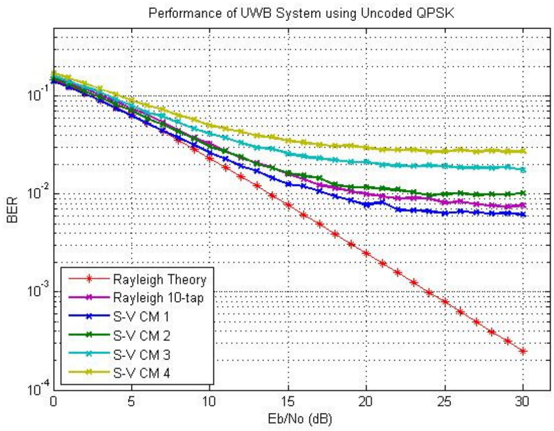


Fig. 6. Error rate of Uncoded QPSK under Rayleigh and UWB Channel

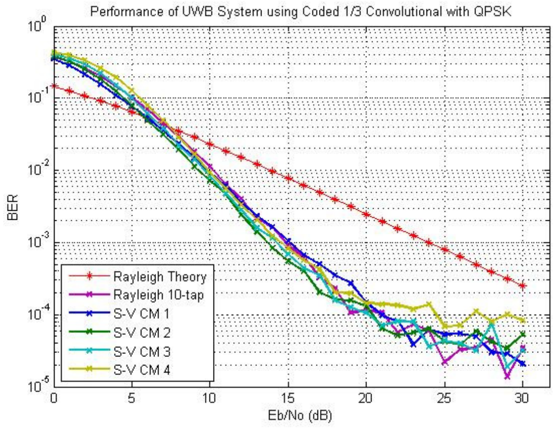
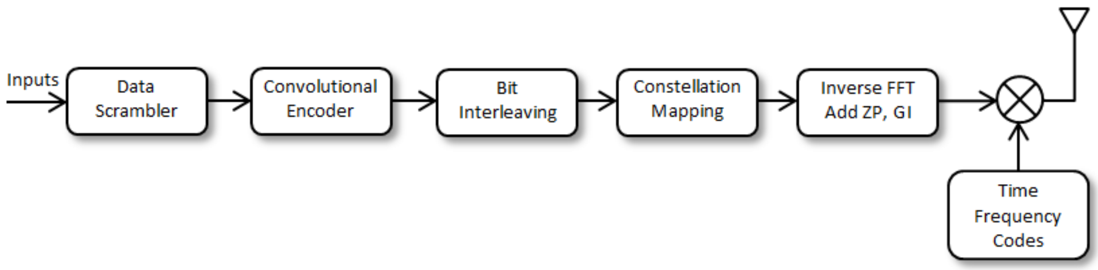
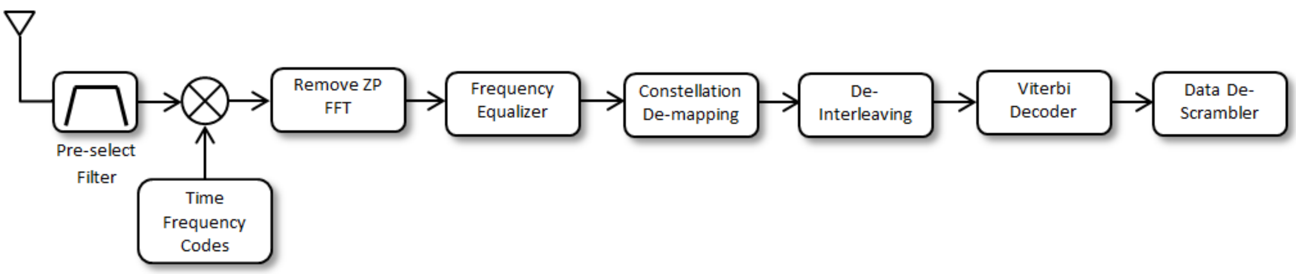


Fig. 7. Error rate of Coded 1/3 QPSK Under Rayleigh and UWB Channel



(a)



(b)

Fig. 5. Multiband OFDM UWB System (a) Transmitter (b) Receiver

V. Conclusion

The Saleh-Valenzuela model has been adapted to the UWB channel modeling by IEEE 802.15.3a standard body describing indoor propagation characteristic. The extremely large bandwidth of UWB serves distinctive indoor channel profile as opposed to conventional wireless environment. Receiving signals are richly multipath due to reflection from nearby objects arrived in cluster and as well as rise to extremely large multipath components, all of which would be part of a cluster. Central limit theorem is commonly invoked and Rayleigh distribution is often used to profile the received signal envelops. However, this is not the case for UWB as the narrow pulse is quite short. The received signals are no longer can be quantified as Rayleigh as only few multipath components overlap within the short duration of impulse. Therefore, log-normal distribution has been derived for UWB system. This paper described the multiband OFDM system performance simulates under UWB channel, based on WiMedia ECMA 368 standard. Future work is considered for simulating much higher bit rate simulation exceeding 1 Gbit/s such as constant envelops modulation, i.e.: MSK and CPM. Current development progress also study on designing low-complexity of receivers for low power and low cost UWB devices.

Acknowledgment

The authors would like to thank Universiti Teknologi MARA and MOHE for supporting this research through grant number 600-RMI/ST/FRGS 5/3/Fst(36/2011) and MOSTI ScienceFund through grant number 06-01-01-SF0391.

References

[1] Revision of Part 15 of the Commission's Rules Regarding Ultra Wideband Transmission System, First Report and Order.

[2] A. Batra et al. "Design of multiband OFDM system for realistic UWB Channel Environments". IEEE Transaction on Microwave Theory and Techniques, vol. 52, pp. 2123-2138, September 2004

[3] H. Viittala, M. Hamalainen, J. Iinatti, "Comparative Studies of MB-OFDM and DS-UWB with Co-Existing Systems in AWGN Channel" in Proc. International Symposium on Personal, Indoor and Mobile Radio Communications, pp. 1-5, September 2006

[4] C. Snow, L, Lampe, R. Schobe, "Performance Analysis of Multiband OFDM for UWB Communication," in Proc. International Conference on Communication, pp. 2573-2578, May 2005

[5] High Rate Ultra Wideband PHY and MAC Standard, 3rd edition ECMA-368, December 2008

[6] H. Q. Lai, W. Siriwongpairat, and K. J. R. Liu, "Performance analysis of MB-OFDM UWB system with imperfect synchronization and intersymbol interference," IEEE Journal on Selected Topic of Signal Processing, vol. 1, pp. 521-534, October 2007

[7] A. Saleh and R. Valenzuela, "A statistical model for indoor multipath propagation," IEEE Journal on Selected Areas Communications, vol. SAC-5, pp. 128–137, February 1987.

[8] A.F. Molisch, J.R. Foerster and M. Pendergrass, "Channel models for ultra wideband personal area networks," IEEE wireless Communication Magazine, vol 10, pp. 14-21, December 2003.

[9] IEEE (2003) 802.15-02/490R-L, "Channel Modelling Sub Committee", Report finals

[10] N.M. Anas, S.K.S. Yusof, R. Mohamad, N.A. Sulaiman, "Analytical Performance of Zero Padded Multibands OFDM under UWB Environments," in Proc. International Conference on Computer Modeling and Simulation, pp. 310-312, April 2011