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Interference Analysis of Partial Response Coded OFDM Signals

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Abstract: Orthogonal Frequency Division Multiplexing (OFDM) is one of the main techniques proposed to be employed in fourth generation wireless systems. However, there are several hurdles that need to be overcomed before OFDM finds widespread use in modern wireless communication systems. The spectra of OFDM are not strictly band limited. As a result, the linear distortion such as multipath causes each subchannel to spread energy into the adjacent channels and consequently cause intersymbol interference (ISI). Moreover, the time variations of the channel destroy the orthogonality among the subcarriers and causes intercarrier interference (ICI). In this study, time domain Partial Response Coding (PRC) is proposed for eliminating interference without the need of cyclic prefix. The expression for the interference power with PRC is derived. Simulation results show that PRC in OFDM systems reduce the ICI power without decreasing the bandwidth efficiency.

Key words: Partial response coding, orthogonal frequency division multiplexing, intercarrier interference

INTRODUCTION

Increasing demand for wireless data communication and services has introduced new technologies capable of handling higher data rates. Third generation wireless mobile systems, like UMTS, are widely expected to cope with such demands. Presently much research is being undertaken for future generation of wireless systems. One of the proposed modulation formats is Orthogonal Frequency Division Multiplexing (OFDM). OFDM has already been adopted in single frequency networks, such as Digital Video Broadcasting (DVB) and Digital Audio Broadcasting (DAB), as well as, in indoor wireless systems, such as IEEE 802.11 and HiperLAN2. Eventhough OFDM is effective in avoiding intersymbol interference due to multipath delay, it is sensitive to time selective fading, which destroys the orthogonality among subcarriers in one OFDM symbol and thus causes Inter-Carrier Interference (ICI) (Cimini, 1985). Several methods have been proposed to reduce the effect of ICI. Self ICI cancellation scheme has been proposed (Zhao and Haggman, 2001). Although, this method can suppress the ICI significantly; it halves the bandwidth efficiency since it transmits each symbol over a pair of adjacent subcarriers with a 180° phase shift. In this study, we propose a new method based on time domain partial response signaling for eliminating ICI.

Partial Response Coding (or Signaling) (Peter and Pasupathy, 1975; Zhao and Haggman, 1998) in the time domain has been studied for single carrier systems to reduce the sensitivity of time offset without sacrificing the bandwidth. In frequency domain, the PRC with correlation polynomial F(D) = 1-D was used to mitigate the ICI caused by carrier frequency offset (Zhang and Geoffrey, 2003; Jayakumari and Pillac, 2005a, 2005b). In this study, partial response signaling is applied to the time domain signal to improve the performance of multicarrier OFDM system. The idea is to exploit the correlation between adjacent symbols to compensate for the effect of time variation in the sub channels. Here, we have analyzed the performance of OFDM system with Class IV PRC. The expression for the ICI power with PRC is derived. Simulation results show that PRC in OFDM systems reduce the ICI power without decreasing the bandwidth efficiency.

SYSTEM DESCRIPTION

Proposed OFDM system with PRC: A baseband model of the proposed OFDM system using PRC is shown (Fig. 1). Before applying data to the Class IV PRC, the binary input sequence $\{a_k\}$ is precoded is to avoid error propagation. The precoded input sequence $\{d_k\}$ is applied to the PRC block. It consists of a tapped delay line with coefficients

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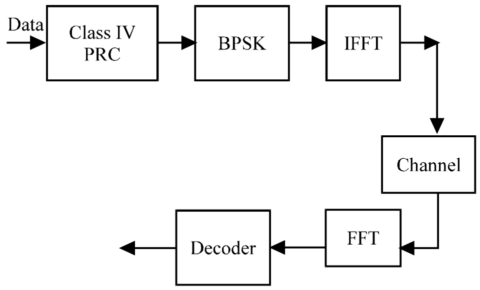

Fig. 1: Proposed OFDM system model using PRC

$\{f_n\}$ in cascade with a filter with frequency response G(T) (Proakis, 1995; Simon and Lindsey, 2003; Jayakumari and Pillai, 2006). The transversal filter has the periodic frequency response:

$$F(\omega) = F(D)\Big|_{D=\exp(-j\omega T)} = \sum_{n=0}^{N-1} f_n \exp(-j\omega nT) \quad (1)$$

where, T is the symbol spacing and F(D) is the PRC system polynomial given by:

$$F(D) = \sum_{n=0}^{N-1} f_n D^n \quad (2)$$

Thus the output of the partial response coder will be:

$$b_k = d_k - d_{k-2} \quad (3)$$

This output is BPSK modulated to get the sequence $\{b_{i,n}\}$.

After performing IFFT, the transmitted samples $s_i(m)$ corresponding to the i^{th} time interval is given by (Jayakumari and Sakunthala, 2007)

$$s_i(m) = \sqrt{\frac{E_s}{N}} \sum_{n=0}^{N-1} b_{i,n} e^{j2\pi\frac{nm}{N}} \qquad m = 0,1,\ldots,N-1 \quad (4)$$

where, N represents the number of carriers in the system. At the receiver the samples obtained, y(l) is given by:

$$y(l) = \sqrt{\frac{E_s}{N}} \sum_{i=-\infty}^{\infty} \sum_{n=0}^{N-1} \sum_{m=0}^{N-1} \left[b_{i,n} e^{j2\pi\frac{nm}{N}} \cdot h(l-m-i(N);l) \right] + w(l) \quad (5)$$

The FFT output is then given by:

$$y_k^{(j)} = \sqrt{\frac{E_s}{N^2}} \sum_{i=-\infty}^{\infty} \sum_{n=0}^{N-1} b_{i,n} \gamma_{i,k,n} + w_k \quad (6)$$

Where,

$$\gamma_{i,k,n} = \sum_{m=0}^{N-1} \sum_{l=0}^{N-1} e^{-j2\pi\frac{kl-nm}{N}} h((l-m)-i(N);l)$$

The FFT output is passed through a decoder to recover the original data (Jayakumari and Pillai, 2007). The receiver can recover the data $\{a_k\}$by subtracting out the effect of previous input symbols. In practice the receiver makes estimates of the data and then uses these to cancel the tails of the pulse responseThe original data sequence $\{a_m\}$ can be recovered from the noise free sampled output from the receiving filter $\{B_m\}$ as:

$$a_m = \frac{1}{2} B_m + (M-1) \quad (\bmod M) \quad (7)$$

where, M represents the number of output levels of the PRC.

In order to keep the error rate expressions simple, it is assumed that the output levels are evenly spaced. Let P_0 represent the probabilities of the outer levels. for M = 2, L = 3, the probabilities are 1/4, 1/2 and 1/4 (Jayakumari and Pillai, 2007b). Then, the probability of error of the proposed system is then approximately:

$$P_e \le 2(1-P_0) Q(d/\sigma) \quad (8)$$

where, S^2 is the noise variance at the decoder and d is the decision distance (half the level separation, equal to unity).

PERFORMANCE ANALYSIS

ICI power of the proposed system: In PRC-OFDM, the data signal is encoded by partial response polynomial. The proposed partial response coding is performed as:

$$b_k = \sum_{n=0}^{L-1} f_n d_{k-n} \quad (9)$$

where, L is the partial response code length and f_n, the correlation coefficients, n = 0,1,…L-1. The coded symbol c_k is then modulated onto N subcarriers. Precoding is also performed before encoding in order to avoid error propagation during the decoding process. If S(k) represents the transmitted signal for the kth subcarrier, then in terms of partial response coding coefficients, the intercarrier interference power can be expressed as:

$$P_{ICI} = \sum_{n=0}^{K-1}\sum_{l=1}^{N-1} f_n^2 \left|S(l)\right|^2 + \sum_{k=1}^{K-1}\sum_{n=0}^{K-l-k} f_n f_{n+k}\left[\sum_{l=2}^{N-1} \begin{matrix} S(l)S^*(l-k+n) \\ +S(l+k-n)S^*(l)\end{matrix}\right] \qquad (10)$$

where, S(l-k) is defined as the ICI coefficient between the lth and kth subcarriers given by:

$$S(l-k) = \left(\frac{\sin\left(\pi(l-k+\varepsilon_n)\right)}{N\sin\left(\frac{\pi}{N}(l-k+\varepsilon_n)\right)}\right) \exp\left(j\pi\left(1-\frac{1}{N}\right)(l-k+\varepsilon_n)\right) \qquad (11)$$

and g_n denotes the frequency offset.

SIMULATION RESULTS

Using computer techniques OFDM systems with and without partial response coding were simulated. Here BPSK modulation is used for signal mapping. The channel model used in this simulation is Rayleigh fading with 5 taps and maximum Doppler shift 100 Hz. The simulation parameters used are shown in Table 1.

It can be seen that the bit error rate could be reduced by 5% using this new technique and the spectral efficiency could be improved by 7%. The effect of PRC in time domain has not been analyzed previously for OFDM systems. Here, Class IV PRC scheme is used. This technique is well known for its simplicity and useful

Table 1: Simulation parameters

Simulation parameters	Conventional system	Proposed system1
No: of carriers	50	50
IFFT size	128	128
Signal mapping	BPSK	BPSK
Symbols/ carrier	100	100
Cyclic prefix length	10 samples per symbol period	---
Correlation polynomial used	-----	$1-D^2$

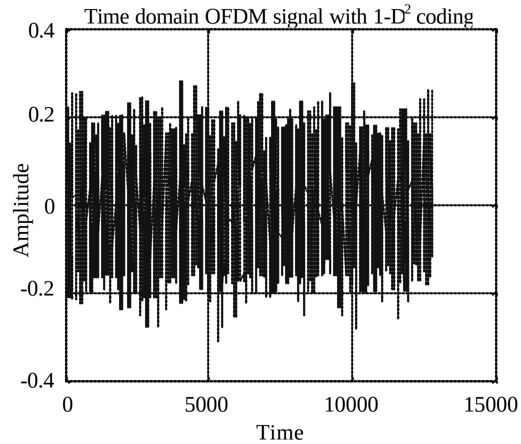

Fig. 2: Time domain shape of OFDM using $1-D^2$ coding

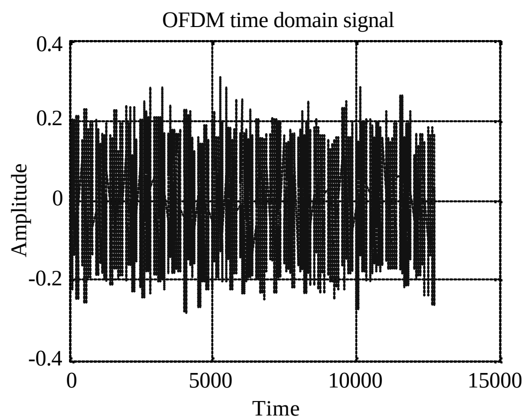

Fig. 3: Time domain shape of OFDM

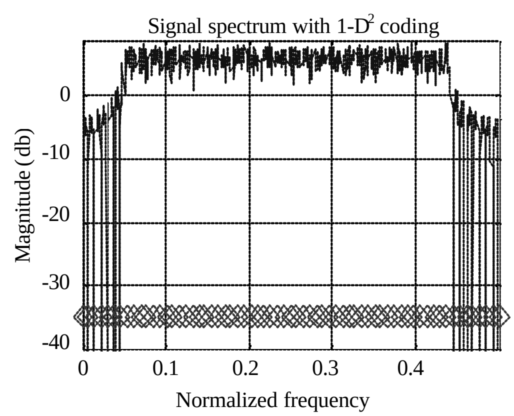

Fig. 4: Spectrum of OFDM using $1-D^2$coding

spectral shapes. Figure 2-5 show the time domain shapes and spectra of partial response coded OFDM and

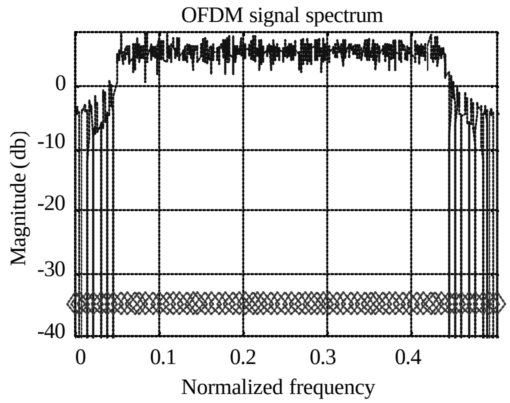

Fig. 5: Spectrum of OFDM

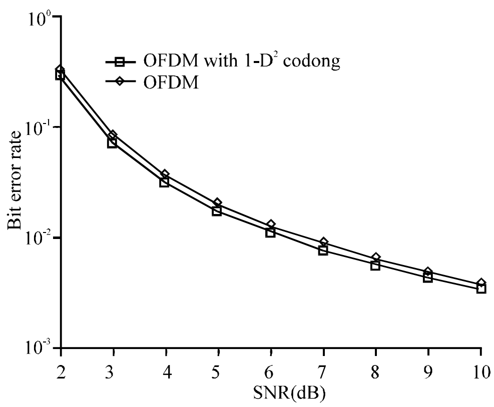

Fig. 6: Comparison of Bit error rate of the Conventional and proposed systems

conventional OFDM signals. Figure 6 shows the plot of bit error rate for the proposed and conventional systems in Rayleigh fading channel. This figure shows the robustness of the proposed signaling technique.

CONCLUSION

The performance of OFDM transmission along with three level partial response coding scheme is analyzed. One of the merits of PRC is that the controlled interference can be used to shape the system spectrum. Also, this spectral shaping makes the system less sensitive to timing errors and allows the practical systems to transmit at the Nyquist rate. The conventional OFDM systems use cyclic prefix to overcome interference which in turn reduce the spectral efficiency. The proposed system is simulated without adding the cyclic prefix. This leads to maximum spectral efficiency. In addition, since no channel equalization is needed for reducing ISI, the proposed scheme is easy to implement without increasing system complexity. Therefore, this is a promising approach for OFDM systems working in a mobile radio environment. Our new method is very promising for wireless high speed data transmission where spectral efficiency is important.

Using this new simple coding technique, for the simulation parameters listed in Table 1, we could improve the spectral efficiency by 7% compared to the conventional system with cyclic prefix. For practical cases in wireless environment for avoiding ISI and ICI, the cyclic prefix length should be almost 40% of the total symbol period for the conventional OFDM system whereas if PRC is used along with the OFDM system, this cyclic prefix can be avoided and in such cases, high spectral efficiency could be achieved.

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