Improved Interference Cancellation for Downlink Wavelet Based Multi-Carrier CDMA System

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Abstract

The current wireless mobile communication systems are occupying higher transmission bandwidths to support multimedia applications with high data rates. The multi-carrier code division multiple access (MC-CDMA) is one of the most promising candidates for the future generations of wireless mobile communications. Inter-symbol interference (ISI) and multiple access interferences (MAI) are the major challenges in the mobile communication systems due to transmission over multipath fading channels. In this paper, a proposed receiver structure based on discrete wavelet transform for the downlink multicarrier code division multiple access (DWT-MC-CDMA) is presented to mitigate these interferences. Based on simulation results, the DWT-MC-CDMA receiver provides a better bit error rate (BER) performance than the conventional downlink discrete Fourier transform multi-carrier code division multiple access (DFT-MC-CDMA) receiver.

Keywords: *Multi-Carrier Code Division Multiple Access (MC-CDMA), Discrete Wavelet Transform (DWT), Inter Symbol Interference (ISI), Multiple Access Interference (MAI).*

1. Introduction

Multi-carrier code division multiple access (MC-CDMA) systems support high data rate transmission in wireless communications [1]. For each user, transmitted signal is converted from narrow band to wideband through spreading [2]. Several coding techniques (e.g., orthogonal variable spreading code (OVSF), Walsh-Hadamard code (W-H), and Gold code) are used for spreading [2]. Multiple access interference (MAI) is a major impairment and can be overcome by using orthogonal codes in the downlink system [3]. Multi-carrier (MC) modulation and demodulation can be implemented by means of inverse fast Fourier transform (IFFT) and fast Fourier transforms (FFT) algorithms respectively. FFT based MC-CDMA uses the cyclic prefix (CP) to reduce both of the inter-carrier interference (ICI) and inter-symbol interference (ISI). The cyclic prefix leads to wasting about 12.5% of the total bandwidth [4]. Elimination of the MAI, the ICI, and the ISI saves the required power for transmission to achieve the desired signal-to-noise ratio (SNR) and to enable transmission over several channels with a limited power [1]. The equalizer is used to compensate the ISI resulting from time-dispersive channels. The minimum mean square error equalizer (MMSE) is one of the promising low-complex equalizers.

In previous studies, wavelet packet MC-CDMA is investigated using the time domain localization property of the wavelet packet. The problem of this system is its high complexity [5].

The objective of this study is to enhance the BER performance of the downlink MC-CDMA system by introducing the proposed system of DWT-MC-CDMA. This system uses the parallel interference cancellation (PIC) to subtract the interference before the linear equalization. In contrast with the conventional downlink DFT-MC-CDMA, the proposed DWT-MC-CDMA system does not require the insertion of CP to be implemented [6]. The wavelet transform is a technique for analysis of the signal in time and frequency domains jointly. It is a multi-resolution analysis where the input signal is decomposed into different frequency components [7]. The advantages of using wavelet transform are that it is more suitable for non-stationary signals and it can create subcarriers of different bandwidth and symbol length.

2. FFT-MC-CDMA with Parallel Interference Cancellation

A single cell CDMA system with K active users is considered, each user transmits BPSK information symbols spreading it using the Walsh-Hadamard codes. These symbols then scrambled to eliminate inter-cell interference ICI [1]. Modulation in baseband then done by the inverse fast Fourier transform (IFFT), The guard interval (CP) is then inserted between symbols to avoid inter-symbol interference caused by multipath fading, and finally, the signal is transmitted over frequency selective fading channel [3].

The propagation channel is assumed to be frequency selective block fading channel, which means that the path gain remains constant over at least one block duration [1].

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The baseband channel response can then be expressed as [8]:

$$h(t) = \sum_{l=0}^{l-1} hl\, \delta(t - \mathcal{T}l) \quad (1)$$

hl: the complex path gain
$\mathcal{T}$l: the propagation delay of paths
L: the number of multipath components of the channel

In this paper, we assume block fading with three multi paths (L=3) the first path with 0.4 amplitude and 0º phase shift, the second path with 0.3 amplitude and 60º phase shift and the third path with 0.4 amplitude and 120º phase shift. The transmitted signal can be formulated as [9].

$$t = D^1 CSb \quad (2)$$

The received block after removal of cyclic prefix is :

$$r = Hcd + n \quad (3)$$

Where d is the vector of transmitted chip sequence NM×1 vector, Hc is an NM×NM circulant matrix describing the channel .and can be written as follows [1].

$$Hc = \begin{pmatrix} h[0] & 0 & . & 0 & h[L-1] & h[L] \\ & h[0] & . & & & . \\ & & . & & 0 & \\ . & . & . & & & h[L-1] \\ h[L-1] & & & . & & \\ 0 & . & & & & 0 \\ & & & . & & \\ 0 & & . & 0 & h[L-1] \; . & h[0] \end{pmatrix} \quad (4)$$

The vector d can be represented as follows:

$$d=F^{-1}CSb \quad (5)$$

Where F^{-1} is an NM× NM IFFT matrix, C is an NM× NM matrix containing the scrambled code, S is an NM × KM matrix containing the spreading code and b is an KM × 1 vector containing the user's data [1].

3. Parallel Interference Cancellation and Rake Receiver

The process of interference cancellation is made after the estimation of channel coefficients and the all interfering users [10]. There are two combinations for interference cancellation the first one is RAKE-PIC and the second is MMSE-PIC, the steps of interference cancellation in both techniques can be summarized as follows; firstly the removal of cyclic prefix is done on the received signal, then the received signal is transformed to the frequency domain by using FFT and can be stated as follows:

$$R = ED_{des} + ED_{int} + N \quad (6)$$

After that, the frequency domain estimation of the channel coefficients is done, then the estimation of the interfering users is done by the RAKE receiver or MMSE equalizer this can be written as follows, For the case of RAKE receiver:

$$b_{int} = sign(real(S_1^T C^H E^H R)) \quad (7)$$

For the case of MMSE equalizer

$$b_{int} = sign(real(S_1^T C^H W_{MMSE} R)) \quad (8)$$

$$W_{MMSE} = (E^H E + (1/_{SNR})I)^{-1} E^H \quad (9)$$

Then the regeneration of the MAI can be done as follows:

$$R_{MAI} = EF^{-1}(CUb_{int}) \quad (10)$$

We can then get an interference free signal in the frequency domain by subtracting (10) from (6)

$$Z = R - R_{MAI} \quad (11)$$

This process is called parallel interference cancellation (PIC). The estimation of the symbols of users of interest can be done for the both schemes as follows:

For the first scheme, the RAKE detection is applied to interference-free signal Z

$$b_{des} = sign(S_{des}^T C^H E^H Z) \quad (12)$$

For the second scheme, the MMSE detection is applied to the interference-free signal Z

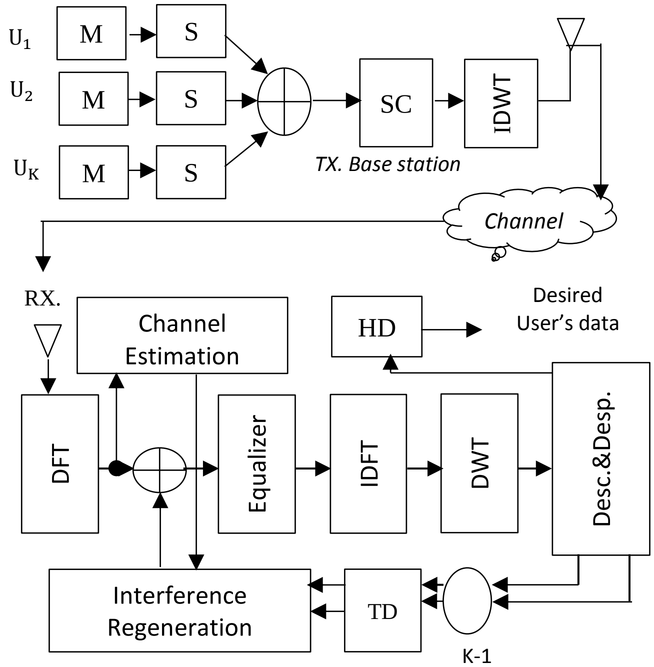
$$b_{des} = sign(S_{des}^T C^H W_{MMSE} Z) \quad (13)$$

4. Downlink DWT-MC-CDMA System

In this study, we present MC-CDMA system based on integrating DWT scheme into MC-CDMA, where DWT is presented as an alternative to the DFT in the previous study [1].

Our hypothesis is that the DWT provides more efficient denoising for non-stationary signals and better reconstruction of the signal after denoising, hence, the BER is supposed to be enhanced.

The block diagram in Fig.1 illustrates the structure of the proposed DWT-M-CDMA system. A downlink single cell CDMA system with K active users over a frequency selective fading channel plus additive white Gaussian noise (AWGN) is proposed. For the DWT-MC-CDMA system, the steps are the same as the conventional DFT-MC-CDMA system in [11] except using IDWT and DWT instead of IFFT and FFT. Each user transmits binary phase shift key (BPSK) information symbols. Those symbols are spread using Walsh-Hadamard code. After spreading, the signal is scrambled using a complex scrambling code, after that the IDWT is applied to the resulting signal, where there is no cycling prefix needed. Then the signal is transmitted through the channel. On the receiver side, DWT is applied to the received signal to de multiplex the multicarrier signal, and then descrambling and despreading are applied.



U: Users M: Modulation
S: Spreading SC: Scrambling
HD : Hard decision Desc.: Descrambling
TD : Tentative decision Desp.: Despreading

Fig. 1 Transmitter and receiver Structure of proposed PIC-equalizer for downlink DWT- MC-CDMA system

The channel impulse response can be stated as follows [11]:

$$h(t) = \sum_{l=0}^{L-1} h_l\, \delta(t - T_l) \qquad (14)$$

Where h_l is the complex path gain, T_l is the propagation delay of the paths and L is the number of multipath components of the channel.

In matrix notation, the signal to be transmitted by the K active users can be stated as follows:

$$t = D^{-1}CSb \qquad (15)$$

Where t is the transmitted signal, D^{-1} is a $2NM \times 2NM$ inverse discrete wavelet transform matrix and (C, S, and b) are given in [1].

The received signal can be formulated as follows [11]:

$$r = H_W t + n \qquad (16)$$

Where r is the received signal, t is an NM ×1 vector that representing the transmitted chip block, H_w is an $2NM \times 2NM$ multipath channel circulant matrix and n is AWGN.

The DFT is applied to the received signal to perform the processes of estimation and equalization in the frequency domain for more simplicity. The frequency domain of the received signal R after applying the DFT is stated as follows:

$$R = ET_{des} + ET_{int} + N \qquad (17)$$

Where E is a diagonal matrix containing the DFT of H_W,T_{des} is the desired data and T_{int} is representing the interference.

The estimation of the interfering users' signal (MAI) which is defined by b_{int} is obtained in the frequency domain by using the MMSE equalizer.

$$b_{int} = sgn(real(S_1^T C^H D F^{-1} W_{MMSE} R)) \qquad (18)$$

$$W_{MMSE} = E^H E + (1/SNR)I)^{-1} E^H \qquad (19)$$

Where D is a $2NM \times 2NM$ discrete wavelet transform matrix, and E is a diagonal matrix containing the FFT of the channel matrixH_W.

The regeneration of the MAI can be formulated as follows:

$$R_{MAI} = ED^{-1}(CS_1 b_{int.}) \qquad (20)$$

Where S_1 is the spreading code of the interfering users.

The interference free signal is then formulated as follows:

$$Z = R - R_{MAI} \tag{21}$$

The estimated symbols of the user of interest b_{des} can be obtained as follows:

$$b_{des} = \mathrm{sgn}(\mathrm{real}(S_{des}^{T} C^{H} D F^{-1} W_{MMSE} Z)) \tag{22}$$

5. Simulation Results

The simulation of the proposed scheme and the previous studies schemes is performed using MATLAB. For the downlink synchronous MC-CDMA system, symbols are transmitted using BPSK modulation. For the simulation, the mobile channel is presumed as frequency selective fading channel with three paths.

In Fig.2, a comparison between the BER performances of the RAKE receiver, zero forcing equalizer, regularized zero-forcing (ZF) equalizer, minimum mean square error (MMSE) equalizer based FFT and the proposed minimum mean square error (MMSE) equalizer based DWT is illustrated at a number of users K=8 and spreading factors SF=16. It is obvious that the proposed DWT-MC-CDMA system provides a better BER performance than that of the DFT-MC-CDMA system. The interpretation of this enhancement is supposed to be obtained by keeping the orthogonality between the subcarriers that is provided by the DWT time-frequency localization property which leads to reducing ISI that lowers the BER [12].

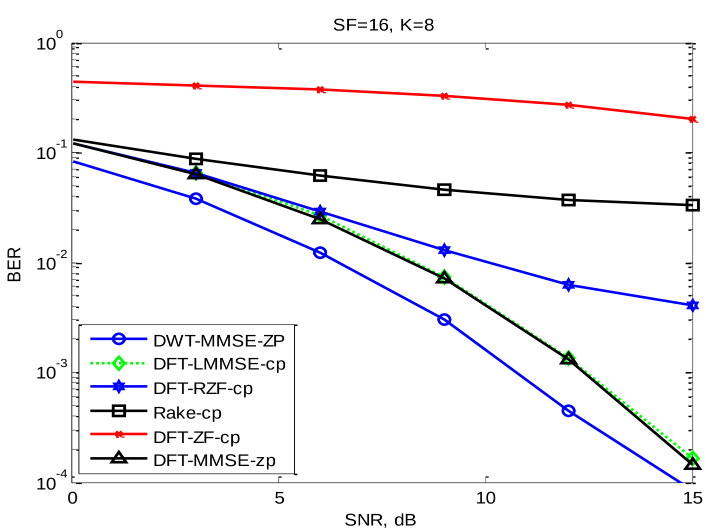


Fig. 2 BER against SNR of RAKE receiver, zero forcing (ZF) equalizer, regulated zero-forcing (RZF), MMSE equalizer AND PROPOSED DWT-MC-CDMA RECEIVER for K=8 and SF=16

As shown in Fig.3, the BER performance of the proposed DWT-MC-CDMA system is enhanced with increasing the spreading factor; however, the number of users is also increased. The interpretation of this enhancement is due to the fact that the high-spreading factor codes provide better autocorrelation properties which mitigate the ISI, In contrast with the low spreading factor codes with poor autocorrelation properties.

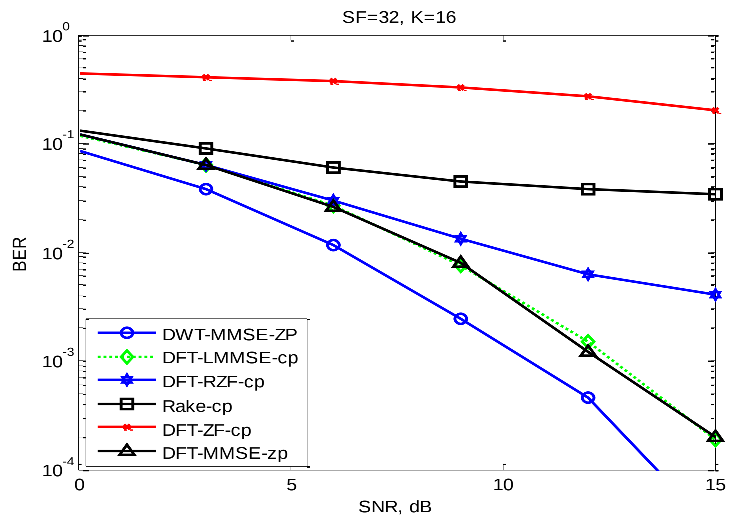


Fig. 3 BER against SNR of RAKE receiver, zero forcing (ZF) equalizer, regulated zero-forcing (RZF), MMSE equalizer and proposed DWT-MC-CDMA receiver for K= 16 and SF =32.

6. Conclusions

The downlink DWT-MC-CDMA system is introduced. The BER performance of the DWT-MC-CDMA system is compared to the conventional downlink FFT-MC-CDMA system. The DWT-MC-CDMA system provides an enhanced BER performance compared to that of the DFT- MC-CDMA system at the same values of the signal to noise ratio. Also, the capacity of the DWT- MC-CDMA is better than that of the DFT-MC-CDMA because of missing the cyclic prefix within the transmitted block. By increasing the spreading factor and number of users, the BER performance of the DWT-MC-CDMA system is still better than that of the DFT-MC-CDMA.

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