Performance Evaluations of ICI Cancellation Schemes in OFDM Systems

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Abstract – OFDM is a successful technique in wireless communication system. Frequency offset in OFDM systems leads to loss of orthogonality among subcarriers, which resulted in intercarrier interference (ICI) to occur. Another main problem of OFDM is the occurrence of high PAPR. To mitigate ICI problem, ICI self-cancellation scheme and frequency domain partial response coding has been proposed. In this paper, we evaluate the performance of ICI self-cancellation schemes and the integer-coefficients partial response coding (PRC). ICI self-cancellation data allocation of $(X_k, X_{k+1}=-X_k^*)$ has the best PAPR performance while the data allocation of $(X_k, X_{k+1}=-X_k)$ has the most CIR enhancement. The integer coefficients PRC outperform the ICI self-cancellation schemes in terms of bandwidth efficiency and in the BER performance especially at high E_s/N_o.

1. Introduction

As a promising technique for high data-rate transmission, Orthogonal Frequency Division Multiplexing (OFDM) is being considered for many emerging wireless applications due to its high spectral efficiency and robustness against frequency selective fading. In fact, with those advantages, it has been successfully used in many environments, such as DAB, DVB, and WLAN.

However, in time variant mobile radio environment, the relative movement between transmitter and receiver resulted in frequency offset due to Doppler frequency shifts, hence the carriers cannot be perfectly synchronised. This imperfection destroys orthogonality among subcarriers and causes intercarrier interference (ICI) to occur in addition to signal rotation and attenuation. Furthermore, the degradation of BER performance increases rapidly with increasing frequency offset occurrence in OFDM system [1].

Several methods have been proposed to reduce the effect of the ICI. Self-ICI-cancellation approach has been proposed, which transmits each symbol over a pair of adjacent or non-adjacent subcarriers with a phase shift of $\pi/2$ [2], [3]. In order to improve the PAPR performance of self-cancellation technique, a simple conjugated data allocation of $(X_k, X_{k+1}=-X_k^*)$ was proposed [4]. The philosophy of ICI canceling modulation, each pair of subcarriers, in fact, transmits only one data symbol in order to improve the system performance at the receiver. These methods can reduce the ICI significantly with a trade off in reduction in bandwidth efficiency.

In single-carrier systems, partial response signaling has been studied to reduce the sensitivity to time offset without sacrificing the bandwidth [5]. Hence, according to duality theorem, partial response in frequency domain is capable of reducing the sensitivity of multicarrier system towards frequency offset caused by Doppler shift in the channel. The idea of ICI self-cancellation scheme is also applicable to partial response filtering of OFDM systems. The partial response with correlation polynomial $F(D) = 1 - D$ was used to mitigate the ICI in OFDM system [6]. ICI is actually deliberately introduced in a controlled manner through the polynomial functions. The optimum weights for partial response coding that minimize the ICI power were derived [7]. However, by using polynomial coefficients with integer values allow suboptimum detection hence reduces the complexity of the receiver.

So far, no literature on performance evaluation on the ICI self-cancellation techniques and partial response coding has been studied. Therefore in this paper, we study the CIR, BER and PAPR performance of the self-cancellation schemes and partial response coded OFDM (PRC-OFDM) system with integer polynomial coefficients employing a simple symbol-by-symbol suboptimum detection technique. This paper is organised as follows. In Section II we describe briefly on ICI cancellation techniques in OFDM. Section III includes the simulation results such as CIR, CDF and BER. Lastly, some concluding remarks are given in Section IV.

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2. ICI Cancellation Techniques in OFDM System

Let the received OFDM signal in the presence of frequency offset be

$$Y(k)=\sum_{l=0}^{N-1}X(l)S(l-k)+W_k \qquad (1)$$

for k=0,1,…,N-1 where N is the number of subcarriers. X_k is the transmitted symbol of the k-th subcarrier. W_k is additive white Gaussian noise (AWGN) with zero mean and variance $N_0/2$ and is assumed to be independent and identically distributed. $S(l-k)$ is the ICI effect of the l-th subcarrier to the k-th which can be represented as follows

$$S(l-k)=\frac{sin(\pi(\varepsilon+l-k))}{N\,sin\left(\frac{\pi}{N}(\varepsilon+l-k)\right)}.exp\left(j\frac{\pi}{N}(N-1)(\varepsilon+(l-k))\right) \qquad (2)$$

where ε is the normalised frequency offset with respect to the frequency separation between subcarriers. By not taking the presence of AWGN into account, the received signal can be expressed as a sum of desired signal C_k and undesired ICI signal I_k

$$Y(k)=C(k)+I(k) \qquad (3)$$

where

$$C(k)=X(k)S(0)$$
$$I(k)=\sum_{l=0,l\neq k}^{N-1}X(l)S(l-k) \qquad (4)$$

The desired signal value C_k depends only on the signal transmitted on subcarrier k, while I_k depends on the signals transmitted on all the other subcarriers. From equation it can be said that as ε becomes larger, the desired signal decreases and the undesired signal increases.

Zhao and Haggman proposed ICI self-cancellation scheme in which a pair of complex signals ($X_k, X_{k+1}=-X_k$) is assigned in adjacent subcarriers, for k=0, 2, …, N-2. However, such allocation with π phase difference between the subcarrier pair causes high PAPR of OFDM symbol defined as

$$PAPR=\frac{\max\limits_{0\leq n\leq N-1}\left[|x_n|^2\right]}{E\left[|x_n|^2\right]} \qquad (5)$$

where max $\left[|x_n|^2\right]$ is the maximum value of $|x_n|^2$ and $E\left[|x_n|^2\right]$ denotes the expectation of the average power value.

ICI self-cancellation with allocation assignment in the form of ($X_k, X_{k+1}=-X_k^*$) was proposed by [4] as a method to reduce high peak signal in the ICI self-cancellation technique.

The baseband model of PR-OFDM is shown in Figure1. In PRC-OFDM, the modulated signal is encoded by partial response polynomial. Precoding is also performed before modulation in order to avoid error propagation during decoding process. Let X_k be the symbols to be transmitted and c_i be the coefficients for partial response polynomial, the transmitted signal at the k-th subcarrier can be expressed as

$$S(k)=\sum_{i=0}^{K-1}c_i X(k-i) \qquad (6)$$

where K is the number of coefficients or length of the polynomial. Without loss of generality, $E|X_k|^2=1$ and $E(X_k X_j^*)=0$ for $k\neq j$ is assumed.

In terms of the partial response coding coefficients, the intercarrier interference power can be expressed as

$$P_{ICI}=\sum_{i=0}^{K-1}\sum_{l=1}^{N-1}c_i^2|S(l)|^2 + \sum_{k=1}^{K-1}\sum_{i=0}^{K-1-k}c_i c_{i+k}\left[\sum_{l=2}^{N-1}S(l)S^*(l-k+i)+S(l+k-i)S^*(l)\right] \qquad (7)$$

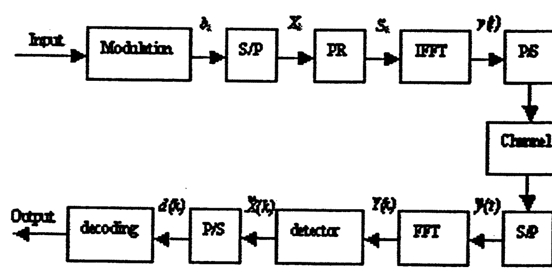

Figure.1: Baseband model of PR-OFDM

3. Simulation Results and Performance Evaluation

Here we present our simulation results for the performance of PRC-OFDM with integer polynomials and ICI self-cancellation system. In PRC-OFDM, different polynomial length (up to K=4) and coefficients are investigated. The coefficients are limited to the value of ±1, ±2 and 0. The number of subcarriers used in this simulation is 64 subcarriers. Our simulation is conducted with the assumption of flat fading channel. Symbol-by symbol suboptimum detection is used at the receiver.

ICI power level can be evaluated by using the CIR [8]. At each polynomial length, the polynomial that gives the lowest carrier to interference ratio (CIR) is chosen. Table I lists the best combination of coefficients for the respective length. The length of polynomial is limited up to 4 as length greater than this gives relatively about the same performance gain [7].

Table: 1
PRC coefficients at the respective length, K

Length, K	PRC coefficients
2	1, -1
3	-1, 2, -1
4	1, -1, 0,-1

For simplicity, K=2 is chosen for comparison with the ICI cancellation technique. Figure 2 shows the theoretical CIR (in decibels) of the mentioned techniques as a function of the normalized frequency offset ε.

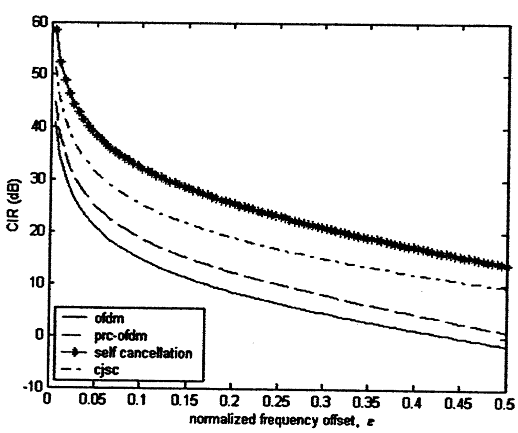

Figure 2: Comparison of CIRs with respect to constant frequency offset

Overall ICI self-cancellation schemes and PRC-OFDM technique enhance the CIR of OFDM systems. At ε=0.25, the self-cancellation gives more than 13-dB improvement over the PRC-OFDM and the conjugate signal allocation ICI self-cancellation (cjsc), gives about 7-dB enhancement. However, the PRC-OFDM double the spectral efficiency compare to the self-cancellation techniques.

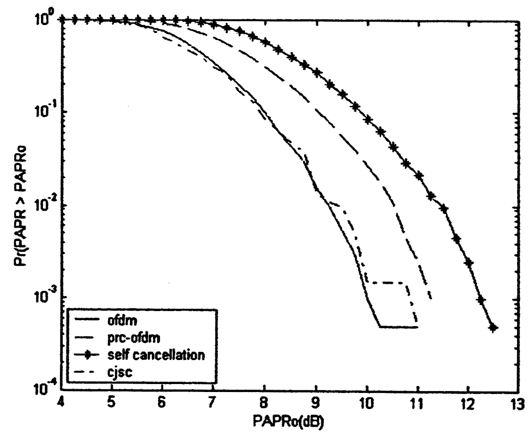

Figure 3: Comparisons of PAPRs

In the PAPR distribution analysis, the complementary cumulative distribution function (CCDF) of an OFDM signal for a given PAPR level, $PAPR_o$ dB, is the probability that the PAPR of the OFDM frame exceeds a certain threshold $PAPR_o$ dB. This is defined as Prob(PAPR >$PAPR_o$ dB). Figure 3 shows the PAPR for N=64. On the overall, the PAPR of OFDM system is better compared to self-cancellations and PRC-OFDM system. It should be mentioned that no envelope stability algorithm was used in this investigation [9]. The conjugate self-cancellation and PRC-OFDM has better PAPR performance compared to self-cancellation scheme. At 10^{-3} probability, the conjugate data algorithm is almost 2 dB and 1 dB lower than self-cancellation scheme and PRC-OFDM respectively. However, it can be observed from Fig.3 that the PAPR of conjugate data algorithm fluctuates in the range of threshold PAPR. This is due to the fact that the phase difference variations between the two adjacent subcarriers resulting in the occurrence of envelope instability before transmission.

From Figure 4, BER for PRC-OFDM improves at high E_s/N_o. However, the ICI self-cancellation schemes deteriorate at high SNR. Redundancy criteria in these schemes improve the performance at low E_s/N_o however the PRC-OFDM outperforms them at higher E_s/N_o.

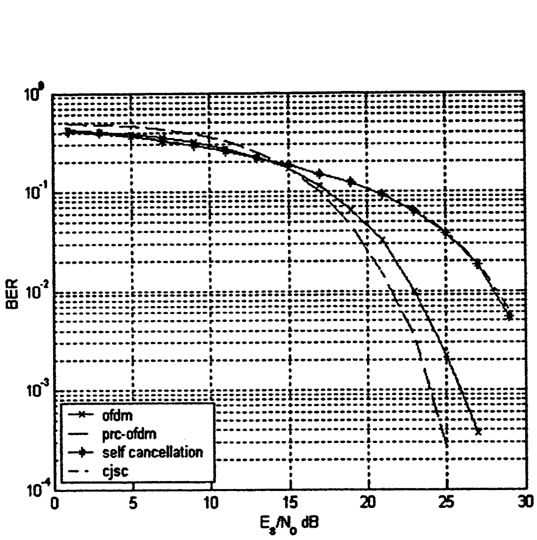

Figure 4: BER comparison at ε=0.15

4. Conclusion

This paper studies the performance of ICI self-cancellation schemes and the PRC-OFDM. Polynomial coefficients with integer values PRC-OFDM system was chosen for this comparison studied in order to reduce the complexity of the receiver. As known, the redundancy property adopted in self-cancellation schemes reduced the bandwidth efficiency by half compared to PRC-OFDM system. Although the CIR gain for PRC-OFDM is the lowest compare to the self-cancellation schemes, the BER is better at higher E_s/N_0. From the PAPR point of view, the PRC-OFDM gives a moderate improvement and can be improved further through an envelope stability algorithm. Therefore, PRC-OFDM with integer polynomial coefficients gives a solution to adverse the effects of both ICI and PAPR in OFDM systems simultaneously in a simple manner. This system is feasible and can be applied in future broadband system development such as MIMO-OFDM system.

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