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A Joint Equalization, Carrier Frequency Offsets Compensation and ICI Cancellation for MIMO SC-FDMA Systems

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ABSTRACT

Third-Generation Partnership Project Long-Term Evolution (3GPP LTE) and Worldwide Interoperability for Microwave Access (WiMAX) standards adopt MIMO-OFDM symbol detection in these standards requires channel state information (CSI) estimation. multiple-input multiple-output (MIMO) orthogonal frequency-division multiplexing (OFDM) techniques. To achieve very high data rates. This project describes different techniques in a Single Carrier Frequency Division Multiple Access (SC-FDMA) system with parameters set according to the standards of 3rd Generation Partnership Project Long Term Evolution (3GPP LTE). The use of Multiple-Input Multiple-Output (MIMO) system promises good improvement in terms of spectral efficiency, link reliability and Signal to Noise Ratio (SNR). Recently the SC-FDMA system has attracted the attention as an efficient technique to the Orthogonal Frequency Division Multiple Access (OFDMA) system in the uplink communication. In this project Regularized Zero-Forcing (RZF) Equalization to compensates for Intersymbol Interference (ISI) created by multipath within time dispersive channels. In this project similarly simple CFOs disrupt the orthogonality between subcarriers, and give rise to Inter-Carrier Interference (ICI), and Multiple Access Interference (MAI) among users and in particular with MIMO (Multiple-Input Multiple-Output) systems. But simple ZF induces noise, makes unsuitable for interference limited environment. So in this project joint Regularized ZF to nullify the ISI, a CFOs to neglect MAI and ICI cancellation schemes for MIMO SC-FDMA system was developed and analyzed by considering BER performance measure. All simulations are done using a MATLAB software and communication toolboxes.

***Keywords*-**Inter-Carrier Interference (ICI), Multiple-Input Multiple-Output(MIMO), Multiple Access Interference (MAI), Orthogonal Frequency-Division Multiplexing(OFDM), Carrier Frequency Offsets(CFOs), Single Carrier Frequency Division Multiple Access (SC-FDMA), Third-Generation Partnership Project Long-Term Evolution (3GPP LTE), Regularized Zero-Forcing (RZF).

I. INTRODUCTION

Modern radio communication systems have to provide higher and higher data rates. As conventional methods like using more bandwidth or higher order modulation types are limited, new methods of using the transmission channel have to be used. Multiple antenna systems (Multiple Input, Multiple Output – MIMO) gives a significant enhancement to data rate and channel capacity. Multiple antennas can be used at the transmitter and receiver, an arrangement called a multiple-input multiple-output (MIMO) system. A MIMO system takes advantage of the spatial diversity that is obtained by spatially separated antennas in a dense multipath scattering environment[1],[2],[3].

The SC-FDMA system for uplink transmission due to its advantages such as the low Peak-to-Average Power Ratio (PAPR), and the use of frequency-domain equalizers. The performance of the SC-FDMA system depends on how well the orthogonality among different subcarriers is maintained at the receiver[4],[5]. The ZF equalizer, the single-user detector and the circular convolution However, since the conventional ZF equalizer suffers noise amplification related problems and increasing complexity due to the required interference matrix inversion operation it is not suitable to apply such receiver in SC-FDMA systems[6],[7].
In SC-FDMA system is sensitive to CFO, which is mainly due to oscillator mismatch and/or Doppler shift [2]. In uplink communications, the received signals are combinations of multiple signals coming from different users, each of which experiences a different CFO.

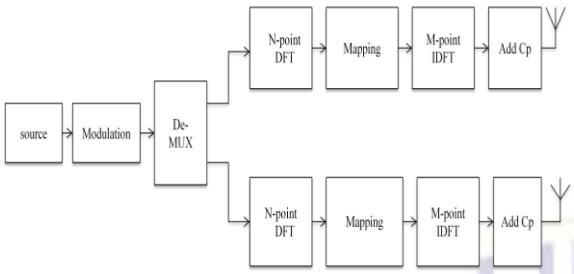
The presence of CFOs between the transmitter and the receiver results in a loss of orthogonality among subcarriers and an Inter-Carrier Interference (ICI). CFOs also introduce Multiple Access Interference (MAI) and degrade the Bit Error Rate (BER) performance. Based on the subcarriers mapping techniques, SC-FDMA systems can be classified into Localized SC-FDMA (LFDMA) systems and Interleaved SCFDMA (IFDMA) systems [4]. In this paper, only the IFDMA systems are considered, since they are more sensitive to CFOs than the LFDMA systems[8],[9],[10].

The proposed scheme performs the equalization, CFOs compensation and ICI cancellation jointly. In what follows, Section II presents the system model, Section III describes the proposed scheme, Section IV studies the complexity of the proposed scheme, Section V evaluates the performance of the proposed scheme simulated and the results are shown in Section 6.

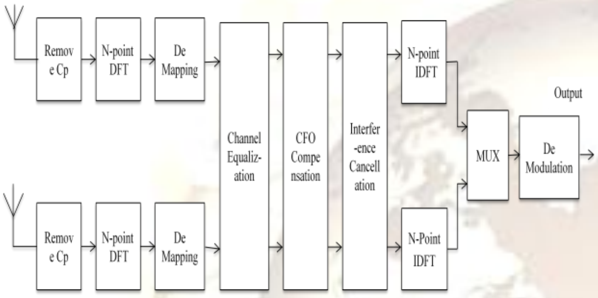
II. MIMO SC-FDMA SYSTEM MODEL

Consider a Spatial Multiplexing SC-FDMA (SM SCFDMA) system with U users. Each user is equipped with Nt transmit antennas and the base station has Nr receive antennas. We will assume Nr = 2, and Nt = 2. The structure of the 2×2 SM SC-FDMA system is depicted in perfect time synchronization. As illustrated in Fig.3.1, the modulated signal is demultiplexed into two sequences.

Transmitter Block



Receiver Block



Consider the uth user. At each transmit antenna of user "u", the output of the demultiplexing block is transformed into frequency-domain via an N-points DFT. Then, the frequency `domain samples are mapped to M ($M > N$) orthogonal subcarriers. The mapped sequence at each transmit antenna is transformed back into time domain via an M-points Inverse DFT (IDFT), and a Cyclic Prefix (CP) of length NC is added to the resulting signal. The transmitted signal from the jth transmit antenna of the uth user can be formulated as an N×1 vector satisfying

$$\widetilde{X}_J^{u} = P_{add}\, F_N^{-1} M_T^{u} F_N x_j^{u} \qquad (1)$$

where FN is the N×N DFT matrix. $F_M^{-1} = F_N^{H}$ is the $N \times N$ IDFT matrix. M_T^u is the M × N (M = Q.N) subcarriers mapping matrix for the uth user. Q is the bandwidth expansion factor. P_{add} is an $(M + N_C) \times M$ matrix, which adds a cyclic prefix of length N_C. The entries for the IFDMA system are given as follows

$$M_T^{u} = [0_{(u-1)\times N}\,;\ u_1^T; 0_{(Q-u)\times N}; \ldots ;\ 0_{(u-1)\times N};\ u_N^T;\ 0_{(Q-u)\times N}] \qquad (2)$$

where $0_{Q'\times N}$ denotes the $Q' \times N$ all-zero matrix. u_l $(l = 1,2,\ldots,N)$ denotes the unit column vector, of length N, with all-zero entries except at l. P_{add} can be represented as

$$P_{add} = [C, I_M]^T \qquad (3)$$

with $C = [0_{Nc\times(M-Nc)}, I_{Nc}]^T$ and I_M denotes the $M \times M$ identity matrix. At the receiver side the CP is removed from the received signal and then the signal is transformed into the frequency domain such as

$$R = \sum_{u=1}^{U} \Pi^{u} H^{u} \bar{X}^{u} + N \qquad (4)$$

where $\bar{X}^u$ is a $2M \times 1$ vector representing the transmitted frequency-domain samples from the uth user after the mapping process. H^u is the $2M \times 2M$ frequency-domain MIMO channel matrix. channels matrix. Π is the $2M \times 2M$ MIMO interference matrix. N is the $2M \times 1$ frequency-domain noise matrix. $\Pi^u = I_2 \otimes \Pi^u_{cirr}$, where $\Pi^u_{cirr} = F_M E^u F_M^{-1}$ M is the circulant interference matrix of the uth user. E^u is an M×M diagonal matrix with entries, $[E^u]_{m,m=}\, e^{j2\pi\varepsilon_u m/m}$, m = 0,….m-1 which describes the CFOs matrix of uth user. ε_u is the CFO at the uth user normalized by the subcarrier spacing. ⊗ denotes the Kronecker product. The matrix H^u in (4) has written as

$$H^u = \begin{bmatrix} H_{11}^u & H_{12}^u \\ H_{21}^u & H_{22}^u \end{bmatrix} \qquad (5)$$

where H_{ij}^u is an M × M matrix representing the transfer function of the channel between the jth transmit antenna and the ith receive antenna. At the receiver side, the CP is removed from the received signal, and then the resulting signal is transformed into the frequency domain.

$$P_{rem} = [0_{(M\times N_C)}, I_M] \qquad (6)$$

After the demapping process, the received signal from the kth user is given by

$$R_d^k = \Pi_d^k H_d^k X^l + \sum_{\substack{u=1\\u\neq k}}^{U} \Pi_d^u H_d^u X^u + n_d$$
$$= \Pi_P^k X^k + n_P \qquad (7)$$

where index d refer to the demapping results. After the demapping, R_d^k has dimension of $2N \times 1$, $X^k = [X_1^k \;\; X_2^k] = (I_2 \otimes M_R^k)\bar{X}^k$, $n_d = (I_2 \otimes M_R^k)\, n$, $\Pi_d^k = I_2 \otimes \bar{\Pi}_d^k$ and $\Pi_d^u = I_2 \otimes \bar{\Pi}_d^k$ $\bar{\Pi}_d^k = M_R^k\, \Pi_{cirr}^k\, M_T^k$ is the N × N interference matrix of the kth user. $\bar{\Pi}_d^k = M_R^k\, \Pi_{cirr}^u M_T^u$ is the N × N interference matrix from the uth user. $n_P = \sum_{u=1, u\neq k}^{U} \Pi_P^u X^u + n_d$ is the MAI and noise matrix , where $\Pi_P^u = \Pi_d^u H_d^u$. M_R^k denotes the subcarrier demapping matrix for the uth user. M_R^u is given by taking the trans position of (2).

The matrices H_d^u and Π_P^u in (7) can be defined as follows

$$H_d^u = \begin{bmatrix} \bar{H}_{11}^k & \bar{H}_{12}^k \\ \bar{H}_{21}^k & \bar{H}_{22}^k \end{bmatrix} \qquad (8)$$

$$\Pi_P^k = \Pi_d^k H_d^k = \begin{bmatrix} \bar{\Pi}_d^k \bar{H}_{11}^k & \bar{\Pi}_d^k \bar{H}_{12}^k \\ \bar{\Pi}_d^k \bar{H}_{21}^k & \bar{\Pi}_d^k \bar{H}_{22}^k \end{bmatrix}$$

$$= \begin{bmatrix} \Pi_{11}^k & \Pi_{12}^k \\ \Pi_{21}^k & \Pi_{22}^k \end{bmatrix} \qquad (9)$$

where $\bar{H}_{ij}^k = M_R^k H_{ij}^k M_T^k$ is an $N \times N$ diagonal matrix. After the demapping process, the impact of the multipath channel and CFOs are removed. The resulting signal is then transformed into the time domain via an N-points DFT. Finally, kia demultiplexing process is performed and followed by the demodulation process.

III. Proposed Regularised Zero-Forcing Equalizer(RZF)

In contrast to OFDMA, SC-FDMA, as its name implies, is a single-carrier system. Frequency-domain LE is an analog to linear transversal equalization in the time domain. Using the ZF (Zero-Forcing) criterion for LE can eliminate the lSI completely, however the large noise enhancement degrades the performance severely. . It uses a regularization term in the second step to get around the noise enhancement problem and to reduce the effect of the MAI. The proposed RZF equalization for the kth user is performed in two steps to reduce the complexity.

In the first step, the RZF equalizer cancels the Inter Antenna Interference (IAI). the ISI and MAI are mitigated in the Second step. In the first step, the impact of the IAI are cancelled by applying the matrix W_1^k and as

$$\hat{X}^k = W_1^k R_d^k \tag{10}$$

and R_d^k is given by (7) ,where W_1^k can be expressed as

$$W_1^k = \begin{bmatrix} I_N & -A_2^k \\ -A_1 & I_N \end{bmatrix} \tag{11}$$

where, $A_1^k = \Pi_{21}^k(\Pi_{11}^k)^{-1}$ and $A_2^k = \Pi_{12}^k(\Pi_{22}^k)^{-1}$

The proposed regularized ZF equalizer is derived to perform the equalization and CFOs compensation processes jointly for MIMO SC-FDMA systems.

In the second step, the impacts to ISI and MAI cancelled by applying the matrix W_2^k as described as

$$\hat{X}^k = W_2^k W_1^k R_d^k = W_2^k (W_1^k \Pi_P^k) X^k + W_2^k W_1^k n_P$$
$$= W_2^k \begin{bmatrix} Q_1^k & 0_{N\times N} \\ 0_{N\times N} & Q_2^k \end{bmatrix} X^k + W_2^k W_1^k n_P \tag{12}$$

where $Q_1^k = \Pi_{11}^k - A_2^k \Pi_{21}^k$, and $Q_2^k = \Pi_{22}^k - A_1^k \Pi_{12}^k$

From this, W_2^k can be constructed as follows

$$W_2^k = \begin{bmatrix} (Q_1^k)^{-1} & 0_{N\times N} \\ 0_{N\times N} & (Q_2^k)^{-1} \end{bmatrix} \tag{13}$$

$$W_1^k W_2^k = (\Pi_P^k)^{-1} \tag{14}$$

The resulting scheme in this case will be refered to as the ZF equalizer. This equalizer is equivalent to the conventional ZF equalizer. When it still $(\Pi_P^k)^{-1}$ suffers. Despite its lower complexity. To avoid the noise enhancement and to minimize the impact to the MAI, a regularization parameter 'α' is used to regularize W_2^k.

A. ICI Cancellation

ICI is different from the co-channel interference in MIMO systems. The co-channel interference is caused by reused channels in other cells, while ICI results from the other sub-channels in the same data block of the same user. Even if only one user is in communication, ICI might occur, yet the co-channel interference will not happen.

1. ICI CANCELLING MODULATION

The inter carrier interference (ICI) cannot be reduced until the CFOs value is reduced. This can be done by increasing the subcarriers separation but the time domain symbol length will be reduced and the guard interval will take a large portion of useful signal resulting in reduction of bandwidth efficiency. For majority of $l-k$ values, the difference of ICI coefficient between two consecutive subcarrier {(S (l-k) and S(l+1-k)} is very small. Therefore, if a data pair (a, -a) is modulated onto two adjacent subcarriers (l , l+1), where a is a complex data, then the ICI signals generated by the subcarrier l will be cancelled out significantly by the ICI generated by subcarrier $l+1$. Assuming the transmitted symbols are such that $X(1) = -X(0), X(3) = -X(2) \ldots X(N-1) = -X(N-2)$, then the received signal on subcarrier k become

$$y'(k) = \sum_{l=0}^{N-1} X(l)S(l-k) + n_k \tag{20}$$

$$y'(k) = X(0)S(0-k) - X(1)S(1-k) + \cdots + n_k \tag{21}$$

$$y'(k) = \sum_{l=0}^{N-2} X(l)[S(l-k) - S(l+1-k)] + n_k \tag{22}$$

Similarly the received signal on subcarrier *K*+1 becomes

$$y'(k+1) = \sum_{l=0}^{N-2} X(l)[S(l-k-1) - S(l-k)] + n_{k+1} \tag{23}$$

In such a case, the ICI coefficient is denoted as

$$S'(l-k) = S(l-k) - S(l+1-1) \tag{24}$$

2. ICI CANCELLING DEMODULATION

ICI modulation introduces redundancy in the received signal since each pair of subcarriers transmit only one data symbol. To take advantage of this redundancy, the received signal at the $(k+1)$th subcarrier, where k is even and is subtracted from the kth subcarrier. This is expressed mathematically as

$$y''(k) = y'(k) - y'(k+1) \tag{25}$$

$$y''(k) = \sum_{l=0}^{N-2} X(l)[-S(l-k-1) + 2S(l-k) - S(l-k+1)] + n_k - n_{k+1} \tag{26}$$

The ICI coefficients for this received signal becomes

$$S''(l-k) = -S(l-k-1) + 2S(l-k) - S(l-k+1) \tag{27}$$

The ICI is reduced by applying ICI cancelling modulation. ICI cancelling demodulation can reduce residual ICI in the received signals. This combined ICI cancelling modulation and demodulation method is called the ICI self cancellation scheme.

IV. RESULTS AND DISCUSSIONS

The simulation results are presented to evaluate the performance of the joint ZF equalization, CFO compensation and ICI cancellation schemes. In order to compare the three different schemes, BER performance used to evaluate the performance of each scheme using MATLAB software is employed with its Communications Toolbox for all data runs for simulation. The simulation parameter assumed for implementation is given in the table.1.

For different constellation, (ie) M=2(BPSK), M=4(QPSK), M=8(8-QAM), M=16(16-QAM) and M=32(32-QAM), the BER performance is analyzed for different values of SNR (dB) individually. Also, the BER performance is analyzed for the various combinations of the three different schemes as (ie) RZF equalization, CFO compensation, RZF and CFO compensation, RZF and ICI, CFO and ICI, and then finally using all schemes as RZF equalization, CFO compensation and ICI cancellation. The performance figures from 4.1 to 4.12 illustrate the variation of BER at different SNR values for the uplink MIMO SC-FDMA system with M=2,4,8,16,32.

Table 4.1 Simulation parameter for SC-FDMA uplink system

Modulation scheme	BPSK,QPSK,8QAM,16QAM,32QAM
Number of subcarriers/bits (N)	128
Transmit Antenna (N_t)	2
Receiver Antenna (N_r)	2
Subcarrier mapping method	IFDMA
Cyclic prefix length	16
FFT size	64
Channel model	AWGN
Operating frequency	5GHz
Regularization parameter (α)	0.1

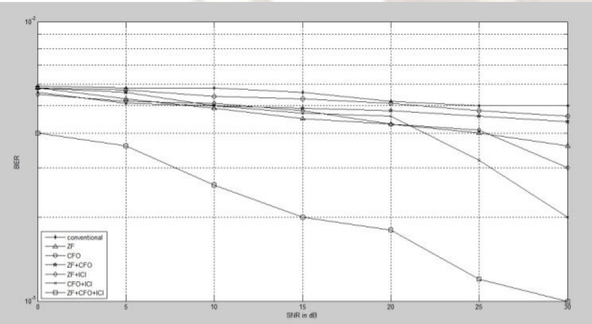


Figure 4.1performance for all schemes with constellation M = 2.

In conventional method without applying equalization, CFO compensation or ICI schemes the system performance seems to be very poor. Similarly, the combination of the others schemes like RZF, CFO compensation and ICI cancellation the perform analysis can be done for the figure 4.1. It is observed that the schemes individually showing moderate performances. but from the combination of the three schemes (RZF, CFO compensation, ICI cancellation) it is possible to achieve the max BER performance of the order of 10^{-3} or more.

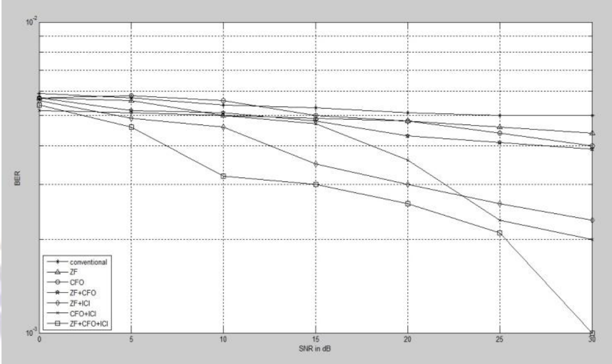


Figure4.2.Performance for all schemes with constellation M = 4

Figure4.2 shows the performance for all schemes with constellation M=4. The result with the conventional system performance compared with other combinations the SNR is increased up to 30 dB and then the minimum error rate is 10^{-2}. After applying the constant CFO the BER is reduced at the same range of RZF equalizer. The comparison of RZF and CFO performance the maximum error rate observed to be 10^{-2} the minimum error rate is increased slowly. Then RZF and ICI the maximum error rate is observed to be 10^{-2} the minimum error rate is increased 10^{-3}. Another one is CFO with ICI the maximum error rate observed to be 10^{-2} the minimum error rate is 10^{-3} . Finally all schemes are applying RZF, CFO compensation and ICI cancellation schemes the maximum error rate is observed to be 10^{-2} the minimum error rate is10^{-3}. Therefore the system performance seems to be better then other's combinations.

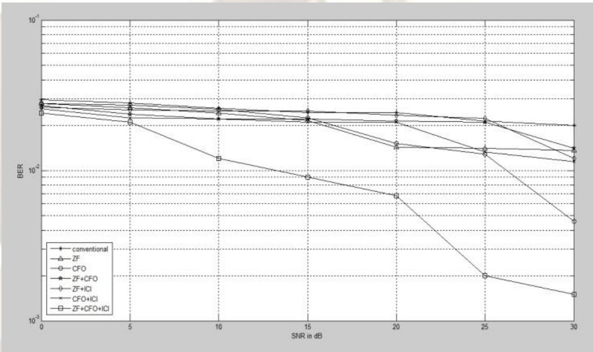


Figure4.3.Performance for all schemes with constellation M = 8

Figure4.3 shows the Performance for all schemes with constellation M = 8. The result with the conventional system performance compared to the proposed schemes as Regularized Zero-Forcing equalizer method, CFO compensation, and ICI cancellation. In conventional system the SNR is increased up to 30 dB and then the error rate is reduced in the range of 10^{-1}. Then the RZF applying the maximum error rate is observed is to be 10^{-1} the minimum error rate is 10^{-2} . After applying the constant CFO the BER is reduced at the same range of RZF equalizer. The

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combination of RZF and CFO performance the maximum error rate is observed to be 10^{-2} the minimum error rate is nearly 10^{-3}. Then RZF and ICI combination the maximum error rate is observed to be 10^{-1} the minimum error rate is 10^{-2}. Then CFO with ICI combination the maximum error rate observed to be 10^{-2} the minimum error rate is 10^{-3}. Finally the three combinations are using RZF and CFO and ICI cancellation schemes the maximum error rate is observed to be 10^{-2} the minimum error rate is10^{-3}. This three combinations given the better result compared to other combinations.

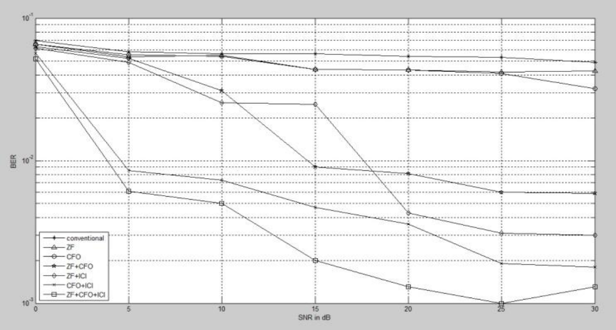


Figure4.4 Performance for all schemes with constellation M = 16

Figure4.4 shows the Performance for all schemes with constellation M = 16. In conventional method without applying equalization, CFO and ICI cancellation schemes the system performance seems to be is very poor. After applying the the proposed Regularized Zero-Forcing equalizer scheme the system performance the maximum error rate is observed to be 10^{-1} the minimum error rate is 10^{-1}. After applying CFO compensation the maximum error rate is observed to be 10^{-1} the minimum error rate is 10^{-2}. Then applying RZF and CFO combination the maximum error rate is observed to be 10^{-1} the minimum error rate is 10^{-2}. RZF and ICI combination the maximum error rate is observed to be 10^{-1} the minimum error rate is 10^{-2}. Then CFO and ICI cancellation method the maximum error rate is observed to be 10^{-1} the minimum error rate is 10^{-3}. Finally all schemes are used RZF equalization and CFO compensation and ICI cancellation method the maximum error rate is observed to be 10^{-1} the minimum error rate is 10^{-3}. Similarly the combination of the others schemes like RZF, CFO and ICI the performance analysis can be done for the figure4.4. The combination schemes shows better performances.

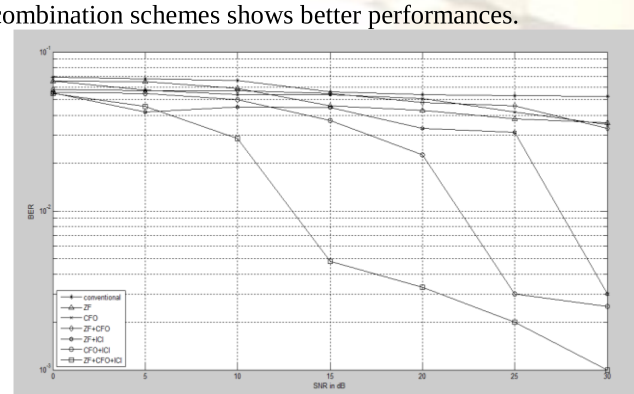


Figure4.5.Performance for all schemes with constellation M = 32

Figure4.5 shows the Performance for all schemes with constellation M=32. In conventional method without applying equalization, CFO and ICI cancellation schemes the system performance seems to be is very poor performance. After applying the proposed Regularized Zero-Forcing equalizer scheme the system performance the maximum error rate is observed to be 10^{-1} the minimum error rate is 10^{-2}. After applying the constant CFO the error rate is observed to be 10^{-1} the minimum error rate is 10^{-2} . The combination of RZF and CFO performance the maximum error rate observed to be 10^{-1} the minimum error rate is 10^{-2}. Then RZF and ICI the maximum error rate is observed to be 10^{-1} the minimum error rate is 10^{-3}. Another one is CFO with ICI the maximum error rate observed to be 10^{-1} the minimum error rate is 10^{-3} . Finally all schemes are used RZF and CFO and ICI cancellation method the maximum error rate is observed to be 10^{-1} the minimum error rate is 10^{-3}. The combination of the others schemes such as RZF, CFO and ICI the performance analysis can be done for the figure4.5. The combination schemes shows better performances. From figures 4.1 to 4.5 for the constellation size for M=2 to 32, it is observed that when increasing the constellation size, on increasing the number of bits per symbol, the BER performance found to be decreasing. This confines to the theoretical concept.

The BER performance of the schemes individually and combined by given in figures 4.6 to 4.12 for different constellation points.

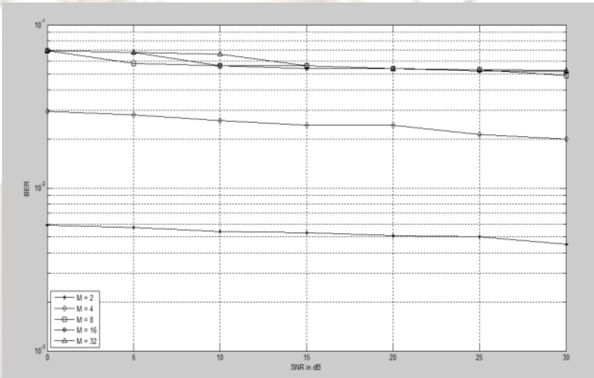


Figure4.6. BER performance using conventional Zero-Forcing equalization

However this becomes as the constellation size of the modulation schemes increases as shown in figure 4.6. different constellation size of M(M=2,M=4,M=8,M=16,M=32). In conventional method without applying equalization, CFO compensation and ICI cancellation schemes the system performance seems to be very poor. Similarly, the different constellation points the BER performance analysis can be done for the figure 4.6. It is observed that the schemes individually showing moderate performances. but from the different constellation of the points(M=2,4,8,16,32) it is possible to achieve the max BER performance of the order of 10^{-3} or more.

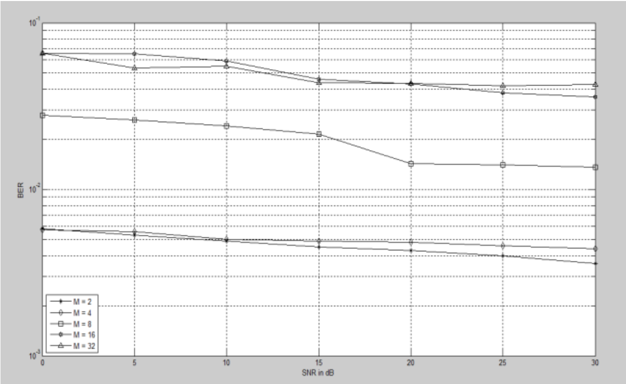


Figure4.7. BER performance of Regularized Zero-Forcing equalization

The RZF equalization applied the constellation size M=2, the error rate observed to be 10^{-2} the minimum error rate is 10^{-3}. The constellation size M=4 the error rate observed to be 10^{-2} the minimum error rate is 10^{-3}. The constellation size M=8 the maximum error rate observed to be 10^{-1} the minimum error rate is 10^{-2}. The constellation size M=16 the maximum error rate 10^{-1} the minimum error rate is 10^{-2}. The constellation size M=32 the maximum error rate 10^{-1} the minimum error rate is 10^{-2} . In figure4.7 the constellation size to be increased the performance of the SNR is to be increased but the error rate is not sufficient in scheme of RZF equalization.

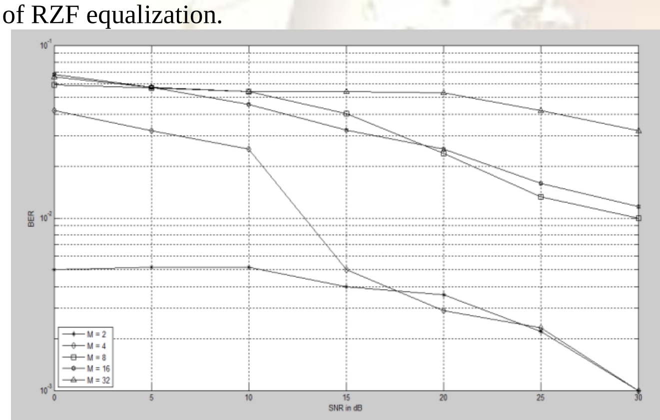
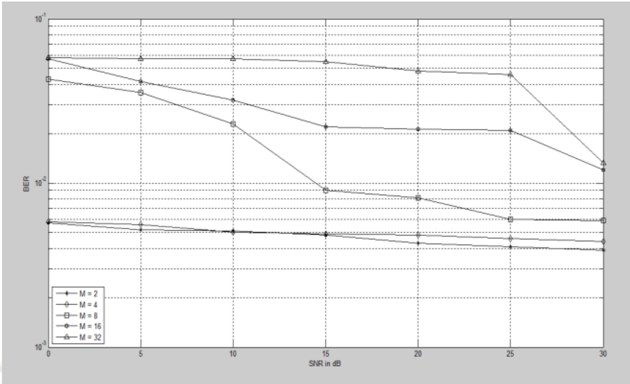


Figure4.8. BER performance using CFO compensation

The figure4.8 shows that BER performance using CFO compensation. The CFO applied the constellation point M=2, the SNR is increased the error rate is observed to be 10^{-1} the minimum error rate is 10^{-3} . The constellation point M=4 the error rate observed to be 10^{-2} the minimum error rate is 10^{-3}. The constellation point M=8 the maximum error rate is 10^{-1} the minimum error rate is 10^{-2}. The constellation point M=16 the maximum error rate 10^{-1} the minimum error rate is 10^{-2}. The constellation point M=32 the maximum error rate 10^{-1} the minimum error rate is 10^{-2}. In all constellation point (M=2,4,8,16,32) the performance analysis can be achieved for the figure 4.8. It is observed that the CFO compensation scheme showing the BER performances.

The figure4.9 shows the BER performance using RZF equalization and CFO compensation. The combination



of RZF equalization and CFO applied the constellation size M=2, the error rate observed to be 10^{-2} the minimum error

Figure4.9. BER performance of RZF equalization and CFO compensation

rate is 10^{-3}. The constellation point M=4 the error rate observed to be 10^{-1} the minimum error rate is 10^{-2}. The constellation point M=8 the maximum error rate observed to be 10^{-1} the minimum error rate is 10^{-2}. The constellation point M=16 the maximum error rate 10^{-1} the minimum error rate is 10^{-2} The constellation point M=32 the maximum error rate 10^{-1} the minimum error rate is 10^{-2}. In the combination of RZF equalization and CFO compensation the analysis of BER performance seems to be not sufficient in this scheme because ICI problem.

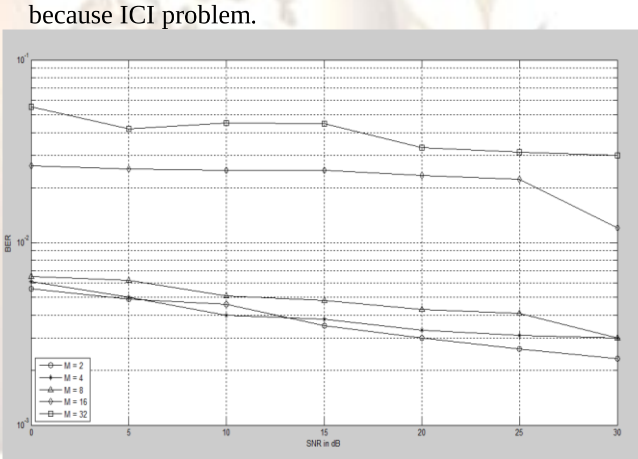


Figure4.10. BER performance using RZF equalization and ICI cancellation

The figure4.10 shows the BER performance using The RZF equalization with ICI cancellation method applied the constellation size to be increased as well as error rate is reduced. The constellation size M=2, the error rate observed to be 10^{-2} the minimum error rate is 10^{-3}. The constellation size M=4 the error rate observed to be 10^{-2} the minimum error rate is 10^{-3}. The constellation size M=8 the maximum error rate observed to be 10^{-1} the minimum error rate is 10^{-2}. The constellation size M=16 the maximum error rate 10^{-2} the minimum error rate is 10^{-3}. The constellation size M=32 the maximum error rate 10^{-2} the minimum error rate is 10^{-3}. In this combination RZF equalization with ICI cancellation the system performance to be better than previous combination.

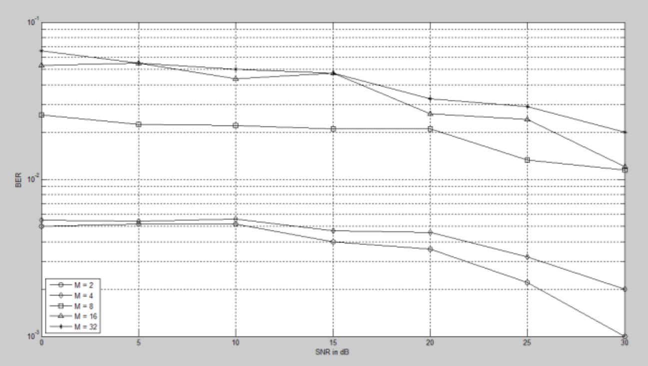


Figure4.11. BER performance using CFO compensation and ICI cancellation

The figure4.11 shows the BER performance using CFO compensation and ICI cancellation. The combination of CFO compensation and ICI cancellation method applied the constellation point M=2, the error rate observed to be 10^{-2} the minimum error rate is 10^{-3}. The constellation point M=4 the error rate observed to be 10^{-2} the minimum error rate is 10^{-3}. The constellation point M=8 the maximum error rate observed to be 10^{-1} the minimum error rate is 10^{-2}. The constellation point M=16 the maximum error rate 10^{-1} the minimum error rate is 10^{-2}. The constellation point M=32 the maximum error rate 10^{-1} the minimum error rate is 10^{-2}.

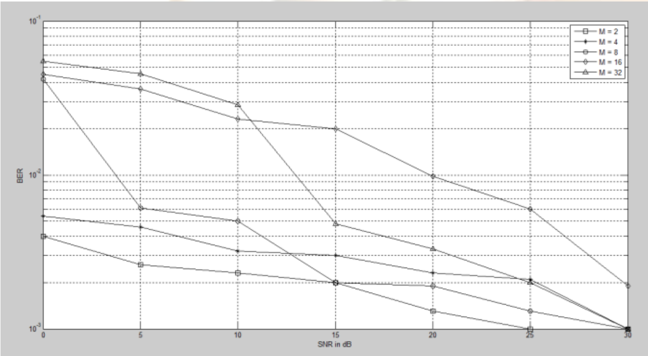


Figure4.12. BER performance using RZF equalization, CFO compensation and ICI cancellation.

From figure 4.6 to 4.12, for the all combinations for RZF equalization, CFO compensation, RZF and CFO, RZF and ICI, CFO and ICI, finally RZF equalization, CFO compensation and ICI cancellation, it is observed that the different constellation points on increasing the number of bits per symbol, the BER performance found to be decreasing. This confines to the theoretical concept.

V. CONCLUSION

In this project, a RZF equalizer for MIMO SC-FDMA systems in the presence of CFOs and ICI, which performs the equalization, CFO compensation and ICI cancellation jointly. The mathematical model of the equalizer is analyzed and implemented by taking into the account to IAI, ISI, MAI as well as noise. The proposed equalizer is seems to achieve better BER performance and also able to mitigate the impact of the CFOs and multipath channel, even in the presence of estimation errors. also it is proved that the proposed equalizer out performs the conventional schemes.

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