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

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**ABSTRACT**

The 3rd-Generation Partnership Project (3GPP) has represented single carrier frequency division multiple access (SC-FDMA) for Long Term Evolution (LTE) uplink access scheme, which combines single carrier modulation with frequency domain equalization. SC-FDMA suffers from Carrier Frequency Offset (CFO) problem, which disrupt the orthogonality between subcarriers and give rise to Inter-Carrier Interference (ICI), which occurs between a user's subcarriers, and Multiple Access Interference (MAI) among users, which occurs between different users' subcarriers. In this paper, a new compensation technique is proposed to mitigate the interference in the frequency domain. Self-Cancellation and Single User Detector (SUD) techniques are compared with the proposed technique. Simulation results show that the proposed Minimum Difference (MD) -Self-Cancellation technique is able to improve BER performance compared to the conventional Self-Cancellation and SUD techniques by about 1.6 dB and 3.8 dB respectively in the presence Additive white Gaussian noise (AWGN) at BER $=10^{-4}$. Also, in Rayleigh fading channel, it is observed that the proposed technique provides a low degradation comparing to conventional Self-Cancellation and SUD techniques by about 0.9 dB and 2.3 dB, at BER $=10^{-3}$, respectively. Furthermore, the proposed MD-Self-Cancellation technique provides a low degradation comparing to the other techniques at high-speed mobility.



## 1. Introduction

SC-FDMA is a new technique for high data rate which is promisingly adopted by 3GPP for uplink transmission in the technology standardized for LTE cellular systems to overcome the drawbacks in OFDMA [1]. The modified version of OFDMA referred to as single-carrier FDMA (SC-FDMA), utilizes single carrier modulation and orthogonal frequency multiplexing, which provides similar throughput performance and complexity. The SC-FDMA system use different orthogonal frequencies (subcarriers) to transmit information symbols as in OFDMA [2]. The main advantage of SC-FDMA over OFDMA includes resistance to frequency-selective fading, efficient spectrum usage, low peak-to-average power ratio (PAPR) and lower complexity [3, 4]. On the other hand, SC-FDMA

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is similar to the OFDMA system that it is susceptible to CFO, which is caused by the mismatch of oscillator between the transmitter and the receiver and Doppler shift. As a result, in these systems, CFO destroys the orthogonality among subcarriers, and gives rise to Multiple-Access Interference (MAI) among users and Inter-Carrier Interference (ICI), thus also decreases the system performance severely [5].

In the literature, there have been a few papers that address the issue of the CFOs [6-9] and developed a lot of techniques so far to mitigate the effect of CFO, such as frequency domain equalization [10], time domain windowing [11], pulse-shaping [12] and self- cancellation [13]. ICI self-cancellation technique is one of the effective methods. At 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 ICI effect on these subcarriers cancels each other [13, 15]. Also, in [16] the SUD, for each user the Discrete Fourier transform (DFT) block is required to detect the information symbols, which tends to increase the complexity of the system.

The main goal of this paper is to deal with the CFOs problem and propose an efficient CFO compensation scheme to enhance the BER performance of the Self-Cancellation and SUD techniques in the presence of CFO. The remainder of this paper is organized as follows: In section 2, CFOs MD- Self-Cancellation in SC-FDMA is described. Equalization with the proposed technique is explained in Section 3, Simulation results are introduced in Section 4. Finally, in section 5, the relevant results of the paper are concluded.

## 2. Proposed CFOS MD-Self-Cancellation SC-FDMA

In this section, the block diagram of the SC-FDMA system with the proposed MD-Self-Cancellation technique in the presence of CFOs with Z users is shown in Figure 1. In SC-FDMA transmitter, the signals are modulated and then transformed into the frequency domain through an N-point DFT. Then, the Self-Cancellation modulation technique and duplicate data are performed and the signal output is denoted as $X^Z$ . After that, the subcarriers are mapped in the frequency domain. Then, Inverse DFT (IDFT) is performed. Finally, a Cyclic Prefix (CP) is added to the resulting signal and transmitted through wireless channel. The transmitted signal from the zth user can be written as follows:

$$\bar{x}^z = P_a D_M^{-1} M_T^z X^z \tag{1}$$

where $M_z^T$is an M × N (M =B.N) subcarrier mapping matrix of the zth user. B is the bandwidth expansion factor. $D_M^{-1}$ is the M × M IDFT matrix. $P_a$ is an ( M + $L_p$) × M matrix, which adds a CP of length $L_p$. At the receiving end, if we assume accurate time synchronization, the received signal will induce the carrier frequency offset (CFO) into the signal. By taking into account the CFOs and the additive noise. The received signal could be written as follows:

$$\bar{y} = \sum_{z=1}^{Z} \bar{O}^z H^z \bar{x}^z + w(n) \tag{2}$$

where$\bar{O}^z{}_{\mathrm{m\times m}} = \mathrm{e}^{\frac{\mathrm{j2\pi\varepsilon_z m}}{\mathrm{M}}}$, m = 0, . . .,$M + L_p - 1$, $\varepsilon_z = \Delta f T$is the CFO of the zth user normalized by the subcarriers spacing. $\Delta f$ is the carrier frequency offset. $H^u$is the channel of the uth user. $\bar{x}^z$ is the transmitted samples of the uth 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.

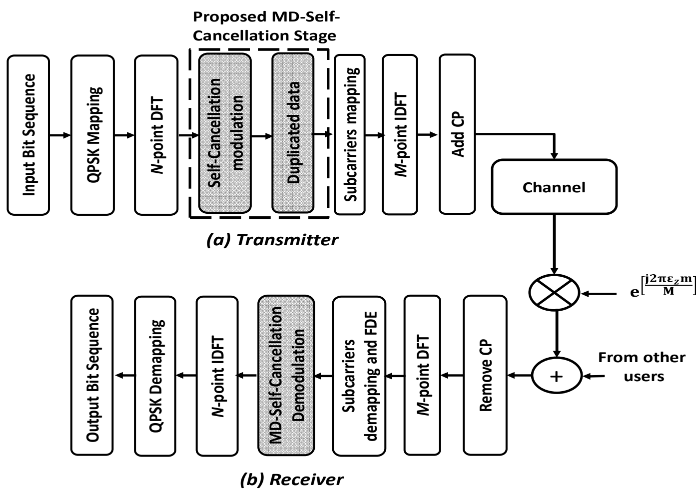


**Fig. 1.** SC-FDMA system with the proposed MD-Self-Cancellation technique

Finally, the detection process takes 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. In the following subsections, the Self-Cancellation and the proposed Minimum Difference Self-Cancellation technique are investigated for the uplink SC-FDMA system.

### *2.1 Self-cancellation technique*

In this section, the main idea of the self-cancellation technique is to one data symbol is mapped on two subcarriers at the 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:

$$Y_1'(k) = \sum_{\substack{g=0 \\ g=even}}^{N-2} X(g)[\, S(\, g - \, k) - \, S(\, g + 1 - k)] + W_1(k) \tag{3}$$

$$Y_1'(k+1) = \sum_{\substack{g=0 \\ g=even}}^{N-2} X(g)[\, S(\, g - \, k - 1) - \, S(\, g - k)] + W_1(k+1) \tag{4}$$

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

$$S_1'(\, g - \, k\,) = S(g - \, k) - S(g + 1 - k\,) \tag{5}$$

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

$$Y_1''(k) = Y_1'(k) - Y_1'(k+1) = \sum_{\substack{g=0 \\ g=even}}^{N-2} X(l)S_1''(g-k) + W_1(k) - W_1(k+1) \quad (6)$$

$$S_1''(g-k) = -S(g-k-1) + 2S(g-k) - S(g+1-k) \quad (7)$$

Due to the duplication coding, the bandwidth efficiency of the self-cancellation scheme is reduced by half.

### *2.2 Proposed MD-Self- Cancellation technique*

In this section, the proposed MD-Self-Cancellation technique is described. Self-Cancellation technique 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, in the proposed MD-Self-Cancellation technique the DFT mapped the data symbols into N subcarriers. In ICI self-cancellation modulation, each subcarrier is mapped on two consecutive subcarriers to mitigate ICI. The transmitted signals be constrained such that X(1)= −X(0), X(3) = −X(2) ,……, X( N – 1) = - X (N – 2), Then transmitted data are duplicated the Self-Cancellation signal at transmitter side shown in Figure 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. At receiver, the received signal can be written as

$$Y'(2k) = Y_1'(k) + Y'_2(k) \quad (8)$$

$$Y_1'(k) = \sum_{\substack{g=0 \\ g=even}}^{N-2} X(g)S_1'(g-k) + W_1(k) \quad (9)$$

$$Y_2'(k) = \sum_{\substack{g=N \\ g=even}}^{2N-2} X(2g)S_2'(2g-k) + W_1(k) \quad (10)$$

The MD-Self-Cancellation coefficient is denoted as

$$S_1'(g-k) = S(g-k) - S(g+1-k) \quad (11)$$

$$S_2'(2g-k) = S(2g-k) - S(2g+1-k) \quad (12)$$

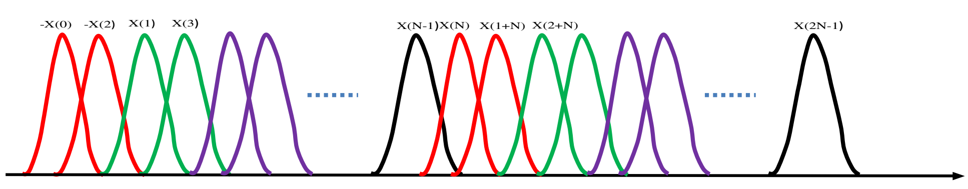


**Fig. 2.** Subcarriers at the transmitter with proposed MD-Self-Cancellation technique

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

If $Y_1'(k) \le Y_2'(k), Y_{min}'(k) = Y_1'(k)$

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

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

$$Y_{min}'(k+1) = \sum_{\substack{g'=0 \\ g=even}}^{N'-2} X'(g')S_1'(g' - k + 1) + W(k + 1) \quad (14)$$

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

$$Y_{min}''(k) = Y_{min}'(k) - Y_{min}'(k+1) = \sum_{\substack{g=0 \\ g=even}}^{N-2} X(g)S''(g - k) + W(k) - W(k + 1) \quad (15)$$

$$S_{min}''(g' - k) = -S'(g' - k - 1) + 2S'(g' - k) - S'(g' + 1 - k) \quad (16)$$

As seen in Equation (16) the minimum ICI coefficient is obtained. Due to the duplication of the transmitted signal, the bandwidth efficiency of the MD-Self-cancellation scheme is reduced by 1/4. To fulfill the demand bandwidth efficiency it is natural to use a larger signal size. For example, using in 5G technique when the bandwidth will be very large.

## 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 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 via IDFT. We shall use the same expression for equalizer coefficients are used as in [17].

## 4. Simulation Results

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

**Table 1**
Simulation parameters of a proposed downlink model

| Parameter | Description |
|---|---|
| System bandwidth | 5 MHz |
| Modulation type | QPSK |
| Cyclic prefix length | 20 samples |
| Transmitter IDFT length (M) | 512 symbols |
| Subcarriers spacing | 9.765625 kHz for M=512 |
| Input block length (N) | 128 symbols |
| Subcarriers mapping mode | Interleaved |
| CFOs (ε) | random=[-0.15,0.15] |
| Number of users (Z) | 4 |
| Channel model | AWGN and Vehicular A channels |
| Channel estimation | Perfect |
| Equalization | ZF, RZF, and MMSE |

Figure 3 demonstrates the relation between the regularization parameter β and the BER for the proposed MD-Self-Cancellation SC-IFDMA system with different SNR values to choice 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 $10^{-2}$. This value is used for the proposed system in RZF-FDE. On the other hand, the BER performance deteriorates for smaller and larger values of β, because we deal with a nonlinear minimization problem for the BER, which has a unique minimum. As a result, we have used β = $10^{-2}$ for the proposed system in RZF-FDE.

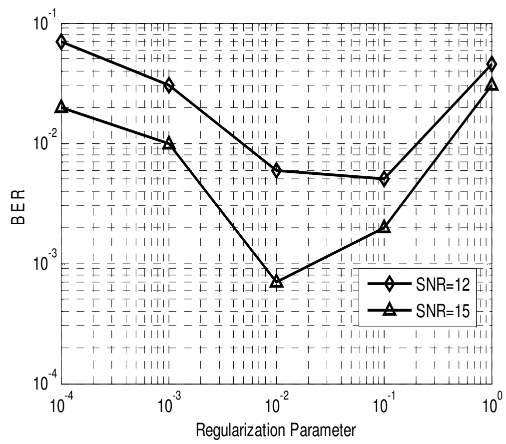


**Fig. 3.** BER vs. the regularization parameter for proposed MD-Self-Cancellation-SC-IFDMA system

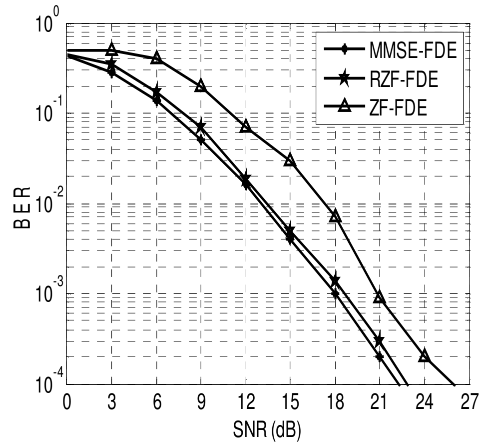


**Fig. 4.** BER of proposed MD-Self-Cancellation-SC-IFDMA system using ZF, RZF, and MMSE-FDEs

Figure 4 shows the BER performance of proposed MD-Self-Cancellation SC-IFDMA system using ZF, RZF (with β = $10^{-2}$), and MMSE FDES. The MMSE equalizer outperforms both ZF and RZF as shown in the results. For example, at BER = $10^{-4}$, MMSE outperforms RZF and ZF by 0.5 dB and 3.5 dB, respectively. According to this figure, it is observed MMSE-FDE is the best FDE, so it used for the proposed MD-Self-Cancellation SC-IFDMA system in all next results. The BER performance versus the SNR over AWGN for the proposed MD-Self-Cancellation-SC-IFDMA system has been shown in Figure 5. At BER =$10^{-4}$, the proposed MD-Self-Cancellation technique provides significant BER performance improvement of the SC-IFDMA system over the Self-Cancellation, SUD techniques and SC-IFDMA without CFO compensation by about 1.6 dB, 3.8 dB, and 8.1 dB, respectively.

The BER performance versus the SNR over Rayleigh channel with random CFOs for the proposed MD-Self-Cancellation-SC-IFDMA system is shown in the Figure 6. At BER =$10^{-3}$, The BER performance at SC-IFDMA without CFO degrades when using MD-Self-Cancellation, Self-Cancellation, SUD and without CFO compensation by about 1.3 dB, 2.1 dB, 3.6 dB and 5.6 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 without CFO compensation by about 0.9 dB, 2.3 dB, and 4.3 dB, respectively.

Figure 7 shows The BER variation with the maximum CFO for the proposed MD-Self-Cancellation-SC-IFDMA system is studied at SNR= 20dB. These figures show that the performance of the 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 system is by about $10^{-4}$ but for ε = 0.15 BER is increased about to $10^{-3}$.

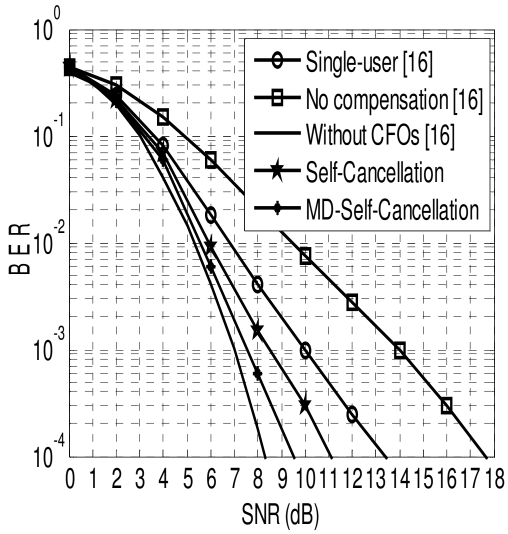


**Fig. 5.** BER of proposed MD-Self-Cancellation -SC-IFDMA system over AWGN channel

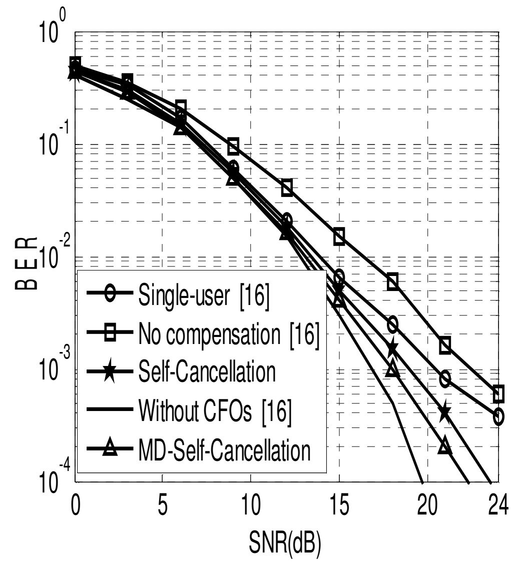


**Fig. 6.** BER of proposed MD-Self-Cancellation -SC-IFDMA system with random CFOs over Vehicular A channel

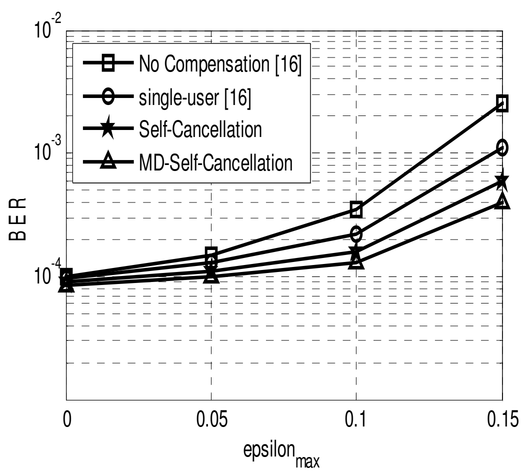


**Fig. 7.** BER vs. $\varepsilon_{max}$ for the proposed MD-Self-Cancellation-SC-IFDMA system at SNR=20 dB

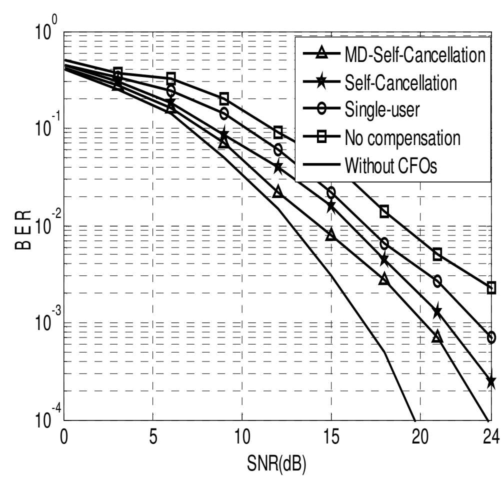


**Fig. 8.** BER against SNR for proposed MD-Self-Cancellation -SC-IFDMA system over Vehicular A channel at mobile speed 240Km/h

In high speed mobile, the BER performance against SNR for proposed MD-Self-Cancellation SC-IFDMA system over Vehicular A channel at a mobile speed of 240km /h with carrier frequency 2 GHz and Doppler spread 223Hz have been studied and shown in Figure 8. Each CFO is a random variable with uniform distribution in [−0.3, 0.3]. At BER $=10^{-3}$, The BER performance at SC-IFDMA without CFO degrades when using MD-Self-Cancellation, Self-Cancellation, and SUD by about 3.4 dB, 4.7 dB, and 6.7 dB, respectively. So, it is observed that the proposed MD-Self-Cancellation technique is better than Self-Cancellation and SUD techniques by about 1.3 dB and 3.1 dB, respectively.

## 4. Conclusion

In this paper, the effect of the CFOs problem on the performance of the SC-FDMA systems has been studied and introduced a new compensation technique to mitigate the effect of ICI caused by frequency offset in SC-FDMA 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 have shown that a significant performance improvement has been achieved with the proposed MD-Self-Cancellation technique better than SUD and conventional Self-Cancellation techniques. Also, at high speed mobile, the MD-Self-Cancellation technique provides a minimum degradation comparing to the conventional Self-Cancellation and SUD techniques. Because of the duplication of the transmitted signal, the bandwidth efficiency of the MD-Self-cancellation technique is reduced by 1/4. Despite this drawback, the proposed MD-self cancellation technique will be most suitable for a lot of application that requires minimum BER performance regardless of the increase in bandwidth.

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