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A novel method for the estimation of carrier frequency offset in OFDM systems

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ABSTRACT

In the latest development of Orthogonal Frequency Division Multiplexing (OFDM) communication system, the system performance can be distracted by the frequency offsets (FOs) which can demolish the orthogonality of the subcarriers, and hence leads to a number of impairments in the received signal, thereby making its detection incorrect. In this paper, a new threshold-based frequency offset estimation algorithm for orthogonal frequency division multiplexing (OFDM) systems is proposed. Through a detailed analysis and simulation over AWGN channel, it has been shown that the proposed method shows good performance i.e. it offers low error variance as the SNR (signal to noise ratio) increases.

Introduction

The inventive and teeming orthogonal frequency division multiplexing (OFDM) communication system has been applied to numerous applications of modern communication technology for instance digital audio/video broadcasting (DAB/DVB), wireless local area networks (WLANS) and the next generation cellular system [1]. One of the drawbacks of OFDM has proven to be its high sensitivity towards frequency differences which is often caused by the Doppler shift and/or mismatch between oscillators in the transmitter and receiver [1].This frequency offset is usually divided into an integer part, which is a multiple of the subcarrier spacing, and a fractional part, which is less than one half of the subcarrier spacing. The former results in a shift of the subcarrier indices, while the latter causes a number of impairments, including attenuation and rotation of each of the subcarriers and inter-carrier interference (ICI) between subcarriers [4].

In the literature several schemes have been proposed in [2]-[6] to estimate the frequency offset. The frequency offset estimation schemes can be classified into two categories: fractional frequency offset estimation schemes [4], [5], [6] and integer frequency offset estimation schemes [2], [3]. For integer frequency offset estimation, an estimation scheme was proposed in [2] (Nogami's scheme) using the cross correlation between the received and locally generated training symbols. However, the scheme in [2] is very sensitive to the timing offset. Thus, in [3] (Bang's scheme), an estimation scheme robust to the timing offset was proposed considering coherence phase bandwidth (CPB) in its estimation process. However, the scheme in [3] still has the problem that the complexity in implementation rapidly increases, as the frequency offset estimation range increases.

In this paper we propose a new integer frequency offset estimation algorithm which shows lower computational complexity than Nogami's [2] and Bang's [3] schemes because the estimation is done on the basis of a threshold. Furthermore, we have also presented analytical and simulation results to show the performance improvement of the proposed estimation scheme over existing schemes. The performance of the proposed method is demonstrated using the variation in the error variance with signal-to-noise ratio.

System Model

In an OFDM system, the complex baseband OFDM signal after the IFFT block at the transmitter can be expressed as

$$x(n)=\frac{1}{N}\sum_{k=0}^{N-1}X(k)e^{j\frac{2\pi nk}{N}} \quad ,n=0,1,2\ldots N-1 \qquad (1)$$

where N is the total number of subcarriers, X(k) denotes the transmitted quadrature amplitude modulation (QAM) or M-ary phase-shift keying (PSK) modulated symbol on the subcarrier k with k = 0, 1, 2, …, N −1.

In the presence of frequency offset, the received OFDM signal r(n) can be expressed as

$$r(n)=x(n)e^{j\frac{2\pi n f_o}{N}}+w(n) \qquad (2)$$

where f_o represent the frequency offset normalized to the subcarrier spacing, Ts is the symbol duration and w(n)is the zero-mean complex additive white Gaussian noise (AWGN).

The frequency offset $f_o$can be divided into an integer part and a fractional part as

$$f_o=\epsilon+\Delta f_f$$

where ϵ is the integer part of f_o and $f_f \in [-0.5,\ 0.5)$ is the fractional part of f_o.

We estimate integer frequency offset and assume that the fractional part f_f is known and perfectly compensated. The received symbol is demodulated using FFT operation. The kth FFT output $R(k)$ can be expressed for k = 0, 1, 2, … ,$N-1$ as

$$R(k)=X(k-\epsilon)+W(k) \qquad (3)$$

where W(k) is the FFT of w(n).

It is clear from the eq.(3) that the integer frequency offset causes a cyclical shift in the FFT output.

Nogami's Scheme

To estimate the integer frequency offset, Nogami's scheme examines the correlation value between the known training symbol and the cyclically shifted version of the received training

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symbol, and then, obtain the integer frequency offset estimate $\hat{\epsilon}$as

$$\hat{\epsilon} = arg\max_{d} \left\{ \sum_{k=0}^{N-1} Z^{*}(k)R(k+d)_{N} \right\} \tag{4}$$

where d is the amount of cyclic shift, (.)N is the modulo-N operator, $R(k)$ is the received pilot symbol and $Z(k)$ is the known pilot symbol. Nogami's algorithm was proposed on the assumption of perfect timing synchronization, so it is not appropriate for cases where a symbol timing offset exists. Thus, its estimation performance degrades in the presence of timing offset.

Bang's Scheme

Bang's scheme adopts the concept of the coherence phase bandwidth for the purpose of weakening the effect of symbol timing offset. In this scheme the total system bandwidth is divided into a number of blocks with coherence phase width i.e.

$$K = \frac{BW}{BW_c} \tag{5}$$

Where K is the number of divided blocks and BW_c is the coherence phase bandwidth.

In this algorithm, the correlation is calculated individually within each small block and then summed.

The estimated coarse frequency offset is obtained as

$$\hat{\epsilon} = \ arg\max_{d} \left\{ \sum_{m=0}^{N-1} \left| \sum_{k=0}^{BW_c-1} Z^{*}(k+mBW_c)R(k+mBW_c + d)_{N} \right| \right\} \tag{6}$$

The drawback of Bang's scheme is that the complexity in implementation rapidly increases, as the frequency offset estimation range increases.

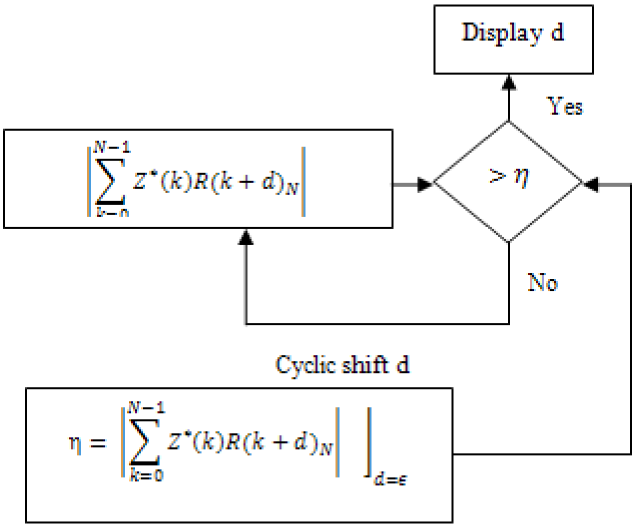

Fig 1. Proposed Frequency Offset Estimation Algorithm

Proposed Estimation Scheme

The proposed frequency offset estimation algorithm is designed for the estimation of integer frequency offset in the OFDM systems and hence it is assumed that the fractional frequency offset is known and perfectly compensated. To estimate the integer frequency offset, we calculate the correlation between the known training symbol and the cyclically shifted version of the received training symbol

$$C = \left| \sum_{k=0}^{N-1} Z^{*}(k)R(k+d)_{N} \right| \tag{7}$$

Assuming $d = \epsilon$ and ignoring AWGN components in (7), the correlation value C gives the threshold η which can be expressed as

$$\eta = \left| \sum_{k=0}^{N-1} Z^{*}(k)R(k+d)_{N} \right| \Bigg|_{d=\epsilon} \tag{8}$$

The algorithm for the proposed scheme is shown in fig 2.

The above algorithm works as follows:

1. Calculate correlation between the known training symbol and the cyclically shifted version of the received training symbol.
2. Then calculate η from equation (8).
3. If the correlation value exceeds η, then d is decided to be the correct estimate of ϵ. Otherwise, the received signal is again cyclically shifted and the above procedure is repeated.

The proposed scheme will show lower computational complexity when compared with others. This is because threshold is used for decision making.

Simulation Results

The simulation has been performed over MATLAB to verify the effectiveness of the proposed frequency offset estimation method. The performance of the proposed method is evaluated using QPSK and 16-QAM modulation. The total number of subcarriers N=1024 are transmitted through AWGN channel, the length of the cyclic prefix is 128 and the number of symbols used is 6.

Fig.2 shows the performance of the proposed method in terms of Error variance Vs Signal-to-noise ratio (SNR) with QPSK. It is worth noting that the proposed scheme shows a remarkable improvement in the performance as the SNR is increased.

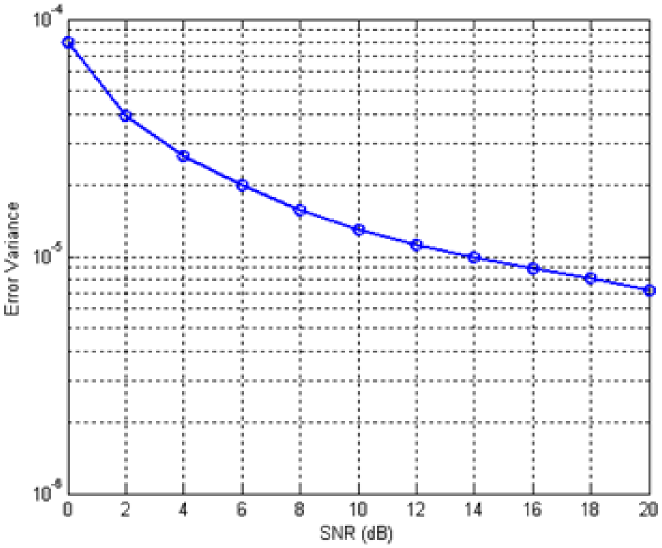

Fig2. Error Variance of frequency offset estimation performance in AWGN channel with QPSK.

Further Table I shows the error variances of the proposed scheme and Nogami's scheme. The table shows that the proposed method obtains better estimation performance when compared to Nogami's scheme. It is seen that the error variance of the proposed scheme is 7×10^{-6} and that of the Nogami's scheme is 5×10^{-5} at SNR=20db.

Table I. Frequency Error Variances of Proposed Method and Nogami's Scheme

	Error Variance	
SNR(in db)	Proposed Scheme	Nogami's Scheme
10	10^{-5}	4×10^{-4}
16	9×10^{-6}	10^{-4}
20	7×10^{-6}	5×10^{-5}

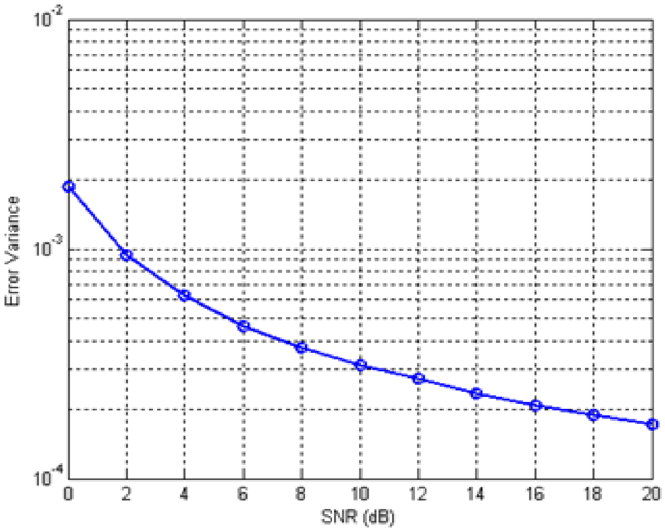

Fig 3. Error Variance of frequency offset estimation performance in AWGN channel with 16-QAM.

Fig.3 shows the performance of the proposed method in terms of Error Variance Vs Signal-to-noise ratio (SNR) with 16-QAM. The figure reveals that the proposed method obtains error variance of 7×10^{-4} at SNR of 20db. From figures 2 and 3 it is evident the performance of the proposed scheme is better at lower modulation techniques. For e.g. the performance of the proposed estimation scheme is better for QPSK than 16-QAM.

The proposed scheme when compared with the Bang's scheme offers almost comparable estimation performance. Also it is evident from the algorithm shown in figure 1 that the proposed method involves less complexity when compared with either Nogami's scheme or Bang's scheme. It is because in Bang's and Nogami's scheme the value of cyclic shift d is said to be correct estimate of the frequency offset if it maximizes the correlation between the known training symbol and the cyclically shifted version of the received training symbol whereas in the proposed method the value of cyclic shift d is said to be correct estimate of the frequency offset if obtained correlation between the known training symbol and the cyclically shifted version of the received training symbol exceeds the value of the chosen threshold. Thus, the proposed method shows lower computational complexity when compared with Bang's and Nogami's scheme.

Conclusion

In this paper, we have proposed a new integer frequency offset estimation scheme based on threshold. The simulation results show that the scheme gives better estimation performance when compared with Nogami's scheme. On the other hand, it maintains the same level of estimation performance when compared with the Bang's scheme. It is also evident that the proposed scheme exhibits much lower complexity than the Bang's and Nogami's schemes by using threshold for decision making.

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