An improved DFT-IDFT based ICI cancellation scheme for OFDM Systems

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Abstract: - Orthogonal frequency division multiplexing is widely known as the promising technique for the broadband wireless mobile communication system. The main drawback of OFDM systems is its sensitivity to frequency offset, which causes intercarrier interference (ICI) in the OFDM symbols. This ICI degrades the bit error rate (BER) performance of the system. In this paper an improved discrete Fourier transform-inverse discrete Fourier transform (DFT-IDFT) based ICI cancellation scheme is proposed to improve the system performance. The simulation results show that there is satisfactory improvement in the bit error rate (BER) performance of the present scheme.

Key-Words: - OFDM, ICI coefficients, Intercarrier interference, Frequency offset.

1 Introduction

OFDM is an emerging modulation scheme in the current broadband wireless mobile communication system due to the high spectral efficiency and robustness to multi-path interference [1]. A well-known disadvantage of the OFDM system is its sensitivity to frequency offset between transmitted and received signals, which may be caused by Doppler shift in the channel [2], or by the difference between the transmitter and receiver local oscillator frequencies. The carrier frequency offset causes loss of orthogonality and then the signals transmitted on each carrier are not independent of each other, thus leading to ICI [3].

All the methods, available in the literature, that have been developed to reduce the effect of frequency offset can be divided into two groups. In first group, the frequency offset in OFDM systems is estimated and corrected at the receiver side and in the second group the frequency offset is reduced at the transmitter side. The first group is termed as the frequency offset estimation and correction, not considered in this paper. Here the second group, called frequency-offset reduction, is considered. In the frequency offset reduction approaches [2, 4-6], available in the literature, either a guard interval or redundant modulation is necessary in order to achieve a trade-off between frequency offset sensitivity and bandwidth efficiency. In this paper, an improved DFT-IDFT-based ICI self-cancellation scheme is proposed that gives satisfactory performance compared to the DFT-based ICI self-cancellation scheme [7], without any redundant modulation and bandwidth efficiency reduction.

The paper is arranged as follows: The OFDM system model and the problem of ICI is discussed in Section 2. Section 3 presents the DFT-based ICI self-cancellation scheme. The proposed DFT-IDFT based ICI Self-cancellation scheme is described in section 4. The simulation results for the proposed scheme, DFT-based ICI self-cancellation scheme, and the normal OFDM system are presented in Section 5. Finally, the last section concludes the paper.

2 System Model And Inter Carrier Interference Problem In OFDM Systems

A typical discrete-time baseband OFDM transceiver system is shown in Fig.1.

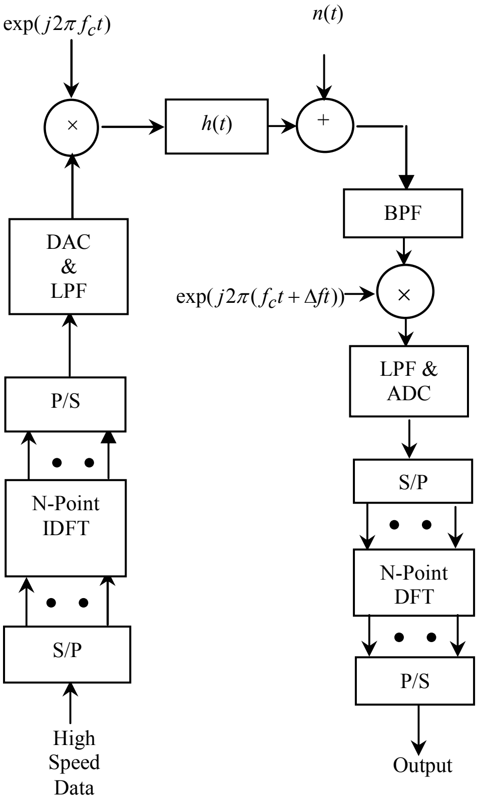

Fig.1: Baseband OFDM communication System.

An OFDM signal consist of N subcarriers with frequency spacing $1/NT_s$, which are modulated by quadrature amplitude modulation (QAM)/ quadrature phase shift keying modulation (QPSK) data with a duration NT_s, where T_s is QAM/QPSK symbol duration of. A serial stream of QAM/QPSK data is partitioned into blocks of length N, as shown in Fig.1.
The sequence $S(m)$ (called the frequency domain symbol) is fed to an IDFT block, producing the signal $s(k)$ (called the time domain symbol) with

$$s(k) = IDFT\{S(m)\} = 1/N\sum_{m=0}^{N-1} S(m)\exp(j2\pi km/N);\ k = 0,1,...,N-1 \qquad (1)$$

If we denote $\mathbf{S} = [S_0, S_1, ..., S_{N-1}]$ a block of N data points, the discrete time OFDM signal can be written in matrix form as

$$\mathbf{s} = 1/\sqrt{N}\mathbf{W}_N\mathbf{S} \qquad (2)$$

where $\mathbf{W}_N$ is an $N \times N$ IDFT matrix. In the presence of noise and carrier frequency offset, Δf , the received signal is demodulated and sampled at the optimum instants. These samples are fed to the receiver DFT block. The result of the DFT of these samples, in the matrix form, is given by

$$\mathbf{Y} = (1/N)\mathbf{W}_N^H\mathbf{E}\mathbf{W}_N\mathbf{S} + \mathbf{n} \qquad (3)$$

where $\mathbf{W}_N^H$ is an $N \times N$ DFT matrix, $\mathbf{n}$ is the additive whit Gaussian noise vector, superscript ^{H} denotes Hermitian transpose, and $\mathbf{E} = diag(1, \exp(j2\pi\varepsilon/N), ..., \exp(j2\pi\varepsilon(N-1)/N))$, and $\varepsilon = \Delta fT$ is the normalized frequency offset.
Let $\mathbf{A} = (1/N)\mathbf{W}_N^H\mathbf{E}\mathbf{W}_N$, then

$$\mathbf{Y} = \mathbf{A}\mathbf{S} + \mathbf{n} \qquad (4)$$

It can be shown that the diagonal elements of matrix **A**, $a_{j,j}$, represent the amplitude of useful signal of jth subcarrier and other elements in the same row represent the amplitude of the interference from all the other subcarriers. Since, **A**≠**I**, **E** destroys the orthogonality among the subcarriers and thus introduces ICI.

3 DFT-based ICI-self Cancellation Scheme

In this scheme, a block of N point input data is equally divided into two parts each of $N/2$ data points, and then each data block is discrete Fourier transformed. After this, the N point data is fed to the IDFT block. The transmitted data in matrix form can be written as

$$\mathbf{s}_D = (1/\sqrt{N})\mathbf{W}_N\mathbf{B}\mathbf{S} \qquad (5)$$

where matrix **B** is the combined effect of two $N/2$-point DFT blocks.

At the receiver, after demodulating the received signal in the presence of noise and frequency offset, the signal is sampled and these samples are fed to receiver N-point DFT block. The result of the receiver DFT is again divided into two equal parts each of $N/2$ data points and then each part of $N/2$ point is applied to an $N/2$-point IDFT block.

If the additive noise is omitted, the received signal can be represented in matrix form as

$$\mathbf{Y}_D = (1/N)\mathbf{B}^H\mathbf{W}_N^H\mathbf{E}\mathbf{W}_N\mathbf{B}\mathbf{S} \qquad (6)$$

Let $\mathbf{A}_D = (1/N)\mathbf{B}^H\mathbf{W}_N^H\mathbf{E}\mathbf{W}_N\mathbf{B}$, then

$$\mathbf{Y}_D = \mathbf{A}_D\mathbf{S} \qquad (7)$$

It has been shown in [7] that unlike the standard OFDM system, the ICI's of subcarriers of the DFT-based scheme are different. Thus, the ICI in this case is reduced significantly.

4 Improved DFT-IDFT-based ICI-self Cancellation Scheme

For the proposed scheme the system model is shown in Fig.2.

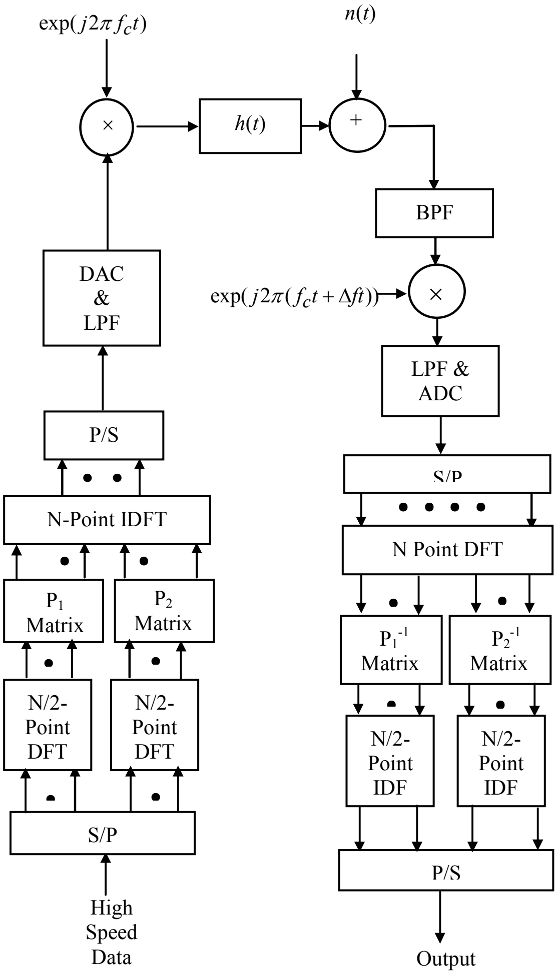

Fig.2: Baseband Communication System of Improved DFT- IDFT based Scheme

The system model of the proposed scheme is similar to that of DFT-based ICI-self cancellation scheme, except that the two-permutation matrix blocks in the transmitter and receiver. The transmitted data can be described in matrix notation as

$$\mathbf{s}_{ID} = (1/\sqrt{N})\mathbf{W}_N\mathbf{PBS} \tag{8}$$

where $\mathbf{s}_{ID}$ is transmitted data vector of the proposed scheme, **P** is the combined effect of permutation matrices $\mathbf{P}_1$ & $\mathbf{P}_2$.

In ideal reception the received signal is expressed in matrix form as

$$\mathbf{Y}_{ID} = (1/N)\mathbf{B}^H\mathbf{P}^{-1}\mathbf{W}_N^H\mathbf{E}\mathbf{W}_N\mathbf{PBS} \tag{9}$$

$$\mathbf{Y}_{ID} = \mathbf{A}_{ID}\mathbf{S} \tag{10}$$

where $\mathbf{A}_{ID} = (1/N)\mathbf{B}^H\mathbf{P}^{-1}\mathbf{W}_N^H\mathbf{E}\mathbf{W}_N\mathbf{PB}$

The analysis of (10) shows that the ICI causing coefficients can be reduced in magnitude by inserting a suitable permutation matrix in the transmitter side and its inverse at the receiver side.

The variation in the magnitudes of ICI coefficients for standard OFDM, DFT-based ICI-self cancellation scheme, and the proposed scheme at different values of normalized frequency offsets are plotted in Fig.3-Fig.5.

To observe the performance of the schemes considered, in this paper, the bit error rate (BER) versus bit energy to noise (E_b/N) ratio can also be plotted for different values of frequency offset.

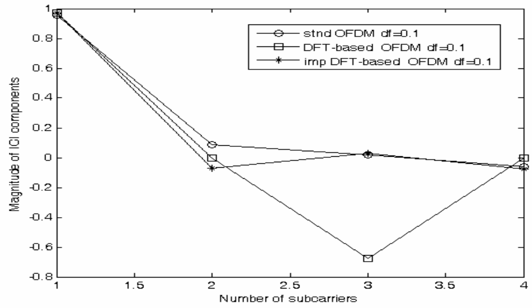

Fig.3 Magnitude of ICI components of standard OFDM, DFT-based, and proposed schemes at $\varepsilon = 0.1$

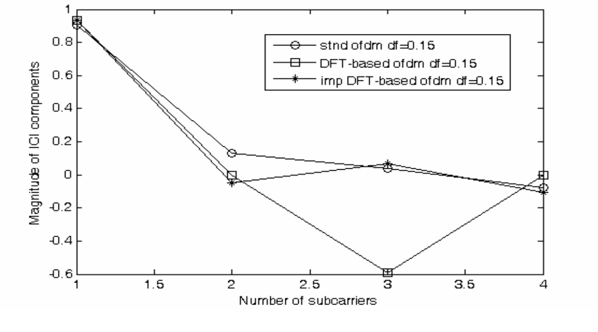

Fig.4 Magnitude of ICI components of standard OFDM, DFT-based, and proposed schemes at $\varepsilon = 0.15$

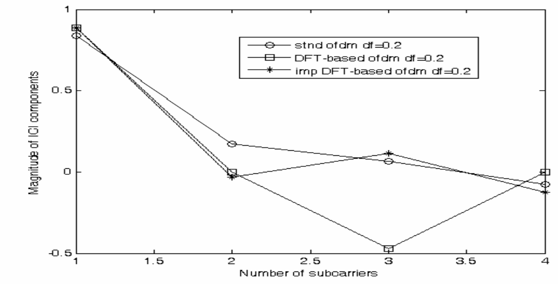

Fig.5 Magnitude of ICI components of standard OFDM, DFT-based, and proposed schemes at $\varepsilon = 0.2$

In Fig.6-Fig.8, the BER versus E_b/N ratio for standard OFDM, DFT-based ICI-self cancellation scheme, and the improved DFT-IDFT based ICI-self cancellation scheme is plotted at $\varepsilon = 0.1, \varepsilon = 0.15, \varepsilon = 0.2$ respectively.

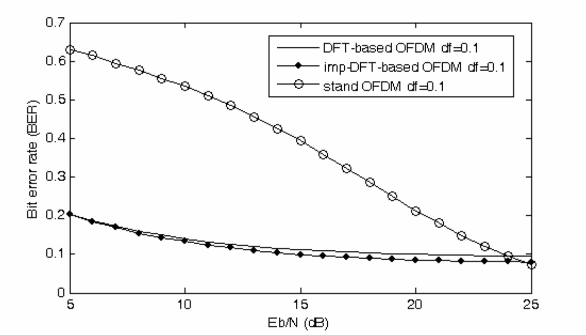

Fig. 6 BER vs E_b/N plot for standard OFDM, DFT-based scheme, and proposed scheme at $\varepsilon = 0.1$

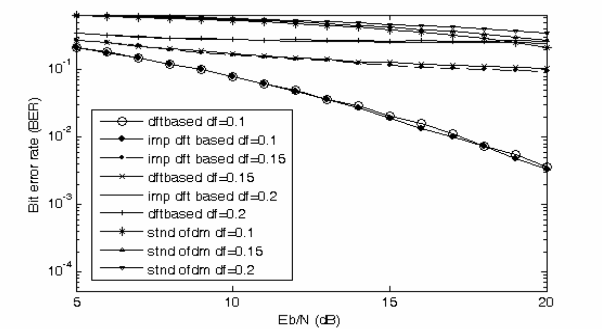

Fig. 7 BER vs E_b/N plot for standard OFDM, DFT-based scheme, and proposed scheme at $\varepsilon = 0.1, \varepsilon = 0.15, \varepsilon = 0.2$

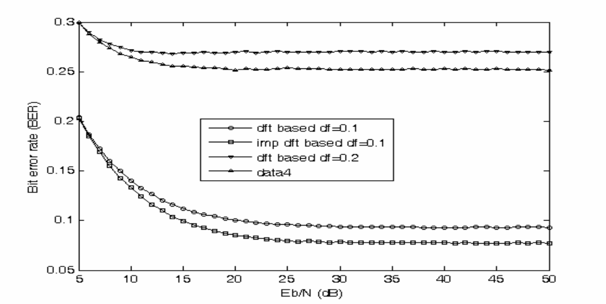

Fig. 8 BER vs E_b/N plot for DFT-based scheme, and proposed scheme at $\varepsilon = 0.1, \varepsilon = 0.2$

5 Observations And Results

The carrier to interference ratio (CIR) for DFT based ICI-self cancellation scheme and proposed scheme can be derived using (7) and (9) respectively as

$$CIR = \frac{\left|a_{d_{j,j}}\right|^2}{\sum_{i=0, i \neq j}^{N-1} \left|a_{d_{j,j}}\right|^2} \qquad (11)$$

where $a_{d_{i,j}}$ are the elements of matrix $\mathbf{A}_D$ The CIR for the DFT-based ICI-self cancellation scheme and the proposed scheme is plotted in Fig.9.

The normal OFDM system, DFT-based ICI-self cancellation scheme, and the proposed scheme are simulated using MATLAB with 4-QAM and QPSK modulation schemes. The desired carrier and the inter-carrier interference coefficients for all considered schemes are plotted in Fig.3-Fig.5 for different values of normalized frequency offset.

These figures, Fig.3-Fig.5, show the variation in the magnitudes of ICI coefficients for standard OFDM, DFT-based ICI-self cancellation scheme, and the proposed scheme at different values of normalized frequency offset. From the plots of ICI coefficients versus normalized frequency offsets, it is clear that the magnitude of ICI causing components for the present scheme are very small at low values of frequency offset.

The system performance in terms of BER can be improved if the magnitude of ICI causing coefficients, with respect to frequency offset, is very small (ideally zero). From Fig.6-Fig.8, it is clear that the magnitude of ICI causing coefficients, for the proposed scheme, is very small. Thus the system performance in terms of BER for the proposed scheme is better than that of DFT based scheme.

Fig.9 shows that the CIR for proposed scheme is better as compared to DFT based scheme for all frequency offsets (e.g. at a normalized frequency offset of $\varepsilon = 0.2$, there is an improvement of about 4 dB in CIR for proposed scheme as compared to DFT based scheme).

The magnitude of the desired carrier component for all the above considered schemes at all frequency offsets is same but the magnitude of ICI coefficients increases as frequency offset increases. The increase in the magnitude of ICI coefficients for standard OFDM and DFT based scheme is more as compared to proposed scheme with increase in ε. Thus, the proposed scheme reduces the magnitude of interference causing coefficients, resulting in considerable reduction in ICI.

Similar conclusion can be drawn from the BER plots of these schemes. The Fig.6-Fig.8 show that the proposed scheme gives better performance in terms of BER as compared to standard and DFT-based ICI self cancellation scheme. Similarly, the CIR of the proposed scheme is approximately 4 dB more than that of DFT based scheme at $\varepsilon = 0.2$

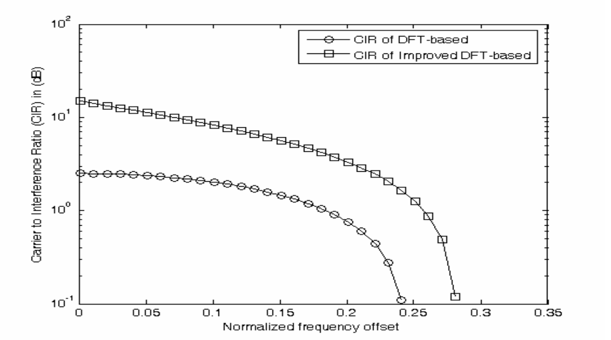

Fig.9 Carrier to interference ratio (CIR) for the DFT-based ICI-self cancellation scheme and the proposed scheme.

6 Conclusions

In this paper an improved DFT-IDFT based ICI-self cancellation scheme is proposed. By analyzing the ICI coefficients and BER plots for different schemes, it can be concluded that the proposed scheme produces better ICI reduction as compared to the DFT-based ICI-self cancellation scheme for small values of normalized frequency offset $(\varepsilon < 0.3)$ without any reduction in the spectral efficiency of the system. For large values of frequency offset there is only slight improvement in the performance of the proposed scheme in terms of BER. Thus, the proposed scheme reduces the ICI effectively as compared to the DFT-based ICI self-cancellation scheme. Further improvement in the performance of the proposed scheme can be studied by developing some algorithms to provide weights to permutation matrices in the transmitter and receiver.

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