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Transmission of Images using Single Carrier Systems with Different Equalization Schemes

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Abstract

Single-carrier frequency division multiple access (SC-FDMA) has been a better choice for increased system capacity in 4G wireless systems and is being redesigned to suit the needs of 5G and beyond 5G (B5G) wireless transmission. However, the existence of multiple access interference (MAI) due to carrier frequency offset (CFO) in multiuser systems has resulted in reduced system capacity. In this paper, we recommend a MAI elimination scheme to accomplish efficient image transmission over SC-FDMA system. It was shown that the proposed regularized zero-forcing (RZF) equalizer is useful in providing better initial estimates of interference and with successive interference cancellation (SIC), MAI can be cancelled successfully from the desired user. Furthermore we conduct several analyses to examine the performance of the image transmission system with different quality metrics such as peak signal to noise ratio (PSNR) and mean square error (MSE).

Key words: *carrier frequency offset, peak signal to noise ratio, regularized zero-forcing, mean square error.*

Introduction

The rapid increase in number of mobile users and increasing demand for mobile broadband services have initiated the need for increased bandwidth efficiency and capacity among cellular networks. Single carrier (SC) transmissions were first proposed to meet these challenges due to its low peak-to-average-power ratio (PAPR) and robust performance in the presence of CFO [1]. However in severe multipath channel SC signaling causes ISI. Orthogonal frequency division multiple access (OFDM) is capable of overcoming the effects of multipath and providing lower complexity with the use of fast Fourier transform (FFT) [2]. Nevertheless, such systems have high PAPR and hence require the power amplifier to have a large linear operating range and thus causing huge burden to low-cost mobile devices. SC-FDMA system has been focused for uplink communication due to its robust transmission over multipath fading channels. Compared to OFDM systems it accomplishes less PAPR and performance through frequency domain equalizers [3-6].

SC-FDMA employs discrete Fourier transform (DFT) as a coding matrix to the input data symbols before mapping of subcarriers and inverse-DFT (IDFT) is performed at the receiver as a decoding matrix after subcarrier demapping [7]. However, as an alternative to DFT discrete cosine transform (DCT) was investigated in [8], where DCT-SC-FDMA was studied and its performance was compared with DFT SC-SC-FDMA and OFDMA. DCT based systems have effective energy compaction property and thus reducing the effect of ISI arising in multipath fading channels [9]. Besides these choices SC-FDMA allows two main categories of subcarrier allocation. The first category is localized SC-FDMA (LFDMA), where the sub-bands of each user occupies a preallocated set of frequency bands. The second category is interleaved SC-FDMA (IFDMA) where the sub-bands of each user is distributed equidistantly over the entire frequency spectrum. IFDMA adds the merits of spread spectrum techniques with multicarrier transmission, but it is more prone to CFO errors and phase noise [10]. These CFO errors are more in a multiuser system due to non-identical local oscillators among the mobile devices in uplink transmissions and Doppler effect. Several reports have been extensively studied to mitigate the dreadful effects of CFO [11].

Transmission of images and multimedia data has attracted attention in many literatures [12]. The transmission of images using OFDM has gained additional attention in literature [13]. In [14] the issues related to coded and uncoded image transmission using OFDMA was studied under various operating parameters. It was shown that the interleaved systems are capable of offering enhanced performance over localized systems with less MSE. A performance comparison between SC-FDMA and OFDMA schemes for image transmission was performed in [15]. When considering efficient energy compaction property and improved interference rejection in image transmission an intelligent wireless network which can adaptably build and accurately realize the wireless communication system is required.

Equalization techniques are commonly utilized to reconstruct the transmitted images in SC-FDMA systems. These include maximum likelihood (ML) equalizer, matched filer (MF) receiver, zero-forcing (ZF) and minimum mean square error (MMSE) equalizer. Equalization techniques were used in multicarrier systems to upgrade the system performance [16-18]. Frequency domain equalization (FDE) was developed to mitigate ISI and improve system performance in multipath channels [19]. FDE is carried out in two possible modes namely post-equalization and pre-equalization [20-22]. In the case of SC-FDMA systems, the ML equalizer has high computational cost compared to other equalizers with increase in transmitting and receiving antennas [23]. Using MF equalizer with signals received through multipath increases interference at the receiver due to the coupling nature of multipath channels. The ZF equalizer and MMSE equalizer has less complexity compared to ML but lead to poor performance degradation. In addition, ZF equalizer is affected by noise amplification and MMSE equalizers requires the knowledge of noise and interference to obtain overwhelming performance in SC-FDMA systems.

Regularized zero-forcing (RZF) was studied in [24] for multiple access systems to reduce system complexity through direct matrix inversion. To enhance the performance of the system in channels with huge MAI for SISO systems, SIC has been studied in multicarrier systems [25]. In these studies it was revealed that MMSE based SIC achieves superior performance compared to ZF-SIC receivers. In this paper, the wireless system with interference is studied, and a DCT based structure for image transmission in SC-FDMA is proposed. The DCT based system utilizes frequency domain spread for image transmission by preserving the energy compaction property to achieve superior performance compared to DFT based SC-FDMA systems. Different from the traditional SC-FDMA architecture, this paper proposes an efficient MAI interference cancellation that can successfully detect interference for each user and eliminate it from the received signal. The main motivation is to propose RZF-SIC equalization scheme for image transmission using DCT SC-FDMA communication system. Simulation results revealed that a dramatic enhancement in bit error rate (BER) is possible over conventional RZF schemes. It was also shown that the proposed equalization scheme is capable of enhancing BER performance compared to other equalization algorithms in channels with severe CFO estimation errors and with variations in normalized CFO for image transmission.

The remainder of the article is organized as follows: The system architecture of DFT based SC-FDMA system is described in section 2. Section 3 presents joint FDE and CFO compensation techniques for DCT based SC-FDMA system and section 4 discusses SIC detection to improve the system performance of IFDMA systems. In section 5, we describe image transmission with the proposed RZF-SIC with simulation results. Finally, section 6 presents the conclusions.

DCT SC-FDMA system with Joint FDE and CFO Compensation

DCT provides excellent energy compaction characteristics and thus reduces ISI to a large extent. These results in improving the BER performance of DCT based SC-FDMA system. At the transmitter the gray scale image is considered as a basic input image which is converted in to a binary format suitable for transmission. The DCT output from the modulator is represented as

$$X(k)=\sqrt{\frac{2}{N}}\beta(k)\sum_{n=0}^{N-1}x(n)\cos\left(\frac{\pi k(2n+1)}{2N}\right),k=0,1,\dots N-1 \quad (1)$$

where $x(n)$ is the modulated data to be transmitted and

$$\beta(k)=\begin{cases}\frac{1}{\sqrt{2}}, & k=0\\ 1, & k=1,2,\dots N-1\end{cases}. \quad (2)$$

The modulated data is mapped using interleaved and localized mapping and then IDCT is performed to obtain a time domain signal

$$S(m)=\sqrt{\frac{2}{M}}\beta(k)\sum_{l=0}^{M-1}s(l)\,\beta(l)\cos\left(\frac{\pi l(2m+1)}{2M}\right),m=0,1,\dots M-1 \quad (3)$$

where $s(l)$ is the subcarrier mapped data. After appending a suitable CP which is enough to avoid ISI, the data is transmitted over the wireless channel represented as

$$X_u=P_{CP}C_M^{-1}S_u^TC_NX. \quad (4)$$

In equation (3) P_{CP} is CP. C_M^{-1} is the inverse DCT matrix corresponding to the transmitted data. C_N is the DCT matrix. The mapping matrix corresponding to localized and interleaved mapping is given by

$$S_u^T=\left[0_{(u-1)N\times N,I_N,}0_{(Q-u)N\times N}\right]^T, \quad (5)$$

$$S_u^T=\left[0_{(u-1)\times N},u_1,0_{(Q-1)\times N},u_2,\dots u_N,0_{(Q-u)\times N}\right]^T, \quad (6)$$

where I_N and $Q'\times N$ are identity and zero matrix. u_n is $1\times N$ matrix with zero elements. The CP discarded data at the BS is represented as

$$Y=\sum_{u=0}^{U-1}\eta_uH_uX_u+n, \quad (7)$$

where η_u is the CFO matrix. $\eta_u=e^{j2\pi\epsilon_um/M},m=0,1,\dots,M+N_c-1$. H_u is uth users channel denoted as

$$H_u=\begin{bmatrix} h_u(0) & 0 & \cdots & . & 0 & h_u(N_c-1) & h_u(1)\\ h_u(1) & h_u(0) & \ddots & . & . & 0 & h_u(2)\\ \vdots & h_u(1) & \ddots & . & . & \ddots & \vdots\\ . & \vdots & \ddots & . & . & \ddots & h_u(L-1)\\ h_u(L-1) & & \cdots & . & . & \ddots & 0\\ \vdots & \vdots & \vdots & . & & \vdots & \ddots\\ 0 & 0 & \cdots & 0 & h_u(L-1) & . & h_u(0)\end{bmatrix} \quad (8)$$

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The received signal is subjected to DFT to obtain

$$Y = F_M Y = \sum_{u=1}^{U} \Psi_u^{cir} \pi_u \bar{X}_u + N. \quad (9)$$

In equation (7), $\Psi_u^{cir} = F_M E^u F_M^{-1}$ and $\bar{X}_u = F_M x_u$. π_u represents a diagonal matrix of channel. The desired user's data corresponding to the *g*th user is given by

$$Y_g^d = \Psi_g^d \pi_g^d X_g + \underbrace{\sum_{u=0, u\neq g}^{U-1} \Psi_u^I \Lambda_u^d X_u + N_d}_{R_u^I} \quad (10)$$

where $\Psi_g^d = S_g^R \Psi_g^{cir} S_g^T$. The term R_u^I denotes the interference caused doe to CFO and ISI. The joint equalization and CFO removal has become one of the major concerns in recovering the desired data from the received signal. In single user detection the CFO is removed at the BS in time domain and DFT processing in performed. This two stage detection degrades the system performance due to variations in frequency offset of neighboring subcarriers. In the case of ZF equalization the ISI is removed in frequency domain resulting in improved performance compared to single user detectors. The weights for ZF is given by

$$W_g^{ZF} = \left(\Psi_g^{EH}\, \Psi_g^E\right)^{-1} \Psi_g^{EH}, \quad (11)$$

where $\Psi_g^E = \Psi_g^d \pi_g^E$. ZF equalization does not compensate the effects of noise and MAI. This causes enhancing the distortion and results in poor BER performance at the receiver. Hence interference cancellation techniques are essential in achieving better performance.

MMSE –SIC and MAI Suppression in DCT SC-FDMA Systems

In uplink image transmission, the detectors used at the BS have to perform equalization, CFO and MAI elimination. The conventional detectors fail to detect the data without using the interfering user's data. MMSE detection techniques with SIC causes extensive up gradation in the estimation of initial data resulting in better support of multipath gain over other techniques. MMSE performs detection using the information of data, noise and channel information. The weights associated with the MMSE channel coefficients is given by

$$w_g^{MMSE} = \left(\Psi_g^{EH} \Psi_g^E + \sum_{u=1, u\neq g}^{U} \Psi_u^{EH} \Psi_u^E + (1/SNR) I_N \right)^{-1} \Psi_g^{EH}. \quad (12)$$

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In Equation (13), MMSE uses the channel knowledge, noise and interference to detect the user's data. This results in increasing the complexity in estimating the SNR and interference.

DCT based IFDMA systems are severely affected at higher values of CFO; this causes the residual MAI after MMSE equalization to degrade the BER performance. This can be minimized by combining MMSE with SIC to enhance the performance of the system and to overcome the residual MAI. SIC works in two stages. In the initial stage, the data symbols of all the interfering users are detected in sequential manner using MMSE equalization. In the next stage, the estimated interference is cancelled from the received signal. This process is repeated until the interference caused by all the interfering users are cancelled successively to eliminate the residual MAI and to improve the signal detection. The *u*th interfering users data estimate after MMSE equalization, IDFT and DCT demodulation is given by

$$b_u^{\wedge} = sgn\left(D_M^H w_{MMSE}^g Y_g^d\right) \quad (13)$$

After regeneration of each interfering user the received signal is successively subtracted with the regenerated data to cancel the interference and reconstruct the useful signal. The use of RZF during interference cancellation causes better performance with less complexity. Finally the interference eliminated signal is demodulated and detected to obtain the desired image from the received signal.

Simulation and Performance Analysis

Extensive simulations are being performed in this study to examine and assesse the image transmission using DCT SC-FDMA system. The cameraman image is considered for the analysis. The basic image is DCT precoded and mapped using localized and interleaved mapping and transmitted over the wireless channel under different SNR values and their performance is measured. In order to study the accuracy of the proposed system, we consider a random multipath channel for analysis and we measure the performance in terms of BER, PSNR and MSE. The PSNR is given by

$$PSNR\ (dB) = 10log_{10}\left(\frac{f_{max}^2}{RMSE^2}\right), \quad (14)$$

The RMSE is given by

$$RMSE = \sqrt{\frac{\sum_{i=1}^{P}\sum_{j=1}^{P}\left(I_0(i,j) - I_r(i,j)\right)^2}{P^2}}\ , \quad (15)$$

where P^2 is a total pixel in the image. I_0 and I_r are the generated and recovered images. As shown in the Figure 1, we consider a cameraman image with size 256 x 256. To study the performance of DCT SC-FDMA in image transmission both IFDMA and LFDMA schemes

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are considered to show the efficiency in terms of MSE and PSNR. The CFO value considered in the simulation is $\epsilon_u = [-0.05, 0.05]$.

Figure 1. Cameraman Image



(i) ZF with LFDMA (ii) MMSE with LFDMA (iii) RZF with LFDMA



(iv) ZF with IFDMA (v) MMSE with IFDMA (vi) RZF with IFDMA

Figure 2. Reconstructed image for DCT SC-FDMA system for SNR = 15 dB.

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(i) ZF with LFDMA (ii) MMSE with LFDMA (iii) RZF with LFDMA

(iv) ZF with IFDMA (v) MMSE with IFDMA (vi) RZF with IFDMA

Figure 3. Reconstructed image for DCT SC-FDMA system with SIC for SNR = 15 dB.

The PSNR values for the reconstructed image with different mapping techniques for the cases of ZF, MMSE and RZF is shown in Figure 2 and Figure 3. It can be observed that at SNR = 15 dB better performance is achieved for the reconstructed image using SIC compared to conventional system. Furthermore, it can be observed that MMSE and RZF achieve close performance. This shows that at high SNR values the performance of RZF is a best choice showing improved performance with low complexity compared to MMSE and ZF.

Figure 4 shows the PSNR vs SNR comparison among different equalization schemes for both LFDMA and IFDMA schemes. The PSNR performance shows that MMSE based LFDMA and IFDMA outperforms over ZF and RZF based equalization techniques. However it can be noticed that RZF based system also performs equally compared to MMSE showing its supremacy over MMSE with less complexity. At SNR=20 dB RZF based DCT SC-FDMA system has a PSNR gain of 8 dB compared to ZF. These results show that DCT SC-FDMA system is capable of improving the system performance during the transmission of images compared to conventional systems.

Figure 5 shows the performance of DCT SC-FDMA system for the recovered image in terms of MSE for different values of SNR. The comparison is depicted for different equalization schemes to study the system performance with optimum equalization technique. It can be visualized from the plot that MMSE based system achieves best performance in terms of less MSE compared to other systems. This is mainly due to its excellent energy compaction characteristics of DCT based SC-FDMA system.

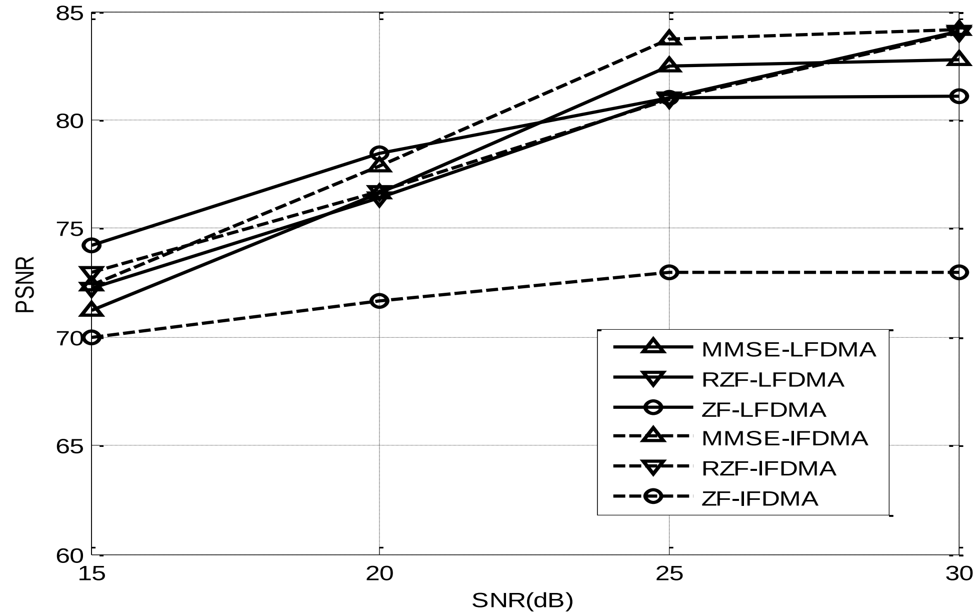

Figure 4. PSNR versus SNR for DCT SC-FDMA system

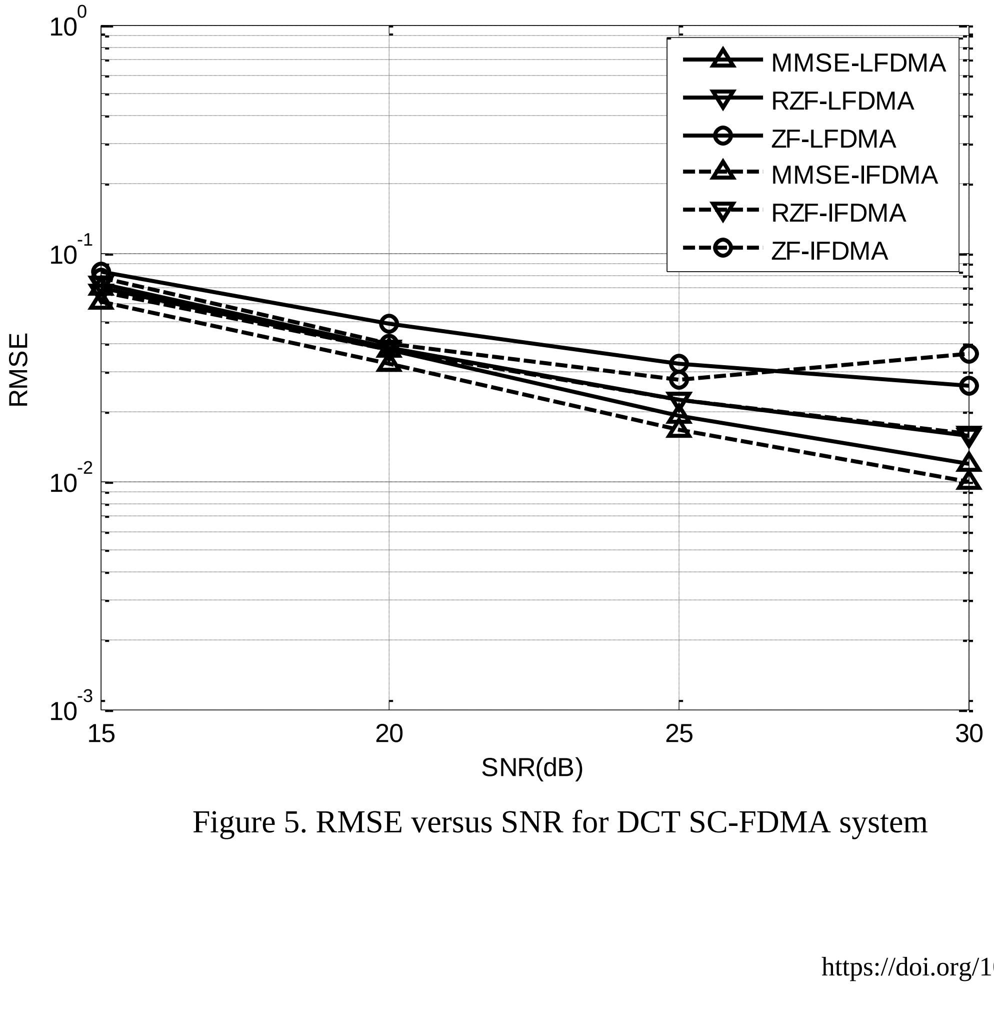

Figure 5. RMSE versus SNR for DCT SC-FDMA system

CONCLUSION

In this paper transmission of images using DCT based SC-FDMA NOMA is studied using different equalization techniques. The performance of the system is compared using different equalization techniques and it was shown that with SIC interleaved system is capable of achieving improved performance over conventional systems. The simulation analysis has shown that considerable improvement in PSNR and reduced MSE is obtained with DCT based SC FDMA system with RZF. The performance analysis has further revealed that the use of RZF has resulted in achieving better performance with less complexity.

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