Improve the Performance of Multi-users MC-CDMA Based on Critically Sampling Multi-wavelet Transform over Wireless Propagation Channel

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Abstract— In this paper, Critically Sampling Inverse Discrete Multi-Wavelet Transform (CSID-MWT) are proposed as a modulator technique instead of Inverse Fast Fourier Transform (IFFT) in the realization of the Multi-Carrier Code Division Multiple Access (MC-CDMA) system. The proposed structure improved the bandwidth efficiency through the elimination of the cyclic prefix (CP) due to the good orthogonality and time-frequency localization properties of the Multi-Wavelet transform. The proposed system was simulated using MATLAB to allow various parameters of the system to be varied and tested. Simulation results showed that the proposed system outperforms conventional MC-CDMA system, and its performance is superior to that of the conventional MC-CDMA with CP.

1. INTRODUCTION

Recently, Multi-carrier Code Division Multiple Access (MC-CDMA) technique based on the combination of orthogonal frequency division multiplexing (OFDM) and conventional CDMA has received much attention among researchers, it is one of the most promising techniques for the future wireless mobile communication systems beyond *3G* [1].

A MC-CDMA system basically applies the OFDM type of transmission to a Direct Sequence (DS)-CDMA signal. In conventional DS-CDMA each user symbol is transmitted in the form of sequential chips, each of which is narrow in time and hence wide in bandwidth. In contrast to this, in MC-CDMA due to the fast Fourier transform (FFT) along with OFDM the chips are longer in time duration and hence narrow in bandwidth. The multiple chips for a data symbols are not sequential but instead transmitted in parallel over many subcarriers. An interesting feature of MC-CDMA is that modulation and demodulation can be easily implemented using simple inverse fast Fourier transform (IFFT) and FFT operators. This transform however has the drawback that it uses a rectangular window, which creates rather high side lobes. Moreover, the pulse shaping function used to modulate each subcarrier extends to infinity in the frequency domain this leads to high interference and lower performance levels [2].

Many researchers replaced the FFT with another transforms to improve the BER performance for the MC-CDMA system. In [3] the FFT was replaced by an orthonormal wavelets in order to reduce the level of interference. It is found that MC-CDMA based on discrete wavelet transform (DWT) are capable of reducing the inter symbol interference ISI and inter carrier interference ICI, which are caused by the loss in orthogonality between the carriers.

In this paper the FFT in MC-CDMA will be replaced with another transform called Multi-wavelet that based on multi-filters. It has two or more low-pass and high-pass filters. The purpose of this multiplicity is to achieve more properties which cannot be combined in other transforms (Fourier and Wavelet).

A very important multi-wavelets filter is the GHM filter proposed by Geronimo, Hardian, and Massopust. In multi-wavelets setting, GHM multi-scaling and multi-wavelets functions coefficients are 2×2 matrices, and during transformation step they must multiply vectors (instead of scalars). This means that multi-filter bank need 2 input rows, where this can be done by preprocessing the input signal of length N to a sequence of length-2 vectors in order to start the analysis algorithm. If the preprocessing produces N length-2 vectors it is said to be an oversampling scheme, while if it produces $N/2$ length-2 vectors the result is a critical sampling will be used in this paper [4, 5].

In the proposed MC-CDMA systems, there is no need for using Cyclic Prefix (CP), which subsequently reduces the system complexity, increases the transmission rate because it decreases the number of symbol per frame, and increases spectral efficiency.

The rest of the paper is organized as follows: Section 2 introduces the proposed system for MC-CDMA Based on multi-wavelet. Performance results are shown in Section 3 and conclusions are given in Section 4.

2. PROPOSED SYSTEM FOR MC-CDMA BASED ON MULTI-WAVELET

The block diagram of the proposed system for MC-CDMA is depicted in Fig. 1 and Fig. 2, where Fig. 1 is the structure of the transmitter of the kth user, and Fig. 2 is the structure of receiver of the kth user. The OFDM modulator and demodulator based on multi-wavelet that used here are shown in the Fig. 3.

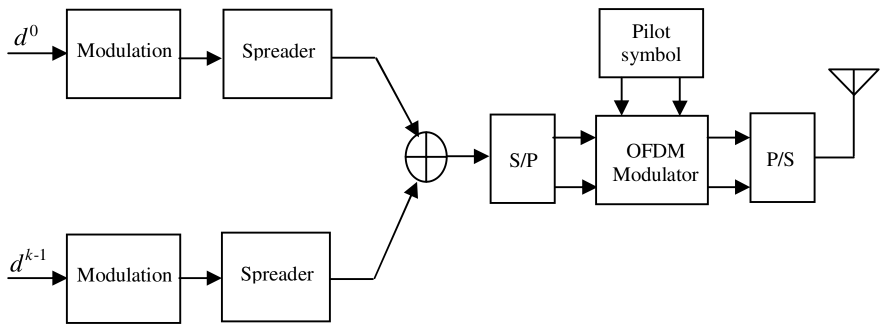

Figure 1: MC-CDMA transmitter model.

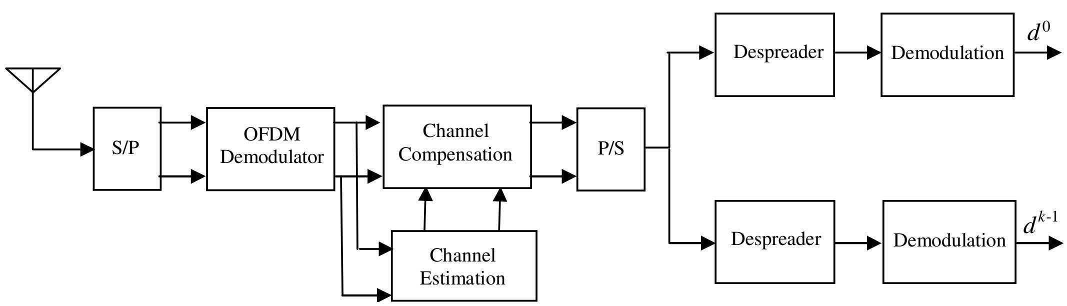

Figure 2: MC-CDMA receiver model.

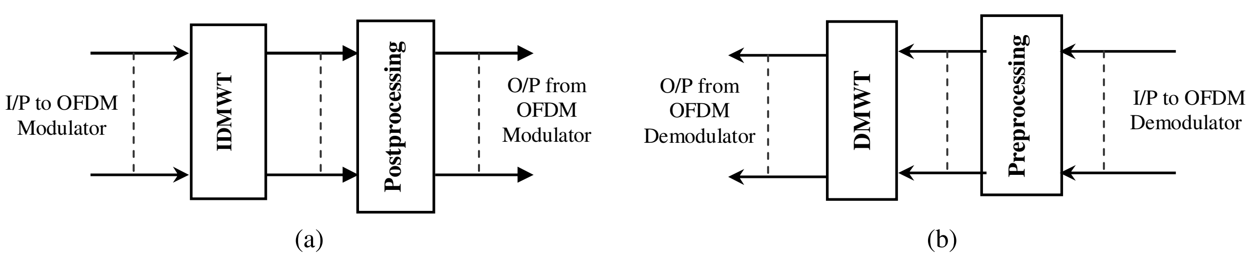

Figure 3: DMWT-OFDM, (a) DMWT-OFDM modulator, (b) DMWT-OFDM demodulator.

At the transmitter, the complex valued data of the user k is multiplied with the user specific spreading code. The coded signals of k active users are added to each other and then serial to parallel converted. The training sequence (pilot sub-carriers) will be inserted and sent prior to information frame. This pilot symbol will been used to make channel estimation that's used to compensate the channel effects on the signal. After that the inverse discrete multi-wavelet transform (IDMWT) with post-processing will be applied to the signal. Now parallel to serial converter (P/S) converts parallel data into serial data stream and transmit over channel.

At the receiver, first S/P converts the data to parallel version. After that the preprocessing and DMWT will be done. Also the channel estimation, channel compensation, despreadingand demodulation the users signal.

To compute a single-level 1-D discrete multi-wavelet transform, the next steps should be followed:

1. Checking input dimensions: input vector should be of length N, where N must be power of 2.
2. Constructing a transformation matrix: Using an $N/2 * N/2$ transformation matrix should be constructed using GHM low- and high-pass filters matrices given in Equations (1) and (2) respectively [6]. After substituting GHM matrix filter coefficients values, an $N * N$ transformation matrix results given in Equation (3).

$$H_0 = \begin{bmatrix} \frac{3}{5\sqrt{2}} & \frac{4}{5} \\ -\frac{1}{20} & -\frac{3}{10\sqrt{2}} \end{bmatrix},\ H_1 = \begin{bmatrix} \frac{3}{5\sqrt{2}} & 0 \\ \frac{9}{20} & \frac{1}{\sqrt{2}} \end{bmatrix},\ H_2 = \begin{bmatrix} 0 & 0 \\ \frac{9}{20} & -\frac{3}{10\sqrt{2}} \end{bmatrix},\ H_3 = \begin{bmatrix} 0 & 0 \\ -\frac{1}{20} & 0 \end{bmatrix} \tag{1}$$

$$G_0 = \begin{bmatrix} -\frac{1}{20} & -\frac{3}{10\sqrt{2}} \\ \frac{1}{10\sqrt{2}} & \frac{3}{10} \end{bmatrix},\ G_1 = \begin{bmatrix} \frac{9}{20} & -\frac{1}{\sqrt{2}} \\ -\frac{9}{10\sqrt{2}} & 0 \end{bmatrix},\ G_2 = \begin{bmatrix} \frac{9}{20} & -\frac{3}{10\sqrt{2}} \\ \frac{9}{10\sqrt{2}} & -\frac{3}{10} \end{bmatrix},\ G_3 = \begin{bmatrix} -\frac{1}{20} & 0 \\ -\frac{1}{10\sqrt{2}} & 0 \end{bmatrix} \tag{2}$$

$$W = \begin{bmatrix} H_0 & H_1 & H_2 & H_3 & 0 & 0 & \dots & 0 & 0 & 0 & 0 \\ 0 & 0 & H_0 & H_1 & H_2 & H_3 & \dots & 0 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \dots & \vdots & \vdots & \vdots & \vdots \\ H_2 & H_3 & 0 & 0 & 0 & 0 & \dots & 0 & 0 & H_0 & H_1 \\ G_0 & G_1 & G_2 & G_3 & \vdots & \vdots & \dots & 0 & 0 & 0 & 0 \\ 0 & 0 & G_0 & G_1 & G_2 & G_3 & \dots & 0 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \dots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 & 0 & \dots & G_0 & G_1 & G_2 & G_3 \\ G_2 & G_3 & 0 & 0 & 0 & 0 & \dots & 0 & 0 & G_0 & G_1 \end{bmatrix} \tag{3}$$

3. Preprocessing rows: critically sampling preprocessing can be computed by applying Equations (4) and (5) to the odd- and even-rows of the input vector respectively [7].

a) For any odd row

$$\begin{aligned} \text{new odd row} = {} & \left(10/8\sqrt{2}\right)[\text{same odd row}] \\ & + \left(3/8\sqrt{8}\right)[\text{next even row}] + \left(3/8\sqrt{2}\right)[\text{previous even row}] \end{aligned} \tag{4}$$

b) For any even-row

$$\text{new even row} = [\text{same even row}] \tag{5}$$

4. Transformation of input vector which can be done by applying matrix multiplication to the $N/2 * N/2$ constructed transformation matrix by the $N * 1$ preprocessing input vector.

3. SIMULATION RESULTS

The proposed MC-CDMA system described in the previous section is simulated for various numbers of active users and its bit error rate (BER) performance is compared with the conventional standard MC-CDMA system based on FFT and MC-CDMA based on DWT using Daubechies wavelet (4 dB). These systems have been examined in different channel models, which is additive white Gaussian noise (AWGN) channel, flat fading channel, and frequency selective fading channel. This system was implemented using MATLAB software (version 7.8). Table 1 shows the parameters of the system that used in the simulation.

Figure 4, shows the BER performance of MC-CDMA in AWGN channel. It is found that the MC-CDMA based on DMWT is better and more significant than the two other systems based on the FFT and DWT. In case of two active users, the BER $= 10^{-3}$ at signal-to-noise ratio (SNR) is about 6.8 dB for DMWT model while it's about 7.5 dB for DWT model and 17.5 dB for FFT model. With increasing the number of users, the bit error rate is increased also, this is due to multiple access interference (MAI).

The BER performance of the MC-CDMA system in the flat fading channel is presented in Fig. 5. From this figure, it can be seen that the DMWT-MCCDMA is close to DWT-MCCDMA and both of them are much better than the FFT-MCCDMA in case of two users, while in case of four users the DMWT-MCCDMA is better than the two other systems, the BER $= 10^{-3}$ at SNR is about 22 dB for DMWT model while it's about 24 dB for DWT model and 33.5 dB for FFT model.

Table 1: Simulation parameters.

Parameter	Value
System BW	5 MHz
Modulation types	QPSK
Spreading code	Walsh-Hadamard code
Spreading factor	16
Number of users	2, 4
Number of sub-carriers	64
Number of cyclic prefix	16
Channel model	Rayleigh fading channel, Jakes model
Doppler Frequency	10 Hz

Figure 6, gives the BER performance of DMWT-MCCDMA in frequency selective fading channel. A 3-rays Rayleigh-distributed multi-path fading channel is assumed here, where the parameters of the channel in this case corresponding to multipath are (0 dB, −4 dB, −8 dB) paths gain and the paths delay are set to (0, 2-sample, 3-sample). It is clearly shown from this figure that the DMWT-MCCDMA needs SNR more than 19 dB to reach 10^{-3} BER, while DWT-MCCDMA needs SNR around 23 dB to reach 10^{-3} BER, and FFT-MCCDMA needs SNR more than 27 dB to reach 10^{-3} BER, in case of two users.

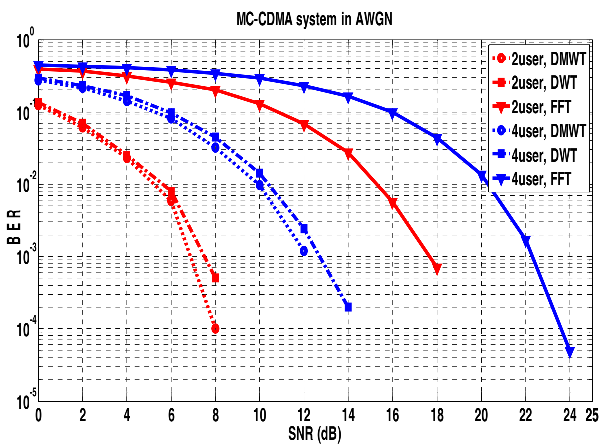

Figure 4: Performance of MC-CDMA in AWGN channel.

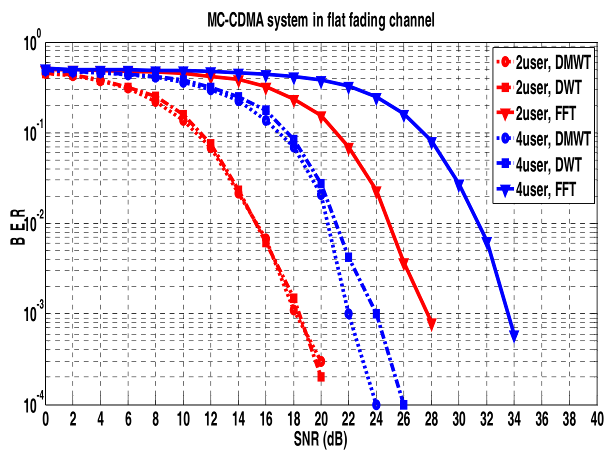

Figure 5: Performance of MC-CDMA in flat fading channel.

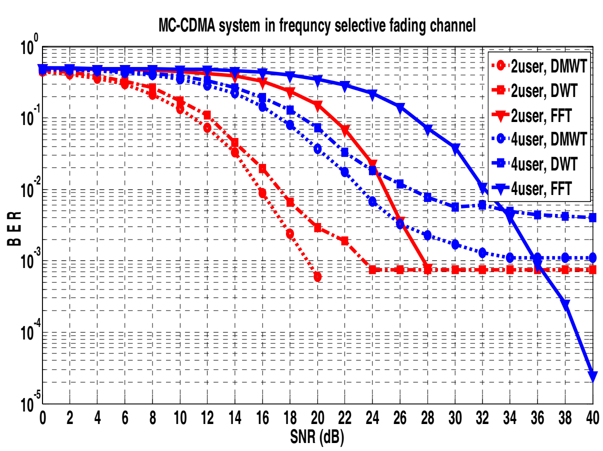

Figure 6: Performance of MC-CDMA in frequency-selective fading channel.

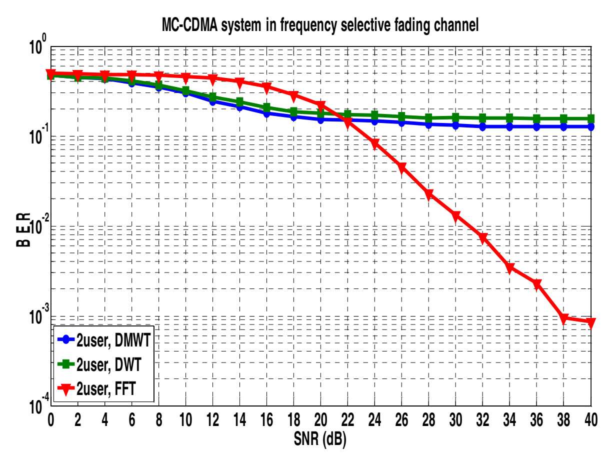

Figure 7: Performance of MC-CDMA in frequency-selective fading channel with Fd = 200 Hz.

Figure 7, shows the effect of Doppler frequency on performance of DMWT-MCCDMA in the frequency selective fading channel where Doppler frequency equal to 200 Hz (fast fading). In fast fading channel, the bit error rate increases for all schemes. From this figure, it is clear that the DMWT-MCCDMA and DWT-MCCDMA have better performance than FFT-MCCDMA up to about SNR = 20 dB, after this value the FFT-MCCDMA became better than the both other systems.

4. CONCLUSIONS

In this paper, the MC-CDMA based on Critically Sampling Multi-wavelet was proposed and compared with the MC-CDMA based on wavelet and MC-CDMA based on FFT in three types of channels. It can be concluded that this structure achieves much lower bit error rates than traditional models based on FFT and wavelet transform. Therefore this structure can be considered as an alternative to the conventional MC-CDMA.

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