Investigation of the Performance of the Wavelet Packet Based Multi-Carrier CDMA Communications in Rayleigh Fading Channel

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ABSTRACT

In this paper, an investigation of the performance of the wavelet transform and wavelet packet based multi-carrier CDMA communications in Rayleigh fading channel is presented for different wavelet families. Replacing the Fourier based complex exponential carriers of MC-CDMA with orthonormal wavelets packets in the application of discrete wavelet packet transform (DWPT) based MC-CDMA is an efficient method to avoid adding the guard band or cyclic prefix and to improve the performance of the system. The bit error rate performance of the wavelet transform and wavelet packet based multi-carrier CDMA Communications in Rayleigh fading channel and additive white Gaussian noise (AWGN) Channels are compared with each other. Also, the results are compared with the performance of FFT based MC-CDMA in Rayleigh fading channel. Wavelet packet multicarrier modulation performs well for the fading channel than conventional MC-CDMA.

Key Words: MC-CDMA, DWPT, DWT, Fading Channels.

1. Introduction

Code Division Multiple Access (CDMA) is a multiplexing technique [1], where a number of users simultaneously and asynchronously access a channel by modulating and spread their information-bearing signals with pre-assigned signature sequences, it has been considered to be a candidate to support multimedia services in mobile radio communications, because it has its own capabilities to cope with asynchronous nature of multimedia data traffic, to provide higher capacity over conventional access techniques such as time-division multiple access (TDMA) and frequency-division multiple access (FDMA), and to combat the hostile channel frequency selectivity. On the other hand, the multicarrier modulation scheme, often called orthogonal frequency-division multiplexing (OFDM), has drawn a lot of attention in the field of radio communications. This is mainly because of the need to transmit high data rate in a mobile environment which makes a highly hostile radio channel.

OFDM systems have advantages such as robustness against multipath and impulse noise. However, the problem of frequency offset [2], [3] is considered one of the main drawbacks of MC-CDMA systems, resulting from Doppler's shift which introduced signal distortion and power loss. Multicarrier CDMA schemes are categorized mainly into two groups. One spreads the original data stream using a given spreading code, and then modulates a different subcarrier with each chip (in a sense, the spreading operation in the frequency domain) (e.g. MC-CDMA), and other spreads the serial-to-parallel (S/P) converted data streams using a given spreading code, and then modulates a different subcarrier with each of the data stream (the spreading operation in the time domain), similar to a normal DS-CDMA scheme[4],[5].

Due to the relationship between circular and linear convolutions in discrete Fourier transform (DFT), multicarrier is one of the modulation techniques which can to cope frequency selective fading for its advantage in frequency diversity, MC-CDMA with its frequency diversity is an attractive modulation scheme for multi-user high data rate wireless communication system. In OFDM and MC-CDMA communications, sub-channel decomposition cannot be achieved without adding guard band or cyclic prefix, where a copy of the end part of the data symbol block is transmitted. This method needs transmitting extra guard interval signals that introduces overhead and thus leads to spectral inefficiency and performance degradation. Replacing the Fourier based complex exponential carriers of MC-CDMA with orthonormal wavelets packets in the application of discrete wavelet packet transform (DWPT) based MC-CDMA is an efficient method to avoid adding the guard band or cyclic prefix and to improve the performance of the system.

In this paper, the performance analysis of wavelet packet modulation (WPM) based MC-CDMA in the Rayleigh fading channel is presented and compared with the same model in the AWGN channel.

2. MC-DS-CDMA

The MC-DS-CDMA transmitter spreads the original data stream over different sub-carriers using a given spreading code in the time domain. Input serial data stream ***d*** is divided to parallel blocks, which length equals number of sub-carriers N_c. In each sub-carrier DS-CDMA is applied with the user specific spreading code $\mathbf{c_k}$ with spreading factor (*SF),* which hasn't to be equal to number of sub-carriers (*Nc*). A matrix $\mathbf{S}_{\boldsymbol{k}}$ is formed as

$$\mathbf{S}_{\boldsymbol{k}}=\mathbf{d}_{\boldsymbol{k}}\mathbf{c}_{\boldsymbol{k}}\,, \quad (1)$$

where $\mathbf{d}_{\boldsymbol{k}}$ is column vector with length N_c and $\mathbf{C}_{\boldsymbol{k}}$ is row vector with length *SF*.

Each column vector from the matrix $\mathbf{S}_{\boldsymbol{k}}$ is fed to IDFT.

MC-DS-CDMA receiver comprises inverse OFDM (with DFT) and single-user or multi-user detector [5].

3. MC-CDMA Modulation

The MC-CDMA transmitter spreads the original data stream over different subcarriers using a given spreading code in the frequency domain [6]. In other words, a fraction of the symbol corresponding to a chip of the spreading code is transmitted through a different subcarrier. In a downlink mobile radio communication channel, we can use the Hadamard Walsh codes as an optimum orthogonal set, because we do not have to pay attention to the auto-correlation characteristic of the spreading codes. MC-CDMA employs DFT to divide the bandwidth into orthogonal and overlapping subcarriers. The n^{th} data symbol for user k, $b_k(n)$ is spread by user corresponding spreading code vector C_k each of the N sub-carriers is modulated by a single chip. All the modulated sub-carriers are added to form the base band signal as:

$$s_k(t) = \sum_{m=0}^{N-1} d_k(n) c_k(m) \exp(j\omega_m t)$$
$$(n-1)T_c \le t \le nT_c \quad (2)$$

The chip duration equals to the symbol duration, Where $T_c = T_s$. The combined signal for all k users, in the synchronized downlink direction is:

$$s_k(t) = \sum_{k-1}^{k} \sum_{m=0}^{N-1} d_k(n) c_k(m) \exp(j\omega_m t)$$
$$(n-1)T_c \le t \le nT_c \quad (3)$$

MC-CDMA based on wavelet packet modulation (WPM) can be designed to achieve both frequency and time domain diversity, thus reduce the distortion in the reconstructed signal while retaining all the significant features present in the signal and the performance of communication systems can be improved.

4. Wavelet packet waveform [9,10]

The data stream is firstly spread by spreading code, and then the same chip modulates each wavelet packet waveform at the same time, wavelet analysis is simply the process of decomposing a signal into shifted and scaled versions of a particular wavelet. An important property of wavelet analysis is the perfect reconstruction, which is the process of rebuilding a decomposed signal into its original transmitted form without deterioration. The discrete wavelet packet decomposition is computed by successive low pass and high pass filtering of the discrete time domain signal as shown in fig. 1 . It is called the mallat-tree decomposition. Its significance is in the manner it connects the continuous-time multi-resolution to discrete time filters. $X(n)$ is the input signal, where n is integer. The low pass filter and high pass filter are denoted by G_0 and H_0 respectively.

When discrete wavelet transform is used [7] at each level, the high pass filter produces detail information, while the low pass filter associated with scaling function produces coarse approximation. At each decomposition level, the half band filters produce signals spanning only half the frequency band. This doubles the frequency resolution as the uncertainty in frequency is reduced by half. The decimation by 2 halves the time resolution as the entire signal is now represented by only half the number of samples. Thus, while the half band low pass filtering removes half of the frequencies and thus halves the resolution, the decimation by 2 doubles the scale. The filtering and decimation process is continued until the desired level is reached. In case of discrete wavelet packet transform (DWPT), at each decomposition level the whole band filters produces signals spanning the entire frequency band.

The DWPT of the original signal is then obtained by concatenating all the coefficients, starting from the last level of decomposition. Therefore, by carefully collecting preferred nodes and putting them together, we can obtain a series of orthogonal "wavelet-packet" carriers, so that those multiband wavelet packet subcarriers can offer us desirable frequency diversity mechanism to mitigate multi path fading and minimize multiple access interference and intersymbol interference. The wavelet Packet reconstruction tree is shown in fig. 2.

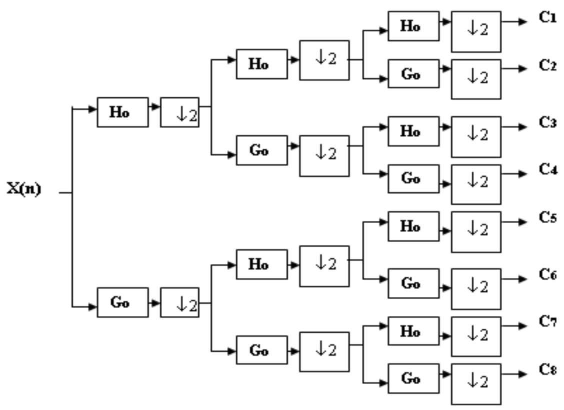


Figure 1: Three levels of wavelet Packet decomposition tree.

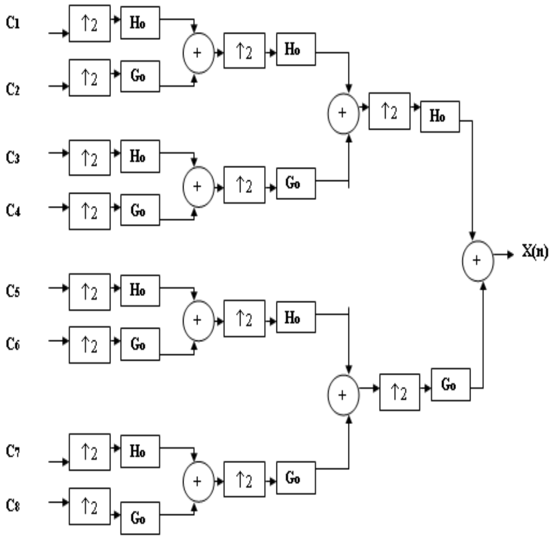


Figure 2: Three levels of wavelet Packet reconstruction tree.

5. Rayleigh fading distribution

In mobile radio channels, the Rayleigh distribution is commonly used to describe the statistical time varying nature of the received envelope of a flat fading signal, or the envelope of an individual multipath component. It is well known that the envelope of the sum of two quadrature Gaussian noise signals obeys a Rayleigh distribution. The Rayleigh distribution has a probability density function (pdf) given by

$$p(r) = \frac{r}{\sigma^2} e^{-\frac{r^2}{2\sigma^2}}, \qquad r \geq 0 \tag{4}$$

6. Wavelet Packet Based MC-CDMA Modulation Technique [8]

The conventional DFT-MC-CDMA is a very low cost and complexity. Due to the convolution property of the DFT, the effect of the multipath channel is converted into a single complex channel coefficient in each sub-carrier. Therefore simpler frequency combining methods can be used to replace usually computationally complex time domain equalization algorithms. Although the use of cyclic prefix (CP) in Guard interval is an easy method to mitigate ISI, it leads to spectral inefficiency as well as loss of data throughput. This leads us to the introduction of other multi-carrier modulation techniques such as filtered multitone (FMT) that do not need the use of the CP. Wavelet based DMT is a form of filtered multitone modulation [6] [7]. Hybrid multi-carrier CDMA techniques try to combine CDMA and OFDM in order to reap the benefits of both techniques. As wavelets promise to provide better time and frequency localization, thus eliminating the need to append CP, we suggest the use of wavelet packet based MC-CDMA, the transmitter is shown in fig.3

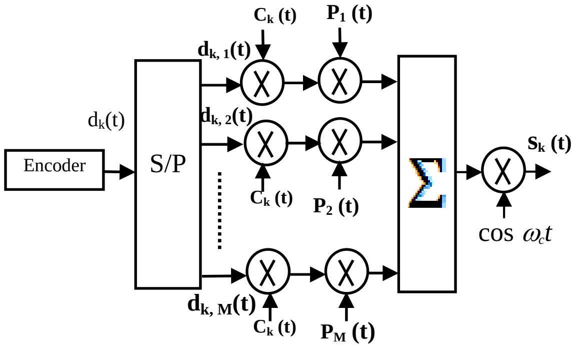


Figure 3: Transmitter Model.

The coded bit stream d_k (t) of user ***k*** is serial to parallel converted into ***M*** parallel branches called sub-channels and spread by PN code $c_k(t)$ with chip interval T_c. The resultant chip sequences are then used to modulate ***M*** wavelet packet functions *pi (t),* ***i=l,*** ..., *M*. Let *R* be the information rate and $\boldsymbol{R_C}$ be the error control code rate, then the symbol interval on each sub channel is $\boldsymbol{T=R_C/R}$.
Assuming BPSK modulation, the transmitted signal of user *k* is

$$s_k(t) = \sum_{m=1}^{N-1} \sqrt{2E_c}\, d_{k,m}(t) c_k(t) P_m(t) \cos(\omega_c t) \tag{5}$$

Where E_c is the energy of the transmitted signal over a chip, $d_{k,m}(t)$ represents the coded data bits on sub-channel *m* of user ***k,***

$$d_{k,m}(t) = \sum_i d_{k,m}^i g_T(t - iT) \tag{6}$$

$$C_k(t) = \sum_{i=0}^{N_c - 1} c_k^i g\ T_c(t - T_c) \tag{7}$$

$$p_m(t) = \sum_i \omega_m(t - iT_c) \tag{8}$$

g_s *(t)* stands for rectangular pulse of duration s. N_c is the period of PN code.

On the receiver side, received signal is reconstructed using filter-banks and each user's data can be retrieved by multiplying the received signal by user-specific spreading code,

The receiver is shown in figure 4**.**

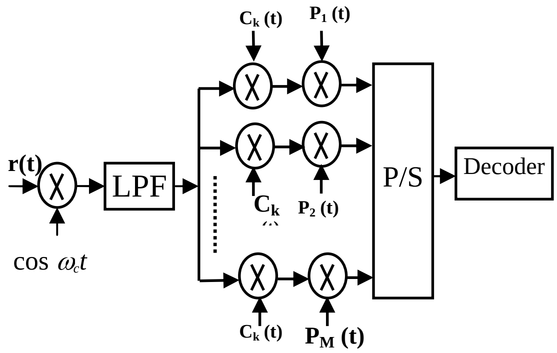
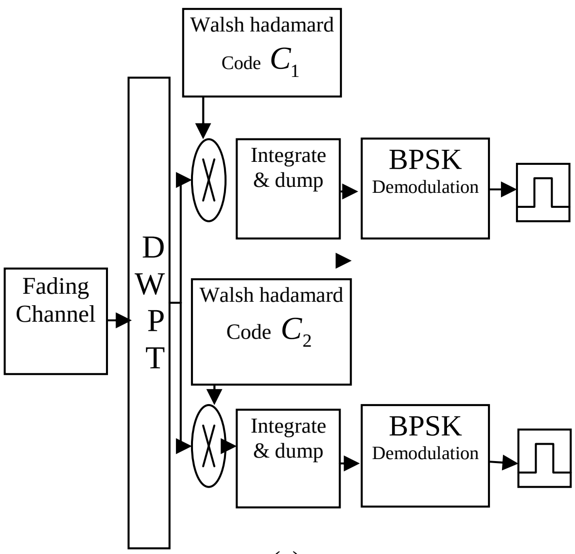


Figure 4: Receiver Model.

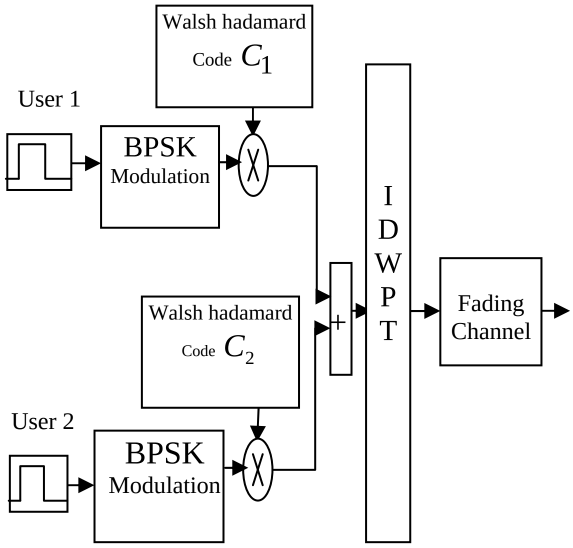
7. Performance Evaluation of Wavelet transform and wavelet Packet Based MC-CDMA Transceiver

The Wavelet transform Based MC-CDMA Transceiver system is simulated using the simulink of matlab 7. The design assumes perfect synchronization between the transmitter and the receiver. This scheme makes use of BPSK modulation as shown in figure 5. For two users (M = 2); figure 6 shows the bit error rate performance of the wavelet transform based hybrid modulation technique in AWGN channel using the wavelet families Haar, daubechies1, biorthogonal-1 and biorthogonal-1/3 orthonormal quadrature mirror filter banks (QMF) and as it can be seen Haar wavelet family has the better BER performance, Figure 7 shows the same system with Rayleigh fading channel, the performance in Rayleigh fading channel is worse than the AWGN channel that is due to the channel impulse response has a multipath delay spread which is greater than the bandwidth of the transmitted message waveform. When this occurs, the received signal includes multiple versions of the transmitted waveform which are attenuated (faded) and delayed in time, and hence the received signal is distorted, but it is better than the conventional DFT based MC-CDMA in Rayleigh fading channel.

Figure 8 shows the effect of wavelet order on the performance of MC-CDMA based DWPT in AWGN channel . Figure 9 shows the same performance in the DWPT based MC-CDMA in Rayleigh fading channel, from the figure it is obvious that daubechies-2 wavelet family has the better BER performance. Also, it can be easily seen that even in a fading channel DWPT based MC-CDMA is performing better than DFT based MC-CDMA in an AWGN channel which is the upper curve in figure 7.



(a)



(b)

Figure 5: Simulated DWPT Based MC-CDMA Transceiver. [(a) Transmitter and (b) Receiver].

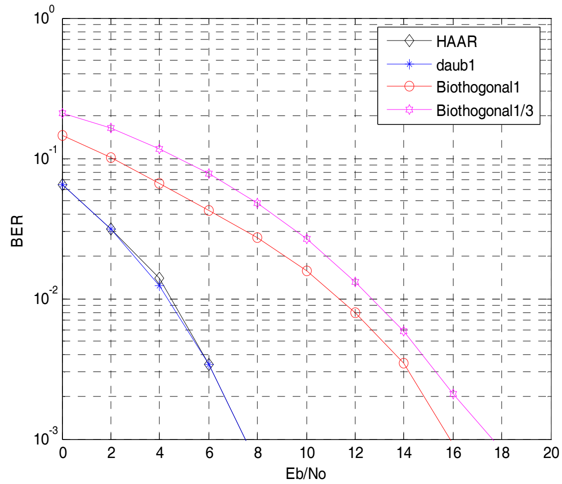


Figure 6: The BER vs. E_b/N_o performance of MC-CDMA BASED DWT in the AWGN channel.

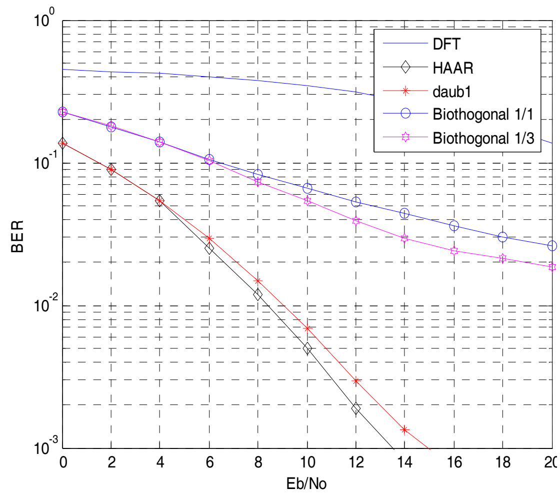


Figure 7: BER vs. E_b/N_o performance of MC-CDMA Based DWT in the Rayleigh Fading channel.

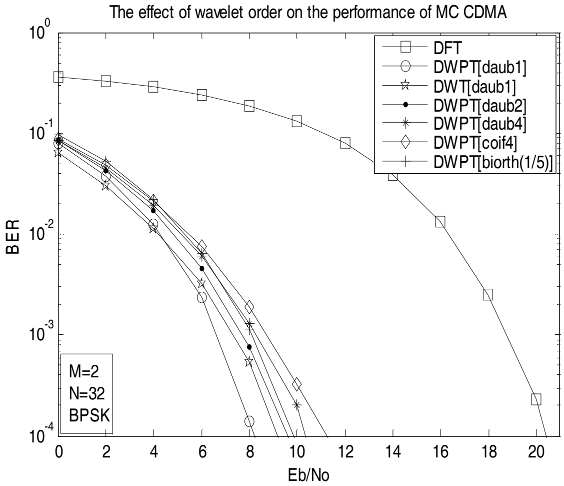


Figure 8. BER vs. Eb/No of DWPT Based MC-CDMA in the AWGN Channel [8]

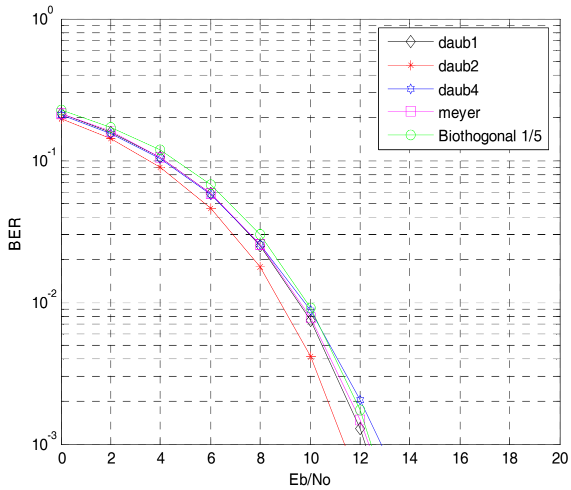


Figure 9. BER Vs. Eb/No Of DWPT in the Reyleigh Fading Channel

8. Conclusions

Haar, daubechies and other wavelets are used to simulate the BER performance for DWT and DWPT based MC-CDMA in Rayleigh fading and AWGN channel. DWT and DWPT based MC-CDMA perform better than DFT based MC-CDMA in the Rayleigh fading channel. Even, when comparing the performance of DWPT based MC-CDMA in Rayleigh fading channel with the performance of DFT based MC-CDMA in AWGN channel, the DWPT performs better. Ideal spectral efficiency can be achieved with the DWPT-MC-CDMA, because no guard band is required.

References

[1] S. S. Hara, R. Prasad, “Overview of Multi-carrier CDMA”, *IEEE Communication Magazine*, vol.35, no. 12, December 1997.

[2] J. Jang and K. B. Lee, “Effects of frequency offsets on MC/CDMA system performance “, *IEEE Communications Letters*, vol.3, No.7, pp. 196-198, July 1999.

[3] J. G. Andrews, and T. H. Meng, "Performance of multicarrier CDMA with successive interference cancellation in a multipath fading channel“, *IEEE Trans. on Communications*, vol. 52, no.5, pp 811-822, May 2004.

[4] H. Zhang, H. Fan, and A. Lindsey "Wavelet Packet Waveforms For Multicarrier CDMA Communications", *Proceedings of IEEE ICASSP 2002*, Florida, USA, Vol. 3, pp. 2557-2560, 2002

[5] K. Fazel, S. Kaiser, "Multi-Carrier and Spread Spectrum Systems", *Wiley, West Sussex England* 2003.

[6] N.Yee, J.P. Linnartz, and G. Fettweis, “Multi-carrier CDMA in indoor wireless radio networks”, *Proc.IEEE Pimrc’93*, pp.109-113, September 1993.

[7] S. Baig, N.D. Gohar, Fazal-ur-rehman, “An efficient wavelet based MC-CDMA transceiver for wireless communications”, *IBCAST* 2005.

[8] R. Wani, S. Cheng and J. Wei, “Wavelet Packet Functions Based Coded MC-CDMA System and Its Performance,” National Mobile Communication Research Lab., Southeast University Nanjing, China ,2000.

[9] Saber I. Hassouna, Ehab F. Badran, Darwish A. Mohamed and Shawki Shaaban**,** “Wavelet Packet Modulation for Multi-carrier CDMA Communications“**,** *Proceedings of the 24th National Radio Science Conference* (NRSC’2007), Cairo, Egypt, 13th-15th March 2007.

[10] M. Akho-Zahieh, “Design and Analysis of Multicarrier Multicode Wavelet Packets Based CDMA Communication Systems with Multiuser Detection", *Thesis*, Graduate Faculty of the University of Akron, August 2006.