ANALYSIS OF INTERCARRIER INTERFERENCE CANCELLATION SCHEME IN OFDM SYSTEMS

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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 issued 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), Relative frequency offset, and 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 systems 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 degrades the 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 fraction 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,

\[ x(t) = \sum_{k=0}^{N-1} d_k e^{j2\pi f_k t}, \quad 0 \leq t \leq T_s \quad (1) \]

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, \( \Delta f \) is the subcarrier spacing, \( T_s \) is data symbol time, \( N \) is the total number of subcarriers.

![Figure 1: OFDM modulator](image)
If there is a multiplicative time-varying distortion \( y(t) \) that is caused by subcarrier frequency offset, then the received signal will be:

\[
y(t) = y(t).x(t) \tag{2}
\]

\[
y(t) = e^{j2\pi at}, \text{ where } \alpha \text{ is a fraction of } \Delta f \text{ which is called the relative frequency offset, and}
\]

\[
\tilde{y} = \delta/\Delta f, \text{ where } \delta \text{ is the subcarrier frequency offset.}
\]

The output of the demodulator at \( k \) subcarrier is:

\[
Y_k = \frac{1}{N} \sum_{m=0}^{N-1} \sum_{k} d_k e^{-j2\pi(f_m-f_k+a)}
\]

Manipulating Eq. 3 using a geometric series, the received signal will be:

\[
Y_k = a_0 d_k + \sum_{m \neq k} a_m d_k
\]

The first term in the right-hand side of Eq. 4 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 the ICI signal, which is the interfering signals, transmitted on subcarriers other than the \( k \) subcarrier.

\[
a_{m,k} = \frac{1}{N} \sin(\pi(f_m-f_k+a)) \cdot e^{j\pi(f_m-f_k+a)(1-1/N)}
\]

Eq.5 is a general form where, \( a_{m,k} \) is of intercarrier interference complex gain between \( m \)th and \( k \)th subcarriers.

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

\[
d_1 = -d_0, \ d_3 = -d_2, ..., \ d_{N-1} = d_{N-2}
\]

for that:

\[
\tilde{y}_k = \sum_{m=0}^{N-2} (a_{m,k} - a_{m,k-1})d_k = \sum_{m=0}^{N-2} a_{m,k} d_k
\]

Eq. 6 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:

\[
\hat{y}_k = -a_{m,k+1} + 2a_{m,k} - a_{m,k-1}
\]

In Eq. 7, more reduction of ICI complex gain by the two terms \( (-a_{m,k+1} - a_{m,k-1}) \), and ICI complex gain will be:

\[
a_{m,k} = -a_{m,k+1} + 2a_{m,k} - a_{m,k-1}
\]

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 \( a_{m,k} \) for the transmitter only and ICI complex gain \( \mathring{a}_{m,k} \) for both transmitter and receiver. It is seen that \(|\mathring{a}_{m,k}| \ll |a_{m,k}| \ll |a_{m,k}| \) for most values of \((m,k)\).
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.

\[
\frac{\text{desired signal power}}{\text{undesired signal power(ICI)}}
\]

The desired received signal power on the \(k\)th subcarrier can be given as:

\[
[C^2] = [(a_0d_k)^2]
\]

(9)

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 Eq. 4:

\[
[I^2] = \left( \sum_{m \neq k}^{N-1} a_{m,k}d_m \right)^2
\]

(10)

From Eq. 9 and Eq. 10, we can obtain the theoretical CIR for subcarrier \(0 \leq k \leq N-1\) as:

\[
CIR = \frac{|a_0d_k|^2}{\sum_{m \neq k}^{N-1} a_{m,k}d_m}
\]

for simplicity let data symbol \(d_k = d_m = 1\), then:

\[
CIR = \frac{|a_0|^2}{\sum_{m=1}^{N-1} a_m^2}
\]

(11)

Eq. 10 consider that CIR is a function of \(N\) and \(\alpha\) but mostly on \(\alpha\).

For deriving theoretical CIR for OFDM with self-cancellation scheme, the desired signal from Eq. 7 will be:

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

(12)

The undesired signal power (ICI) is:

\[
[I^2] = \left( \sum_{m=2,4,6,...}^{N-1} (-a_{m,k+1} + 2a_{m,k} - a_{m,k-1})d_m \right)^2
\]

(13)

Then CIR for OFDM with self-cancellation will be:

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

(14)

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 Eq. 14, and the CIR for standard OFDM system calculated by Eq. 11. 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, QPSK, 16QAM and 64QAM)
under the same conditions of bandwidth efficiency and relative frequency offset. The channel is modeled as AWGN with ICI complex gain $e^{j2\pi at}$.

The simulation done here shows the absolute, real and imaginary values for ICI complex gain for both standard OFDM and OFDM with Self-cancellation scheme. The simulations were performed using 0.2 and 0.4 for $\alpha_1$ and $\alpha_2$ respectively, and the number of subcarrier is $N = 16$.

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

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

These figures show that for a larger relative frequency offset $\alpha$, the weight of the desired signal component $a_{0}$, decreases, while the weights of the ICI components $a_{n,k}$ 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 $\alpha$. It is clear that there is an improvement in BER of OFDM system with self-cancellation scheme compared to the 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 clear that OFDM with self-cancellation show better BER performance compared to the standard OFDM. However, the improvement in BER is at the expense of bandwidth efficiency.

6. CONCLUSION

Analysis and derivations for ICI complex gains to be 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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REFERENCES


