Selective Self ICI Cancellation Scheme for OFDM Systems

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Abstract: - Orthogonal frequency division multiplexing (OFDM) is a well-suited multiplexing scheme for the fourth generation (4G) communication systems. The major drawback of OFDM systems is intercarrier interference (ICI), which degrades the system performance considerably. A self ICI cancellation scheme, proposed by Zaho, and Armstrong, improves the system performance in terms of symbol error rate (SER) and carrier to interference ratio (CIR) but reduces the system throughput to half as compared to normal OFDM. This paper presents a selective ICI self-cancellation scheme that improves the system throughput and reduces the SER for higher order modulation schemes (i.e. for 16-QAM, 32-QAM etc).

Key-Words: - ICI Self-cancellation, selective ICI Self-cancellation, OFDM, frequency offset.

1 Introduction
Broadband wireless services require high bit rate transmission over mobile radio channels. In a mobile radio channel, the time dispersion can be significant compared to the symbol period, which results in inter symbol interference (ISI). To reduce the effect of ISI the symbol duration must be much larger than the channel delay spread [1]. In OFDM, the entire channel is divided into many narrowband sub channels, which are transmitted in parallel, thereby increasing the symbol duration and reducing the ISI. Therefore, OFDM is very attractive technique for the transmission of high bit rate data in a radio environment. A major drawback of OFDM in many applications is that it is very sensitive to frequency errors caused by frequency differences local oscillators in the transmitter and the receiver. The carrier frequency offset causes a number of impairments e.g. attenuation and rotation of each of the subcarriers and intercarrier interference (ICI) between subcarriers. A number of methods have been developed to reduce this sensitivity to frequency offset, including the use of self ICI cancellation schemes [2].

In case of an ideal Nyquist channel, the ICI resulting from carrier frequency offset is derived at each demodulated subcarrier at the receiver in terms of each transmitted subcarriers and $N$ complex weighting factors [3]. ICI cancellation schemes can be related and described in terms of these weighting factors. The major disadvantage of this scheme is that it is less bandwidth efficient than normal OFDM as only half as many input data symbols can be transmitted per OFDM symbol. Based on the analysis of the of self ICI cancellation method, and its disadvantage of low bandwidth efficiency, a selective self ICI cancellation scheme is developed in order to improve the bandwidth efficiency. The presented ICI cancellation scheme improves the bandwidth efficiency of the self ICI cancellation method.

This paper is organized as follows: Section 2 introduces self ICI cancellation OFDM system, the analysis of ICI and self ICI cancellation schemes. The proposed scheme is discussed in Section 3. Simulation results are given in Section 4 to demonstrate the effectiveness of the proposed scheme. Finally, a summary appears in Section 5.

2 Self-ICI Cancellation Scheme
A typical OFDM transceiver system with self ICI cancellation scheme is shown in Fig.1. In the OFDM system there are $N$ subcarriers and the symbol duration is $T$, where $T=NT_s$ and $t_s$ is the duration of input data (e.g. 16-QAM data). A serial stream of QAM data is partitioned into blocks of length $N$, as shown in Fig.1. The sequence $X(m)$ (called the frequency domain symbol) is fed to an Inverse Discrete Fourier Transform (IDFT) block, producing the signal $x(k)$ (called the time domain symbol) with

$$x(k) = IDFT\{X(m)\} = \frac{1}{N} \sum_{m=0}^{N-1} X(m) \exp(j2\pi km/N); k = 0,1,\ldots,N-1$$ (1)
Denoting a block of \( N \) data point by \( X = \{ -X_1, X_1, -X_3, X_3, \ldots, -X_{N-1}, X_{N-1} \} \), the discrete time OFDM signal can be written in matrix form as

\[
x = 1/\sqrt{N} W_N X^T
\]  

(2)

where \( W_N \) is an \( N \times N \) IDFT matrix. In the presence of noise and carrier frequency offset, \( \Delta f \), 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

\[
Y = (1/\sqrt{N}) W_N^H E W_N X^T + n
\]  

(3)

where \( W_N^H \) is an \( N \times N \) DFT matrix, \( n \) is the additive white Gaussian noise vector, superscript \( H \) denotes Hermitian transpose, and \( E = \text{diag}(1, \exp(j 2 \pi c / N), \ldots, \exp(j 2 \pi c (N - 1) / N)) \), and \( c = \Delta f T \) is the normalized frequency offset. Let \( C = (1/\sqrt{N}) W_N^H E W_N \), then

\[
Y = CX^T + n
\]  

(6)

It can be shown that the diagonal elements of matrix \( C \), \( c_{jj} \), represent the amplitude of useful signal of \( j \)th subcarrier and other elements in the same row represent the amplitude of the interference from all the other subcarriers. These coefficients are known as the weighting coefficients. Since, \( C \neq I \), \( E \) destroys the orthogonality among the subcarriers and thus introduces ICI. In this scheme most of the ICI is cancelled because of self ICI cancellation coding. For example, the decoded value for the zeroth subcarrier is given by

\[
Y_0 = (c_0 - c_i) X_0 + (c_2 - c_3) X_2 + \ldots + (c_{N-2} - c_{N-1}) X_{N-2}
\]  

(7)

The ICI now depends on the difference between the adjacent weighting coefficients rather than on the coefficients themselves. To maximize the overall SNR, the values \( Y_0, Y_1, \ldots, Y_{N-2} \) should be subtracted in pairs. This further reduces the ICI as shown in (8)

\[
Y_0 - Y_1 = ((-c_{-1} + 2c_0 - c_i) X_0 + \ldots + (-c_{N-3} + 2c_{N-2} - c_{N-1}) X_{N-2})
\]  

(8)

From (8), it is clear that when there is no carrier frequency offset \( Y_0 - Y_1 = 2X_0 \). Thus all of the received power is decoded into wanted signal, and the self ICI cancellation scheme gives no reduction in overall SNR compared with normal OFDM [3]. A drawback of this scheme is that it is less bandwidth efficient than normal OFDM as only half as many complex QAM values can be transmitted per symbol.

### 3 Proposed Scheme

The major disadvantage of the self ICI cancellation scheme is its throughput, because in this scheme one complex input data value is mapped on two adjacent subcarriers i.e. \( X_0 = -X_1, X_1 = -X_3, \ldots \). Thus the self ICI cancellation scheme employs fifty percent redundant data in its transmission. In order to improve the system throughput as compared to above mentioned self ICI cancellation scheme redundant symbols should be transmitted only on a few selected subcarriers. So in the present scheme the redundant QAM values are transmitted only on a
few selected subcarriers. The OFDM transceiver system with the proposed self ICI cancellation scheme is shown in Fig.2.

In this scheme, the high bit rate input data (i.e. higher order QAM data) is divided into low bit rate parallel data. Then this parallel low bit stream is converted into $N$ data values by inserting some redundant data. The redundancy in the original data is inserted based on the power of the individual data values as follows:

Let us assume that $S(l)$ is a 16-QAM input data where $l < N$. If the average power of $S$ is $P_{av}$, then the redundancy in $S(l)$ can be inserted corresponding to values of $S(l)$ for which power of $S(l)$ is $< P_{av}$. By doing this the throughput as well as the symbol error rate of the present scheme can be improved compared to the self ICI cancellation scheme.

4 Observations and Results

The normal OFDM system, self ICI cancellation scheme, and the proposed scheme are simulated using MATLAB with 16-QAM modulation scheme. The symbol error rate versus SNR for all considered schemes are plotted in Fig.3-Fig.5 at different values of normalized frequency offset.
The above figures represent the symbol error rate of the proposed scheme is little bit improved as compared to self ICI cancellation scheme. In the proposed scheme for the same signal constellation and therefore the resulting SER average power of OFDM symbol is less employing less SNR. From the simulation results it is also clear that there is about 12% improvement in throughput of the proposed scheme as compared to self ICI cancellation scheme.

5 Conclusion

In this paper a selective ICI cancellation scheme is proposed. By analyzing the SER plots for different schemes at different values of frequency offset, it can be concluded that the proposed scheme produces better SER performance as compared to the self ICI cancellation scheme and normal OFDM for small values of normalized frequency offset ($\varepsilon \leq 0.1$). Also the spectral efficiency of the proposed scheme is better than the self ICI cancellation scheme. For large values of frequency offset the SER performance of both the schemes is comparable but there is improvement in the throughput of the proposed scheme. Thus, the proposed scheme improves the SER and increases the throughput (spectral efficiency) as compared to the self ICI cancellation scheme. The simulation results show that the improvement in the throughput of the proposed scheme is about 12 percent as compared to the self ICI cancellation scheme. Further improvement in the performance of the proposed scheme can be studied by analyzing the developed scheme for higher order signal constellation.

References: