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A Novel Bit Error Rate Analysis and Improved ICI Reduction Method in OFDM Communication Systems

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Abstract In this paper, we have proposed a novel method for the bit error rate (BER) analysis with frequency offset and improved inter-carrier-interference (ICI) reduction in the OFDM digital communication system. We also analyze the sub-carrier index before and after cancellation of the frequency offset and discuss the carrier-to-interference ratio (CIR). The results of the present analysis are compared with the others reported literatures.

Keywords OFDM · Bit error rate · Frequency offset · Communication · Carriers · Inter-carrier- interference

1 Introduction

Orthogonal frequency division multiplexing (OFDM) is considered an effective approach for the future high speed wireless multimedia communication systems [1–10]. The basic principle of OFDM is to split the high data stream into number of lower rate data streams which are transmitted simultaneously over number of sub-carriers. However, this technique makes an inefficient use of available bandwidth. The overlapping of multi-carrier modulation technique, almost 50% bandwidth can be saved but it introduces cross-talk between sub-carriers. This effect of cross-talk is reduced by using the orthogonality between different modulated sub-carriers. OFDM is a modulation scheme that allows digital data to be efficiently and reliably transmitted over a radio channel, even in the multipath environment and it eliminates the effects of multipath by breaking the signal into many narrow bandwidth carriers. This results in a low symbol rate, thereby reducing the amount

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of inter-symbol-interference (ISI). Furthermore, a guard period is inserted to start of each symbol to remove the effects of ISI for multipath signals delayed less than the guard period. OFDM signals are made from a sum of sinusoids, each corresponding to a sub-carrier. The baseband frequency of each sub-carrier is chosen to be an integer multiple of the inverse of the symbol time. This ensures that all sub-carriers have an integer number of cycles per symbol. As a consequence, the sub-carriers are orthogonal to each other because on multiplying the waveforms of any two sub-carriers and integrate over the symbol period the result is zero. The mixing of two sub-carriers are same as the multiplication of two sine waves together, which provides the sum and difference frequency components. These sub-carrier frequencies are always integers such as the frequency of two mixing sub-carriers have integer number of cycles [1, 3, 4]. We can integrate the result by taking the integral of each frequency component separately then combining the results by adding the two sub-integrals because the system is linear. These two frequency components after the mixing of two sub-carriers have an integer number of cycles over the period and so the sub-integral of each component will be zero, as the integral of a sinusoid over an entire period is zero. Both the sub-integrals are zeros and so the resulting addition of the two will also be zero, thus we have established that the frequency components are orthogonal to each other [9, 10].

As we know, the high spectral efficiency and multipath immunity are two major features of the OFDM communication systems. However, it is very sensitive to the carrier frequency offset between transmitter and a receiver, which destroys the orthogonality between sub-carriers and creates ICI. The reduction of signal amplitude and introduction of the ICI are two destructive effects caused by the carrier frequency offset in OFDM. So it needs to reduce ICI. There are several methods [11–16] have been developed for BER analysis of OFDM system. Kang *et al.* [13] and Zhao and Haggman [14] discuss the self-cancellation scheme for the OFDM to reduce the effects of frequency offset error. In [15] BER upper bound of the OFDM system is analyzed without ICI self-cancellation where as in [16] it is analyzed using self-cancellation technique but this method is less accurate. Yeh *et al.* [17] have discussed the ICI mitigation using conjugate-cancellation but they have not provided any mathematical analysis for the calculation of ICI.

In this paper, we have presented the BER analysis and improved ICI cancellation technique for the OFDM system. In the proposed OFDM system, at the transmitter, IFFT is performed for first part of the data and FFT for the second part of data. At the receiver, FFT is performed for first part of the data and IFFT for the second part of data. These combined operation forms an ICI cancellation scheme for mitigating frequency offset of the OFDM system as shown in Fig. 1. We have also derived a formula for the BER with frequency offset which improved the ICI reduction of the OFDM system. The organization of the paper is as follows. In Section 2, we discuss the system model of the OFDM. The Section 3 discusses the conjugate cancellation scheme of ICI. The result of the proposed scheme is discussed in Section 4 and finally, Section 5 concludes the work.

2 System model

Figure 1 shows a typical discrete-time base band equivalent model of the OFDM digital communication systems. The input binary serial data stream is encoded using suitable modulation technique (M- QAM, BPSK, and QPSK) as shown in Fig. 1. Further, the symbols are transferred in the serial-to-parallel converter (S/P) in this stage duration of bits is increased. First part of parallel bit stream is subjected to IFFT block and second part is subjected to FFT block. The modulated symbols are serialized using a parallel-to-serial converter (P/S). Now, the guard band addition is performed because at the receiver one

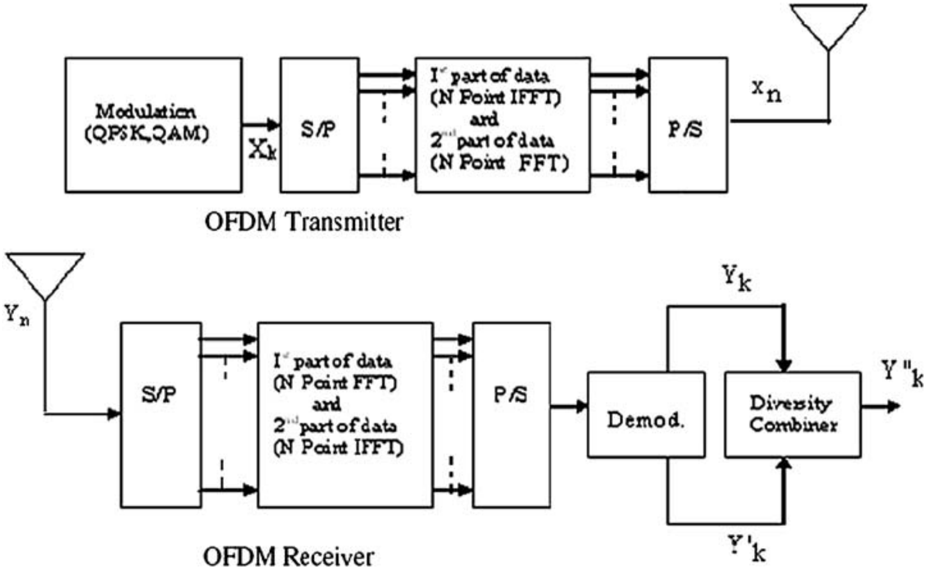

Fig. 1 The system model for the OFDM digital communication systems.

OFDM symbol is overlapped with the other symbol due to the multipath distortion. To eliminate the problem of ISI a guard time inserted between two symbols and duration of the guard interval should be greater than the maximum delay spread. The guard time is consist with no signal at all. In the next block digital signal is converted to analog via the digital-to-analog converter (D/A) before send sent down to the channel. At the receiver side, the guard interval is removed and the received symbol is converted from analog to digital using the analog-to-digital converter (A/D). In the next process data is transferred to the serial to parallel converter and then data is sent in IFFT and FFT block. After FFT and IFFT block data is sent for parallel to serial (P/S) conversion and then for demodulation. The ICI cancellation is performed after demodulation using the diversity combiner.

3 Proposed ICI cancellation scheme

The input data bits are encoded by using suitable modulation technique like (QPSK or QAM) and the output of this block is X_k. The IFFT out put at the transmitter is [1]:

$$x_n = \frac{1}{N}\sum_{k=0}^{N-1} X_k e^{2\pi jnk/N} \tag{1}$$

$$n = 0,\ 1,\ 2\text{-----------}N\text{-}1.$$

where N≥2k+1, and k is the number of sub-carries and N is the period of IFFT. The frequency offset arises due to the frequency mismatch of oscillator of the transmitter and receiver as discussed in [1]. At the received sequence after passing through the channel can be expressed as:

$$y_n = e^{\left(j2\pi\,\varepsilon n/_N\right)}[x_n * h_n] + W_n \tag{2}$$

The frequency offset is constant over the one IFFT period as shown in [1–5] and [11–15]. There are two deleterious effects caused by frequency offset; one is the reduction of signal amplitude in the output of the filters matched to each carriers and the second is introduction of ICI [1]. Due to the ICI, the performance of OFDM system is decreases greatly. After some mathematical manipulation the above equation can be expressed as:

$$y_n = \frac{1}{N}\left[\sum_{k=0}^{N-1} X_k H_k e^{2\pi jn(k+\varepsilon)/N}\right] + W_n \tag{3}$$

where H_k is the channel transfer function at the frequency of k^{th} sub-carrier, ε is the relative frequency offset of the channel, and W_n is Additive White Gaussian Noise (AWGN). Most types of the noise present in radio communication systems can be modeled accurately using AWGN. This noise has a uniform spectral density (making it white) and Gaussian distribution in amplitude. Thermal and electrical noise from amplification, primarily have White Gaussian Noise properties allowing them to be modeled accurately with AWGN. Also most other noise sources have AWGN properties due to transmission being OFDM. OFDM signals have a flat spectral density and Gaussian amplitude distribution provided that numbers of carriers are large. The output of DFT demodulator can be expressed as:

$$\begin{aligned} \mathrm{Y_k} &= \sum_{n=0}^{N-1}\left\{\frac{1}{N}\left[\sum_{k=0}^{N-1} H_k X_k e^{2\pi jn(k+\varepsilon)/N}\right] + W_n\right\} e^{-2\pi jk\,n/N} \\ Y_k &= (X_k H_k)\left\{\frac{\sin \pi\varepsilon}{N(\pi\varepsilon/N)}\right\} e^{j\pi(N-1)/N} + I_k \end{aligned} \tag{4}$$

The first component on the right-hand side of above equation is the modulation value X_k which is modified by channel transfer function. This component experiences an amplitude reduction and phase shift due to the frequency offset. Second term is the ICI term, which arises due to frequency mismatch of oscillator transmitter and receiver. So the ICI can be expressed as:

$$I_k = \sum_{l=0}^{N-1} \frac{1}{N} X_l H_l \sum_{n=0}^{N-1} e^{2\pi jn\,(l+\varepsilon-k)/N}\Bigg|_{l\neq k} \tag{5}$$

Above summation term is in the geometric progression of total N terms with common factor is $\exp(2\pi\ (l+\varepsilon - k))$. The expansion of summation factor is as below:

$$I_k = \sum_{l=0}^{N-1} \frac{1}{N} X_l H_l \left[1 + e^{2\pi j\ ((l+\varepsilon-k)/N)} + e^{4\pi j((l+\varepsilon-k)/N)} + \cdots + e^{2\pi j(N-1)((l+\varepsilon-k)/N)}\right]$$

After addition of the above geometric progression, we get:

$$I_k = \sum_{l=0}^{N-1} \frac{1}{N} X_l H_l \underbrace{\left[\frac{1 - e^{2\pi j(l+\varepsilon-k)}}{1 - e^{2\pi j((l+\varepsilon-k)/N)}}\right]}_{P}$$

Bracketed term is taken as P for simplicity and simplified as:

$$P = \left(\frac{1 - e^{2\pi j((l+\varepsilon-k)}}{1 - e^{2\pi j((l+\varepsilon-k)/N)}}\right) \times \left(\frac{e^{-\pi j(l+\varepsilon-k)}}{e^{-\pi j((l+\varepsilon-k)/N)}} \times \frac{e^{-\pi j((l+\varepsilon-k)/N)}}{e^{-\pi j(l+\varepsilon-k)}}\right)$$

or

$$P=\left(\frac{\sin\pi(l+\varepsilon-k)}{\sin\pi((l+\varepsilon-k)/N)}\right)\times\left(\frac{e^{-\pi j(((l+\varepsilon-k)/N))}}{e^{-\pi j(l+\varepsilon-k)}}\right)$$

So now equation (5) can be written as:

$$I_k=\sum_{\substack{l=0\\ l\neq k}}^{N-1}\frac{1}{N}X_lH_l\left[\frac{\sin\pi(l+\varepsilon-k)}{\sin\pi\left(\frac{l+\varepsilon-k}{N}\right)}\right]e^{\,j\pi(N-1)\left(\frac{l+\varepsilon-k}{N}\right)} \tag{6}$$

The sequence $S(l-k)$ is defined as the ICI coefficient between lth and kth sub-carriers, which can be expressed as:

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

The first term in the right-hand side of (7) represent the desired signal. Without frequency error (ε=0), $S(0)$ takes its maximum value S(0)=1. The second term is ICI component. As we know, if ε becomes larger, the desired part $|S(0)|$ decreases and the undesired part $|S(l-k)|$ increases. $S'(l-k)$ is ICI coefficient of the self-cancellation technique and given by equation (10) of [14]. $S'(l - k)$ is the proposed ICI coefficient. $W_n$is Additive White Gaussian Noise it is assumed to be zero without loss in generality as given in [17]. Taking the FFT of same data X_k at the transmitter (2nd part of the data) from Fig. 1 the data duplication is necessary for the ICI cancellation as given in [11, 13–18]. The bandwidth efficiency is reduced due to duplication of data but it is comparable with the other ICI cancellation techniques as in [11, 13–16, 20].

$$x'_k=\sum_{n=0}^{N-1}X_ke^{-(2\pi jnk/N)} \tag{8}$$

and

$$y'_k=\left[\sum_{n=0}^{N-1}X_kH_ke^{2\pi jn(-k+\varepsilon)/N}\right]+W'_n\ \mathrm{k}\ =\ 0,\ 1,\ 2\ \ldots\ldots\ldots \mathrm{N}-1. \tag{9}$$

Output of the IDFT demodulator can be expressed as:

$$\mathrm{Y}'_\mathrm{k}=\frac{1}{\mathrm{N}}\sum_{\mathrm{k}=0}^{\mathrm{N}-1}\left\{\left[\sum_{\mathrm{n}=0}^{\mathrm{N}-1}\mathrm{H_kX_k}e^{2\pi \mathrm{jn}(-\mathrm{k}+\varepsilon)/\mathrm{N}}\right]+\mathrm{W}'_\mathrm{n}\right\}e^{2\pi\mathrm{jkn/N}} \tag{10}$$
$$\mathrm{Y}'_\mathrm{k}=\underbrace{(\mathrm{X_kH_k})\left\{\frac{(\sin\pi\varepsilon)}{\mathrm{N}\sin(\pi\varepsilon/\mathrm{N})}\right\}e^{\mathrm{j}\pi\varepsilon(\mathrm{N}-1)/\mathrm{N}}}_{\mathrm{I}}+\underbrace{\mathrm{I}'_\mathrm{k}}_{\mathrm{II}}$$

The first component is the modulation value X_k is modified by channel transfer function. This component experiences an amplitude reduction and phase-shift due to the frequency offset. Second term is the ICI term, which arises due to frequency mismatch of oscillator transmitter and receiver. So ICI can be expressed as:

$$\mathrm{I}'_\mathrm{k}=\sum_{l=0}^{N-1}\frac{1}{N}X_lH_l\sum_{n=0}^{N-1}e^{2\pi jn((k+\varepsilon-l)/N)}\Bigg|_{l\neq k} \tag{11}$$

Above summation term is in geometric progression of total N terms of common factor is exp $(2\pi(l-\varepsilon-k))$ and expand summation factor as below.

$$\mathrm{I}'_{\mathrm{k}} = \sum_{l=0}^{N-1} \frac{1}{N} X_l H_l \left[1 + e^{2\pi j\ ((-l+\varepsilon+k)/N)} + e^{4\pi j((-l+\varepsilon+k)/N)} + \cdots + e^{2\pi j(N-1)((-l+\varepsilon+k)/N)}\right]$$

or

$$\mathrm{I}'_{\mathrm{k}} = \sum_{l=0}^{N-1} \frac{1}{N} X_l H_l \underbrace{\left[\frac{1-e^{2\pi j(-l+\varepsilon+k)}}{1-e^{2\pi j((-l+\varepsilon+k)/N)}}\right]}_{P'}$$

Bracketed term is taken as P' and it can be modified as:

$$P' = \left(\frac{1-e^{2\pi j((k+\varepsilon-l)}}{1-e^{2\pi j((k+\varepsilon-l)/N)}}\right) \times \left(\frac{e^{-\pi j(k+\varepsilon-l)}}{e^{-\pi j((k+\varepsilon-l)/N)}} \times \frac{e^{-\pi j((k+\varepsilon-l)/N)}}{e^{-\pi j(k+\varepsilon-l)}}\right) \tag{12}$$

$$P' = \left(\frac{\sin\pi(k+\varepsilon-l)}{\sin\pi((k+\varepsilon-l)/N)}\right) \times \left(\frac{e^{-\pi j((k+\varepsilon-l)/N)}}{e^{-\pi j(k+\varepsilon-l)}}\right)$$

$$I'_k = \sum_{\substack{l=0\\ l\neq k}}^{N-1} \frac{1}{N} X_l H_l \left[\frac{\sin\pi(l+\varepsilon-k)}{\sin\pi\left(\frac{l+\varepsilon-k}{N}\right)}\right] e^{\,j\pi(N-1)\left(\frac{l+\varepsilon-k}{N}\right)}$$

$\mathrm{W'}_{\mathrm{n}}$ is also the Additive White Gaussian Noise. It is assumed to be zero without loss in generality in above discussion as shown in [17]. ICI term at the output of the receiver is:

$$I''_k = \frac{I_k + I'_k}{2} \tag{13}$$

By substituting the value from equation (6) and (12) in equation (13), we get:

$$I''_k = \frac{1}{2} \sum_{l=0}^{N-1} e^{j\pi(N-1)((l+\varepsilon-k)/N)} X_l H_l \left\{ \left(\frac{\sin\pi(l+\varepsilon-k)}{\pi(l+\varepsilon-k)}\right) + \left(\frac{\sin\pi(k+\varepsilon-l)}{\pi(k+\varepsilon-l)}\right) \right\} \tag{14}$$

Case 1: If $l-k$=even numbers, then

$$I''_k = \frac{1}{2} \sum_{l=0}^{N-1} e^{j\pi(N-1)((l+\varepsilon-k)/N)} X_l H_l \frac{\sin\pi\varepsilon}{\pi} \left\{ \left(\frac{1}{(l+\varepsilon-k)}\right) - \left(\frac{1}{(l-\varepsilon-k)}\right) \right\}$$

$$= -\frac{1}{2} \sum_{l=0}^{N-1} e^{j\pi(N-1)((l+\varepsilon-k/N))} X_l H_l \frac{\sin\pi\varepsilon}{\pi} \left\{ \frac{2\varepsilon}{(l-k)^2-\varepsilon^2} \right\}$$

Science $(l-k) \rangle\ \varepsilon$ so ε^2 can be neglected in compression of $(l-k)^2$.

$$\approx -\sum_{l=0}^{N-1} e^{j\pi(N-1)((l+\varepsilon-k)/N)} X_l H_l \frac{\sin\pi\varepsilon}{\pi} \left\{ \frac{\varepsilon}{(l-k)^2} \right\}$$

$$= -\sum_{l=1}^{N-1} e^{j\pi(N-1)((l+\varepsilon-k)/N)} X_l H_l \frac{\sin\pi\varepsilon}{\pi} \left\{ \frac{\varepsilon}{(l)^2} \right\} \Bigg|_{l\neq 0}$$

For simplification of calculation of ICI term, we are approximating exponential phase term given $e^{j\pi(N-1)((l-k+\varepsilon)/N)}$with one. If we do not approximate phase term with one even then resultant ICI after cancellation becomes same because for calculation of variance of ICI after cancellation. In order to evaluate the statistical properties of ICI after conjugate cancellation assume E(I″k)=0 and assuming average channel gain $E\left[|H_l|^2\right] = |H|^2$ is constant and $E\left[|X_l|^2\right] = |X|^2$. Now, we will find variance of inter carrier interference:

$$E\left[|I''_k|^2\right] = |X|^2 \sum_{l=1}^{N-1} E\left\{|H_l|^2\right\} \left(\frac{\sin\pi\varepsilon \times \varepsilon}{\pi}\right)^2 \left\{\frac{1}{(l)^2}\right\}^2 \tag{15}$$

Here, l=1 ……N−1, and N≥2K+1, so we can write $-K \langle\, l \,\langle\, K$. Also l^4 is even function, equation can be written as:

$$E\left[|I''_k|^2\right] = |X|^2 \sum_{l=-K}^{K} E\left\{|H_l|^2\right\} \left(\frac{\sin\pi\varepsilon \times \varepsilon}{\pi}\right)^2 \left\{\frac{1}{(l)^2}\right\}^2 \leq |X|^2|H|^2 \left(\frac{\sin\pi\varepsilon \times \varepsilon}{\pi}\right)^2 2\sum_{l=0}^{\infty} \left\{\frac{1}{(l)^2}\right\}^2$$

Variance of ICI is:

$$\sigma_{ICI}{}^2 = |X|^2|H|^2(\sin\pi\varepsilon \times \varepsilon)^2 \times 0.2195 \tag{16}$$

Case 2: If $l - k$= odd numbers, then

$$\begin{aligned}
I''_k &= -\frac{1}{2}\sum_{l=0}^{N-1} e^{j\pi(N-1)((l+\varepsilon-k)/N)} X_l H_l \frac{\sin\pi\varepsilon}{\pi}\left\{\left(\frac{1}{(l+\varepsilon-k)}\right) + \left(\frac{1}{(k+\varepsilon-l)}\right)\right\} \\
&= -\frac{1}{2}\sum_{l=0}^{N-1} e^{j\pi(N-1)((l+\varepsilon-k)/N)} X_l H_l \frac{\sin\pi\varepsilon}{\pi}\left\{\left(\frac{1}{(l+\varepsilon-k)}\right) - \left(\frac{1}{(l-\varepsilon-k)}\right)\right\} \\
&= \frac{1}{2}\sum_{l=0}^{N-1} e^{j\pi(N-1)((l+\varepsilon-k)/N)} X_l H_l \frac{\sin\pi\varepsilon}{\pi}\left\{\left(\frac{2\,\varepsilon}{(l-k)^2-\varepsilon^2}\right)\right\}
\end{aligned}$$

Since, $l - k \rangle\rangle\, \varepsilon$ so ε^2 can be neglected in compression of $(l - k)^2$

$$\begin{aligned}
&\approx \sum_{l=0}^{N-1} e^{j\pi(N-1)((l+\varepsilon-k/N)} X_l H_l \frac{\sin\pi\varepsilon}{\pi}\left\{\left(\frac{\varepsilon}{(l-k)^2}\right)\right\} \\
&\approx \sum_{l=0}^{N-1} e^{j\pi(N-1)((l+\varepsilon-k/N)} X_l H_l \frac{\sin\pi\varepsilon}{\pi}\left\{\left(\frac{\varepsilon}{(l-k)^2}\right)\right\} \\
&= \sum_{l=1}^{N-1} e^{j\pi(N-1)((l+\varepsilon-k/N)} X_l H_l \frac{\sin\pi\varepsilon \times \varepsilon}{\pi}\left\{\frac{1}{(l)^2}\right\}\Bigg|_{l\neq 0}
\end{aligned}$$

Now, we find variance of the ICI as:

$$E\left[|I''_k|^2\right] = |X|^2 \sum_{l-1}^{N-1} E\left\{|H_l|^2\right\} \left(\frac{\sin\pi\varepsilon \times \varepsilon}{\pi}\right)^2 \left\{\frac{1}{(l)^2}\right\}^2 = |X|^2 \sum_{l=-K}^{K} E\left\{|H_l|^2\right\} \left(\frac{\sin\pi\varepsilon \times \varepsilon}{\pi}\right)^2 \left\{\frac{1}{(l)^2}\right\}^2 \tag{17}$$

Here, l=1 ....N−1 and N ≥ 2K+1, so we can write $-K \langle\, l \,\langle\, K$. Also l^4 is even function above can be written as:

$$E\left[|I''_k|^2\right] = 2|X|^2\sum_{l=1}^{K}E\left\{|H_l|^2\right\}\left(\frac{\sin\pi\varepsilon\ \times\ \varepsilon}{\pi}\right)^2\left\{\frac{1}{(l)^2}\right\}^2 \leq 2|X|^2\sum_{l=1}^{\infty}E\left\{|H_l|^2\right\}\left(\frac{\sin\pi\varepsilon\ \times\ \varepsilon}{\pi}\right)^2\left\{\frac{1}{(l)^2}\right\}^2$$
$$= |X|^2|H|^2\left(\frac{\sin\pi\varepsilon\ \times\ \varepsilon}{\pi}\right)^2 2\sum_{l=1}^{\infty}\left\{\frac{1}{(l)^4}\right\}$$

Variance of the ICI is:

$$\sigma_{ICI}{}^2 = |X|^2|H|^2\left(\frac{\sin\pi\varepsilon\ \times\ \varepsilon}{\pi}\right)^2 2\times 1.083 \tag{18}$$

$$\sigma_{ICI}{}^2 = |X|^2|H|^2(\sin\pi\varepsilon\ \times\ \varepsilon)^2\times 0.2195$$

The BER of QPSK modulated OFDM system is given in [19]:

$$\mathrm{BER} = 1/2 * \mathrm{Q}\left(\sqrt{\mathrm{E_s/N_0}}\right) \tag{19}$$

The BER of QPSK OFDM system after ICI cancellation as given by:

$$BER \leq 1/2{*}Q\sqrt{|\mathrm{X}|^2|\mathrm{H}|^2\{(\sin\pi\varepsilon)/\pi\varepsilon\}^2\Big/\left(\mathrm{N_\circ} + |\mathrm{X}|^2|\mathrm{H}|^2(\sin\pi\varepsilon)^2\times .2195\right)} \tag{20}$$

$$= 1/2{*}Q\sqrt{\frac{|\mathrm{X}|^2|\mathrm{H}|^2}{\mathrm{N_\circ}}\{(\sin\pi\varepsilon)/\pi\varepsilon\}^2\Big/\left(1+\frac{|\mathrm{X}|^2|\mathrm{H}|^2}{\mathrm{N_\circ}}(\sin\pi\varepsilon)^2\times .2195\right)}$$

$$\mathrm{BER} = 1/2{*}Q\sqrt{\frac{\mathrm{E_b}}{\mathrm{N_o}}\{(\sin\pi\varepsilon)/\pi\varepsilon\}^2\Big/\left(1+\frac{\mathrm{E_b}}{\mathrm{N_\circ}}(\sin\pi\varepsilon\times\varepsilon)^2\times .2195\right)}$$

4 Results and discussion

For simulation of Fig. 2, the modulation of QPSK at N=64 and guard interval seven is considered. Figure 2 shows the compression of BER between the self-cancellation method and proposed improved method for the frequency offset 0.1 and 0.2. The main concept of the self-cancellation scheme is to modulate one data symbol onto to the next sub-carrier with predefined inversed weighting coefficients “-1”. By doing so, the ICI signal generated within a group can be self-cancelled each other [14]. In the frequency offset 0.2, by using self-cancellation method BER greater than 10^{-1} at SNR=0dB and BER less than10^{-4} at SNR=10dB and for proposed method BER is 10^{-1} for 0dB SNR and BER is just less than 10^{-5}at 10dB SNR. But for normalized frequency offset 0.1 for self-cancellation method BER at 0dB SNR is greater than 10^{-1} and BER is less than 10^{-5} at 10dB SNR whereas for proposed improved cancellation method BER 10^{-1} at 0dB SNR and greater than 10^{-5} at 10dB SNR. So proposed improved cancellation scheme is better than ICI self-cancellation in [16]. Figure 3 also shows compression of the BER for higher alphabet size (16QAM OFDM system) at N=64. Figure 4 shows compression of the carrier to interference ratio (CIR) among different methods like [14], standard OFDM system and proposed scheme for normalized frequency offset 0.5 our result is comparable with [21]. The systems ICI power level can be evaluated by using CIR [1]. The carrier-to-interference of the proposed scheme is close to that of conventional OFDM systems. It means that the effect of ICI distortion in

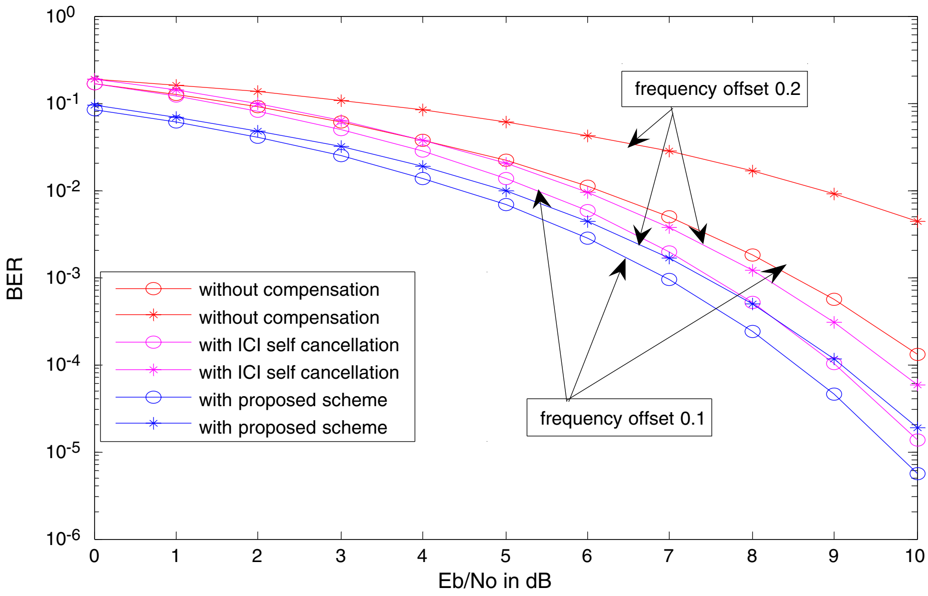

Fig. 2 Comparison between the proposed improved ICI cancellation schemes with the self-cancellation scheme.

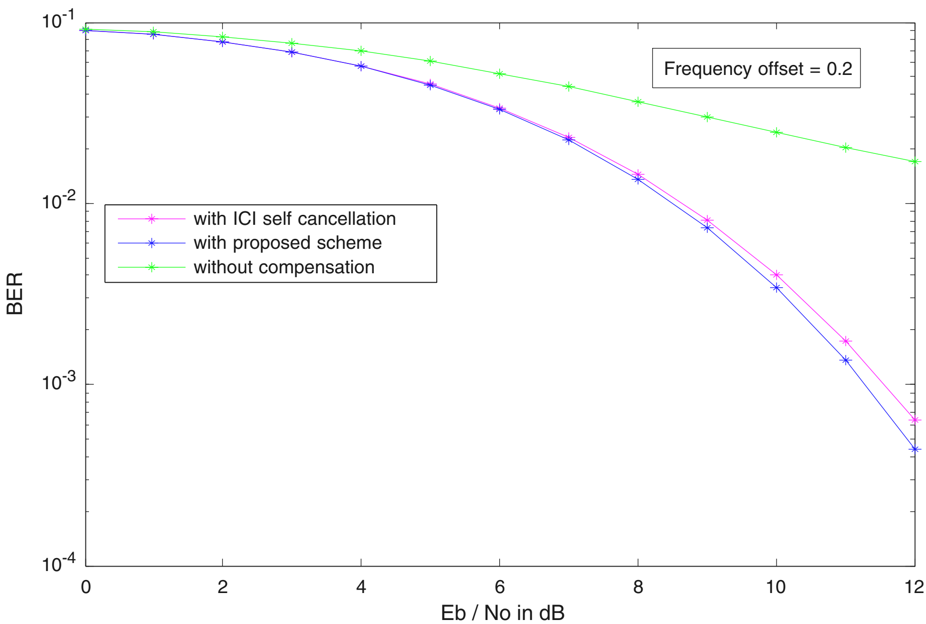

Fig. 3 Compression between proposed conjugate ICI cancellation schemes with self cancellation scheme for 16QAM OFDM system.

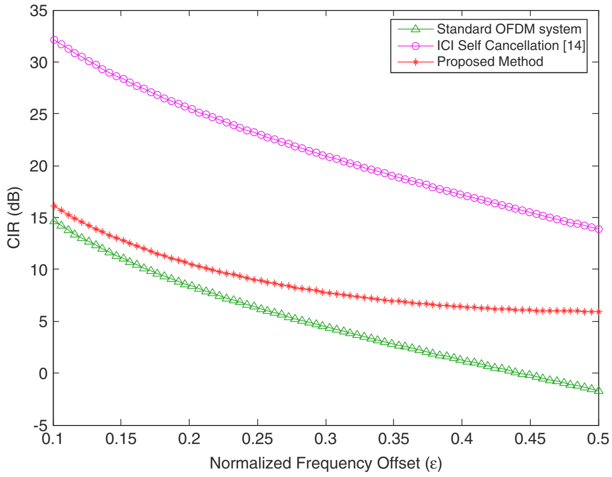

Fig. 4 Carrier to interference ratio (CIR) versus normalized frequency offset and comparison of the proposed scheme with [14].

the proposed scheme is close to the one in the conventional OFDM systems. There are three types of ICI coefficients such as $S(l-k)$ for the standard OFDM system, $S'(l-k)$ for ICI canceling modulation which is proposed and $S''(l-k)$ for combined ICI canceling modulation and demodulation. This combined ICI canceling modulation and demodulation methods is called the ICI self-cancellation scheme. Figure 5 shows compression of ICI coefficient before and after cancellation of ICI.

5 Conclusion

In this paper, we have suggested a simple improved ICI cancellation scheme to reduce the frequency offset sensitivity of the OFDM communication systems. The proposed parallel

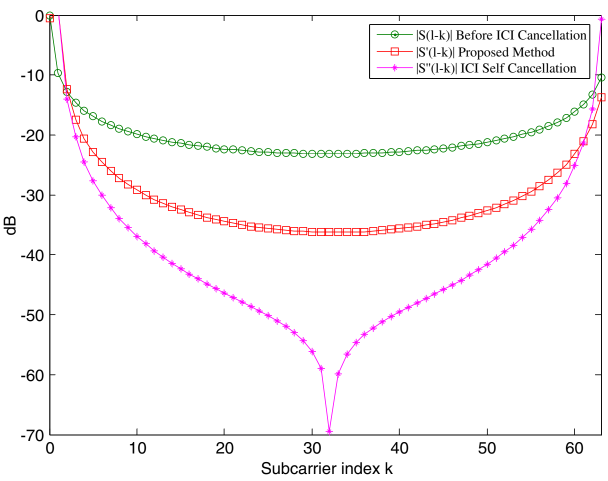

Fig. 5 Compression of the ICI coefficient before and after cancellation of ICI. It is also compared with [14].

algorithm employs an FFT at the transmitter and an IFFT at the receiver. The regular OFDM samples, which generated by the IFFT, are transmitted as the 1st block, and the FFT outputs are transmitted as the 2nd block. At the receiver, results of the 1st output generated by the FFT, are combined with the 2nd output generated by the IFFT. This combined operation forms a parallel inter carrier interference cancellation scheme for mitigating frequency offset of OFDM system. Proposed method provides better bit error rate than [14].

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