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An Efficient Transmission of Image over SC-FDMA System in The Presence of CFO

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***Abstract*— The image transmission over wireless communication system requires high reliability of the received signal with high data rate during the transmission. This paper investigates and analyzes the impacts of CFOs on wireless image transmission when SC-FDMA system is used with different subcarriers mapping schemes, and different channel models as well as different CFO compensation schemes. Mean Square Error (MSE) and Peak Signal to Noise Ratio (PSNR) are the two performance metrics that are used for evaluating the quality of the received images. The simulation results show that CFOs disturb the orthogonally among the subcarriers in SC-FDMA systems and degrade PSNR and MSE performances of the SC-FDMA system. Furthermore, the simulation results bring out the effectiveness of the suggested compensation scheme to remove the impact of CFOs and enhance the clarity of the received image. The results also show that SC-FDMA system provides better performance when the Localized subcarrier and MMSE compensation schemes are used.**

Keywords*— *CFO, SC-FDMA, image transmission, PSNR, MSE, Single-User, MMSE.

I. Introduction

The wireless image transmission are widely used in many different applications in our life such as remote sensing via satellite, nuclear medicine, telemedicine, teleconferencing, broadcast television and accessing internet services on mobile phones and other applications. Therefore, increasing demands for wireless image transmission has recently attracted attention of a lot of researchers. Thus, many works and researches have been done to development of numerous techniques for image transmission over wireless noisy channels. These techniques are improved from generation to another. One of the most recent techniques that were developed is SC-FDMA system which is adopted by 3rd Generation Partnership Project Long Term Evolution (3GPP-LTE) for uplink transmission [1]. SC-FDMA system has inherent advantages of OFDMA. In addition, it can utilize orthogonal frequency multiplexing, single carrier modulation and frequency domain equalization to improve PAPR performance. However, SC-FDMA suffers some challenges and the critical one of them is CFO which leads to inter-carrier interference (ICI) and multiple access interference (MAI) [2]. Feedback and compensation methods are proposed to reduce and mitigate the effects of CFO when SC-FDMA system is used for uplink transmission [3-5].

In previous research paper [6], the impact of the CFOs on the performance of the Discrete Fourier Transform SC-FDMA (DFT-SC-FDMA) and the Discrete Cosine Transform SC-FDMA (DCT-SC-FDMA) systems was investigated and new MMSE scheme has been proposed. Additionally, a hybrid scheme comprising the proposed MMSE scheme and a Parallel Interference Cancellation (PIC) stage has been suggested and investigated to further enhance the performance of interleaved subcarriers mapping systems. In the simulation results, the Bit Error Rate (BER) performance has been used.

In this paper, the first contribution is to investigate and analyze the impacts of CFO on SC-FDMA performance with consideration of different subcarriers mapping schemes where the localized subcarrier mapping (LFDMA) and interleaved subcarrier mapping (IFDMA) schemes are used. Furthermore, different channel models are taken into account where Vehicular A and Stanford University Interim (SUI) models are used. In addition, different CFO compensations are considered including the single user and the Minimum Mean Square Error (MMSE) techniques.

The second contribution is investigation and examination of wireless image transmission over a recent SC-FDMA system in the presence of CFO. These data types require high quality of services. For obtaining comparative results, the measures that are used for evaluating the quality of the received image are MSE and PSNR [7]. To the authors' knowledge, these contributions collectively are not considered in the available literature.

The rest of the paper is organized as follow. An overview of related work is presented in Section 2. Section 3 shows system model. Section 4 presents CFO compensation methods. Section 5 discusses the simulation results. Finally, Section 6 concludes this work.

II. Related Work

There are several works in the literature that have dealt with the image transmission over wireless systems and other works have considered the impacts of CFOs on SC-FDMA performance but no work has considered the impact of CFO on the wireless image transmission. This section mainly focuses on some of those previous works. In [8], BPSK modulation technique is used to evaluate the performance of image transmission over OFDM system using MC-CDMA.

OFDM system with 16-QAM is used to analyze transmission of three gray scale images of size (200 x 320) with presence of generalized K-fading channel in [9]. An asymmetric modulation method known as Hierarchical Quadrature Amplitude Modulation has been proposed for the transmission of images over erroneous wireless channels in [10]. In [11], a selective approach for wireless image transmission has been proposed with consideration of both the channel state information (CSI) and the image information to design the system. In [12], joint source channel coding with consideration of MIMO-OFDM has been used to propose an efficient image transmission system over hybrid wireless network. In [13], OFDM system has been used to analyze the performance of image transmission through Rayleigh channel with BPSK, QPSK, 16-QAM, and 64-QAM modulation techniques. Transmission of a watermarked image by using OFDM system over AWGN wireless channel is analyzed using 16-PSK and 16-QAM modulation systems in [14].

The effect of CFO on DFT-S-OFDM system was analyzed for both single user and multiple user accessing scenarios in [15]. In [16], the impact of CFOs on SC-FDMA-IDMA was investigated with considering an uncoded system and an Additive White Gaussian Noise (AWGN) channel model. A semi-blind CFO estimation scheme for SC-FDMA system with interleaved allocation using parallel factor (PARAFAC) analysis was proposed in [17]. In [18], the CFO compensation problem in SC-IFDMA was studied. The authors have applied the linear decorrelation multi-user detection technique and proposed a new low-complexity time domain linear CFO compensation scheme, which is referred to as TD-LCC. In [19], a suppression method has been proposed with exploitation of block type pilots to overcome the multi CFOs problem. The effect of CFO on the performance of LTE uplink system is analyzed and investigated with respect to varying modulations schemes and different amount of offset in [20]. In [21], the impacts of CFO on the received OFDM signal are examined with considering to three different CFO estimation techniques in terms of their MSE.

From the previous survey, it is noted that not research has considered the impacts of CFOs on wireless image transmission when SC-FDMA system is used with different subcarriers mapping schemes, and different channel models, which is the main objective of this work.

III. SC-FDMA System Model in The Presence of CFO

In this section, the SC-FDAM model is described for two different subcarrier mapping methods, namely, localized and interleaved. Fig. 1 depicts structure of the uplink SC-FDMA system in the presence of CFOs. Let's consider an LTE uplink SC-FDMA system where data is being transmitted by U users and a total number of M subcarriers with N subset of subcarriers for each user, i.e. $U=M/N$.

At the transmitter, the encoded data is mapped into multilevel sequence of complex numbers in one of the possible modulation formats. Afterwards, the modulated symbols are grouped into blocks, each containing N symbols. Then, the next step is to perform N-DFT after which the signal can be expressed as follows:

$$X_k = \sum_{i=0}^{N-1} x_i e^{\frac{-j2\pi nk}{N}}\ ,\ k=0,\ 1,\ \ldots,\ N\text{-}1 \qquad (1)$$

Where $\boldsymbol{x_i}$ is the modulated symbol and $\boldsymbol{X_k}$ is the frequency domain sample. The resulting signal is then mapped into M carrier amplitudes which are transformed to complex time domain signals by the *M-point* Invers DFT (IDFT). Then the result signal can be formulated as follows:[2]

$$\bar{x}_m = \frac{1}{M}\sum_{l=0}^{M-1} \bar{\mathcal{X}}_l e^{\frac{j2\pi ml}{M}} \qquad , m = 0,1, \ldots, M-1 \qquad (2)$$

Where $\bar{\mathcal{X}}_l$ represents the frequency-domain samples after the subcarriers mapping scheme. After that, cyclic prefix of length N_c is inserted at the head of IDFT outputs to reduce the Inter-Symbol Interference (ISI) effect. Finally, the uplink signal is transmitted through the wireless channel and the received signal can be expressed as the following formula [5]:

$$\tilde{\boldsymbol{z}} = \sum_{\boldsymbol{u}=\boldsymbol{1}}^{\boldsymbol{U}} \widetilde{\boldsymbol{D}}^{\boldsymbol{u}}\, \boldsymbol{G}^{\boldsymbol{u}} \tilde{\boldsymbol{x}}^{\boldsymbol{u}} + \widetilde{\boldsymbol{W}} \qquad (3)$$

Where $\widetilde{\boldsymbol{D}}^u$ is an $(M+N_C-1) \times (M+N_C-1)$ diagonal matrix with elements $[\widetilde{D}^u]_{m,m} = e^{\frac{j2\pi m\varepsilon_n}{M}}$, $m=0,\ldots, M+N_C-1$, which describes the CFO of the u^{th} user. $\varepsilon_n=\Delta fT$ is the normalized CFO of the u^{th} user where T is the sampling time and Δf is the carrier frequency offset. $\boldsymbol{G}^u$ is an $(M+N_C-1)\times(M+N_C-1)$ matrix describing the channel of the u^{th} user. $\tilde{\boldsymbol{x}}^u$ is an $(M+N_C-1)\times 1$ vector containing the transmitted samples after the cyclic prefix of the u^{th} user. $\widetilde{\boldsymbol{W}}$ is an $(M+N_C-1)\times 1$ AWGN noise vector.

At the receiver side, the opposite operations are performed. The first step is to remove the CP and to apply the M-DFT. The frequency domain received signal is given by:

$$\boldsymbol{R} = \sum_{\boldsymbol{u}=\boldsymbol{1}}^{\boldsymbol{U}} \boldsymbol{\mathcal{P}}_{\boldsymbol{c}}^{\boldsymbol{u}}\, \boldsymbol{L}^{\boldsymbol{u}} \bar{\boldsymbol{X}}^{\boldsymbol{u}} + \boldsymbol{W}_{\boldsymbol{DF}} \qquad (4)$$

Where $\boldsymbol{\mathcal{P}}_c^u = \boldsymbol{F}_M \boldsymbol{D}^u\, \boldsymbol{F}_M^{-1}$ is a circulant matrix representing the CFO from the u^{th} user, $\boldsymbol{F}_M$ is an $M\times M$ DFT matrix and its inverse DFT (IDFT) is $\boldsymbol{F}_M^{-1}$, $\boldsymbol{L}^u$ is an $M\times M$ diagonal matrix represent the channel in the frequency domain, $\bar{\boldsymbol{X}}^u = \boldsymbol{F}_M \bar{\boldsymbol{x}}^u$ is an $M\times 1$ vector representing the transmitted samples from the u^{th} user after the mapping process, $\boldsymbol{W}_{DF}$ is the DFT of $\boldsymbol{W}$. After the demapping process, the equalization and the N-point IDFT are applied to estimate the modulated time-domain symbols of k^{th} user. Finally, the detection and the decoding processes take place in the time domain.

IV. Effect of CFO and Compensation

Despite all the common advantages of SC-FDMA, however SC-FDMA system highly suffers from CFO. It leads to dissolves the orthogonality among uplink users and between uplink users and base station (see Fig. 2).

The normalized CFO has two parts, first part is called integral CFO (IFO) and the second part is fractional CFO which causes the leakage of the orthogonality between the sub-carriers. Consequently, in the literature survey many methods and algorithms have been proposed to estimate and suppress CFO. All those researches can be categorized into two classes: feedback and compensation. In the first method, the base station receiver estimates the CFO for every sender separately.

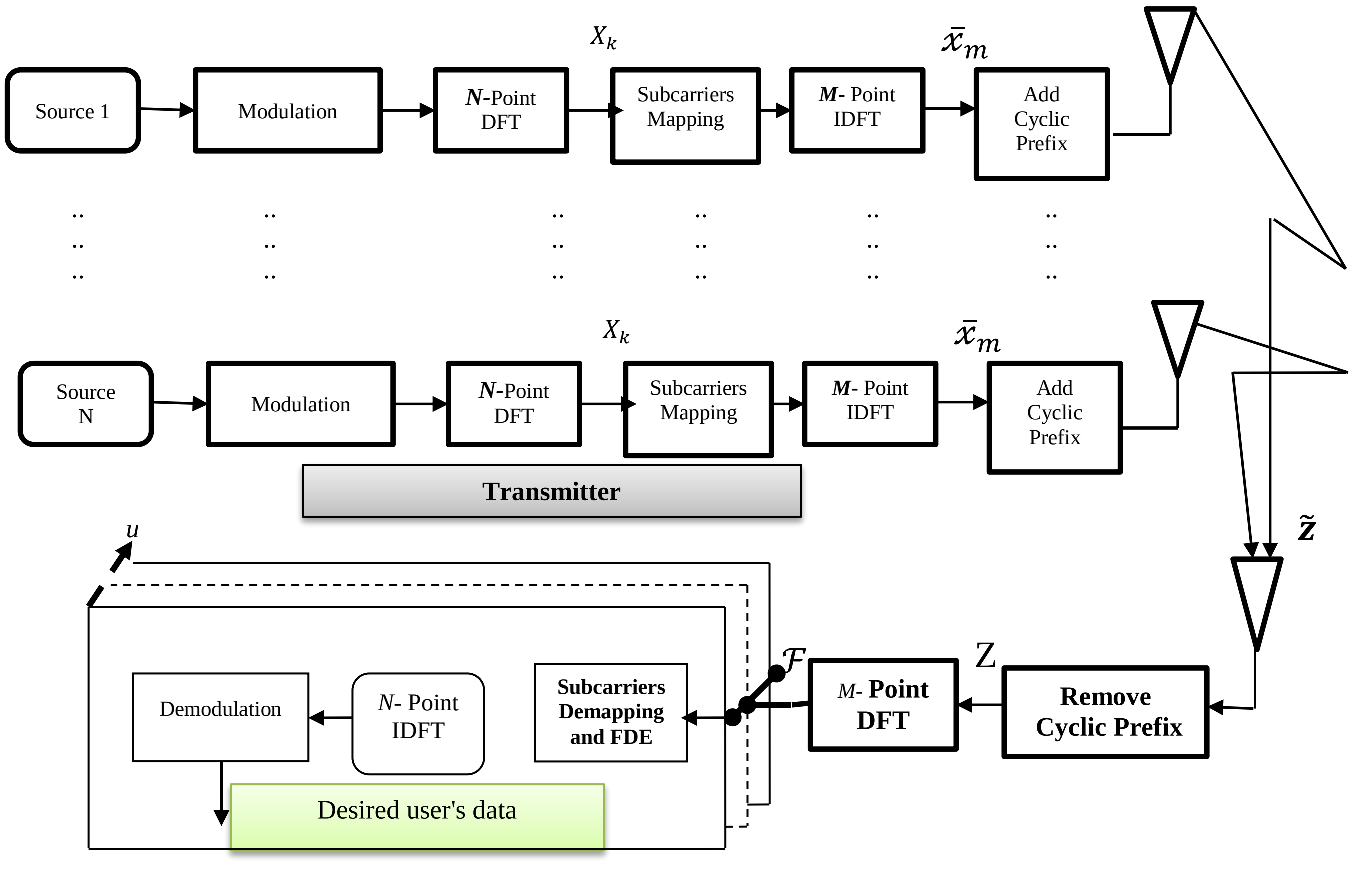

Fig. 1. Structure of the uplink SC-FDMA system in the presence of CFOs.

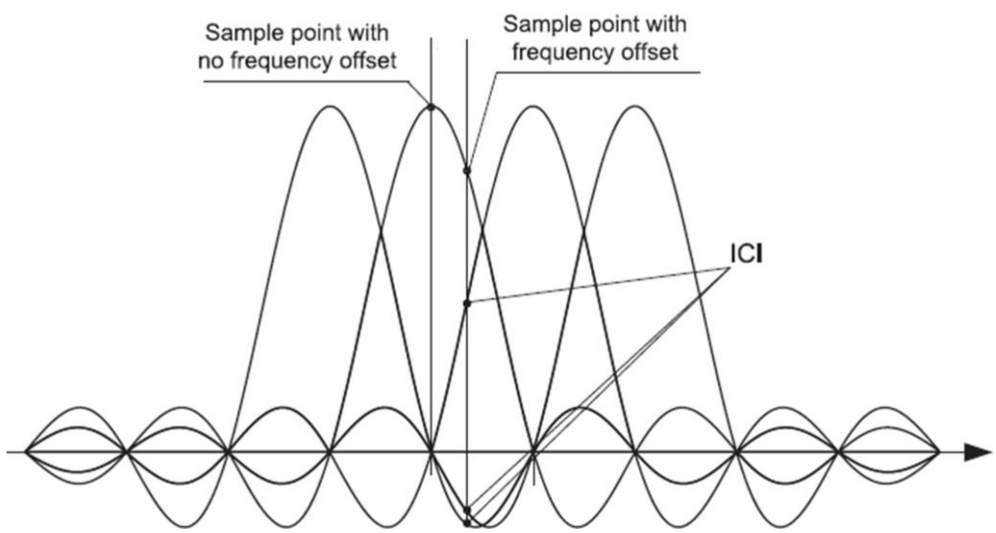

Fig. 2. FDMA signal with frequency offset

The measured CFOs are sent backward to the senders which adjust their local oscillations accordingly. In the second method, synchronization is accomplished at the base station by CFO estimation and compensation [3], [15]. The common techniques of this method are Single-User Detector and MMSE.

A. Single-user detector

In the single-user technique, once the BS receives the arrival signal it compensates CFO for each user based on the samples of time domain, and then DFT-processed for each user are used as shown in Fig. 3. The single-user detector is applied on the equation (3) as follows:

$$\boldsymbol{Z}' = \widetilde{\boldsymbol{T}}^{k*}\tilde{\boldsymbol{z}} = \boldsymbol{G}^{k}\tilde{\boldsymbol{x}}^{k} + \widetilde{\boldsymbol{T}}^{k*}\sum_{u=1,\neq k}^{U} \boldsymbol{D}^{u}\boldsymbol{G}^{u}\tilde{\boldsymbol{x}}^{u} + \widetilde{\boldsymbol{T}}^{k*}\boldsymbol{W} \qquad (5)$$

Where $\tilde{\boldsymbol{z}}$ is the arrival signal at the receiver site, $\widetilde{\boldsymbol{T}}^{k*}$ is an $(M + N_C\text{-}1) \times (M + N_C\text{-}1)$ diagonal matrix which describes single-user CFOs compensation.

B. Joint MMSE Equalization and CFOs compensation scheme

In this subsection, joint MMSE equalization and CFOs compensation is suggested. It is called MMSE. The MMSE technique is performed in the frequency domain to accomplish CFOs compensation in the SC-FDMA systems. In this technique, single DFT stage is required for all users as shown in Fig. 4. The received signal after the demapping process can be described as the following equation:

$$\boldsymbol{R}_d^k = \boldsymbol{P}_P^k\boldsymbol{X}^k + \boldsymbol{N}_p \qquad (6)$$

Where $\mathbf{P}_{\mathrm{P}}^{\mathrm{k}} = \boldsymbol{P}_{\mathrm{d}}^{\mathrm{k}}\boldsymbol{L}_{\mathrm{d}}^{\mathrm{k}}$ is the N×N interference matrix of the k^{th} user, $\boldsymbol{P}_{\mathrm{d}}^{\mathrm{k}}$ is a circulant matrix representing the ICI interference from the k^{th} user and $\boldsymbol{L}_{\mathrm{d}}^{\mathrm{k}}$ is an $N \times N$ diagonal matrix containing the channel in the frequency domain after the demapping process of k^{th} user, $\boldsymbol{X}^k$ is the transmitted symbols, $\boldsymbol{N}_P$ is an $N\times 1$ vector representing the noise after the demapping process and given by $\boldsymbol{N}_P = \sum_{u=1,u\neq k}^{U}\boldsymbol{P}_{R_d}^{u}\boldsymbol{X}^u + \boldsymbol{N}_d$ is the MAI-plus-noise matrix where $\boldsymbol{P}_R^u = \boldsymbol{P}_r^u\boldsymbol{L}_d^u$ is the $N\times N$ interference matrix from the u^{th} user.

After the joint MMSE equalization and CFOs compensation scheme, the frequency-domain samples of the k^{th} user can be written as follows:

$$\overline{\boldsymbol{R}}^k = \boldsymbol{W}_{MMSE}^k\,\boldsymbol{R}_d^k \qquad \textbf{(7)}$$

where W_{MMSE}^k is the CFOs compensation matrix. It is given by:

$$\boldsymbol{W}_{\boldsymbol{MMSE}}^{\boldsymbol{K}} = (\boldsymbol{P}_p^k\ \ \boldsymbol{P}^{k^H} + (1/SNR)I_N)^{-1}\boldsymbol{P}^{k^H} \qquad (8)$$

Finally, an N-point IDFT, demodulation, and decoding processes are performed. The main advantage of the CFOs MMSE scheme is that it minimizes the MAI and the noise. Thus, the residual MAI is lower than that in the single-user detector.

V. Subcarriers Mapping Methods

There are some techniques for mapping symbol transmission to SC-FDMA subcarriers. The most widely used subcarrier mapping techniques are namely Interleaved and Localized mapping techniques [22-23]. The first mode is the localized SC-FDMA (LFDMA) in which the scheduler assigns consecutive subcarriers to convey information from a particular user. The second mode is interleaved SC-FDMA (IFDMA) in which the users are assigned distributed subcarriers over the entire frequency band. Fig. 5 shows general view of localized and distributed mapping technique.

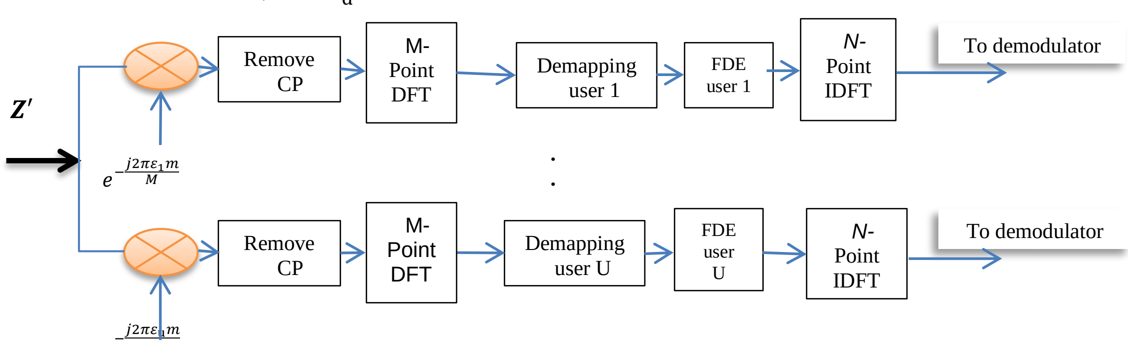

Fig. 3. The single-user detector for the SC-FDMA system.

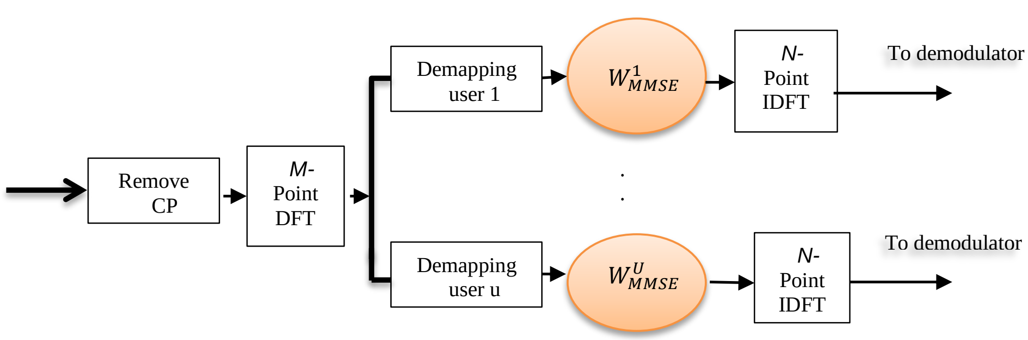

Fig. 4. The CFOs MMSE compensation scheme for the SC-FDMA system

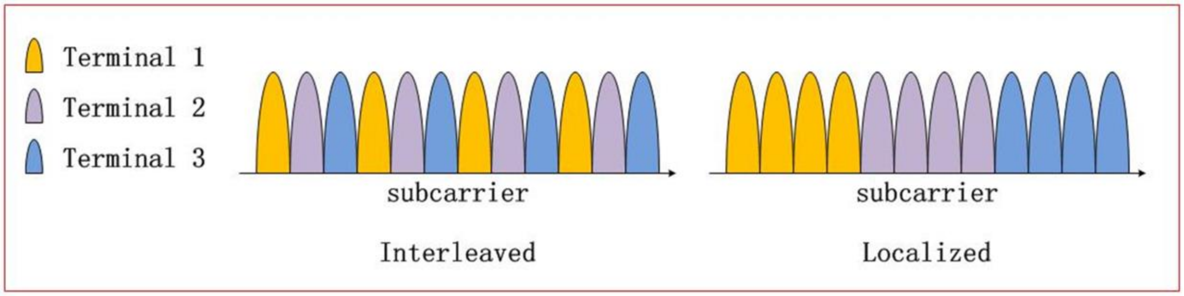

Fig. 5. Localized and Interleaved mapping technique

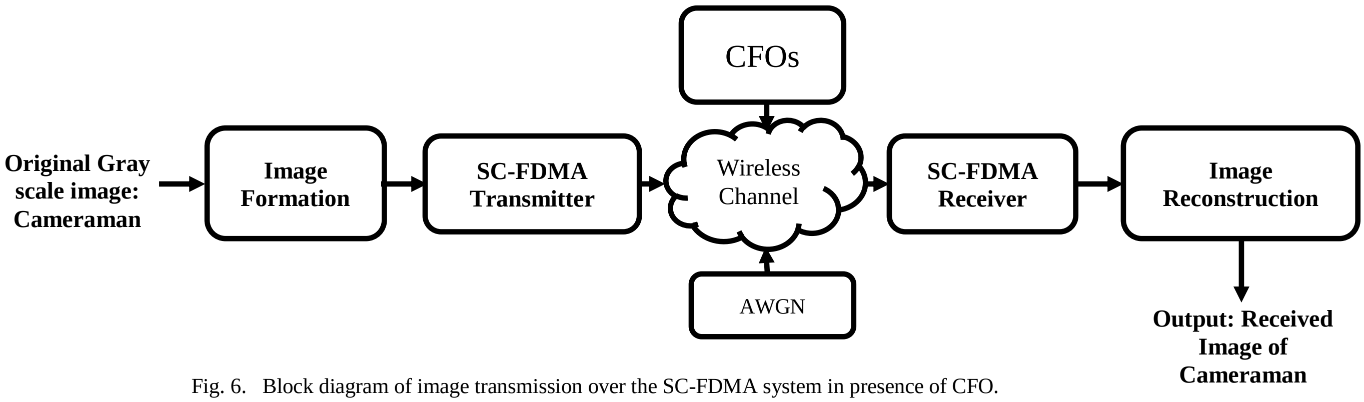

Fig. 6. Block diagram of image transmission over the SC-FDMA system in presence of CFO.

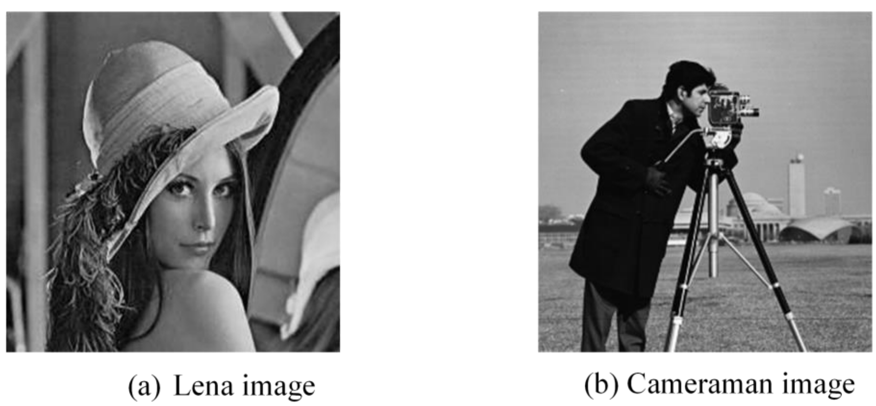

Fig. 7. Cameraman and Lena images

VI. Simulation Results and Discussion

This section is divided into four subsections: the first subsection summarizes image transmission principles over SC-FDMA, the second subsection shows the simulation parameters and finally the third and the fourth subsections present and discuss the results with Vehicular A channel model and SUI3 channel model respectively.

A. Image Transmission Principles over SC-FDMA

One of the contributions in paper is the wireless image transmission over SC-FDMA system in the presence of CFOs with and without CFO compensation as shown in Fig 6. The Cameraman and Lena images are used (see Fig. 7).

As shown in Fig. 6, the first step is the images formation by which the original image is transformed into a form that can be processed by SC-FDMA transmitter. The second step is to send the processed image through wireless channel that is subjected to frequency selective channel fading, CFOs and AWGN. At the receiver, the received image is reconstructed with and without CFOs compensation. The quality of the reconstructed image will be compared to the original transmitted image by using two metrics MSE and PSNR. PSNR represents the ratio between the maximum possible power of a signal and the power of the corrupting noise that affects the fidelity of this signal. It can be calculated by the following formula [24]:

$$PSNR = 10 \log\left(\frac{f_{max}^2}{MSE^2}\right) \quad (9)$$

Where f_{max} is the maximum pixel value in the image. On the other hand, the MSE is defined as the following:

$$MSE = \frac{\sum_{i=1}^{M}\sum_{j=1}^{M}\left(I_o(i,j) - I_r(i,j)\right)^2}{M^2} \quad (10)$$

where M is number of pixels and I_o and I_r are the transmitted and the received images, respectively.

B. Simulation Parameters

Experimental results have been carried out by using MATLAB simulator to study the impact of CFOs on SC-FDMA. The details of the simulation parameters are tabulated in Table 1.

TABLE 1: MATLAB SIMULATION PARAMETERS

Parameter	Description
N	32
M	128
U	4
Channel Models	vehicular A and SUI3
Channel Coding	Convolutional code with rate 1/2
Image Size	cameraman and Lena images of size 256x256
Subcarriers mapping mode	IFDMA and LFDMA
Modulation scheme	QPSK
Noise environment	AWGN
CFO Compensation	Single-User and MMSE
Channel bandwidth	5 MHz
Cyclic prefix (CP)	20 samples

All of the following obtained results of both PSNR and MSE of the received image are presented for the LFDMA and IFDMA systems in the absence of CFOs and the presence of CFOs for different compensation schemes. In all results different SNR values are used from 0 through 30 dB with 5 dB steps.

C. Vehicular A Model

The first sets of the results are carried out with consideration of Vehicular A channel model.

a) PSNR Performance:

The PSNR values are tabulated in Table 2 for LFDMA and IFDMA systems.

Figs. 8 and 9 show the comparison in PSNR performance as SNR is varied when the image is received and reconstructed. From these figures, it is deduced that the PAPR increases as SNR increases. Furthermore, it is noted that when MMSE is used then the PSNR performance is better than single-user.

The reason behind this result is that single-user completely removes the ICI and does not remove MAI from the other users [25, 26]. In addition, it is clear that the PSNR performance is slightly better when IFDMA subcarrier is used than LFDMA subcarrier. These figures also show that IFDMA system is more sensitive from CFOs than LFDMA, because LFDMA is more robust to MAI than IFDMA [25].

b) MSE Performance

In this subsection, MSE performance is examined and tested. The obtained MSE values are summarized in Table 3.

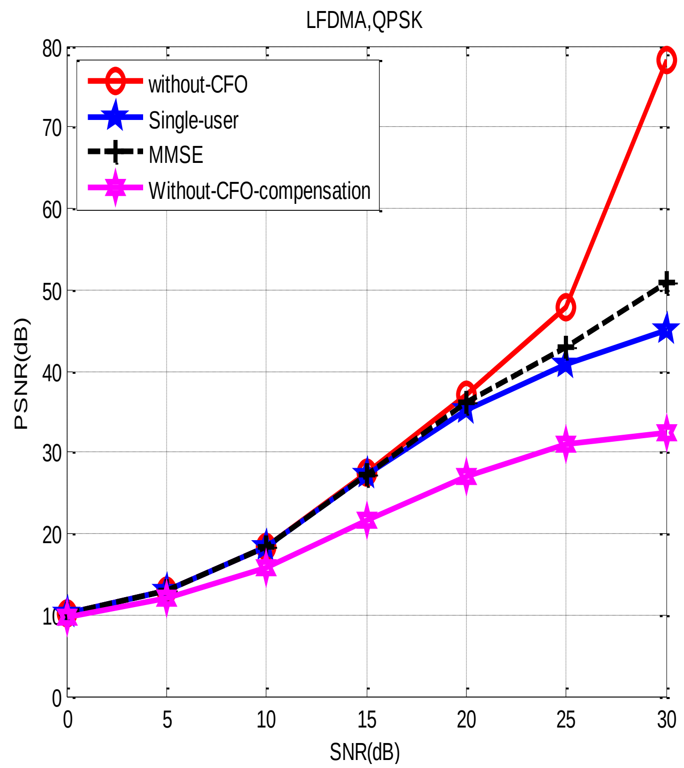

Fig. 8. PSNR versus SNR of the cameraman image transmission over LFDMA system.

TABLE 2: PSNR VALUES OF THE RECEIVED CAMERAMAN IMAGE OVER LFDMA AND IFDMA SYSTEMS.

SNR (dB)	without CFO		single user		MMSE		without CFO compensation	
	LFDMA	IFDMA	LFDMA	IFDMA	LFDMA	IFDMA	LFDMA	IFDMA
0	10.1844	9.9110	10.1796	9.8907	10.1719	9.8398	9.7773	9.5899
5	13.0508	13.1659	13.0258	12.5649	12.9930	12.9088	12.0104	11.9477
10	18.4768	20.3583	18.3747	18.0796	18.4524	19.5521	15.8392	16.6550
15	27.4634	31.8144	27.1891	25.6018	27.1367	29.9768	21.6033	23.1142
20	37.0046	47.1320	35.1740	31.4451	36.0983	42.4128	26.9734	29.5771
25	47.7625	Inf	40.7193	31.6020	42.8133	49.2641	30.9972	32.4408
30	78.2338	Inf	45.0188	29.7878	50.9930	54.6559	32.4487	32.5429

TABLE 3: MSE VALUES OF RECEIVED CAMERAMAN IMAGE OVER LFDMA AND IFDMA

SNR (dB)	without CFO		single user		MMSE		Without CFO compensation	
	LFDMA	**IFDMA**	**LFDMA**	**IFDMA**	**LFDMA**	**IFDMA**	**LFDMA**	**IFDMA**
0	0.0958	0.1021	0.0959	0.1025	0.0961	0.1038	0.1053	0.1099
5	0.0495	0.0482	0.0498	0.0554	0.0502	0.0512	0.0629	0.0639
10	0.0142	0.0092	0.0145	0.0156	0.0143	0.0111	0.0261	0.0216
15	0.0018	6.5851e-004	0.0019	0.0028	0.0019	0.0010	0.0069	0.0049
20	1.9932e-004	1.9355e-005	3.0381e-004	7.1696e-004	2.4556e-004	5.7375e-005	0.0020	0.0011
25	1.6740e-005	0	8.4737e-005	6.9151e-004	5.2320e-005	1.1847e-005	7.9483e-004	5.7006e-004
30	1.5018e-008	0	3.1486e-005	0.0011	7.9562e-006	3.4230e-006	5.6903e-004	5.5682e-004

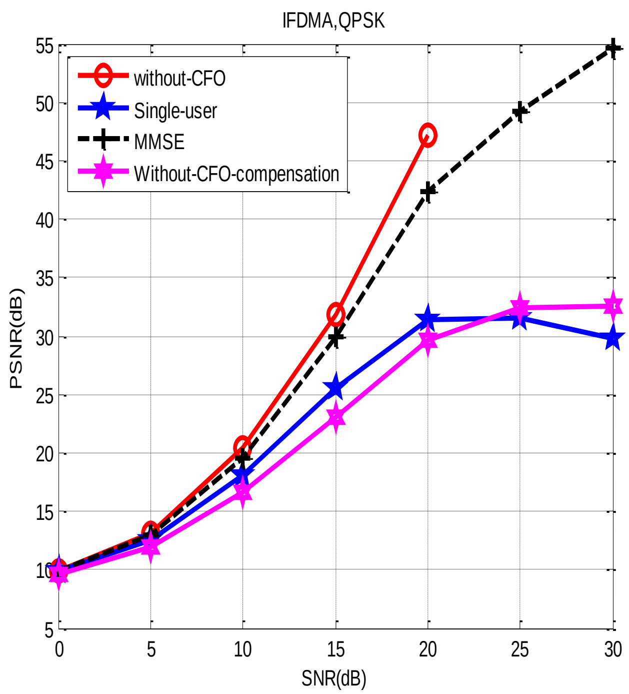

Fig.9 PSNR versus SNR of the cameraman image transmission over IFDMA system

Fig. 10 and 11 show MSE as a function of SNR with different scenarios. As shown in the figures, MSE performance of MMSE is better than single-user in both subcarrier mapping approaches. The reason behind this result is that MMSE can reduce MAI [26, 27]. Furthermore, it is noted that the performance of IFDMA system is better than LFDMA system.

c) Clarity Investigation

To examine the quality of the received image over LFDMA and IFDMA systems in the presence of CFOs and with and without CFO compensation, the received images at a SNR = 25dB are selected and displayed in Figs. 12 and 13 when the QPSK is used. It is clear that the quality of the received images using the MMSE scheme is better than the single-user scheme.

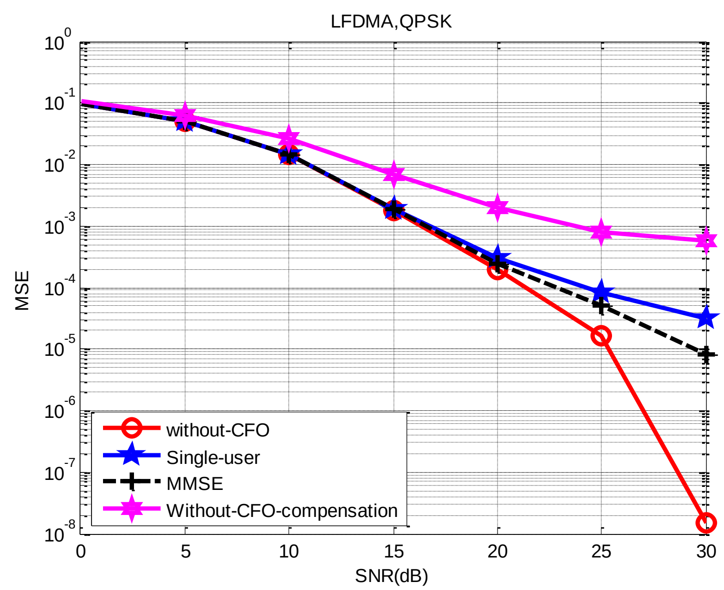

Fig. 10: MSE versus SNR of the cameraman image transmission over LFDMA system.

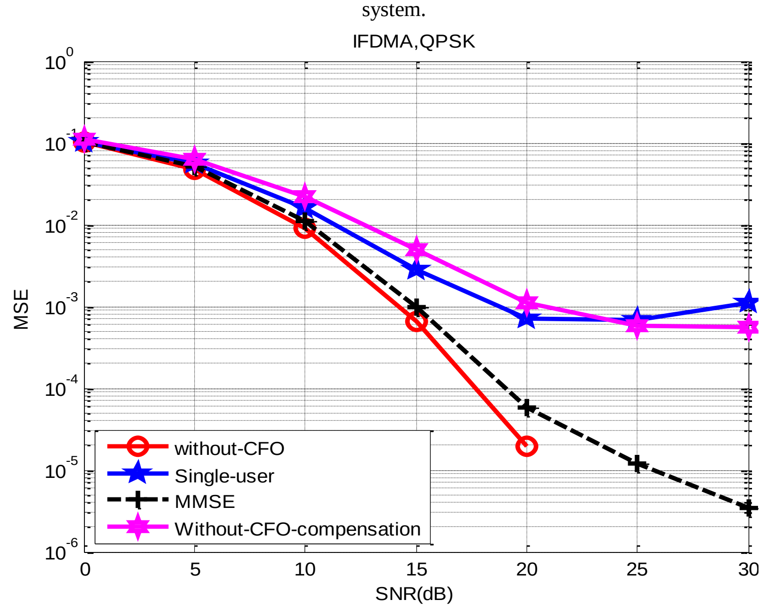

Fig. 11: MSE versus SNR of the cameraman image transmission over IFDMA system.

(a) Without CFO.

(b) CFO-without compensation.

(c) MMSE scheme.

(d) single-user

Fig. 12: The received cameraman images using LFDMA system at 25dB.

(a)Without CFO.

(b) CFO-without compensation.

(c) MMSE scheme.

(d) Single-User

Fig. 13: The received cameraman images using IFDMA system at 25dB.

D. SUI3 Model

Similarly to what have been performed in the Vehicular A model, same things will be performed with SUI3 model and described in the following subsections.

*a) **PSNR Performance***

The obtained PSNR values are shown in Table 4 for LFDMA and IFDMA systems.

Figs. 14 and 15 represent the PSNR of the received image as a function of SNR. It is clear that the both MMSE and single-user schemes improve the PSNR performance of the SC-FDMA system in the presence of CFOs. However, when MMSE scheme is used, the PSNR performance is better than single-user scheme due to the mentioned reasons previously.

*b) **MSE Performance***

The obtained MSE values are listed in Table 5 for LFDMA and IFDMA systems. Figs. 16 and 17 illustrate the MSE of the received image versus SNR for the SC-FDMA in the presence of CFOs with different compensation schemes. It is clear that the MMSE scheme provide slightly better performance as compared to the single user scheme due the same reasons mentioned in the previous section. Additionally, it can be seen that the performance of both of MMSE and single user scheme for IFDMA system is better than LFDMA.

*c) **Clarity Investigation***

For more clarification, the quality of the received image over LFDMA and IFDMA systems in the presence of CFOs with and without CFO compensation is selected and examined at a SNR=25dB and shown in Figs. 18 and 19. It is clear that the quality of the received images using the MMSE scheme is better than the single-user scheme.

From Figs. 8-19 and Tables 2-4, it is clear that PSNR and MSE performances are better for SUI3 than that for the vehicular A channel due the mobility. This indicates that image transmission over SUI3 with little SNR is possible.

TABLE 4: PSNR VALUES OF RECEIVED CAMERAMAN IMAGE OVER LFDMA AND IFDMA

SNR (dB)	without CFO		single user		MMSE		Without CFO compensation	
	LFDMA	IFDMA	LFDMA	IFDMA	LFDMA	IFDMA	LFDMA	IFDMA
0	10.1176	10.0063	10.1296	9.9474	10.1148	9.9541	9.7078	9.6253
5	16.0307	16.2719	15.8224	14.4796	15.8796	15.3270	13.4231	13.3724
10	26.3941	27.0430	25.7072	21.5160	26.0355	25.4766	19.7650	19.7795
15	37.5388	38.1086	36.1580	28.2751	37.7697	36.5646	26.0257	26.6676
20	45.7003	49.7335	43.5027	30.8154	43.8753	44.8806	31.3280	31.5187
25	Inf	Inf	51.7160	30.6071	57.7416	48.4094	32.9191	33.7501
30	Inf	Inf	Inf	29.2462	Inf	49.2927	32.5935	33.2611

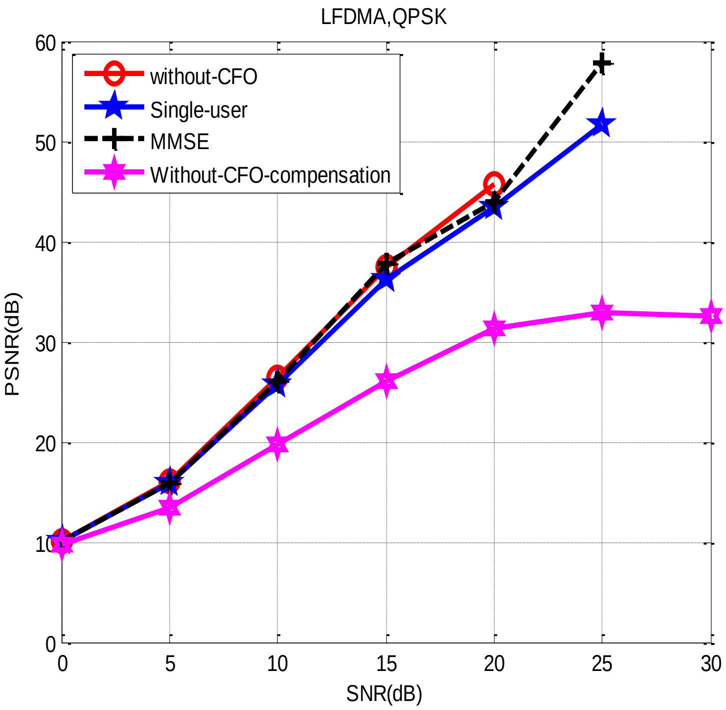

Fig. 14: PSNR versus SNR of the cameraman image transmission over LFDMA system.

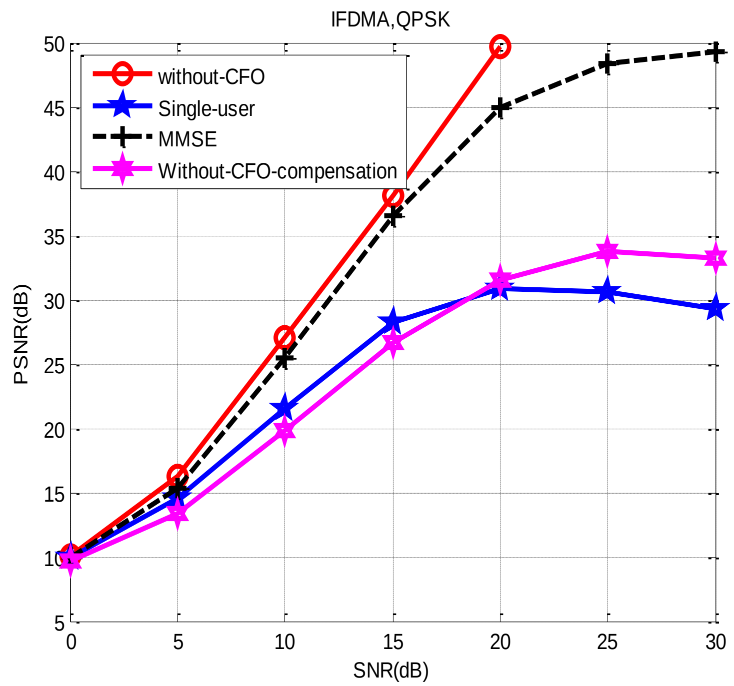

Fig. 15: PSNR versus SNR of the cameraman image transmission over IFDMA system.

TABLE 5: MSE VALUES OF RECEIVED LENA IMAGE OVER LFDMA AND IFDMA SYSTEMS

SNR (dB)	without CFO		single user		MMSE		Without CFO compensation	
	LFDMA	IFDMA	LFDMA	IFDMA	LFDMA	IFDMA	LFDMA	IFDMA
0	0.0973	0.0999	0.0971	0.1012	0.0974	0.1011	0.1070	0.1090
5	0.0249	0.0236	0.0262	0.0356	0.0258	0.0293	0.0455	0.0460
10	0.0023	0.0020	0.0027	0.0071	0.0025	0.0028	0.0106	0.0105
15	1.7625e-004	1.5458e-004	2.4222e-004	0.0015	1.6712e-004	2.2057e-004	0.0025	0.0022
20	2.6913e-005	1.0633e-005	4.4641e-005	8.2882e-004	4.0970e-005	3.2504e-005	7.3655e-004	7.0490e-004
25	0	0	6.7359e-006	8.6954e-004	1.6820e-006	1.4423e-005	5.1061e-004	4.2169e-004
30	0	0	0	0.0012	0	1.1769e-005	5.5036e-004	4.7194e-004

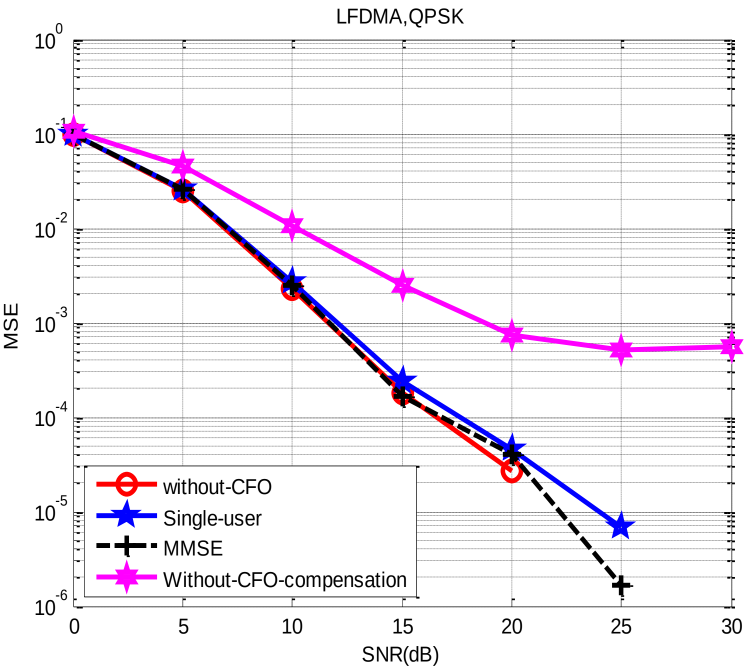

Fig. 16: MSE versus SNR of the Lena image transmission over LFDMA system

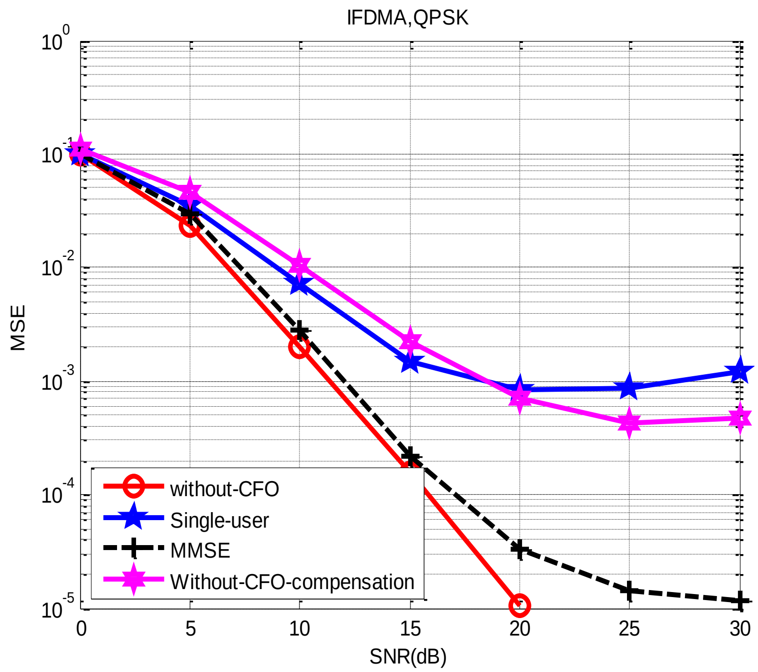

Fig. 17: MSE versus SNR of the Lena image transmission over IFDMA system

(a) Without CFOs.

(b) CFO-without compensation.

(c) MMSE scheme.

(d) single-user scheme.

Fig. 18: The received Lena images using LFDMA system at 25dB.

(a) Without CFOs.

(b) CFO-without compensation

(c) MMSE scheme

(d) Single-user scheme.

Fig. 19: The received Lena images using IFDMA system at 25dB.

VII. CONCLUSION

Image transmission over noisy wireless channels is a challenge task and the detection of the received image becomes so difficult, especially when the received image is corrupted by CFOs. This paper has been studied and investigated the issue of wireless image transmission over SC-FDMA system in the presence of CFOs with consideration of different subcarriers mapping schemes and different channel models. Single-user and MMSE CFOs compensation schemes have been used to mitigate the impacts of CFOs. The obtained results have been shown that CFOs degrade PSNR and MSE performances and so CFOs compensation is very important. Also, results have been shown that the clarity of the received image was enhanced when using CFOs compensation. It is also found that the performance of MMSE CFOs compensation scheme is better than that of single user scheme. Results also indicated that it is possible to transmit clearly image over SUI3 channel than over vehicular A channel with small SNR, especially when IFDMA system is used.

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