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An Improved ICI Reduction in MIMO OFDM System

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***Abstract*— The combination of Multiple-Input and Multiple-Output(MIMO) and Orthogonal Frequency Division Multiplexing(OFDM) is taken into account as the foremost promising techniques for 4th and next generation wireless communications due to its high data rate transmission capability in multipath attenuation atmosphere. It makes economical use of bandwidth by allowing subcarriers within the spectrum to overlap and maintain orthogonality among them. The most challenge featured by OFDM is to combat ICI that happens once orthogonality is lost as mainly as a result of frequency offset. This paper proposes an improved ICI cancellation technique with detailed analysis and simulation over AWGN channel that achieves better BER(bit error rate) to SNR(Signal-to-noise ratio) improvement than existing ICI cancellation schemes.**

***Keywords*— MIMO-OFDM, ICI, Self Cancellation (SC), Maximum Likelihood (ML,) frequency offset, BER, SNR.**

1. INTRODUCTION

A MIMO-OFDM wireless communication system is a combination of MIMO and OFDM Technology that has been currently recognized as one of the most competitive technology for 4G mobile wireless systems. MIMO system achieves high capacity by transmitting independent information over different antennas simultaneously. OFDM is an effective technique to mitigate inter-symbol interference that multipath delay may cause in a frequency selective environment [1, 2]. It makes economical use of bandwidth by allowing subcarriers within the spectrum to overlap and maintain orthogonality among them. The most challenge featured by OFDM is to combat ICI that happens once orthogonality is lost as mainly as a result of frequency offset. MIMO-OFDM system with frequency offset (FO) is being evaluated to provide the system with low complexity and maximum diversity.

A number of techniques have been developed for reducing ICI in OFDM systems. Among these technique includes ICI Self-Cancellation scheme and Maximum Likelihood method. Y.Zhao proposed ICI self-cancellation scheme [2] in which redundant data is transmitted onto adjacent sub-carriers such that the ICI between adjacent sub-carriers cancels out at the receiver. Though this method is implemented with ease but its drawback is that the same data is modulated into two or more carriers, thus reducing spectral efficiency and band width efficiency. So to overcome this method another technique called ML method was employed. This method was suggested by Moose [1]. In this approach, the frequency offset is first statistically estimated using a ML algorithm and then cancelled at the receiver. This technique involves the replication of an OFDM symbol before transmission and comparison of the phases of each of the subcarriers between the successive symbols. Though ML method performs better than SC method but due to the large size of the system constellation and the codeword structure, OFDM has become more complex and time consuming in MIMO system.

To overcome these problems, an Improved ML method been designed which combines both the drawbacks of ML and SC and been confirmed through the simulation results that the proposed scheme has the ability to reduce ICI effectively with a low decoding complexity of bit error rate (BER) performance especially at high signal to noise ratio (SNR). This paper is organized in sections as follows: In section II, OFDM system model description and the effect of ICI is discussed. In Section III, the existing ICI cancellation SC, ML method presented. In section IV, proposed improved ML method designed to cancel the effect of ICI in the OFDM system. In section V, the simulation results are shown. Finally, a conclusion is given in section VI.

2. SYSTEM MODEL DESCRIPTION AND ICI PROBLEM

Figure 1 describes the block diagram of an OFDM system for ICI reduction. The system model contains 2 sections: OFDM Transmitter and also OFDM Receiver. At the transmitter part, binary input data is encoded and through serial-to-parallel converter and generated into N parallel bit streams each. These parallel streams are then modulated (QPSK modulation) and carried over at entirely different carrier frequencies. The Inverse Fast Fourier Transform (IFFT) block transforms the frequency – domain data samples on many subcarriers, that are equidistantly distributed in the frequency domain [2].The number of subcarriers is usually a power of two to allow efficient implementation of the IFFT/FFT (fast Fourier transform) [4] then passed through ICI

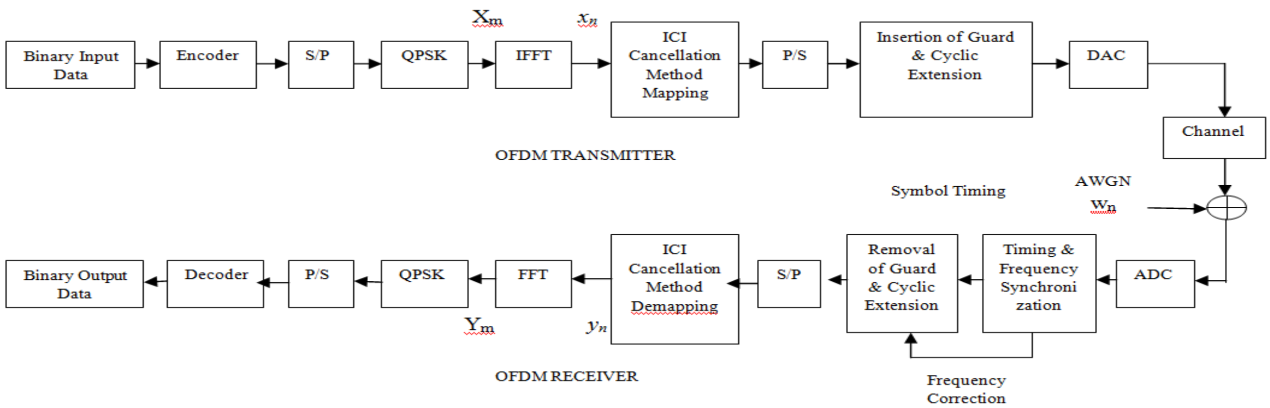

Figure 1. Block diagram of OFDM system

cancellation mapping block where redundancy added to the input symbol in a specific way so as to give the system immunity against frequency offset. These modulated symbols are serialized using parallel-to-serial converter. To avoid overlapping of symbols guard band is added .These digital symbols is converted to analog via the digital-to-analog converter (D/A) before being sent down to the channel. The signal passed through AWGN channel adding noise. At the receiver part, exactly the reverse of OFDM transmitter is done and generates a binary output data. In an OFDM system, the complex baseband OFDM signal after the IFFT block at the transmitter can be expressed as

$$x(n)=\frac{1}{N}\sum_{m=0}^{N-1} X(m)\, e^{\frac{j2\pi nm}{N}}, \quad n = 0,1,2 \dots N-1 \qquad (1)$$

where N is total number of subcarriers.the X_m are the baseband symbols modulated with QPSK on each sub-carrier. At the receiver, the signal is converted back to a discrete N point sequence y(n), corresponding to each sub-carrier.

The received signal after being affected by the frequency offset can be written as

$$y(n) = x(n)e^{\frac{j2n\epsilon}{N}} + w(n) \qquad (2)$$

where ε is the normalized frequency offset expressed as $\Delta f N T_s$ with Δf being the frequency difference between the transmitted and received carrier frequency, T_s is the symbol period, and $w(n)$ is the AWGN introduced in the channel. At the receiver, after the FFT block, the received signal on the subcarrier *m* suffering from the frequency offset can be written as

$$Y(m) = \sum_{n=0}^{N-1} e^{\frac{-j2\pi nm}{N}}, \quad m = 0,1,2 \dots N-1 \qquad (3)$$

In an OFDM system, the received signal on subcarrier k can be further simplified as:

$$Y(k) = X(k)S(0) + \sum_{m=0, m\neq k}^{N-1} X(m)S(m-k) + W_k \qquad (4)$$

where W_k is the FFT of $w(n)$. The first and the second term in the right-hand side of (4) represent the desired signal and the ICI components respectively. The ICI components are the interfering signals transmitted on sub-carriers other than the

kth sub-carrier. The first term is desired signal, with ε=0, S(0) has maximum value S(0)=1. The second term is ICI component. The sequence $S(m\text{-}k)$ is the complex ICI coefficient between m^{th} and k^{th} subcarriers are given as [2]:

$$S(m-k) = \frac{\sin(\pi(m+\varepsilon-k))}{N\sin\left(\frac{\pi}{N}(m+\varepsilon-k)\right)} . \exp\left(j\pi\left(1-\frac{1}{N}\right)(m+\varepsilon-k)\right) \qquad (5)$$

In the above equation is the normalized frequency offset defined as a ratio between the frequency offset (which remains constant over each symbol period) and subcarrier spacing. For a zero frequency offset S(k) reduces to unit impulse sequence.

3. ICI CANCELLATION METHOD

3.1 Self Cancellation Method

ICI self-cancellation is a scheme that was introduced by Yuping Zhao and Sven-Gustav Häggman in 2001 in [2] to combat and suppress ICI in OFDM. The main idea was to modulate the input data symbol onto a group of subcarriers with predefined coefficients such that the generated ICI signals within that group cancel each other, hence the name self- cancellation. ICI Cancelling modulation works as follows: In an OFDM communication system, assuming the channel frequency offset normalized by the subcarrier separation is ε, the received signal on subcarrier *k* can be written as

$$r(k)=X(k)S(0)+\sum_{l=0, l\neq k}^{N-1} X(l)S(l-k)+n_k, k=0,1,\dots\dots,N-1 \qquad (6)$$

where N is the total number of the subcarriers *X* (*k*) denotes the transmitted symbol for the *k*th subcarrier and n_k is additive noise . The first term in the right-hand side of (6) represents the desired signal. The second term is the ICI components. The sequence *S (l-k)* is defined as the ICI coefficient between *l*th and *k*th subcarriers, which can be expressed as

$$S(l-k)=\frac{\sin(\pi(l+\varepsilon-k))}{N\sin\left(\frac{\pi}{N}(l+\varepsilon-k)\right)}.\exp\left(j\pi\left(1-\frac{1}{N}\right)(l+\varepsilon-k)\right) \qquad (7)$$

It is seen that 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)... X (N-1) = -X (N-2), then the received signal on subcarrier *k* becomes

$$r'(k) = \sum_{\substack{l=0 \\ l=even}}^{N-2} X(l)[S(l-k) - S(l+1-k)] + n_k \quad (8)$$

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

$$r'(k+1) = \sum_{\substack{l=0 \\ l=even}}^{N-2} X(l)[S(l-k-1) - S(l-k)] + n_{k+1} \quad (9)$$

In such a case, the ICI coefficient is denoted as

$$S'(l-k) = S(l-k) - S(l+1-k) \quad (10)$$

To further reduce ICI, ICI Cancelling demodulation is done. The demodulation is suggested to work in such a way that each signal at the *k*+1th subcarrier (now *k* denotes even number) is multiplied by "-1" and then summed with the one at the *k*th subcarrier. Then the resultant data sequence is used for making symbol decision. It can be represented as

$$r''(k) = Y'(k) - Y'(k+1)$$
$$= \sum_{\substack{l=0 \\ l=even}}^{N-2} X(l)[-S(l-k-1) + 2S(l-k) - S(l-k+1)] + nk - nk + 1 \quad (11)$$

The corresponding ICI coefficient then becomes

$$S''(l-k) = -S(l-k-1) + 2S(l-k) - S(l-K+1) \quad (12)$$

If the data symbol 'a' is modulated in to the 1st sub-carrier then '-a' is modulated in to the 2nd sub-carrier. Hence the ICI generated between the two sub-carriers almost mutually cancels each other. The combined modulation and demodulation method is called the ICI self-cancellation scheme.

The reduction of the ICI signal levels in the ICI self-cancellation scheme [2] leads to a higher carrier to interference ratio (CIR). From (12) theoretical CIR can be calculated as

$$CIR = \frac{\left| -S(-1) + 2S(0) - S(1) \right|^2}{\sum_{l=2,4,6,\ldots}^{N-1} \left| -S(l-1) + 2S(l) - S(l+1) \right|^2} \quad (13)$$

The main drawback of this method is reduction of bandwidth efficiency. So another scheme is used called as Maximum Likelihood Method.

3.2 Maximum Likelihood Method

In this method, the frequency offset is first estimated statistically using a maximum likelihood algorithm. This technique involves the replication of an OFDM symbol before transmission and comparison of the phases of each of the subcarriers between the successive symbols [1].

When an OFDM symbol of sequence length N is replicated in the transmitter, the receiver receives in the absence of noise, the 2N point sequence r(n) given by

$$r(n) = \frac{1}{N}\left[\sum_{k=-K}^{K} X(k)H(k)e^{j2\pi n(k+\varepsilon)/N}\right], n = 0,1,..N-1 \quad (14)$$

where X(k) are the 2K+1 complex modulation values used to modulate 2K+1 subcarriers. H(k) is the channel transfer function for the k^{th} carrier. The first set of N symbols is demodulated using an N-point FFT to yield the sequence $R_1(k)$ which is equal to (4.16)

$$R_1(k) = \sum_{n=0}^{N-1} r(n)e^{-j2\pi nk/N} \quad (15)$$

(4.17)

The second set is demodulated using another N- point FFT to yield the sequence

$$R_2(k) = \sum_{n=N}^{2N-1} r(n)\, e^{-\frac{j2\pi nk}{N}}$$
$$= \sum_{n=0}^{N-1} r(n+N)e^{-\frac{j2\pi nk}{N}}, \quad k = 0,1,2..N-1 \quad (16)$$

From equation (2) we have

$$r(n+N) = r(n)\exp(2\pi j\varepsilon) \leftrightarrow R_2(k) = R_1(k)\exp(2\pi j\varepsilon)$$

that is frequency offset is the phase difference between the sequences $R_1(k)$ and $R_2(k)$. Adding white Gaussian noise we get (4.19)

$$Y_1(k) = R_1(k) + W_1(k) \quad (17)$$

$$Y_2(k) = R_1(k)\exp(2\pi j\varepsilon) + W_2(k) \quad (18)$$

We observe that between the first and second FFTs, both the ICI and the signal are altered in exactly the same way, by a phase shift proportional to frequency offset [4]. It was shown by Moose that carrier frequency offset can be estimated using Maximum Likelihood (ML) algorithm and is equal to [4]:

$$\hat{\varepsilon} = \left(\frac{1}{2\pi}\right)\tan^{-1}\left\{\frac{\sum_{k=-K}^{K} \text{Imag}[Y_2(k)Y_1^*(k)]}{\sum_{k=-K}^{K} \text{Real}[Y_2(k)Y_1^*(k)]}\right\} \quad (19)$$

where $\hat{\varepsilon}$ is the estimated carrier frequency offset for subcarrier number one i.e. smallest carrier frequency. For subcarrier number k the frequency offset is $k\hat{\varepsilon}$. In the absence of noise, the angle of $Y_2(k)Y_1^*(k)$ is $2\pi\varepsilon$ for each k. This maximum likelihood estimate is a conditionally unbiased estimate of the frequency offset and is computed using the received data. Once the frequency offset is known, the ICI distortion in the data symbols is reduced by multiplying the received symbols with a complex conjugate of the frequency shift and applying the FFT,

$$\hat{x}(n) = FFT\{y(n)e^{-j\frac{2\pi\hat{\varepsilon}}{N}}\} \quad (20)$$

4. PROPOSED ML METHOD

In the proposed method let the number of subcarriers in the OFDM modulator as *K*. In the case of MIMO-OFDM, the repetition is done with *r*=2 where *r* is how many times the data is repeated. At the OFDM transmitter, the data been modulated on the subcarriers *k* and its adjacent subcarrier *k+1* using QPSK modulation and then the repeated symbols are signed-reversed to form a new conjugate ICI cancellation scheme to the repeating symbols so that the phase difference between two adjacent subcarriers varies with respect to signal itself [7].

In this paper, another decoding technique is proposed known as orthogonal combiner at the receiver which uses different pairs to combine the received signals. The channel coefficient is $H_{m,n}(k)$ whereas the values of *m, n and k* are indexes of transmitting antennas, receiving antennas and time. Then the pairs $\left(H^*_{1,1}(2), H_{2,1}(1)\right), \left(H^*_{2,1}(2), -H_{1,1}(1)\right)$ and $\left(H^*_{1,2}(2), H_{2,2}(1)\right), \left(H^*_{2,2}(2), -H_{1,2}(1)\right)$ that are used to combine the received signals Y_1 and Y_2 at k and $k+1$ for time domain become:

$$Y_1(k) = H_{1,1}(2)^* Y_T(k) + H_{2,1}(2) Y_T(k+1)^* \quad (21)$$

$$Y_2(k) = H_{1,2}(2)^* Y_T(k) + H_{2,2}(2) Y_T(k+1)^* \quad (22)$$

$$Y_1(k+1) = H_{2,1}(1)^* Y_T(k) - H_{1,1}(1) Y_T(k+1)^* \quad (23)$$

$$Y_2(k+1) = H_{2,2}(1)^* Y_T(k) - H_{1,2}(1) Y_T(k+1)^* \quad (24)$$

Where $Y_1(k)$ and $Y_1(k+1)$ is the received signal Y_1 at time k and $k+1$ using orthogonal combiner. Similarly, received signal $Y_2(k)$ and $Y_2(k+1)$ at time k and $k+1$. $Y_T(k)$ and $Y_T(k+1)$ is the received signal at time *k and k+1.** represents conjugate term.

Similarly, the frequency domains that are being used to combine the received signal are; $\left(H^*_{1,2}(1), H_{1,1}(1)\right), \left(H^*_{2,2}(1), -H_{1,1}(1)\right)$ for the received signals Y_1 and $\left(H^*_{1,2}(2), H_{2,1}(2)\right), \left(H^*_{2,2}(2), -H_{1,1}(2)\right)$ for the received signals Y_2. The received signal for the frequency domain becomes:

$$\overline{Y_1(k)} = H_{1,2}(1)^* Y_F(k) + H_{1,1}(1) Y_F(k+1)^* \quad (25)$$

$$\overline{Y_2(k)} = H_{1,2}(2)^* Y_F(k) + H_{2,1}(2) Y_F(k+1)^* \quad (26)$$

$$\overline{Y_1(k+1)} = H_{2,2}(1)^* Y_F(k) - H_{1,1}(1) Y_F(k+1)^* \quad (27)$$

$$\overline{Y_2(k+1)} = H_{2,2}(2)^* Y_F(k) - H_{1,1}(2) Y_F(k+1)^* \quad (28)$$

Where $\overline{Y_1(k)}$ and $\overline{Y_1(k+1)}$ is the received signal Y_1 at frequency k and $k+1$ using orthogonal combiner. $Y_F(k)$ and $Y_F(k+1)$ is the received signal at frequency *k and k+1.* Substituting Eqs. (13), (14), (17) and (18), then the transmit symbol 1 resulted at using orthogonal combiner is:-

$$\widehat{S_1} = Y_1(k) + Y_2(k) + \overline{Y_1}(k) + \overline{Y_2}(k) \quad (29)$$

and substituting Eqs. (15), (16), (19) and (20) into Eq. (30)

$$\widehat{S_2} = Y_1(k+1) + Y_2(k+1) + \overline{Y_1}(k+1) + \overline{Y_2}(k+1) \quad (30)$$

The average E_b/N_o with the combination of time and frequency is as obtained below:

$$\xi = \frac{2(\alpha_{ij})\sigma_H^2 \sigma_S^2}{\sigma_W^2} \quad (31)$$

where ξ is average signal to noise ratio, α_{ij} is complex gain, σ_H^2 average power of channel gain, σ_S^2 is average energy of the transmit symbols and σ_w^2 is average noise. In the proposed method, the average E_b/N_o becomes higher, the noise in system becomes lower.

5. SIMULATION RESULTS

5.1 Performance

In order to compare the three different cancellation schemes (SC, ML and proposed Improved ML) BER curves were used to evaluate the performance of each scheme. For the simulations in this paper, MATLAB was employed with its Communications Toolbox for all data runs. Modulation scheme used is QPSK. The simulation parameters for the proposed scheme are shown in Table 1.

Table 1. Simulation Parameters

Number of subcarriers	256
Mapping Scheme	4-QPSK
Channel	AWGN
Frequency offset	[0,0.3,0.4,0.5]
SNR	0:20
IFFT size	1024

5.2 BER Performance

Figure 2 to Figure5 provides comparisons of the performance of the SC, ML and Improved ML schemes for different values of the frequency offset. From the below figures it has been analyzed through simulation results ,as frequency offset goes higher improved ML scheme performs much better than ML and SC methods. In the proposed work frequency offset at 0, 0.1 , 0.3 and 0.4 is taken for the analysis of ICI cancellation schemes. Table 2. summarizes required values of SNR for BER specified at 10^{-4}.

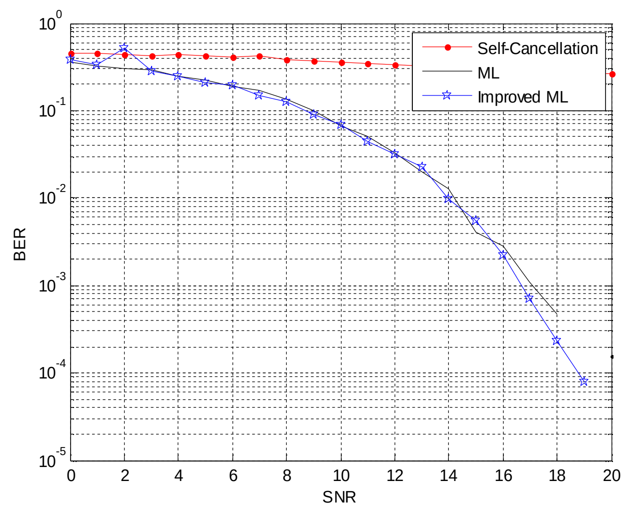

Figure 2. BER Performance with ICI cancellation, ε=0 for 4-QPSK

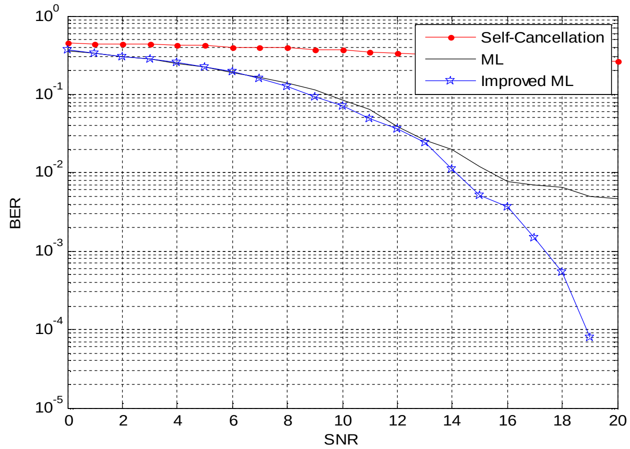

Figure 3. BER Performance with ICI cancellation, ε=0.1 for 4-QPSK

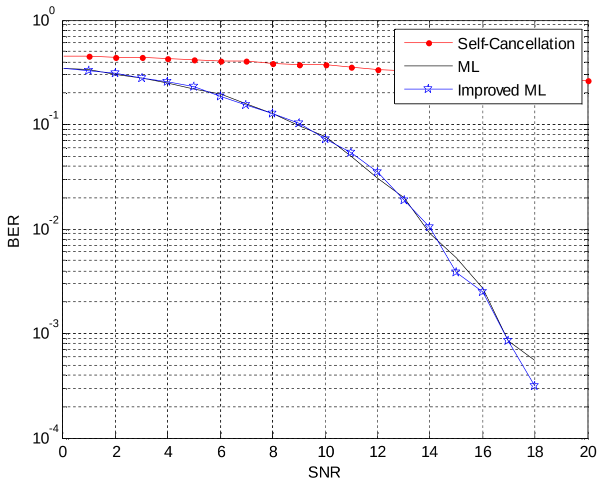

Figure 4. BER Performance with ICI cancellation, ε=0.3 for 4-QPSK

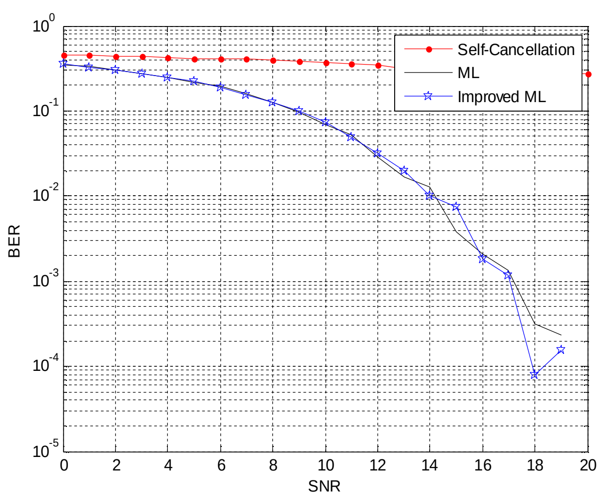

Figure 5. BER Performance with ICI cancellation, ε=0.4 for 4-QPSK

Table.2. Required SNR and Improvement for BER 10^-4 for QPSK

S.No.	Method	ε=0	ε=0.1	ε=0.3	ε=0.4
1	SC	Nil	Nil	Nil	Nil
2	ML	Nil	Nil	Nil	Nil
3	Improved ML	19 dB	19 dB	18 dB	18 dB

The above table shows that Improved ML corrects the frequency offset with improved SNR for BER upto 10^-4 where as the existing ICI cancellation fails to reduce ICI for this much bit and cannot perform for the above mentioned frequency offsets so indicated as nil.

6. CONCLUSION

This paper proposes a novel ICI reduction technique for MIMO-OFDM system to lessen the effect of frequency offset. The performance of the proposed OFDM system can be computed by finding their bit error rate (BER) for different values of signal to noise ratio (SNR) in AWGN channel. In the proposed scheme, the data needs to be transmitted over adjacent subcarriers with repeated symbols signed and reversed to form conjugate data resulting in the reduced bandwidth efficiency. When inputs are transmitted from Tx (transmitter) antennas, they are affected by the channel. Each Rx (receiver) antenna is receiving signals from each Tx antenna. Now the received signal at Rx antenna is not a product of single channel response and single input signal but it is combination of signals from each Tx antenna multiplied with their respective channel responses. However, in the presence of larger frequency offsets, where the communication can be greatly affected, the OFDM system using the proposed ICI reduction technique performs much better than the standard OFDM system and the OFDM systems using existing ICI cancellation methods. Therefore, it can be concluded that with the proposed scheme the need for channel equalization for reducing ICI can be eliminated and hence, easy to implement without increasing the system complexity.

REFERENCES

[1] Moose, P.H., “A technique for Orthogonal Frequency Division Multiplexing Frequency offset correction”, *IEEE Transactions on Communications*, vol.42, no.10, 1994.

[2] Yuping Zhao and Sven-Gustav Häggman, “Intercarrier Interference Self-Cancellation Scheme for OFDM Mobile Communication Systems”, *IEEE Transactions On Communications*, vol. 49,no. 7,pp.1185-1191, JULY 2001.

[3] Yi-Hao Peng, Ying-Chih Kuo, Gwo-Ruey Lee, and Jyh-Horng Wen, “Performance analysis of a new ICI-Self-Cancellation-Scheme in OFDM Systems ”, IEEE Transactions on Consumer Electronics, vol. 53, no. 4, pp.1333-1338, November 2007.

[4] Christian Oberli, "ML-based Tracking Algorithms for MIMO-OFDM", *IEEE Transactions on Wireless Communications,* vol. 6, no. 7, pp.2630-2639, July 2007.

[5] Yi-Hao Peng, Ying-Chih Kuo, Gwo-Ruey Lee, and Jyh-Horng Wen, "Performance analysis of a new ICI-Self-Cancellation-Scheme in OFDM Systems ", IEEE Transactions on Consumer Electronics, vol. 53, no. 4, pp.1333-1338, November 2007.

[6] Yong-Hwa Kim and Jong-Ho Lee, "Joint Maximum Likelihood Estimation of Carrier and Sampling Frequency Offset for OFDM Systems", *IEEE Transactions on Broadcasting,* vol.57, no.2, pp.277-283, June 2011.

[7] Azlina Idris, Kaharudin Dimyati, Shaifah K.Syed Yusuf, "Evaluating a new subcarrier mapping ICI-SC scheme using Linear Maximum Likelihood alamouti combiner decoding technique",*Journal of Engineering Science and Technology*, vol.6,no.6,pp.664-673, 2011.