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Comparison of ICI Cancellation Schemes for BER Performance Improvement of OFDM System

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Abstract

OFDM is excellent performance for promising broadband communication systems. Spectrum OFDM has high data rate transmission capability with high bandwidth efficiency which makes OFDM robust to multipath fading. But one of the major weakness of Orthogonal Frequency Division Multiplexing (OFDM) is Inter Carrier Interference (ICI). And this ICI cause BER performance degradation. To overcome this weakness Various techniques have been proposed by various authors including Time Domain Windowing, Frequency Domain Equalization, Maximum Likelihood Estimation (MLE) , Extended kalman filtering (EKF) and ICI self cancellation technique, Data Conjugate ICI Self Cancellation. In this paper three ICI reduction techniques such as Extended kalman filtering (EKF) and ICI self cancellation, Data Conjugate ICI Self Cancellation has been compared on the basis of BER performance.

Keywords: ICI ,OFDM, EKF,MLE.

1. Introduction

OFDM is an outstanding performance for promising broadband communication systems such as digital audio broadcasting (DAB), high-definition television (HDTV), wireless local area network (IEEE 802.11a and HIPERLAN/2). OFDM is promising as the supreme modulation scheme that encodes the digital data on numerous carrier frequencies [1]. And their subcarrier is compactly spaced and overlap with each other, due to this overlapping spectrum OFDM has high data rate transmission capability with high bandwidth efficiency which makes OFDM robust to multipath fading. OFDM is very supreme case of multi-carrier modulation. The basic theory of OFDM is that, dividing the single signal which is of high data rate into numerous signals which is of low data rate and modulate each of these new low data rate signal with orthogonal frequency channel or subcarrier and at the receiver end, they are combined to generate the original signal. But one of the major weaknesses of OFDM system is loss of orthogonality. The causes of loss of orthogonality and amplitude reduction of OFDM signal lead to ICI, because OFDM system is very sensitive to carrier frequency offset (CFO), this ICI destroy the orthogonality of the spectrum and signal can't be received without interference. To overcome this weakness Various techniques have been proposed by various authors including Time Domain Windowing, Frequency Domain Equalization, Maximum Likelihood Estimation (MLE) , Extended kalman filtering (EKF) and ICI self cancellation technique, Data Conjugate ICI Self Cancellation. This paper provides the BER comparison of three ICI reduction techniques such as Extended kalman filtering (EKF), ICI self cancellation, Data Conjugate ICI Self Cancellation scheme.

2. OFDM System Model & Analysis of ICI

A basic OFDM system contains modulation scheme, serial to parallel transmission, parallel to serial transmission and IFFT/FFT [5]. Fig.1, illustrate the block diagram of OFDM system. The input data stream is converted into parallel data Stream and mapped with modulation scheme. Then the symbols are mapped with Inverse Fast Fourier Transform (IFFT) and converted to serial stream. The complete OFDM symbol is transmitted through the channel

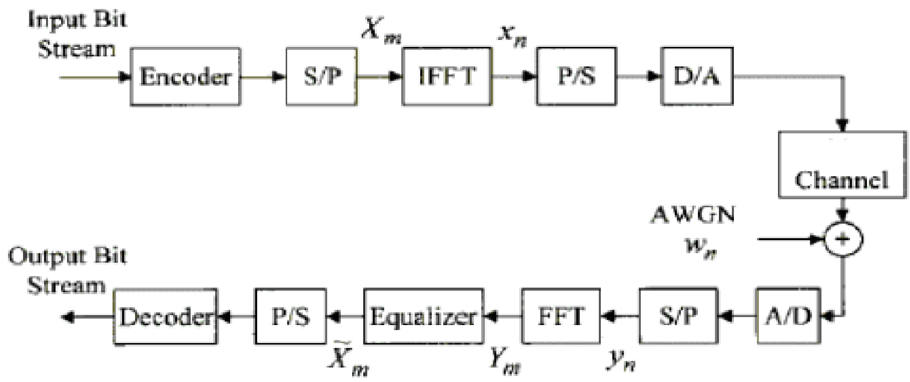

Fig. 1: Block Diagram of FFT Based OFDM System.

Therefore OFDM symbol can be expressed as

$$x(n) = \frac{1}{N}\sum_{m=0}^{n-1} X(m)e^{j2\pi nm/N} \quad \text{(1)}$$

Where x (n) denotes the sample of the OFDM signal, X (m) denotes the modulated symbol within subcarrier and N is the number of subcarriers..

The received symbol stream is given by

$$y(n) = x(n)e^{j2\pi n\varepsilon/N} + w(n) \quad \text{(2)}$$

Where ε represents the normalized frequency offset, that is $\varepsilon = \Delta f/(1/NT)$ where Δf is the frequency difference between the transmitter and the receiver, and NT denotes the interval of an FFT, w(n) is the AWGN introduced in the channel and T is the subcarrier symbol period. The effect of the channel frequency offset on the received symbol stream can be understood by considering the received symbol Y (K) on the K^{th} sub-carrier. In an OFDM communication system, assume is channel frequency offset, the received signal on subcarrier k can be written as

$$Y(K) = X(K)S(0) + \sum_{l=0, l\neq K}^{N-1} X(l)S(l-K) + n_K \ldots\ldots\ldots\ldots \quad \ldots\ (3)$$
$$K = 0,2 \ldots\ldots\ldots\ldots\ldots N-2$$

Where w (m) corresponds to the FFT of the samples of the w (n).Where N is the total number of the subcarriers $X(K)$ denotes the transmitted n_K symbol is an additive noise sample. $S(l-K)$ Is the complex coefficient for the ICI components in the received signal. The sequence $S(l-K)$ is defined as the ICI coefficient between l^{th} and K^{th} subcarriers, which can be expressed as

$$S(l-K) = \frac{\sin(\pi(1+\varepsilon-K))}{N\ \sin(\frac{\pi(1+\varepsilon-K)}{N})} \exp(j\pi(-1/N)(1+\varepsilon-K) \quad (4)$$

The first term in the right-hand side of (3) represents the desired signal. The second term is the ICI components.

3. ICI Self Cancellation Scheme

ICI Cancelling Modulation The main concept of this scheme is 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

The ICI self-cancellation scheme requires that the transmitted signals be constrained such that

$$x(1) = -x(0), x(3) = -x(2)..x(N-1) = -x(N-2) \ \ldots\ldots\ldots\ (5)$$

Then the received signal on subcarrier k becomes

$$Y'(K) = \sum_{\substack{l=0 \\ l=enen}}^{N-2} x(l)[S(l-K) - S(l+1-K)]n_k.. \quad \ldots\ldots\ldots\ldots\ (6)$$

Similarly the received signal on subcarrier k+1 becomes

$$Y'(K) = \sum_{\substack{l=0 \\ l=enen}}^{N-2} x(l)[S(l-K-1) - S(l-K)]n_{k+1}. \quad (7)$$

At the demodulator he received signal at the $(K+1)^{th}$ subcarrier, where K is even is subtracted from the K^{th} subcarrier. This is expressed mathematically as

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

Subsequently, the ICI coefficients for this received signal becomes

$$S''(l-K) = -S(l-K-1) + 2S(l-K) - S(l-K+1 \quad (9)$$

4. Extended Kalman Filter ICI Cancellation Scheme

The Kalman filter is a very powerful recursive estimation algorithm. As a recursive filter, it is mainly useful to non-stationary method such as signals transmitted in a time-variant radio channel. In estimating non-stationary processes, the Kalman filter computes estimates of its own performance as part of the recursion and use this information to update the estimate at each step. Therefore, the estimation procedure is adjusted to the time-variant statistical characteristics of the random process.

There are two stages in the EKF scheme to mitigate the ICI effect: the offset estimation scheme and the offset correction scheme.

4.1. Offset Estimation Scheme

To estimate the quantity $\varepsilon(n)$ using an EKF in each OFDM frame, the state equation is built as

In this case we are estimating an unknown constant ε .This constant is distorted by a non-stationary process x (n), an observation of which is the preamble symbols preceding the data symbols in the frame. The observation equation is

$$y(n) = x(n)e^{\frac{j2\pi n'\varepsilon(n)}{N}} + w(n) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

where y(n) denotes the received preamble symbols distorted in the channel, w(n) the AWGN, and x(n) the IFFT of the preambles X(k) that are transmitted, which are known at the receiver. Assume there are N_p preambles preceding the data symbols in each frame are used as a training sequence and the variance σ^2 the AWGN w (n) is stationary. The computation procedure is described as follows.

1. Initialize the estimate $\hat{\varepsilon}(n)$ and corresponding state error P (0)
2. Compute the H (n), the derivative of y (n) with respect to $\varepsilon(n)$ at $\hat{\varepsilon}(n-1)$, the estimate obtained in the previous iteration
3. Compute the time-varying Kalman gain K (n) using the error variance P (n-1), H(n), and , σ^2
4. Compute the estimate $\hat{y}(n)$ using x (n) and $\hat{\varepsilon}(n-1)$
5. Update the estimate $\hat{\varepsilon}(n)$ by adding the K (n)-weighted error between the observation y (n) and $\hat{y}(n)$ to the previous estimation $\hat{\varepsilon}(n-1)$.
6. Compute the state error P (n) with the Kalman gain K(n), H(n), and the previous error P(n-1).
7. If n is less than N_p increment n by 1 and go to step 2; otherwise stop.

It is observed that the actual errors of the estimation $\hat{\varepsilon}(n)$ from the ideal value $\varepsilon(n)$ are computed in each step and are used for adjustment of estimation in the next step.

4.2. Offset Correction Scheme

The ICI distortion in the data symbols x (n) that follow the training sequence can then be mitigated by multiplying the received data symbols y(n) with a complex conjugate of the estimated frequency offset and applying FFT, i.e.

$$\hat{x}(n) = FFT\left\{y(n)e^{-j\frac{2\pi n'\hat{\varepsilon}}{N}}\right\}\ldots \qquad .(11)$$

As the estimation of the frequency offset by the EKF ICI cancellation scheme is pretty efficient and accurate, it is expected that the performance will be mainly influenced by the variation of the AWGN

5. Data Conjugate ICI Self Cancellation Scheme

In the data-conjugate scheme, subcarrier signals are remapped in the form of $x'(k) = x(k), x'(k+1) = -x^*(k)$ for k=0, 2,4...N-2 Where $x(k\,)$ is the information data to the subcarrier before modified ICI cancelling modulation and $-x^*(k)$ is the information data to the subcarrier after modified ICI cancelling modulation. At the receiver end the original data can be recovered by multiplying '-1' to the received signal at the (k+1) subcarrier and then added to the one at the 'k' subcarrier.

That is

$$Y''(k) = Y'(k) + (-Y^*(k+1))\ldots \qquad (12)$$

6. Simulation Result

BER performance curve is used to examine the performance of the ICI Self Cancellation schemes. For simulation MATLAB was employed with its communication toolbox. And the simulations were performed using an AWGN channel.

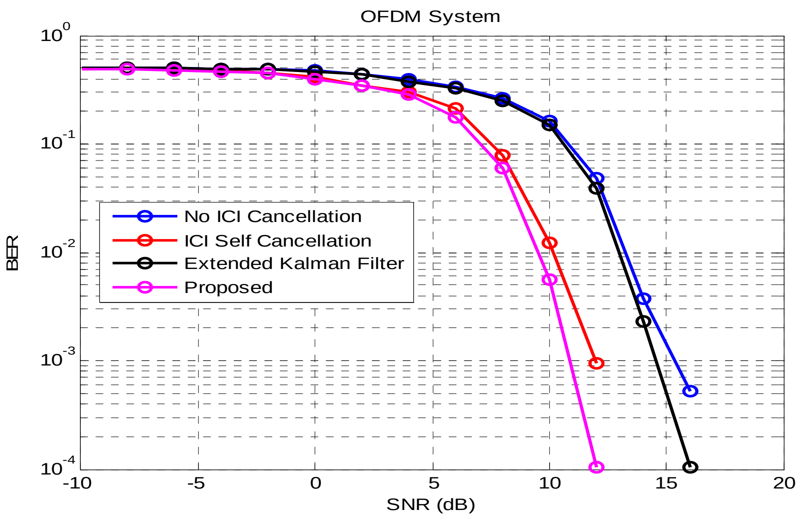

Fig. 2: BER performance of Standard OFDM system, ICI Self Cancellation Scheme, EKF ICI Cancellation scheme and Data conjugate ICI cancellation Scheme.

6.1 Discussion

Hence from the figure we can see that the BER reduces significantly for the proposed (Data conjugate ICI self cancellation) scheme in comparison to the ICI Self cancellation scheme and Extended Kalman Filtering ICI cancellation scheme, at the low SNR. And at the high SNR the BER of Data Conjugate ICI self cancellation scheme is almost zero.

7. Conclusion

This paper studies the various ICI self-cancellation schemes to cancel the effect of ICI caused by frequency offset in OFDM systems. Simulation results shows that BER performance of Extended Kalman Filtering ICI Cancellation Scheme is Better than the BER performance of standard OFDM system without ICI cancellation, and BER performance of ICI self cancellation is even better than the BER performance of Extended Kalman Filtering ICI Cancellation Scheme and BER performance of Data Conjugate ICI Self Cancellation is much better than the BER performance of the ICI self cancellation Scheme.

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