Minimum Difference Self Cancellation Technique for SC-FDMA-CDMA System

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Abstract: - Single Carrier-Frequency Division Multiple Access-Code Division Multiple Access (SC-FDMA-CDMA) suffers from Carrier Frequency Offset (CFO) problem, chiefly for Long Term Evolution (LTE) uplink. In this paper, we present a proposed compensation technique to mitigate the impact of Inter-Carrier Interference (ICI) and Multiple-Access Interference (MAI). The proposed technique is compared with similar compensation techniques namely, Self-Cancellation and Single User Detector (SUD) techniques. Simulation results show improvement in BER performance compared to these techniques. In the presence Additive white Gaussian noise (AWGN), the proposed Minimum Difference (MD) - Self-Cancellation technique outperforms the Self-Cancellation and SUD techniques by 1.4 dB and 2.1 dB, respectively at BER $=10^{-4}$. Also, in Rayleigh fading channel, it is observed that, the proposed MD-Self-Cancellation technique provides a minimum degradation compared to conventional Self-Cancellation and SUD techniques by about 1.1 dB and 3.9 dB, respectively.

Key-Words: - SC-FDMA-CDMA, CFO, ICI, MAI.

1 Introduction

SC-FDMA has been selected by 3rd-Generation Partnership Project (3GPP) for LTE uplink access technique due to its low Peak to Average Power Ratio (PAPR) advantage. The SC-FDMA system suffer from CFO, due to frequency mismatches between the transmitter and receiver. As a result, in these system, the orthogonality between subcarriers has been disrupted and give rise to ICI, and MAI among users [1, 2]. CDMA system introduces several advantages including easy frequency planning in cellular environments, high immunity against MAI and flexible data rate adaptation. The combination of Direct Sequence-CDMA (DS-CDMA) and SC-FDMA leads to the SC-FDMA-CDMA system [3, 4]. Like other SC-FDMA based systems [2], SC-FDMA-CDMA is sensitive to CFO, which is mainly caused by Doppler shift and mismatch of oscillator between the transmitter and the receiver. CFO destroys the orthogonality between subcarriers, consequently decreases the system performance severely [5]. There are a lot of techniques have been developed so far to mitigate or cancel the effect of CFO, such as frequency domain equalization [6], time domain windowing [7], pulse-shaping [8] and self- cancellation [9]. In [10], the authors suggested two new ICI cancellation techniques to reduce the frequency offset sensitivity of the OFDM systems. These two systems are based on conjugate repetition of the symbols at the transmitter side and conjugate multiplication (adding the phases in polar form of complex numbers) of the data symbols at the output of the FFT block of the receiver.

One of the effective methods is ICI self-cancellation technique. Where the transmitter side, one data symbol is modulated onto a group of sub-carriers with appropriate weighting coefficients. At the receiver side these groups of subcarriers are combined so the impacts of ICI on these subcarriers cancel each other [9, 11]. Also, in [12] the SUD, for each user a Discrete Fourier Transform (DFT) block is required to detect the information symbols, which tends to increase complexity of the system.

In this paper, we propose a new CFO compensation to enhance the BER performance of the Self-Cancellation and SUD techniques in the presence of CFO.

This paper is organized as follows: In section 2, the proposed CFOs MD- Self-Cancellation SC-FDMA-CDMA is described. Equalization with the proposed technique is explained in Section 3, Simulation results are given in Section 4. Finally, in section 5, the relevant results of the paper are concluded.

2 Proposed CFOs MD-Self-Cancellation SC-FDMA-CDMA

In this section, the block diagram of the SC-FDMA-CDMA system with the proposed MD-Self-Cancellation technique in the presence of CFOs with *Z* users is shown in figure 1. The information symbols b_z = { b_z (n), *n=1,2,...,N*} ∈ {0,1,… ,$2^M - 1$}of user z, where z=1,2,… ,Z, *M* is a modulation level for their data symbols. In the transmitter, the complex data symbol of size *N* is denoted by $d_z(n) = [d_z(1), d_z(2), \dots d_z(N)]$, is multiplied with user specific spreading code $c_z = [c_z(1), c_z(2), \dots c_z(L)]^T$, where the maximum number of active users Z is determined by L which is the maximum number of orthogonal spreading codes. The length of cyclic prefix added is L_p sampling periods. The data b_z is first mapped into complex-valued data symbol d_z that it is multiplied with the Orthogonal Walsh-Hadamard codes that are used as a spreading code, yielding X_z as given by:

$$(X_z)_{L\times N} = d_z \otimes \frac{c_z}{\sqrt{L}} \tag{1}$$

The X_z is passed to *N*-point DFT pre-coded operation. After that, the Self-Cancellation modulation technique and duplicate data are performed. The signal can be expressed as follows:

$$X_z = F_N \; x_z \tag{2}$$

Where $X_z = [X_z(1), X_z(2), \dots X_z(N)]^T$ is an $N \times 1$ vector. F_N is the $N \times N$ DFT matrix. Then, it is mapped using subcarrier mapping technique. Finally, an *M*- point Inverse DFT (IDFT) is implemented and a Cyclic prefix (CP) is added as follows:

$$\overline{X_z} = P_a \; F_M^{-1} \, M_z^T \; X_z \tag{3}$$

Where $M_z^T$is an $M \times N$ (*M =B.N*) subcarrier mapping matrix of the zth user. *B* is the bandwidth expansion factor. F_M^{-1} is the $M \times M$ IDFT matrix. P_a is an $(M + L_p) \times M$ matrix, which adds a CP of length L_p. At the receiving end, if assume accurate time synchronization, the received signal could be written as follows:

$$y = \sum_{z=1}^{Z} \bar{O}_z \, H_z \, \overline{X_z} + W(n) \tag{4}$$

Where $\bar{O}_{z\ \mathrm{m,m}} = e^{\frac{j2\pi\varepsilon_z m}{M}}$, m = 0, . . ., $M + L_p - 1$,. $\varepsilon_z = \Delta f T$ is the CFO of the zth user normalized by the subcarriers spacing. Δf is the carrier frequency offset. H_z is the channel matrix of the zth user. $\overline{X_z}$is the transmitted data samples of the zth user. $W(n)$ *is* the Additive White Gaussian Noise (AWGN). Then the CP is removed from the received signal and the signal is transformed via an *M*-point DFT into the frequency domain. Then, FDE and subcarriers demapping are performed. The proposed MD-Self-Cancellation demodulation is performed. After that, the resulting signal is transformed via an *N*-point IDFT into time domain.

After the user data is implemented by inverse SC-FDMA, the received data can be formulated as follows:

$$\acute{r} = \left(\acute{r}_1, \acute{r}_{21}, \dots, \acute{r}_n, \dots \acute{r}_{N,}\right), \tag{5}$$

$$\acute{r}_k = \left[\acute{r}_n(1), \acute{r}_n(2), \dots \acute{r}_n(L_p)\right]^T$$

The operation of de-spreading is employed that the received data are multiplied with the transpose of spreading code. Then we obtain:

$$r = (c_z)^T . \frac{\acute{r}}{\sqrt{L}} \tag{6}$$

$$r = \left(r_1, r_2, \dots, r_z, \dots r_Z\right)^T,$$

$$r_z = [r_z(1), r_z(2), \dots, r_z(n), \dots r_z(N)]$$

Finally, the detection process take place in the time domain. We convert decimal integer symbols to a binary string and count BER. There are a lot of techniques that were developed to compensate for the CFOs in multicarrier communication systems.

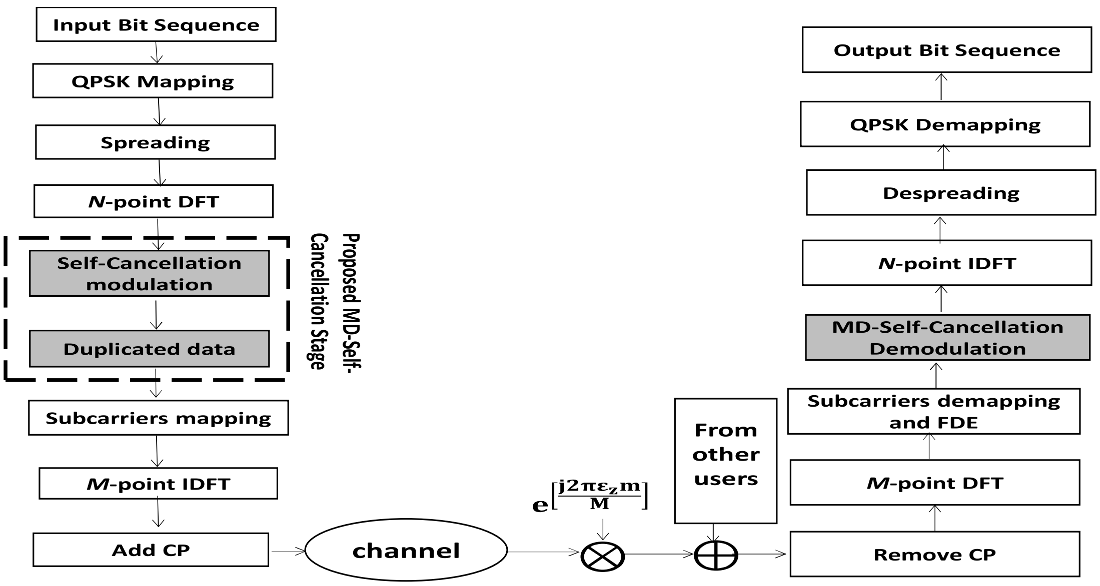

Figure 1. SC-FDMA-CDMA system with the proposed MD-Self-Cancellation technique

In the following subsections, the Self-Cancellation and the Minimum Difference Self-Cancellation techniques are investigated for the SC-FDMA-CDMA system.

2.1 Self-Cancellation technique

In this section, the main idea of self-cancellation technique is to one data symbol is mapped on two subcarriers at transmitter side and at receiver end these groups of subcarriers are combined so the effects of ICI on these subcarriers cancel each other, hence the name self- cancellation. In Self-Cancellation technique one data symbol is mapped on two consecutive subcarriers to mitigate ICI. So transmitted data symbols are $X(1)= -X(0)$, $X(3) = -X(2)$,……, $X(N-1) = -X(N-2)$, N is the number of the total subcarriers Then the received signal $Y_1'(k)$ is determined by the difference between two adjacent subcarriers *k and k+1*., which can be expressed as:

$$Y_1'(\mathrm{k}) = \sum_{\substack{g=0 \\ g=even}}^{N-2} X(g)[S(g-k) - S(g+1-k)] + W_1(k) \quad (7)$$

$$Y_1'(\mathrm{k+1}) = \sum_{\substack{g=0 \\ g=even}}^{N-2} X(g)[S(g-k-1) - S(g-k)] + W_1(k+1) \quad (8)$$

Where $X(g)$ denotes the modulated symbol within the l th subcarrier and k th subcarriers and $W_1(k)$ corresponds to the FFT of the samples of $w(n)$, which is AWGN introduced in the channel. In such a case, the ICI coefficient is denoted as:

$$S_1'(g-k) = S(g-k) - S(g+1k) \quad (9)$$

At the demodulator the received signal at the $(k+1)$ th subcarrier, where k is even is subtracted from the k th subcarrier is:

$$Y_1''(k) = Y_1'(k) - Y_1'(k+1)$$

$$= \sum_{\substack{g=0 \\ g=even}}^{N-2} X(l) S_1''(g-k) + W_1(k) - W_1(k+1) \quad (10)$$

$$S_1''(g-k) =$$

$$-S(g-k-1) + 2S(g-k) - S(g+1k) \quad (11)$$

2.2 Proposed MD- Self-Cancellation technique

In this section, the proposed MD- Self-Cancellation technique is described. Self-Cancellation technique is therefore reduces the CFO effect on the system performance. The system performance can be enhanced if the noise has less effect on the received symbol so, it is proposed to repeat the Self-Cancellation signal at transmitter side shown in Fig.2. i.e.,$X(1+N)= -X(0+N)$, $X(3+N) = -X(2+N)$,……, $X(2N-1) = -X(2N-2)$, where $N=0:2N-1$.

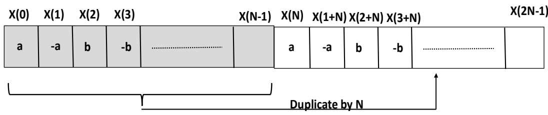

Fig.2. Mapping of proposed MD-Self-Cancellation stage.

At receiver, The received signal can be written as:

$$Y'(2k) = Y_1'(k) + Y'_2(k) \quad (12)$$

$$Y_1'(k) = \sum_{\substack{g=0 \\ g=even}}^{N-2} X(g) S_1'(g-k) + W_1(k) \quad (13)$$

$$Y_2'(k) = \sum_{\substack{g=N \\ g=even}}^{2N-2} X(2g) S_2'(2g-k) + W_1(k) \quad (14)$$

The MD-Self-Cancellation coefficient is denoted as:

$$S_1'(g-k) = S(g-k) - S(g+1-k) \quad (15)$$

$$S_2'(2g-k) = S(2g-k) - S(2g+1-k) \quad (16)$$

A comparison between the two copies is made to equalized frequency domain received symbols at which the noise effect is minimum to form *N*-IDFT Minimum Difference Self- Cancellation symbol $Y'_{min}(k)$. The $Y'_{min}(k)$ is constructed according to the criterion:

If $Y_1'(k) \leq Y_2'(k)$, $Y'_{min}(k) = Y_1'(k)$

If $Y_1'(k) > Y_2'(k)$, $Y'_{min}(k) = Y_2'(k)$

$$Y'_{min}(k) = \sum_{\substack{g'=0 \\ g=even}}^{N'-2} X'(g') S_1'(g'-k) + W(k) \quad (17)$$

$$Y'_{min}(k+1) = \sum_{\substack{g'=0 \\ g=even}}^{N'-2} X'(g') S_1'(g'-k-1) + W(k+1) \quad (18)$$

The MD-Self-cancellation demodulation stage can be performed using the Y'_{min}(k) vector.

$$Y''_{min}(k) = Y'_{min}(k) - Y'_{min}(k+1) = \sum_{\substack{g=0 \\ g=even}}^{N-2} X(g) S''(g-k) + W(k) - W(k+1) \quad (19)$$

$$S''_{min}(g'-k) = -S'(g'-k-1) + 2S'(g'-k) - S'(g'+1-k) \quad (20)$$

3 Equalization For the proposed technique

The design of the Frequency Domain Equalizers (FDEs) for the proposed MD-Self-Cancellation technique are investigated for the uplink SC-FDMA-CDMA system. The received signal is equalized in the frequency domain after the DFT block. Then, the equalized signal is transformed back into the time domain by using the IDFT. We shall use same expression for equalizer coefficients are used as in [13]. In Direct Sequence-Spread Spectrum (DS-SS), the value of processing gain G_p has no effect on the received $\frac{E_b}{N_0}$. In other words, SS techniques offer no error performance advantage over thermal noise [14].

4 Simulation Results

In this section, the BER performance of the proposed MD-Self-Cancellation-SC-FDMA-CDMA system is evaluated by simulations using MATLAB package. Interleaved Frequency Division Multiple Access (IFDMA), Localized Frequency Division Multiple Access (LFDMA) and Distributed Frequency Division Multiple Access (DFDMA) are different sub-carrier mapping techniques for SC-FDMA-CDMA. In this paper, we will focus on Interleaved SC-FDMA-CDMA (SC-IFDMA-CDMA). The simulation parameters are given in Table 1.

Table 1. Simulation parameters

Parameter	Description
System bandwidth	5 MHz
Modulation type	QPSK
Cyclic prefix length	20 samples
M	512 symbols
Subcarriers mapping mode	Interleaved
CFOs (ε)	random=[-0.15,0.15]
Number of users (Z)	4
N	128 symbols
Spreading code	Walsh-Hadamard codes
spreading factor	4
spreading length	32
Channel model	AWGN and Vehicular A channels
Channel estimation	Perfect
Equalization	ZF, RZF and MMSE

Fig.3 demonstrates the relation between the BER for the proposed MD-Self-Cancellation-SC-IFDMA-CDMA system with different SNR values and the regularization parameter β to select the minimum BER that required to use in Regularized Zero Forcing (RZF)-FDE. According to this figure, for the lowest BER the best choice of β is 10^{-3}. This value is used for the proposed system in RZF-FDE.

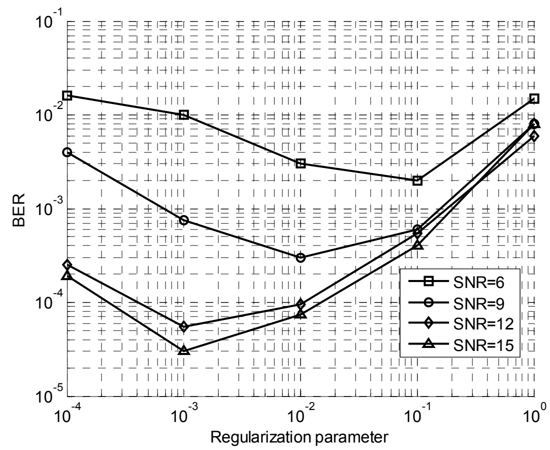

Fig.3. BER vs. the regularization parameter for proposed MD-Self-Cancellation-SC-IFDMA-CDMA system.

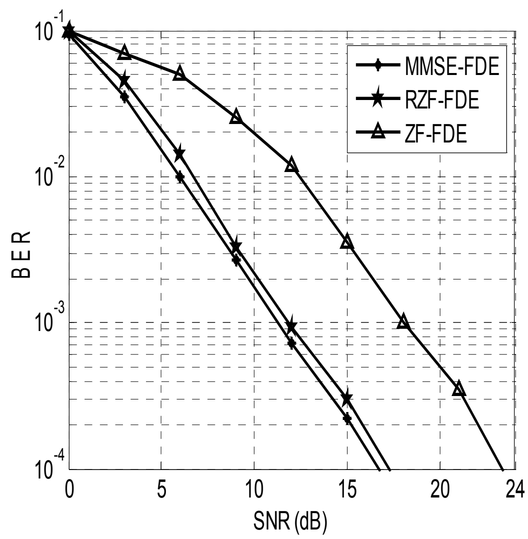

Fig.4. BER of proposed MD-Self-Cancellation-SC-IFDMA-CDMA system using ZF, RZF, and MMSE-FDEs.

Fig.4 shows the BER performance of proposed MD-Self-Cancellation-SC-IFDMA-CDMA system using ZF, RZF (with β = 10^{-3}), and MMSE FDES. It is observed from the results that, the MMSE equalizer outperforms both ZF and RZF. For example, at BER = 10^{-4}, MMSE outperforms RZF and ZF by 0.6 dB and 6.5 dB, respectively. According this figure, it is observed MMSE-FDE is the best FDE, so it used for the proposed MD-Self-Cancellation-SC-IFDMA-CDMA system in all next results.

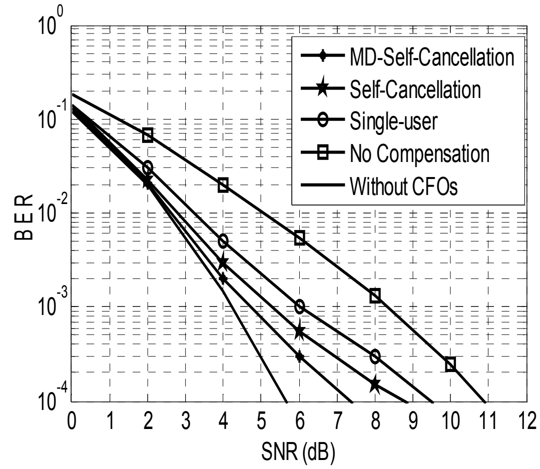

Fig.5. BER of proposed MD-Self-Cancellation-SC-IFDMA-CDMA system over AWGN channel.

The BER performance versus the SNR over AWGN for the proposed MD-Self-Cancellation-SC-IFDMA-CDMA system has been shown in Fig.5. At BER $=10^{-4}$, the proposed MD-Self-Cancellation technique provides significant BER performance improvement of the SC-IFDMA-CDMA system over the Self-Cancellation, SUD techniques and SC-IFDMA-CDMA without CFO compensation by about 1.4 dB, 2.1 dB and 3.5 dB, respectively.

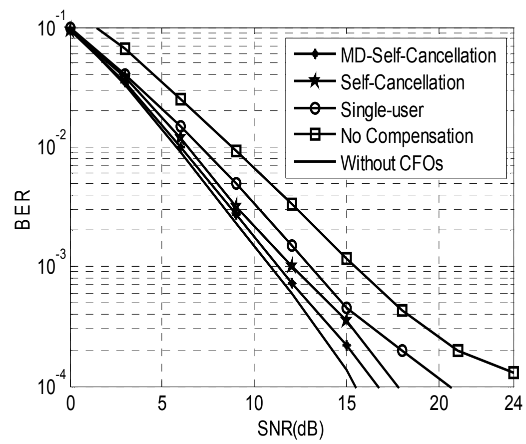

Fig.6. BER of proposed MD-Self-Cancellation-SC-IFDMA-CDMA system with random CFOs over Vehicular A channel.

Fig.6 shows the BER performance versus the SNR over Vehicular A channel with random CFOs for the proposed MD-Self-Cancellation-SC-IFDMA-CDMA system. At BER $=10^{-4}$, The BER performance at SC-IFDMA-CDMA without CFO degrades when using MD-Self-Cancellation, Self-Cancellation, SUD and without CFO compensation by about 1.2 dB, 2.3 dB, 5.1 dB and 8.5 dB, respectively. So, it is observed that, the proposed MD-Self-Cancellation technique provides a minimum degradation comparing to Self-Cancellation, SUD techniques and SC-IFDMA-CDMA without CFO compensation by about 1.1 dB, 3.9 dB and 7.3 dB, respectively.

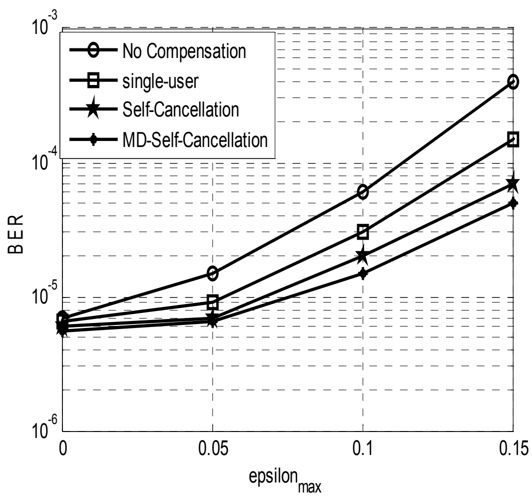

Fig.7. BER vs. ε_{max} for the proposed MD-Self-Cancellation-SC-IFDMA-CDMA system at SNR=15 dB.

The BER variation with the maximum CFO for the proposed MD-Self-Cancellation -SC-IFDMA-CDMA system has been studied at SNR= 15dB and shown in Fig.7. These figure show that the performance of system with CFOs, and without CFOs compensation deteriorates when the CFOs are increased. From this figure, it is clear that, the performance of MD-Self-Cancellation technique is better than that of Self-Cancellation, SUD techniques and without CFO compensation. For ε = 0.1 BER for MD-Self-Cancellation SC-IFDMA-CDMA system is by about 10-5 but for ε = 0.15 BER is increased to 10^{-4}.

5 Conclusion

In this paper, we introduce a new compensation technique to mitigate the effect of ICI caused by frequency offset in SC-FDMA-CDMA system. The MD-Self-Cancellation technique is proposed to enhance the BER performance of the conventional Self-Cancellation and SUD techniques in the presence of CFO. Simulation results show that, the proposed MD-Self-Cancellation technique is better than SUD and conventional Self-Cancellation techniques. In AWGN, With BER = 10^{-4}, the proposed MD-Self-Cancellation technique outperforms the conventional Self-Cancellation and SUD techniques by 1.4 dB and 2.1 dB, respectively. Also, in Rayleigh channel, it can be observed that, the proposed MD- Self-Cancellation technique provides a minimum degradation comparing to conventional Self-Cancellation and SUD techniques by about 1.1 dB and 3.9 dB, respectively.

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