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Spectral Efficiency Performance Analysis of Multi-Band Orthogonal Frequency Division Multiplexing Physical Layer using Channel Division Multiple Access under Ultra Wide BandChannel

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ABSTRACT

This contribution presents an investigation into methods for maximizing the spectral efficiency of Multi Band Orthogonal Frequency Division Multiplexing (MBOFDM) system. As part of this an asymptotic analysis of a new waveform based on the integration of Channel Division multiple access technique (ChDMA) in Multi-Band OFDM system over Ultra Wide Band high data rate channel is presented. This system allows to combat frequency selectivity and to solve problems related to the coexistence of many users. In order to serve multiple users simultaneously, this new multiple access system brings an interesting degree of freedom as it is based on the use of the Channel Impulse Responses (CIR) as user signatures. We will discuss the benefits of the multiple access scheme performance, and then we evaluate the spectral efficiency when the number of frequency dimensions and the number of users increases at a constant ratio. Also, we present an analysis of the impact of the power delay profile (PDP) on the spectral efficiency of MBOFDM-ChDMA-UWB system assuming a correlation between the delay and the energy of the paths. As a result we observe that the spectral efficiency performance depends on the system load, the power delay profile and the noise variance.

Keywords: *MBOFDM, ChDMA, UWB, spectral efficiency,PDP*.

1. INTRODUCTION

Since the FCC (Federal Communications Commission) approved the deployment of UWB on an unlicensed basis in the 3.1–10.6 GHz band in 2002, it has been attracting considerable attention from both the academic and industrial researchers [1]. Besides, the indoor channel model considered bythe Institute of Electrical and Electronics Engineers (IEEE) 802.15.3a standardization group for WPAN application is presented in this work. The standardizations activity of wireless personal area networks (WPANs) takes place in the IEEE international standards working group 802.15. In late 2001, the IEEE established the 802.15.3a study group to define a new physical layer concept for short range high data rate WPAN applications. This was to serve the requirements of companies wishing to deploy very high data rate applications, such as video transmission, with data rates greater than 110 (Mb/s) at adistance of 10 m. The technical requirements, including high data rate, short range, system scalability, low cost and low power, led to the adoption of UWB technology by the standardization group [2].There have been a lot of research and studies on the resource allocation and capacity analysis in UWB system based on the WiMedia solution. However, to this date, most studieson multiband UWB systems have been devoted to the physical layer issues. The aim of this paper is to present a new multiple access scheme based in the CIR of each user which is considered as a modulation. In 2006, the authors propose a multiple access technique called Channel Division Multiple Access technique [3, 4].The goal of ChDMA is to enhance the spectral efficiency of the MBOFDM system without requiring any change of the actual licensed system. ChDMA waspresented to guarantee efficient multiuser communication. Each user modulates its signal with its own impulse response. The remainder of this paper is organized asfollows. In section II, we briefly describe the MBOFDM system in which may be used in high datarate networks especially 802.15.3a channel. Then, we present and discuss the concept of ChDMA as an efficient multiple access technique behind MBOFDM in UWB high data rate channel. We observe that ChDMA is a good choice as it simplifies the transmitter complexity and exploits the natural diversity of the wireless channel to provide multi-user communication. In Section III, we investigate the asymptotic spectral efficiency of ChDMA-MBOFDM-UWB system in the case of an optimal receiver. Then, section IV is dedicated to a discussion about the performance analysis of the new waveform. In Section V, we detail the impact of the power delay profile on the spectral efficiency of the system. In Section VI, we present the obtained results. Finally, sectionVIII investigates the contribution of ChDMA in MBOFDM UWB channel with some perspectives proposal.

2. IMPLEMENTATION OF THE MB-OFDM UWBSYSTEM

2.1.Multiband OFDM solution

The MB-OFDM approach is the primary candidate for high data rate UWB applications. The WiMedia solution consists in combining OFDM with a multi-banding technique that divides the available band into 14 sub-bands of 528 MHz, as illustrated in Figure 1. An OFDM signal can be transmitted on each sub-band using a 128point Inverse Fast FourierTransform (IFFT). Out of the 128 subcarriers used, only 100 are assigned to transmit data. Different data rates from 53.3to 480 Mbit/s are obtained through the use of forward error correction (FEC) [5].

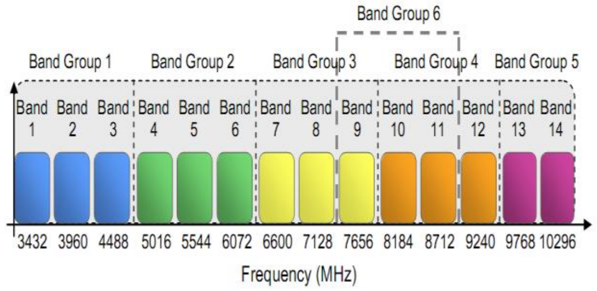

Figure 1. UWB spectrum bands in the MB-OFDM system [2]

The architecture of the MB-OFDM transmitter is describedin Figure .2 [6].

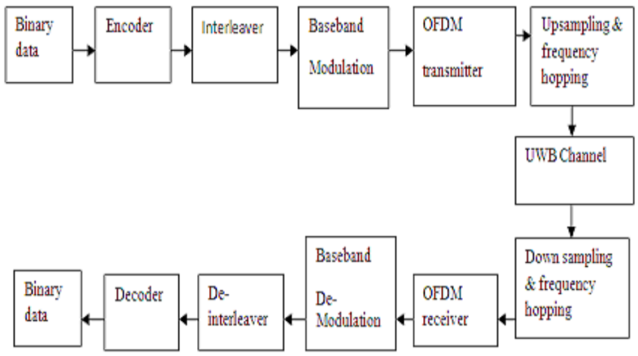

Figure 2. MB-OFDM system [6]

Transmitted data rates in each sub-band depend on the coding rate.The modulation type applied to the different subcarriers of the OFDM multiplex is a quadrature phase-shift keying (QPSK). The main parameters of the MB-OFDM UWB system are listed in Table 1.

TABLE 1. MBOA DATA RATES [7]

Data rate	Modulation	Coding Rate (R)	Conjugate Symmetric	Time Spreading Factor	Coded bits
53.3	QPSK	1/3	Yes	2	100
80	QPSK	1/2	Yes	2	100
110	QPSK	11/32	No	2	200
160	QPSK	1/2	No	2	200
200	QPSK	5/8	No	2	200
320	QPSK	1/2	No	1	200
400	QPSK	5/8	No	1	200
480	QPSK	3/4	No	1	200

2.2.IEEE 802.15.3a channel modeling

The evaluation of UWB physical layer adopted by the IEEE 802.15.3a channel results from Saleh-Valenzuela model for indoor application. This ray defined model takes into account clusters phenomena highlighted during channelsmeasurements. Mathematically, the impulse response of the multipath model is given by [8, 17]:

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

With:

- $\alpha_{k,l}^{i}$ is the multipath gain coefficient related to the l thcluster within the multipath k over the realization i.
- T_l^i refers to the delay of the lthcluster.
- X_i is the log-normal shadowing.
- $\tau_{k,l}^i$ represents the delay of the kth multipathcomponent relative to the lthcluster arrival time.

The authors in [8] describe thecluster's distributions of arrival time and the ray arrival time as:

$$P(T_l/T_{l-1}) = \Lambda \exp[-\Lambda (T_l - T_{l-1})], \quad l>0$$
$$P(\tau_{k,l}|\tau_{(k-1),l}) = \lambda \exp[-\lambda (\tau_{k,l} - \tau_{(k-1),l})], \; k>0.$$

Where: Λ represents cluster arrival rate and λ is the ray arrival rate. Table 2, provides the mean excess delay τ_m, and the root mean square delay spread, τ_{rms}, for the 4 channel models CMi (i = {1,…,4}).

TABLE 2. CHARACTERISTICS OF WIDEBAND CHANNELS CMI [9]

Characteristics	CM1	CM2	CM3	CM4
Mean excess delay (ns) : τ_m	5,05	10,38	14,18	
Root mean square delay spread: τ_{rms}	5,28	8,03	14,28	25
Distance (m)	<4	<4	4 - 10	10
LOS/NLOS	LOS	NLOS	NLOS	NLOS

3. PROPOSED SYSTEM DESCRIPTION

3.1. Studied system

The proposed system basically consists in an evolution of the MBOA system which is depicted in Figure 2. Channel division multiple access (ChDMA) simplifies the transmitter while allowing simultaneous access. It provides a solution to multiuser access in low duty cycle systems. All the presented results are performed under the assumption of ideal channel knowledge (CSI) in the reception, which allows the receiver to detect and demodulate the signals by assimilating the channel as a code. Consequently, the channels work as codes that can be exploited at the receiver to separate the signals transmitted by different users. Since the users have different locations, each transmitted signal is affected by other channel, the signaling scheme provides enough diversity to separate the information sent by different users [10].The concept of ChDMA is presented in Figure 3 [3].

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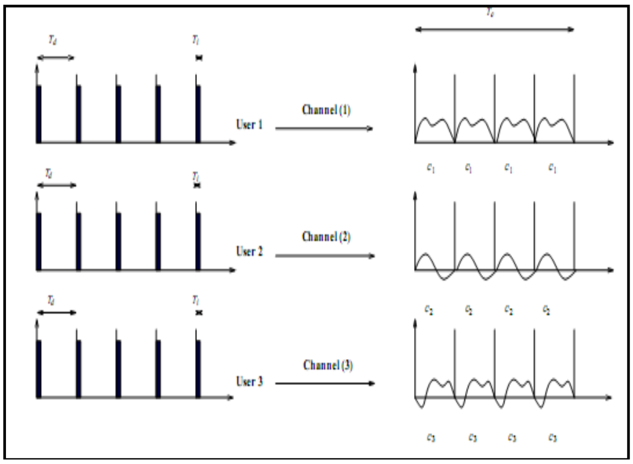

Figure 3. Channel Division Multiple Access signaling.

3.2. Proposed System principal

We consider an uplink MBOFDM-ChDMA-UWB system with k users that access simultaneously and synchronously. As the transmitted signal is distorted by the channel and the distortion can be considered as a modulation, the receiver is able to detect each waveform using the CIR related to each user.

Additionally, ChDMA is a technique where the channel is fundamental on its performance. As a result, we offer to rewrite the expression for the channel impulse response for CM1 like the author in [11]:

$$h(t)=\alpha_{o,o}\boldsymbol{\delta}(t)+\sum_{k=1}^{K}\alpha_{k,0}\ \delta(t-\tau_{k,0})+\sum_{l=1}^{L}\alpha_{0,l}\,\delta(t-T_l) +\sum_{l=1}^{L}\sum_{k=1}^{K}\alpha_{k,l}\,\delta(t-T_l\text{-}\tau_{k,l}).(2)$$

The channel impulse response for CM2, CM3, and CM4 takes the same form of (2) without the first two terms because these channel models do not inherit the LOS. Then, the received signal is given by:

$$y = Hx+n. \qquad (3)$$

Where y is the N dimensional vector with x is the transmitted symbols. The noise vector n is assumed to be zero mean circularly symmetric complex Gaussian (ZMCSCG) to have a distribution $\mathcal{N} \sim (0,\sigma_n^2)$; $H =[H_0,\ldots\ldots\ldots\ldots,H_{K-1}]^T$ is (N*K) channel matrix ,where each channel coefficient is given by:

$$H_k = \sum_{l=0}^{L-1} h_l\, e^{-j2\pi kl/N}.$$

3.3. Spectral efficiency analysis

The system spectral efficiency is typically measured in (bit/s/Hz). It is a measure of the quantity of users or amount of information that can be simultaneously supported by a limited radio frequency bandwidth in a defined system. It may for example be defined as the maximum throughput summed over all users in the system, divided by the channel bandwidth. It isessentially used to compare the performance of different systems.

3.4.Optimal Receiver

The optimal receiver is defined as the receiver that minimizes the probability of symbol error among all receiver structures. It is based on the analysis of the posteriorprobabilities of the transmitted signal [12]. The spectral efficiency is defined as:

$$\gamma = (1/N)^* \log_2\det(I_N + (1/\sigma^2)\, HH^H) \qquad (4)$$

Where: σ^2 is the noise variance and N the channel vector length. Equation (4) can also be represented like the author in [10]:

$$\gamma= (1/N)^*\log_2\det(I_N + \rho\, HH^H). \qquad (5)$$

Where ρ is defined in [10] by:

$$\rho = \frac{\gamma}{\beta}\frac{E_b}{No} \text{with } \beta= (K/N).$$

3.5.Spectral efficiency behavior in the asymptotic regime:

In this section we study the spectral efficiency behavior in the asymptotic regime, when the system is large. In fact, the asymptotic analysis allows providing a good understanding of the ChDMA limiting behavior in MBOFDM-UWB channel.

The author in [10] allows us to write the spectral efficiency represented in (4) in terms of the eigenvalues $(\lambda_1\ldots\ldots\lambda_m)$ of HH^H like:

$$\gamma= (1/N)^*\sum_i^N \log(1 + \rho\lambda_i\ (HH^H)).(6)$$

Following, the author in [13], in asymptotic regime, when N→+∞, the spectral efficiency can be represented in terms of the eigenvalue distribution of HH^H yields to obtain:

$$\gamma_\infty = \int \log(1 +\rho\,\lambda)\, df_{HH}{}^{H}\ . \qquad (7)$$

We conclude that the spectral efficiency is deterministic and only depends on a few macroscopic system parameters in asymptotic regime.

4. PERFORMANCE EVALUATION

The purpose of this section is to validate numerically the precedent assumptions to derive the asymptotic results and to compare the resulting spectral efficiency with known results in the literature. Figure 4 compares the spectral efficiency as a function of the signal to noise ratio, in case of finite simulated channels considering an optimal receiver in detection, with the asymptotic theoretical spectral efficiency of ChDMA MBOFDM UWB system.

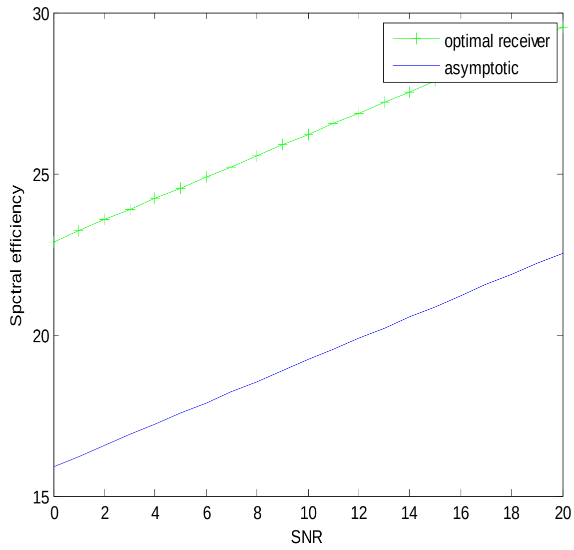

Figure 4. Comparison between optimal and asymptotic spectral efficiency

We evaluated expressions (4) and (7) via Monte Carlo simulation using 1000 realizations of each UWB channel model CM1. We consider the case of perfect CSI in the receiver with the main OFDM parameters of the MBOFDM solution are summarized in Table 3[9].

TABLE 3. Main MBOFDM solutionparameter

Parameter	Value
IFFT/FFT size	128
Sampling frequency	528 MHz
Transmission bandwidth	507,37 MHz
Number of data subcarriers	100
Number of pilot subcarriers	12
Number of guard subcarriers	10
N_{ST} : Total number of used subcarriers	122
Δ_F : Sub-carrier frequency spacing	4,125 MHz (=528MHz/128)
T_{FFT} : IFFT/FFT period	242,42 ns ($1/\Delta_F$)
T_{CP} : Zero Paddind prefix duration	60,61 ns
T_{GI} : Zero Paddind guard interval duration	9,47 ns
T_{SYM} : Symbol interval	312,5 ns ($T_{FFT}+T_{CP}+T_{GI}$)

The obtained results show the difference betweenasymptotic and theoretical spectral efficiency of MBOFDM-ChDMA-UWB channel. It can be observed that at the receiver, as the signal-to-noise ratio increases, the spectral efficiency increases as well. We conclude that as the number of dimensions increase, the spectral efficiency of the system decrease relatively to the curve of the optimal receiver. Such aresult justifies the increasing interest behind using optimal receiver in WiMedia communication and shows the betterchoice of the channel. We have shown that under the asymptotic case assumption, the spectral efficiency becomes deterministic, which means that it is independent of thedifferent channel realizations.

5. POWER DELAY PROFILE

5.1.System model

If we use the Theorem (4.1) related to (SVD Decomposition) from [10], it allows to consider (N× K)matrix H. Then, there exists a factorization of the form

$$H = UDV^H$$

Where U is a (N ×N) unitary matrix, D is a (N ×K) diagonal matrix, and V is a (K × K) unitary matrix. Such a factorization is called singular value decomposition, being the nonnegative elements on the diagonal of matrix D the singular values of matrix H. Following this theorem, the relation (4) can be written as:

$$\gamma = (1/N)*\log_2 \det(I_N + \rho\, DV^H D^H V) \qquad (8)$$

5.2.Case of study

We propose throughout this section to discuss the impact of the power delay profile, for this reason we consider case 2 proposed by the author in [14].

Based on the assumption that elements characterizing each cluster are mutually dependent but statisticallyindependent of elements of any other cluster, the amplitude X and $\lambda_{k,l}$are joint dependent random variables. Also, the joint distribution allows to take into account the power delay profile under the assumption that random variable X depend of the delays $\lambda_{k,l}$. If we consider a frequency domain channel coefficient H_i, the probability density function (PDF) is $P(h_i)$.The h_i coefficient are zero mean random variable which is circularly symmetric complex Gaussian distributed.

To characterize the matrix channel H, we discuss the covariance matrix covariance R defined by:

$$R = E\{h_k h_k^H\}$$

Following the Toeplitz structure of the matrix R described in [15], the Eigen decomposition holds when $N \to \infty$:

$$R_\infty = \lim_{N\to\infty} F_N^H\, D\, F_N$$

Where F_N the Fourier matrix and D is a diagonal matrix where the elements are defined by the author in [14] by:

$$\begin{cases} (PDP*L)/(W_c * T_l)\ ;\ (NW_cT_l)*(l-1)/L \le n-1 \le (NW_cT_l)*l/L & (9) \\ D_{n,n}=0 \quad \text{otherwise} \end{cases}$$

Where PDP refers to power delay profile related to the number of the multipath channel, W_c represents the frequency resolution, T_l is the arrival time of the first path of the lth cluster and L is the number of multipath.

5.3.Power delay profile analysis

The (averaged) PDP represents the exponential decay of each cluster; also it reflects the decay of the total cluster power with the delay. The detailed definition is given following the author in [8]:

$E[\,|\xi_l\,\beta_{k,l}|^2] = \Omega_0 e^{\frac{-T_l}{\Gamma}} e^{\frac{-\tau_{k,l}}{\gamma}}$ (10)

With Ω_0 represents the average energy of the first path of the first cluster, Γ and γ are, respectively, defined as constants that characterize the exponential decay of each cluster and each ray. The graphical representation of the power delay profile is represented by Figure 5 [16], which shows arrival time of the different contribution versus received power.

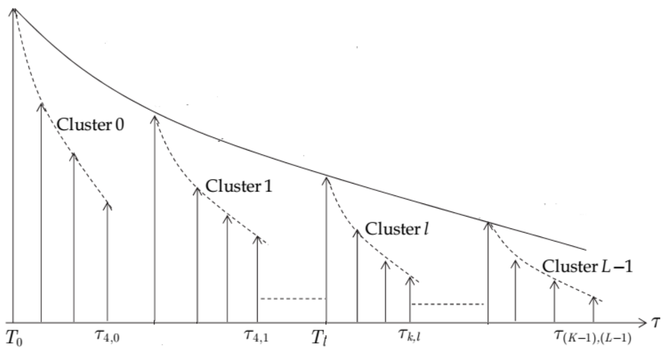

Figure 5. Typical PDP for SV channel model.

6. RESULTS

In this section, we present the results obtained based on therandom generation of the channel by employing the diagonal matrix D. In fact, if we refer to (9) and replace PDP with his previous expression in (10), we can present the results of spectral efficiency obtained byemploying the matrix D.We assume, respectively, the number of frequency samples N, the frequency resolution Wc, the number of multipath L, 128, 40 MHz and 100.

Figure 6 presents the impact of PDP on the spectral efficiency. As the SNR increase, the spectral efficiency of the simulated channel increase and this depend intimately on the system parameters. The obtained result shows that the energy is equally spread over all the bandwidth. In this respect,PDP has been shown to be a useful measure, and we have employed it to identify the optimum number of parameters to represent the performance. This increase of spectral efficiency is also due to the attractive choice of OFDM for UWB communication because it can capture the multipath energy efficiently.

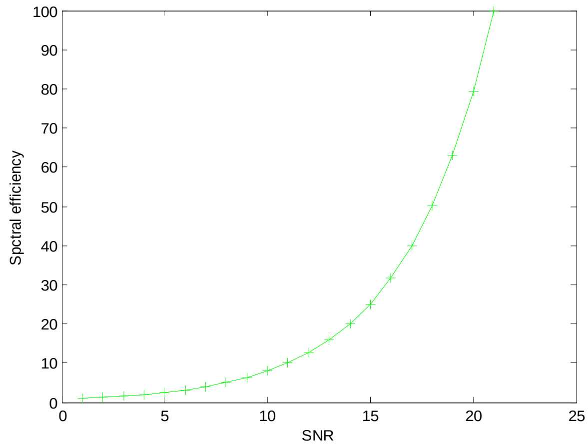

Figure6. Impact of the power delay profile

The obtained result shows that the clusters are disjoint because we have an increase of spectral efficiency. However, we can find generally some overlap between the lth and (l + 1)th clusters.

7. CONCLUSION

The ChDMA technique has been proposedas an effective solution for providingmultiple accesses and allowing simultaneous access in MBOFDM channel over the ultra-widebandspectrum in short range wireless links. Themost important idea behind using ChDMA solution is to exploit the channel diversity as codes are naturally generated. Although, the existence of other multiple access schemes, they would present very low spectral efficiencies for this reason we have had the idea to use the natural channel dispersion as code signatures to perform the multiple access. Furthermore, the performance of the scheme is directly related to the kind of receiver that is employed. Some analytic expressions of the spectral efficiency were derived based on results of random matrix theory. We validated the asymptotic equations via simulation results. As the idea of the ChDMA feasibility seems interesting, some aspects on the performance of such a system require further analysis, we have been shown inthis paper the impact of the power delayprofile in the spectral efficiency. Further research topic need to be considered like the impact of channel estimation on the spectral efficiency of the multiple access system.

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