Modified SSR ICI Self-cancellation Scheme for Reducing Bit Error Rate in OFDM Systems

V. BHARATH KUMAR1, R. S. PRATAP SINGH2

1PG Scholar, Dept of ECE, PBR Visvodaya Institute of Technology and Sciences, Kavali, AP, India.
2Assoc Prof, Dept of ECE, PBR Visvodaya Institute of Technology and Sciences, Kavali, AP, India.

Abstract: Symmetric symbol repeat (SSR) inter carrier interference (ICI) self-cancellation scheme has showed to be easy and convenient technique to decrease ICI caused by frequency offsets. It utilize data allocation and merging of (1,-1) on two symmetrically placed subcarriers to moderate the effect of ICI. The data allocation factors (1,-1) are not an optimum. In this paper, optimal data allocation (1-λ) and combining (1-μ) scheme is proposed to maximize CIR performance for an estimated normalized frequency offset ε. But, this requires nonstop CFO estimation and feedback circuitry. A sub-optimal scheme uses sub-optimal pair (λ,μ) is also proposed to completely eliminate the requirement of CFO estimation. Simulation results prove the outperformance of the proposed optimal scheme over conventional SSR ICI self-cancellation scheme. Sub-optimal scheme can be applied for the any range of ε and a sub optimum value can be (λ,μ) calculate using proposed sub-optimal scheme. The CIR of SSR ICI self-cancellation scheme using the proposed sub-optimal approach is also found to be better than conventional SSR ICI self-cancellation.

Keywords: OFDM, ICI, CIR, BER.

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is being used for high data rate wireless applications [1]. It is a multicarrier modulation technique which incorporates orthogonal subcarriers. High Peak to Average Power ratio and Inter carrier Interference (ICI) are two main disadvantages of the OFDM systems. In OFDM systems ICI occurs due to frequency offset in between the transmitter and receiver carrier frequencies or Doppler Effect [2]. Many techniques have been developed to reduce the effect of ICI; ICI cancellation is a simple and convenient technique. ICI self-cancellation scheme [3] utilizes data allocation and combining of (1,-1) on two adjacent subcarriers i.e. same data is modulated at k-th and k+1-th subcarriers using (1,-1) as data allocation and are combined at the receiver with weights 1 and -1. It is one of the most promising techniques to reduce ICI, however, its performance humiliation at higher frequency offsets. Another technique known as conjugate cancellation [4].

In this scheme, OFDM symbol and its conjugate are multiplexed, spreaded and combined at the receiver to reduce the effect of ICI. However, this scheme shows a significant improvement in CIR at very low frequency offsets and its performance degrades as carrier frequency offset increases. At higher frequency offset >0.25 its CIR performance is worse than standard OFDM system. Extension to conjugate cancellation is Phase Rotated Conjugate Cancellation (PRCC) [5] in which an optimal value of phase is multiplied with the OFDM symbol and its conjugate signal to be transmitted on different path. The best value of the phase depends on the frequency offset and hence requires continuous carrier frequency offset (CFO) estimation and feedback circuitry, which raises the hardware complexity. Another ICI self-cancellation scheme [6] was proposed by Sathanantham, Rajatheva and Slimane, which utilizes data allocation and combining of (1,-1) at k-th and N-1-k-th subcarrier. This scheme shows better CIR performance than ICI self-cancellation scheme. One of the major advantages of this scheme is to achieve the frequency diversity and hence its performance in frequency selective fading channel found to be better than ICI self-cancellation scheme [3].

In this paper, we have proposed an optimum data allocation scheme for SSR ICI cancellation scheme to improve the CIR performance. The scheme is based on SSR ICI self-cancellation scheme, in which a data is modulated at two symmetrically placed subcarriers i.e. k-th and N-1-k-th and utilizes a data allocation of (1-λ) to improve CIR
performance. To further decrease the effect of ICI, received modulated data signal at \(k^{th}\) and \(N-1-k^{th}\) subcarriers are combined with weights \(1\) and \(\mu\) The \(\lambda\) and \(\mu\) are the optimal values resulting in maximum CIR. The best values of \(\lambda\) and \(\mu\) are the function of normalized frequency offset i.e. for every normalized frequency offset, there exist an unique value of \(\lambda\) and \(\mu\). This process requires continuous CFO estimation. To overcome this problem, we have proposed a suboptimal approach to find suboptimal values \((\lambda_{so}, \mu_{so})\).

The obtained sub-optimal values are independent of normalized frequency offset. Thus, the proposed scheme does not need any CFO estimation or feedback circuitry and hence eliminates the requirement of complex the hardware circuitry.

II. BACKGROUND

A. OFDM System

The discrete time OFDM symbol at the transmitter can be expressed as:

\[
X[n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} x(k) e^{j2\pi nk/N}, \quad n = 0, 1, 2, N-1
\]  

(1)

Where is total numbers of subcarriers and denotes the modulated data symbol transmitted on subcarrier. Due to AWGN channel and frequency offset, the received OFDM signal can be written as :

\[
y[n] = x[n]e^{j2\pi n/ N} + w[n], n = 0, 1, 2, \ldots, n-1
\]  

(2)

Where \(\epsilon\) is the normalized frequency offset and \(w[n]\) is the sample of additive white Gaussian noise. The received data signal on \(k^{th}\) subcarrier can write as:

\[
y(k) = x(k) + \sum_{l=0}^{N-1} x(l) e^{j2\pi l/k} + w(k), \quad k = 0, 1, \ldots, N-1
\]  

(3)

Where \(w(k)\) is the \(k^{th}\) sample of DFT of additive noise. The sequence \(s(1-k)\) is defined as the ICI coefficient between \(k^{th}\) and \(l^{th}\) subcarriers, which can be expressed as

\[
s(l-k) = e^{j\pi(1+i-k)(1-\frac{k}{N})} \frac{\sin(\pi(l-1-k))}{n \sin(\pi(l-1-k))}
\]  

(4)

The CIR at the \(k^{th}\) subcarrier can be written as

\[
CIR_0 = \frac{|s(k)|^2}{\sum_{l=0}^{N-1} |s(l-k)|^2}
\]  

(5)

B. SSR ICI Self-cancellation Scheme

In SSR ICI self-cancellation scheme [6], the data symbol to be transmitted at the \(k^{th}\) subcarrier is repeated at the \(N-1-k^{th}\) subcarrier with opposite polarity, i.e.

\[
X(N-1) = -x(0), \ldots, x(N-1-k) = -x(K)
\]

The block diagram of the proposed SSR ICI self-cancellation scheme is depicted in Fig. 1. The received data signal at the \(k^{th}\) subcarrier is thus given by

\[
Y(k) = \sum_{l=0}^{N-1} x(l) s(l-k) + w(k)
\]  

(6)

Combining the received data at \(k^{th}\) and \(N-1-k^{th}\) subcarriers, we have

\[
Y''(k) = Y(k) - Y'(N - 1 - k)
\]  

(7)

Using (6)&(7) we have

\[
Y''(k) = \sum_{l=0}^{N-1} x(l) s(l-k) - s(N-1-i-k) - s(1+k+1-N) + s(k-l) + w(k) - w(N-1-k), \quad k = 0, 1, 2, \ldots, N - 1
\]  

(8)

Thus, CIR of conventional SSR ICI self-cancellation scheme can be written as

\[
CIR_e = \frac{|-s(N-1-2k) + 2s(0) - s(1-N+2k)|^2}{|\sum_{l=0}^{N-1} s(l-k) - s(N-1-l-k) - s(1+k+1-N) + s(k-l)|^2}
\]  

(9)

III. PROPOSED SCHEME

In the proposed scheme at the transmitter a data allocation \((1,2)\) is utilized at \(k^{th}\) and \(N-1-k^{th}\) subcarriers. i.e.

\[
X(N-1) = \lambda x(0), x(N-2) = -\lambda x(1), \ldots, x(N-1-k) = -\lambda x(k)
\]

Hence, the received data signal at the \(k^{th}\) subcarrier is

\[
Y(k) = \sum_{l=0}^{N} x(l) s(l-k) - \lambda s(N-1-l-k) + w(k)
\]  

(10)

After combining the received data at \(k^{th}\) and \((N-1-k)^{th}\) subcarriers with weight \(1\) and \(-\mu\), we have

\[
Y''(k) = Y(k) - \mu Y'(N-1-k)
\]  

(11)

\[
Y''(k) = \sum_{l=0}^{N} s(l-k) - \lambda s(N-1-l-k) - \mu s(1+k+1-N) + s(k-l) + w(k)
\]  

(12)

Thus CIR of proposed optimal SSR ICI self-cancellation scheme is given by

\[
CIR_p = \frac{|-\mu s(2k+1-N) + (1+\lambda \mu) x(0) - \lambda s(N-1-2k)|^2}{\sum_{l=0}^{N} |s(l-k)|^2 + |s(N-k+1) - s(1+k+1-N) - \mu s(l-k) + \mu x(l-k)|^2}
\]  

(13)

The optimal values of \(\lambda\) and \(\mu\) have been found by using an optimization technique known as Nelder Mead Simplex Algorithm [8]. The optimum values of \(\lambda\) and \(\mu\) are
calculated for \(\varepsilon \in [0.03, 0.25]\) at a very small interval of \(\Delta \varepsilon\), which results in maximum CIR for the given \(\varepsilon\). Thus for every \(\varepsilon\), we have a unique optimal value of \(\lambda_0\) and \(\mu_0\) and these are denoted by \((\lambda_{0\sigma}, \mu_{0\sigma})\). The optimum values \((\lambda_{0\sigma}, \mu_{0\sigma})\) are to be used for data allocation and combining the data at \(k^{th}\) and \(N - 1 - k^{th}\) subcarriers to maximize the CIR of the OFDM system. But, this will require a continuous CFO estimation.

For each pair of \((\lambda_{0\sigma}, \mu_{0\sigma})\), the CIR has been calculated, which forms a CIR matrix as shown

\[
CIR_p(\varepsilon, \lambda_{0\sigma}, \mu_{0\sigma}) = \begin{bmatrix}
CIR_p(\varepsilon_1, \lambda_{0\sigma}, \mu_{0\sigma}) & \cdots & CIR_p(\varepsilon_n, \lambda_{0\sigma}, \mu_{0\sigma}) \\
\vdots & \ddots & \vdots \\
CIR_p(\varepsilon_1, \lambda_{0\sigma}, \mu_{0\sigma}) & \cdots & CIR_p(\varepsilon_n, \lambda_{0\sigma}, \mu_{0\sigma})
\end{bmatrix}
\]

(14)

Here, \(CIR_p(\varepsilon_1, \lambda_{0\sigma}, \mu_{0\sigma})\) corresponds to maximum value of CIR for \(\varepsilon_1\), and \(CIR_p(\varepsilon_n, \lambda_{0\sigma}, \mu_{0\sigma})\) corresponds to maximum CIR for \(\varepsilon_n\) and so on and

\[
\nu = \frac{(\varepsilon_H - \varepsilon_L)}{\Delta \varepsilon} + 1
\]

(15)

Where, \(\varepsilon_L\) and \(\varepsilon_H\) are the lowest and the highest possible values of the normalized frequency offset. Here, we have considered \(\varepsilon_H=0.25\) and \(\varepsilon_L=0.03\). To avoid the problem of continuous estimation, sub-optimal pair \((\lambda_{50\sigma}, \mu_{50\sigma})\) amongst all \((\lambda_{0\sigma}, \mu_{0\sigma})\) has been found by using the following criterion as

\[
(\lambda_{50\sigma}, \mu_{50\sigma}) = \max_{\varepsilon} \mu_1 \cdot \left[\frac{\sum p \cdot CIR(\varepsilon, \lambda_{0\sigma}, \mu_0)}{\nu}\right]
\]

(16)

In the above expression, \(\rho\) represents the maximum CIR of a particular row of the matrix given by (14) and the second term represents the mean deviation of the CIR of that row from the peak \(\rho\) of that row. Thus irrespective of the value of \(\varepsilon, (\lambda_{50\sigma}, \mu_{50\sigma})\) can be used for data allocation and combining to get a sub-optimal CIR performance. In the proposed scheme, \(\Delta \varepsilon\) is taken as 0.02 and thus \(\nu\) is 12. Applying the above described algorithms, sub-optimal values are \(\lambda_{50\sigma} = 0.6164\) and \(\mu_{50\sigma} = 1.0351\). This optimization and sub-optimization technique can be applied for any range as required.

IV. RESULTS & DISCUSSION

In this paper, we have considered an OFDM system with \(N=256\) subcarriers and QPSK modulation scheme is used to modulate each of the subcarriers. The simulation model of the OFDM system is shown in Fig.1. The computer model using MATLAB are performed to evaluate CIR and BER performance. Fig. 2 shows the CIR performance of regular OFDM system, SSR ICI self-cancellation [6], Proposed SSR ICI self-cancellation using optimal & sub-optimal approach.
Fig. 3 shows BER performance of the regular OFDM system, straight SSR ICI self-cancellation and the proposed SSR ICI self-cancellation using sub-optimal approach. As seen from Fig. 2 the CIR performance of the proposed best approach is about 20dB better than the conventional SSR ICI self-cancellation scheme. However, the proposed sub-optimal approach also provides better CIR scheme performance over conventional SSR ICI self-cancellation scheme, proposed suboptimal approach provides a gain of more than 10dB at $\varepsilon = 0.15$ over conventional SSR ICI self-cancellation scheme. The CIR performance of proposed SSR ICI self-cancellation scheme is slightly worse than conventional SSR ICI self-cancellation scheme for $\varepsilon \in [0.03, 0.08]$. The BER performance of the proposed SSR ICI self-cancellation scheme is very much improved in comparison to standard OFDM system and very close to conventional SSR ICI self-cancellation scheme.

V. CONCLUSIONS
The proposed scheme very well improves the CIR performance of the OFDM system without increasing hardware complexity. The proposed sub optimal scheme completely removes the requirement of CFO estimation. However, the proposed scheme is slightly less efficient than conventional SSR ICI self-cancellation in terms of BER.

VI. REFERENCES

Author’s Profile:
V. Bharath Kumar has received his B.Tech degree in Electronics Communication Engineering from SRR Engineering College affiliated to JNTUH, Hyderabad in 2009 and pursuing M.Tech degree in DSCE in PBR Visvodaya Institute of Technology and Sciences affiliated to JNTUA, Anantapur in 2012-2014.

R. S. Pratap Singh has received his B.Tech in Electronics and Communication Engineering from Vijaya Nagara Engineering College, Bellary affiliated to Gulbarga University in 1994 and M.Tech degree in DSCE from PBR Visvodaya Institute of Technology and Sciences affiliated to JNTUA, Anantapur. He is dedicated to teaching field from the last 14 years. He has guided 10 P.G and 100+ U.G students. His research areas included Communications. At present he is working as Associate Professor in PBR Visvodaya Institute of Technology and Sciences, Kavali, Andhra Pradesh, India.