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Analysis of Intercarrier Interference Cancellation Scheme in OFDM Systems

Naser S. Elmisbah[1], Elessaid S. Saad[1]

Faculty of Engineering, Karary University, 12304, Khartoum Sudan
[1]*nasirkarary@gmail.com*

ABSTRAKSI

Multipleks Pembagi Frekuensi Ortogonal (OFDM) adalah skema modulasi multi-pembawa yang tengah berkembang, diadopsi untuk beberapa standar nirkabel seperti IEEE 802.11a dan HiperLAN2. Dalam sistem OFDM, performanya sangat peka terhadap kesalahan frekuensi subpembawa (offset). Makalah ini menunjukkan analisis dan derivasi dari penguatan kompleks interferensi antar pembawa (ICI) yang digunakan dalam skema pembatalan diri dan ketergantungannya pada offset frekuensi subpembawa. Simulasi menunjukkan bahwa perbaikan dalam kinerja yang lebih baik dicapai untuk sistem yang menggunakan skema pembatalan. Selain itu, analisis dan simulasi menunjukkan bahwa teori rasio pembawa terhadap gangguan (CIR) untuk OFDM dengan skema pembatalan lebih besar dari konvensional dengan lebih dari 14dB.

Kata Kunci: Multipleks Pembagi Frekuensi Ortogonal (OFDM), Interferensi Antar Pembawa (ICI), penguatan kompleks ICI.

ABSTRACT

Orthogonal Frequency Division Multiplexing (OFDM) is an emerging multi-carrier modulation scheme, which has been adopted for several wireless standards such as IEEE 802.11a and HiperLAN2. In OFDM systems, the performance is very sensitive to subcarrier frequency errors (offset). This paper shows the analysis and derivations of intercarrier interference (ICI) complex gain that used in self-cancellation scheme and its dependence on subcarrier frequency offset. Simulation shows that better improvement in performance is achieved for systems that use this cancellation scheme. Moreover, analysis and simulation show that theoretical carrier-to-interference ratio (CIR) for OFDM with cancellation scheme is greater than conventional one by more than 14dB.

Keywords: Orthogonal Frequency Division Multiplexing (OFDM), intercarrier interference (ICI), ICI complex gain.

1. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is a promising technology for broadband transmission. It has been widely used for wireless. In OFDM systems, a serial data stream split into parallel streams that modulate a group of orthogonal sub-carriers. Due to its multicarrier feature, OFDM systems are more sensitive than single carrier systems to frequency synchronization errors.

The most significant problem of orthogonal frequency division multiplexing systems, it is sensitivity to carrier frequency errors (offset), these random frequency errors in OFDM system distort orthogonality between subcarriers, as a result, intercarrier interference (ICI) occurs. The undesired ICI degrades the performance of the system [1].

Several methods for reducing ICI in OFDM systems have been developed. These methods include frequency domain equalization [2], time domain windowing [3], pulse shaping [4], M-ZPSK modulation [5], maximum likelihood estimation [6], correlative coding [7] and ICI self-cancellation scheme [8].

The carrier frequency offset is produced at the receiver because of the local oscillator instability and variability of operating conditions at transmitter and receiver, Doppler shifts caused by the relative motion between the transmitter and receiver, or the phase noise introduced by other channel impairments. The degradation is caused by the reduction in the signal amplitude of the desired subcarrier and by the ICI from the neighboring subcarriers.

The amplitude loss occurs because the desired subcarrier is no longer sampled at the peak of the equivalent $sinc$ function of the DFT. Adjacent subcarriers cause interference because they are not sampled at their zero crossings. The overall effect of subcarrier frequency offset effect on system performance.

The characteristics of ICI are similar to Gaussian noise; hence, it leads to degradation of the performance. The amount of degradation is proportional to the fractional of subcarrier frequency offset, which is equal to the ratio of subcarrier frequency offset to the subcarrier spacing.

2. SELF-CANCELLATION SCHEME

This scheme works as follow, at the transmitter side, one data symbol is modulated onto a group of adjacent subcarriers with a group of weighting gains. The weighting gains are designed so that the ICI caused by the channel frequency errors can be minimized. At the receiver side, the received signals at these subcarriers are linearly combined with the proposed gains. Thus, the residual ICI contained in the received signals can then be further reduced.

This method is suitable for multipath fading channels and flat channels. In this method, channel estimation and channel equalization are not required. It is simple in implementation and effective.

3. DERIVATION OF ICI COMPLEX GAIN

From Figure 1, let us consider an OFDM signal,

$$x(t) = \sum_{k=0}^{N-1} d_k \, e^{j2\pi f_k t} \;, \qquad 0 \le t \le T_s \tag{1}$$

where $\{d_k\}_{k=0}^{N-1}$ is data symbols, $f_k = k.\Delta f$ is the kth modulated subcarrier frequency, k is the subcarrier index, Δf is the subcarrier spacing, T_s is data symbol time, N is the total number of subcarrier.

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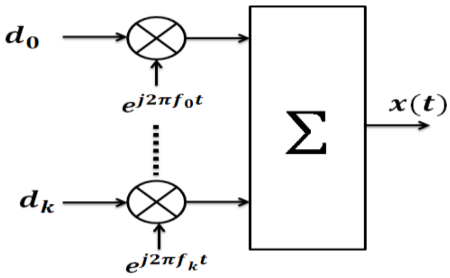

Figure 1 OFDM modulator

If there is a multiplicative time-varying distortion $\gamma(t)$ that, caused by subcarrier frequency offset, then the received signal will be:

$$y(t) = \gamma(t).\, x(t) \tag{2}$$

$\gamma(t) = e^{j2\pi\alpha t}$, where α is a fraction of Δf which is called relative frequency offset , and $\alpha = {}^{\delta}/_{\Delta f}$, where δ is the subcarrier frequency offset.

The output of the demodulator at kth subcarrier is:

$$Y_k = \frac{1}{N}\sum_{m=0}^{N-1} y(t)\, e^{-j2\pi f_m t} \tag{3}$$

$$= \frac{1}{N}\sum_{m}^{N-1}\sum_{k}^{N-1} d_k e^{-j2\pi(f_m - f_k + \alpha)} \tag{4}$$

Manipulating Equation 4 using a geometric series, the received signal will be:

$$Y_k = \underbrace{a_0 d_k}_{\text{desired signal}} + \sum_{\substack{m=0 \\ m\neq k}}^{N-1} \underbrace{a_{m,k} d_k}_{\text{undesired signal(ICI)}} \tag{5}$$

The first term in the right-hand side of Equation 5 represents the desired signal. The second term is the ICI components. The self-cancellation method relies on the fact that the real and imaginary parts of the ICI complex gain change gradually with respect to the subcarrier index k; therefore, the difference between consecutive ICI complex gains $a_{m,k} - a_{m,k+1}$ is very small.

The undesired signal is ICI signal, which is the interfering signals, transmitted on subcarriers other than the kth subcarrier.

$$a_{m,k} = \frac{1}{N} \cdot \frac{\sin\left(\pi(f_m - f_k + \alpha)\right)}{\sin\left(\frac{\pi}{N}(f_m - f_k + \alpha)\right)} \cdot e^{j\pi(f_m - f_k + \alpha)\left(1 - \frac{1}{N}\right)} \tag{6}$$

Equation 6 is a general form where, $a_{m,k}$ is of intercarrier interference complex gain between mth and kth subcarriers.

To derive an ICI complex gain expression at the transmitter, let us apply self-cancellation scheme, and assume that:

$d_1 = -d_0,\ d_3 = -d_2,\ \ldots, d_{N-1} = d_{N-2}$ for that:

$$\hat{Y}_k = \sum_{\substack{m=0\\even}}^{N-2} (a_{m,k} - a_{m,k-1}) d_k = \sum_{\substack{m=0\\even}}^{N-2} a\grave{}_{m,k}\, d_k \tag{7}$$

Equation 7 shows that the ICI complex gain is equal to $a_{m,k} - a_{m,k-1}$ for the transmitter site, which is less than that in standard OFDM.

In addition, if self-cancellation scheme done at the receiver, the final received signal will be:

$$\hat{\hat{Y}}_k = \sum_{\substack{k=0\\even}}^{N-2} (-a_{m,k+1} + 2a_{m,k} - a_{m,k-1}) d_k \tag{8}$$

$$\hat{\hat{Y}}_k = (-a_{-1} + 2a_0 - a_1) d_m + \sum_{\substack{m=2\\even}}^{N-2} (-a_{m,k+1} + 2a_{m,k} - a_{m,k-1}) d_k \tag{9}$$

In Equation 9, more reduction of ICI complex gain by the two terms $(-a_{m,k+1}, -a_{m,k-1})$, and ICI complex gain will be:

$$\grave{\grave{a}}_{m,k} = -a_{m,k+1} + 2a_{m,k} - a_{m,k-1} \tag{10}$$

Figure 2 shows that for $\alpha = 0.2$ and $N = 64$ a comparison between ICI complex gain $a_{m,k}$ for standard ODFM, ICI complex gain $a\grave{}_{m,k}$ for the transmitter only and ICI complex gain $\grave{\grave{a}}_{m,k}$ for both transmitter and receiver.

It is seen that $|\grave{\grave{a}}_{m,k}| \ll |a\grave{}_{m,k}| \ll |a_{m,k}|$ for most values of (m, k).

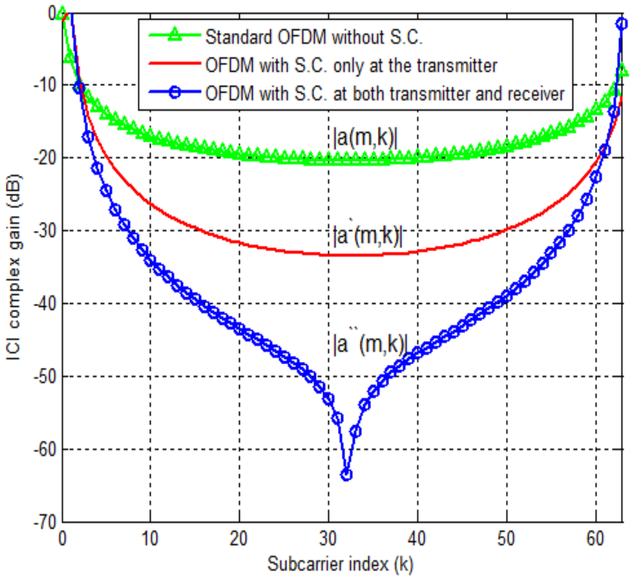

Figure 2. Comparison between ICI complex gains

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4. DERIVATION OF CIR

The system ICI power level can be evaluated by using the carrier-to-noise ratio (CIR). While deriving the theoretical CIR expression, the additive noise is omitted.

$$\frac{desired\ signal\ power}{undesired\ signal\ power(ICI)} \tag{11}$$

The desired received signal power on the k^{th} subcarrier can be given as:

$$\overline{[C^2]} = \overline{[(a_0 d_k)^2]} \tag{12}$$

if we assumed that, the signal has zero mean and the symbols transmitted on the different subcarriers are statistically independent. The undesired signal power (ICI) can be derived from Equation 12:

$$\overline{[I^2]} = \overline{\left[\left(\sum_{\substack{m=0\\m\neq k}}^{N-1} a_{m,k} d_m\right)^2\right]} \tag{13}$$

From Equation 12 and 13, we can obtained the theoretical CIR for subcarrier $0 \leq k \leq N-1$ as:

$$CIR = \frac{|a_0 d_k|^2}{\left|\sum_{\substack{m=0\\m\neq k}}^{N-1} a_{m,k} d_m\right|^2} \tag{14}$$

for simplicity let data symbol $d_k = d_m = 1$, then:

$$CIR = \frac{|a_0|^2}{\left|\sum_{m=1}^{N-1} a_m\right|^2} \tag{15}$$

Equation 14 consider that CIR is a function of N and α but mostly on α.
For deriving theoretical CIR for OFDM with self-cancellation scheme, the desired signal from Equation 9 will be:

$$\overline{[C^2]} = \overline{|(-a_{-1} + 2a_0 - a_1)|^2} \tag{16}$$

The undesired signal power (ICI) is:

$$\overline{[I^2]} = \left| \left(\sum_{\substack{m=2,4,\ldots \\ k\neq m}}^{N-1} (-a_{m,k+1} + 2a_{m,k} - a_{m,k-1}) d_m \right) \right|^2 \quad (17)$$

Then CIR for OFDM with self-cancellation will be:

$$CIR = \frac{\overline{|(-a_{-1}+2a_0-a_1)|^2}}{\sum_{m=2,4,6,\ldots}^{N-1} \left|[-a_{m,-1}+2a_m-a_{m,1}]\right|^2} \quad (18)$$

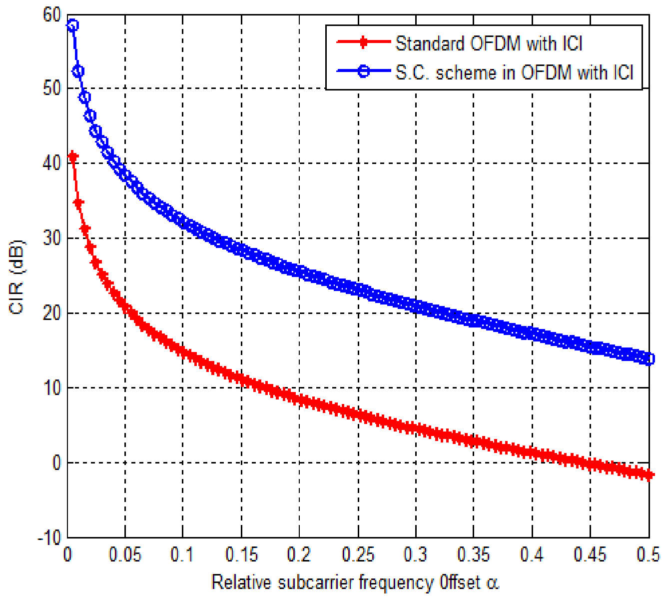

Figure 3. A comparison of CIR between standard OFDM and self-cancellation one

Figure 3 shows the comparison of the theoretical CIR curve for OFDM with self-cancellation scheme, calculated by Equation 18, and the CIR for standard OFDM system calculated by Equation 15. As expected, the CIR is greatly improved using the ICI self-cancellation scheme. The improvement can be greater than 14 dB. In addition, it shows the results for the improvement of the CIR should increase the power efficiency in the system and gives better results for the bit error rate.

5. SIMULATIONS

In order to evaluate the performance of OFDM systems in the presence of frequency offset between the transmitter and the receiver, Bit Error Rate (BER) curves were used. For the simulations in this paper, MATLAB was employed. The OFDM transceiver system is implemented as specified by Figure 4.

This figure demonstrates the basic OFDM system model that is used to simulate an OFDM transmitter and receiver including ICI self-cancellation scheme for different types of mapping (BPSK and QPSK) under the same conditions of

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bandwidth efficiency and relative frequency offset. The channel is modeled as AWGN with ICI complex gain $e^{j2\pi\alpha t}$.

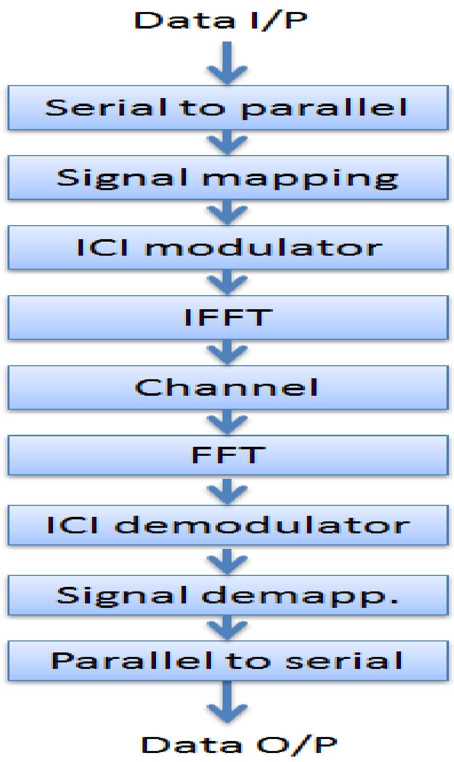

Figure. 4 Simulation flow-chart

The simulation done here shows that absolute, real and imaginary value for ICI complex gain for standard OFDM and for OFDM with Self-cancellation scheme. The simulations have been done using 0.2 and 0.4 for α_1 and α_2 respectively, and the number of subcarrier is $N = 16$.

The simulation shows the effect of ICI on the received signal. The ICI complex gains $a_{m,k}$ for absolute, real and imaginary values are plotted respectively for all subcarriers in Figure 5 (a, b and c).

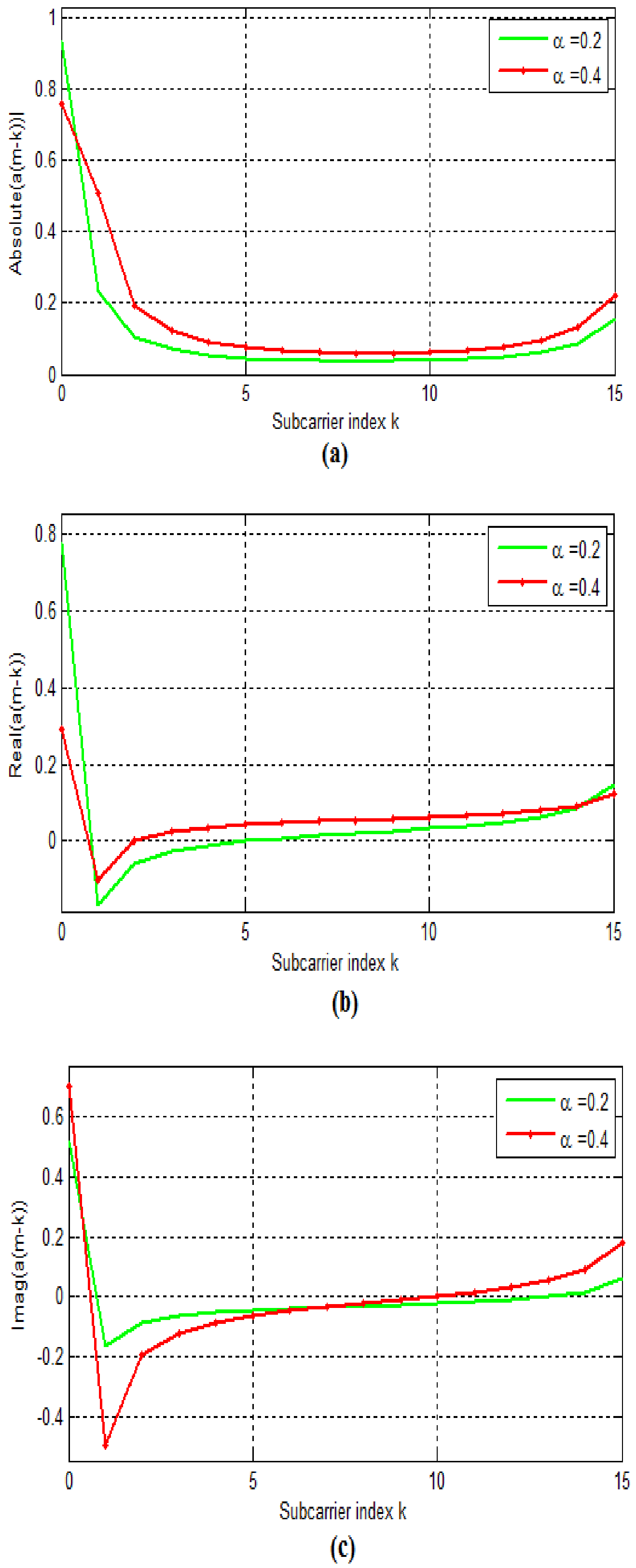

Figure 5. ICI complex gain (a) Absolute (b) Real (c) Imaginary

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These figures show that for a larger relative frequency offset α, the weight of the desired signal component a_0, decreases, while the weights of the ICI components $a_{m,k}$ increase. Also, these figures show that, the adjacent subcarrier has the maximum contribution to the ICI complex gain. This fact is used in the ICI self-cancellation scheme.

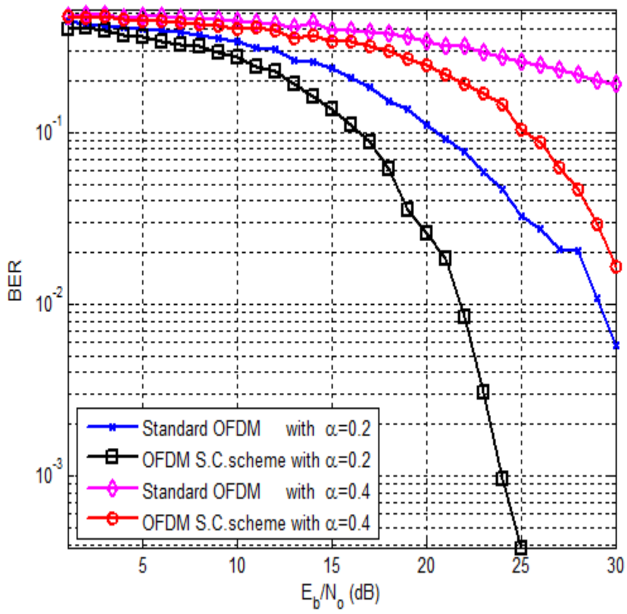

Figure 6. A comparison between standard and self-cancellation OFDM BPSK systems

Figure 6 shows the comparison between standard OFDM and OFDM with self-cancellation scheme for BPSK modulation for different values of relative frequency offset α. It is clearly that there is better improvement in BER for OFDM system that using self-cancellation scheme than standard one.

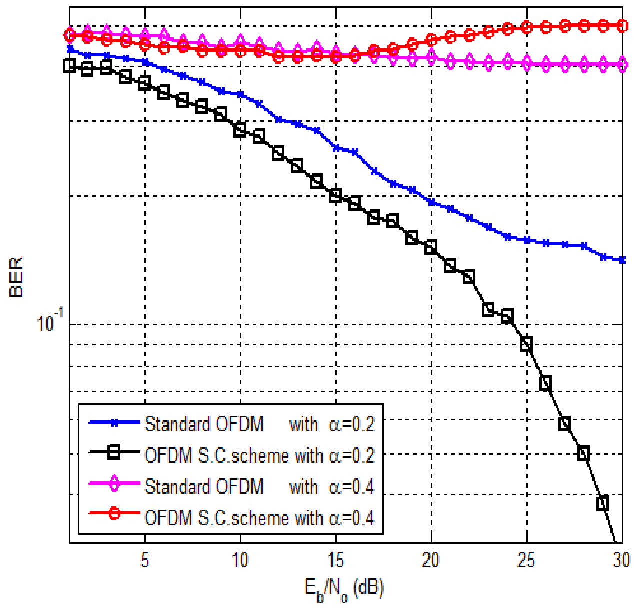

Figure. 7 A comparison between standard and self-cancellation OFDM QPSK systems

Also Figure 7 shows a comparison between conventional OFDM and OFDM with self-cancellation both using QPSK modulation. It is clearly that OFDM with self-cancellation do better in BER than standard OFDM. However, the improvement in the error rate BER happened at the expense of bandwidth efficiency.

6. CONCLUSIONS

The analysis and derivations for ICI complex gains that used in self-cancellation scheme have been done Also CIR simulation shows great improvement for the analyzed scheme. OFDM system using the ICI self-cancellation scheme is much better in performance than standard OFDM systems.

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