

Multiband OFDM UWB System Performance under Saleh-Valenzuela Channel

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Abstract— Multiband Orthogonal Frequency Division Multiplexing (OFDM) has been deployed for practical implementation of low cost and low power UWB devices due to its ability to mitigate the narrowband interference and multipath fading effects. This paper review and investigates the performance of multiband OFDM techniques for UWB system under Saleh-Valenzuela channel modelling, proposed in IEEE wireless Personal Area Network (PAN) standard committee. The baseband systems described in this paper is based on ECMA-368 standard simulates under four different type of Saleh-Valenzuela channel model, namely CM 1 until CM 4.

Keywords— Multiband OFDM, UWB, ECMA-368, Saleh-Valenzuela, wireless PAN

I. INTRODUCTION

The term UWB has been first used by U.S. Department of Defence (DoD) in 1989 for their high classified projects such as ground radar communications, positioning systems and altimetry. However in late 1990s, much work in UWB field becomes more commercialized and the development of UWB technology has greatly proliferated. In 1998, a substantial change in the history of UWB when Federal Communications Commission (FCC) in United States has 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 -41.3 dBm/MHz.

UWB co-exist with other existing system such as Global Positioning System (GPS), microwave ovens and IEEE 802.11 series includes out-of-band IEEE 802.11b/g system. Conservative FCC's regulations required a low emitted power over wide spectrum from UWB devices to optimize its used and refrained interference to existing services. FCC defined UWB transmission system in terms of the emitted signal bandwidth is more than 20% of its centre frequency, or more than 500MHz. The long-term vision of this technology is to realize high data-rate over short-range communication replacing cables. Its enable wide variety user devices application includes wireless monitor, highly efficient data transfer in between camcorder and HDTV, wireless printing capability and among others example. UWB devices must not only optimize to provide higher rate data link, but it must be

cost effective, low in power consumption and capable to support multiple data-rates.

The paper is organized with Section II briefed the multiband OFDM architecture and Saleh-Valenzuela channel modelling. Section III described the UWB baseband system implementation and its performance under the UWB channel while Section IV concluded the paper and proposed the future works.

II. SYSTEM MODELLING

Multiband OFDM for UWB system technology has been selected by several industry organizations such as Multiband OFDM Alliance (MBOA), WiMedia, and Wireless USB because of its diverse set of short-range wireless technology. In 2005, European Computer Manufacturers Association (ECMA) released ECMA-368 standard meant for high-rate UWB PHY and MAC implementation based on multiband OFDM. Since then, this technology becomes prominent as compelling solution for replacing cables in wired services for even higher data rate connected wirelessly. In this work, multiband OFDM based on ECMA-368 is referred.

A. Multiband OFDM Architecture

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 Figure 1. The advantage of the multiband approach allows the information to be processed over a much smaller bandwidth [3], 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 [2]. Relationship between the centre 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 centre frequency and the respective sub band number.

$$f_c(n_b) = 2904 + (528 \times n_b), n_b = 1, \dots, 14 \quad (1)$$

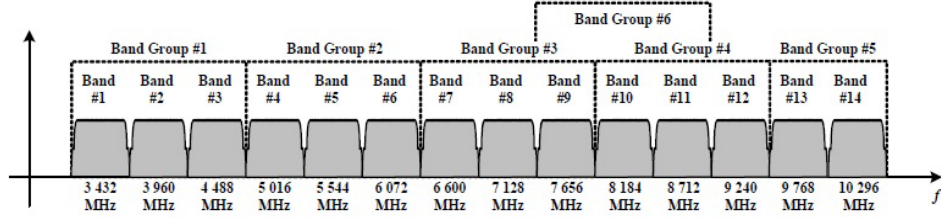


Figure 1. UWB Frequency Band Planning [2]

UWB devices operate in short range communication such as indoor environment are exposed to highly dispersive channels in which a large multipath energy arrives at the receiver. The performance of the UWB system is determined by its robustness to multipath channel environments, ability to handle narrow-band interferers and others UWB interferers. In UWB system, multicarrier system of OFDM is combined with multi-band technique to modulate the information in each sub band to efficiently captured multipath energy at the receiver. The principle is to split a high data-rate stream into a numbers of a parallel lower rate stream transmitted simultaneously.

B. Indoor Channel Modelling: Saleh-Valenzuela

In 2003, Saleh-Valenzuela model has been adopted by IEEE 802.15.3a standard body as the reference to the UWB channel modelling that described indoor propagation environments. 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 ray within a cluster. Different parts of the same object may give rise to extremely large multipath components, all of which would be part of a cluster. The UWB channel described in [4] is given by

$$h_i(t) = X_i \sum_{l=0}^L \sum_{k=0}^K \alpha_{k,l}^i \delta(t - T_l^i - \tau_{k,l}^i) \quad (2)$$

where i refers to the impulse response realization while l and k refer cluster and arrival within the cluster respectively. T_l^i and $\tau_{k,l}^i$ representing the delay of the l^{th} cluster and the delay of the k^{th} multipath component of the l^{th} cluster. $\alpha_{k,l}^i$ are the multipath gain coefficients and X_i is the log-normal shadowing for the i^{th} channel realization. The distribution of cluster arrival time and the ray arrival time are given by

$$p(T_l | T_{l-1}) = \Lambda \exp[\Lambda(T_l - T_{l-1})], l > 0 \quad (3)$$

$$p(\tau_{k,l} | \tau_{(k-1),l}) = \lambda \exp[-\Lambda(\tau_{k,l} - \tau_{(k-1),l})], k > 0 \quad (4)$$

Note that, Λ and λ are the cluster arrival rate and ray arrival rate respectively while the coefficient are defined as below.

$$\alpha_{k,l} = p_{k,l} \xi_l \beta_{k,l} \quad (5)$$

where,

$$20 \log_{10}(\xi_l \beta_{k,l}) \sim \text{Normal}(\mu_{k,l}, \sigma_1^2 + \sigma_2^2), \quad (6)$$

or

$$|\xi_l \beta_{k,l}| = 10^{\frac{(\mu_{k,l} + n_1 + n_2)}{20}} \quad (7)$$

where $n_1 \sim \text{Normal}(0, \sigma_1^2)$ and $n_2 \sim \text{Normal}(0, \sigma_2^2)$ are independent and corresponding to the fading on each cluster and ray, respectively. $p_{k,l}$ is equiprobable ± 1 to account for signal inversion due to reflection as ξ_l referring to the fading associated with the l^{th} cluster and $\beta_{k,l}$ reflects the fading associated with the k^{th} ray of the l^{th} cluster. $\mu_{k,l}$ is given by

$$\mu_{k,l} = \frac{10 \ln(\Omega_0) - 10^{T_l} / \Gamma - 10^{\tau_{k,l}} / \gamma}{\ln(10)} - \frac{(\sigma_1^2 + \sigma_2^2) \ln(10)}{20} \quad (8)$$

Performance of multiband OFDM under UWB channel in this research are analyses using all four types derived in Saleh-Valenzuela channel. CM 1 is based on line of sight (LOS) condition at a distance below 4m. Meanwhile, CM 2 and CM 3 are based on non-LOS conditions up to 4 m and 4 to 10 m respectively. The CM 4 is generated to fit 25 ns delay spread to represent extreme non-LOS multipath channel model. There are 5 important parameters that define this model: cluster arrival rate; Λ , ray arrival rate; λ , cluster decay factor; Γ , ray decay factor; γ and standard log-normal shadowing; σ for each multipath channel. All parameters are considered for channel modelling as formulated in [4]. Table 1 shows the related parameters based on the derivation described earlier.

TABLE 1. PARAMETERS FOR SALEH-VALENZUELA CHANNEL

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
σ (dB)	3.3941	3.3941	3.3941	3.3941

III. PERFORMANCE RESULTS : MULTIBAND OFDM BASEBAND IMPLEMENTATION

UWB system occupies bandwidths of 528 MHz on each sub band are combined with OFDM techniques [5] in which support of Band Group 1 is mandatory. For the sake of simplicity, only three-band multiband OFDM is used throughout this research. Figure 2 shows typical multiband OFDM transmitter and receiver architecture where the time-frequency kernel is used to specify the centre frequency for the transmission of each OFDM symbol. At the receiver, a pre-select filter is implemented correspond to single-band selection with the assumption of perfect time and symbol synchronisation throughout this work. We also consider both phase and frequency offset during the transmission does not occur. Comparative analysis of multiband OFDM loosely based on the ECMA-368 standard proposal carried out under Saleh-Valenzuela channel modelling is describes next.

Forward error correction codes also known as channel coding of convolutional encoder type are used for error controlling in which a redundancy being introduced during the transmission. It is being used in conjunction with frequency or time domain spreading to vary the information data rates support in ECMA standard. The system capable to support data rates of 55, 80, 110, 160, 200, 320 and 480 Mbps, however this work neither implements nor explains the details on spreading techniques. The convolutional encoder employs industrial standard code rate, R of 1/3 with generator polynomial $[133, 145, 175]_8$ where $[\cdot]_8$ refer to octal number representation. Other convolutional code rates of 1/2, 5/8 or 3/4 are supported by puncturing, and again it is beyond the scope of this work. Viterbi algorithm is used at the receiver to decode the code. Figure 4 below depicted the convolutional encoder structure.

The multiband OFDM 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 4.125 MHz. In addition, the 122-subcarriers are modulated using quadrature phase shift keying (QPSK) modulation. The discrete-time signal is created by taking the inverse Discrete Fourier Transform (IDFT) of the low-rate complex stream as follows [2]:

$$s_n[k] = \frac{1}{\sqrt{N_{FFT}}} \left[\sum_{l=0}^{N_D} C_{D,n}[l] e^{\frac{j2\pi M_D[l]k}{N_{FFT}}} + \sum_{l=0}^{N_G} C_{G,n}[l] e^{\frac{j2\pi M_G[l]k}{N_{FFT}}} + \sum_{l=0}^{N_P} C_{P,n}[l] e^{\frac{j2\pi M_P[l]k}{N_{FFT}}} \right] \quad (9)$$

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 [2].

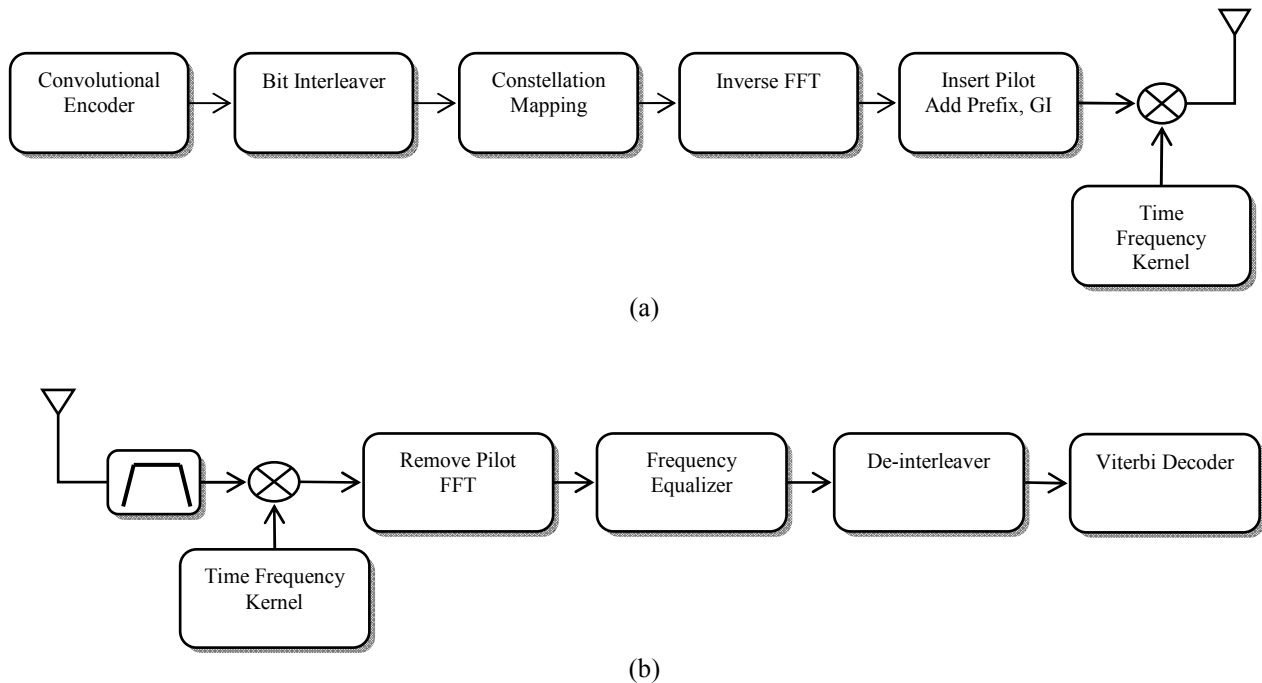


Figure 2. Multiband OFDM System (a) Transmitter (b) Receiver

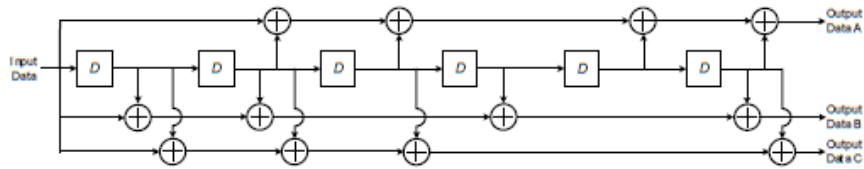


Figure 3. Convolutional Encoder Rate $R = 1/3$, constraint length, $K = 7$ [2]

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 Figure 4. 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.

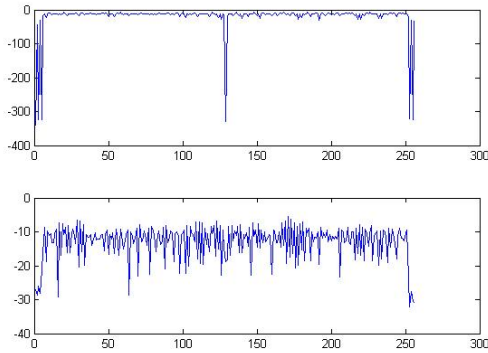


Figure 4. Ripples structure in PSD for (a) ZP and (b) CP

The realistic of the UWB channel is simulated under UWB system with four channel model; CM 1, CM 2, CM 3 and CM 4, which being characterized by cluster arrival rates, ray arrival rate within clusters, cluster decay factors and ray decay factors. Typically, the UWB channel fading is lognormal distribution is less severe than the Rayleigh fading [9], the analysis used multipath Rayleigh fading as the assumption to provide the upper bond performance benchmark on the bit-error rate (BER). In this work, all approaches of perfect frequency and timing synchronization are assumed to be perfect.

Figure 5 shows the performance result of UWB baseband system using uncoded QPSK modulates under Rayleigh and 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 [7]. Result also shown that zero padded suffixes could not resolve the multipath effect

efficiently at signal-to-noise ratio greater than 20 dB. Error rate tend to saturate at this point as the circular convolution property does not retained as opposed to cyclic prefix approach. This can be solve using a techniques called overlap-add (OLA) method.

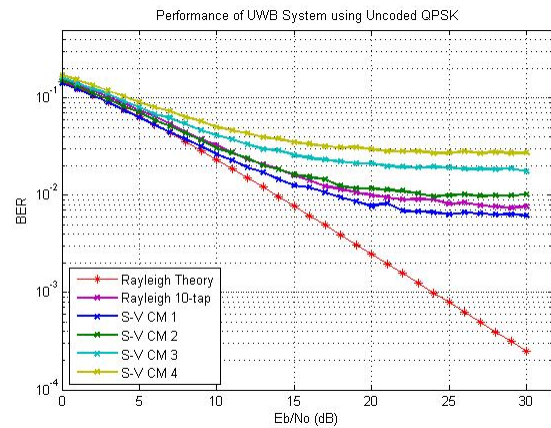


Figure 5. Bit error rate of Uncoded QPSK

Figure 6 shows the performance when cyclic prefix is used. In contrast with earlier discussion, error floor does not occurred in which both Rayleigh and Saleh-Valenzuela channel modelling behaved most likely are the same for a considerable signal power exceed 25 dB. This trend follows when a convolutional code rate of 1/3 is used in conjunction of multiband OFDM techniques. Literally, we can achieve error rate of 10^{-3} at signal power of 12-14 dB for all Saleh-Valenzuela channel cases as shown in Figure 7.

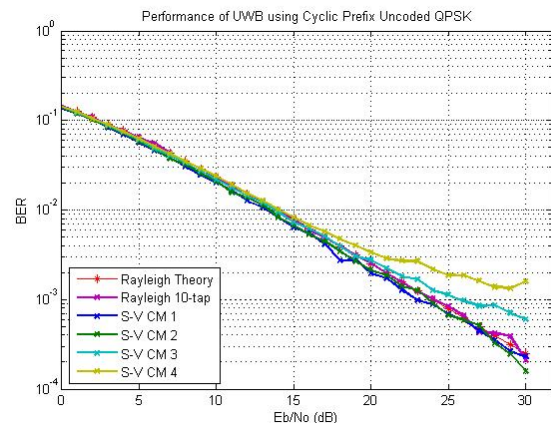


Figure 6. Bit error rate of Uncoded QPSK using cyclic prefix

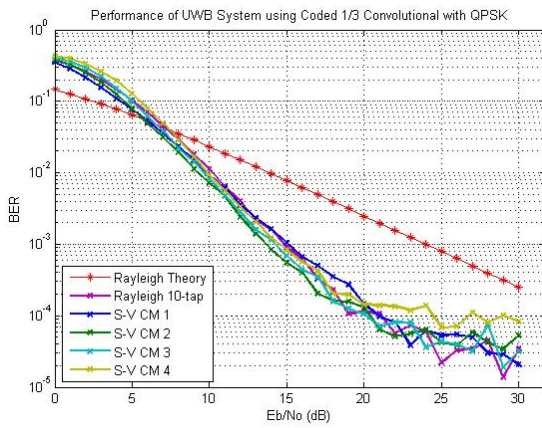


Figure 7. Bit error rate of Coded QPSK

IV. CONCLUSION

Based on the proposed channel modelling in IEEE 802.15.3a standard body, the Saleh-Valenzuela propagation analysis has been observed using four different types of channel models. Result shows that the zero padded suffixes could not resolved multipath effects efficiently in which the error rate saturated at energy per bit-to-noise ratio above 15dB. 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.

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REFERENCES

- [1] Revision of Part 15 of the Commission's Rules Regarding Ultra Wideband Transmission System, First Report and Order.
- [2] *High Rate Ultra Wideband PHY and MAC Standard*, 2nd edition ECMA-368, Dec. 2007
- [3] 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, Sep. 2004
- [4] 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, Dec. 2003.
- [5] 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, Oct. 2007
- [6] C. Snow, L. Lampe, R. Schober, "Performance Analysis of Multiband OFDM for UWB Communication," in *Proc. International Conference on Communication '05*, pp. 2573-2578, May 2005
- [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, Feb. 1987.
- [8] H. Nikookar and R. Prasad, *Introduction to Ultra Wideband for Wireless Communication*, 1st ed. Springer 2008.
- [9] N. M. Anas et. al. "Analytical Performance of Zero Padded Multibands OFDM under UWB Environments," in *Proc. International Conference on Computer Modeling and Simulation '11*, pp. 310-312, April 2011