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Impact of Partial Response Coding for Reduction of Inter Channel Interference in OFDM System

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Abstract: Nowadays, a major challenge in communication is to send maximum possible information through minimum Band Width. Orthogonal Frequency Division Multiplexing (OFDM) has opened an era for both wired and wireless communication to enhance spectral efficiency to a maximum extent. Time variance of wireless channels destroys the orthogonality among subchannels in Orthogonal Frequency Division Multiplexing (OFDM) system and causes Inter Channel Interference (ICI), which result in an error floor. In this paper, we study Partial Response Coding(PRC) for reducing the effect of the Inter Channel Interference (ICI). Based on the general expression of the ICI power for OFDM with PRC, the optimum weight for PRC that minimize the ICI power has derived. Numerical and simulation result shows that use of more tap have the ability to reduce ICI.

Key words: Inter Channel Interference (ICI), Partial Response Coding (PRC), Orthogonal Frequency Division Multiplexing (OFDM)

INTRODUCTION

For some days a promising technique for high date-rate transmission[1] orthogonal frequency division multiplexing has been successfully used in many environment such as Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB), hyper LAN-II etc. In a classical OFDM system, the entire channel is divided into many orthogonal subchannels and information symbols are transmitted in parallel over these subchannels with a long symbol duration to deal with the frequency-selective fading of wireless environments. However it can be shown[2-5] that time variation of wireless channels over an OFDM symbol period destroys orthogonality among subchannels and causes the Inter Channel Interference (ICI). If not compensated for, the ICI will result in an error floor, which increases the Doppler frequency and symbol duration. Several methods[6-13] has been proposed to reduce the effect of the ICI. One of the most commonly used methods is frequency domain equalizer[6,7].Ann and Lee proposed[6], a pilot symbol assisted frequency domain equalizer was. Jenon. *et al.*,[7], Development equalization technique suitable to time-varying multipath channel. The antenna diversity is an effective way to combat the effects of time variation of wireless channels, hence can reduce the ICI as shown by Russell and Stuber[2] . Another way to deal with the ICI is time domain windowing in by Muschalhic[8] and Armstrone[9]. Diggavi, *et al.*, [10], ICI suppression in multiple-input multiple-output (MIMO) OFDM is studied. Recently a self ICI cancellation approach[11] has been proposed, which transmit each symbol over a pair of adjacent subchannels with a 180° phase shift. This method can suppress the ICI significantly with a reduction in bandwidth efficiency. Partial Response Coding (PRC) in the time domain has been studied for single carrier systems to reduce the sensitivity of time offset[12] without sacrificing the bandwidth. In the frequency domain, the PRC with correlation polynomial $F(D)=1-D$ was used to mitigate the ICI caused by carrier frequency offset, [13].

In this study we study general frequency domain PRC for suppressing the ICI caused by the Doppler frequency shift or carrier frequency offset. We describe an OFDM system with PRC and tried to derive the exact ICI expression. With the expression we obtain the optimum weights for PRC based on minimizing the ICI and analyze its performance. Numerical and Simulation results are presented to demonstrate the performance improvement of OFDM system with optimum PRC.

MATERIAL AND METHOD

An OFDM signal described Weinstein[15]and Alrddad Lassalle[16] consists of *N* subcarriers spaced by the frequency distance Δf. Thus, the total system bandwidth B is divided into N equidistant subchannels.

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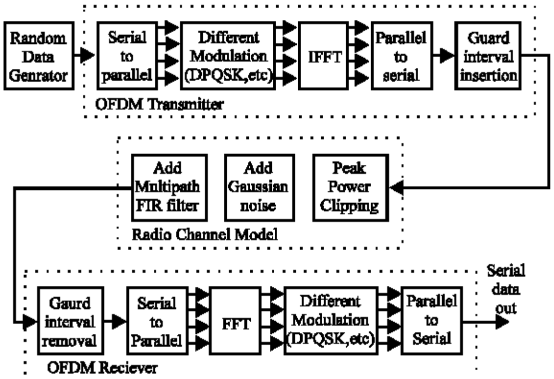

Fig .1: Currently used OFDM system

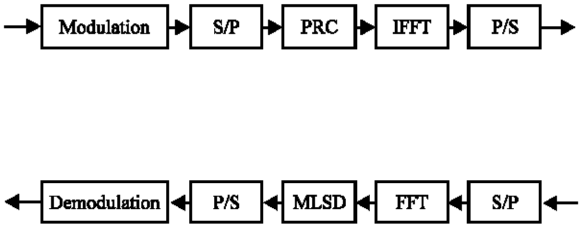

Fig. 2 OFDM system with PRC

All subcarriers are mutually orthogonal within a time interval of length $T_S = 1/\Delta f$. Since the system bandwidth B is subdivided into N narrowband subchannels, the OFDM block duration T_S is N times as large as in the case of a single-carrier transmission system covering the same bandwidth. Typically, for a given system bandwidth, the number of subcarriers is chosen such that the symbol duration is large compared to the maximum delay of the channel. (Fig .1) shows an existing system without the encoding process PRC.

The base band model of OFDM with PRC is shown in (Fig.. 2(a). At the transmitter, the modulated signal is encoded by PRC. Let x_k be the symbols to be transmitted and c_i be the weights for PRC with unit norm, i.e,

$$\sum_{i=0}^{K-1} c_i^2 = 1 \tag{1}$$

Where k is the number of weights of PRC. Without loss of generality, we assume $E|X_k|=1$ and $E(x_k x_i^*)=0$ for $k\neq 1$ then the transmitted signal at the *k*th subchannel can be expressed as

$$s_k = \sum_{i=0}^{K-1} c_i x_{k-i} \tag{2}$$

From the above expression shows that the transmitting data grouped into a symbol. Hence there is a possibility to minimization of the inter channel interference between data or signal less than the raw bit transformation through channels.

The coded signals can be recovered by a Maximum-Likelihood (ML) sequence detector [14] at the receiver. The OFDM signal in time domain is

$$y(t) = \sum_k s_k e^{j2\pi f_k t} \quad \text{for} \quad 0 \le t < T_s \tag{3}$$

Where $f_k = f_0 + k\Delta f$ is the frequency of the *k*th subchannel, $\Delta f = 1/T_s$ is the subchannel spacing and T_s is the symbol duration. After passing through a time-varying channel with the impulse response $h(t,\tau)$, the received signal is

$$\bar{y}(t) = \int h(t,\tau) y(t-\tau) dr \tag{4}$$

The channel impulse response for the frequency selective fading channel can be described by

$$\bar{s}_m = a_0 s_m + \sum_{k\neq m} a_{m-k} - s_k \tag{5}$$

Where τ_l is the delay of the lth path and $\gamma_l(t)$ is the corresponding path gain. Here, we assume that the complex stochastic processes $\gamma_l(t)$ are independent for different l's and have the same statistics but different variance $\in_l$ for simplicity, we first consider the flat-fading channel and omit the subscription l. Then the received signal becomes $\bar{y}(t) = \gamma(t)y(t)$
The demodulated signal can be written as

$$\bar{s}_m = \frac{1}{T_s}\int_0^{T_s} \bar{y}(t) e^{-j2\pi f_m t} dt \tag{6}$$

Here, the integration is used instead of the discrete Fourier transform (DFT). As indicated[5], the difference is negligible. It has been drivenLi and cimini[5] that the demodulated signal can be expressed as

$$\bar{s}_m = a_0 s_m + \sum_{k\neq m} a_{m-k} - s_k \tag{7}$$

Where α_l is defined as

$$a_l = \frac{1}{T_s}\int_0^{T_s} \gamma(t) e^{-j2\pi l\Delta f t} dt \tag{8}$$

Here, α_0 is the gain of the desired signal and α_l, for $l\neq 0$, represents the gain of the interfering signals from others subchannels. For time invariant channels, $\gamma(t)$ is a constant and α_l for $l\neq 0$; consequently, there is no ICI. In general, for time varying channels, $\alpha_l \neq 0$ for some $l\neq 0$, the ICI exists.

The total ICI power is defined as

$$P_{ICI} = E\left|\sum_{1\neq 0} a_1 s_{m-1}\right|^2 \qquad (9)$$

From OFDM without PRC [5], it is

$$\overline{P}_{ICI} = 1 - 2\int_0^{f_d} P(f)\sin c^2(fT_s)df \qquad (10)$$

Where f_d is the maximum Doppler frequency shift, P(f) is the power spectral density of $\gamma(t)$ and Sin c(x) = Sin (πx)/(πx)

P_{ICI} for OFDM with PRC can be expressed as

P_{ICI}

$$1 - 2\int_0^{f_d} P(f)\sin c^2(fT_s)df + I_{PRC}(c_K, f_d T_s) \qquad (11)$$

where

I_{PRC} $(c_k, f_d T_s)$

$$= \int_0^{f_d} \frac{8\sin(\pi f T_s)^2 P(f)}{\pi^2}\left(\sum_{k=1}^{K-1}\sum_{i=0}^{K-1-k}\frac{c_i c_{i+k}}{k^2 - f^2 T_s^2}\right)df$$

$$= \int_0^{f_d} \frac{8\sin(\pi f T_s)^2 P(f)}{\pi^2} I(c_K, fT_s)df \qquad (12)$$

with

$c_K = [c_0, c_1, \ldots\ldots\ldots, c_{k-1}]^T$

and

$$I(c_K, fT_s) = \sum_{k=1}^{K-1}\sum_{i=0}^{K-1-k}\frac{c_i c_{i+k}}{k^2 - f^2 T_s^2}$$

OPTIMUM PRC FOR OFDM

In the previous section, we have introduced OFDM with PRC and derived the expression of the ICI power. In this section we will investigate optimum PRC weight and analyze its performance.

Optimum weights for PRC: From Expression 12, the ICI power introduces two parts: the ICI power for OFDM without PRC; and $I_{PRC}(c_k, f_d T_s)$ contributed by PRC. Therefore, the only way to reduce the ICI power is to minimize $I_{PRC}(c_k, f_d T_s)$ with respect to C_k. In the integral of $I_{PRC}(c_k, f_d T_s)$, the first part 8 Sin $(\pi f T_s)^2$ $P(f)/\pi^2$ is always positive. So we need only make the last part as small as possible. When $f^2T^2 << 1$, the last part can be approximated as

$$I(c_K, fT_s) \approx g(c_K) = \sum_{k=1}^{K-1}\sum_{i=0}^{K-1-k}\frac{c_i c_{i+k}}{k^2} = c_K^T R_K c_K$$

where R_k is defined as

$$R_K = \begin{bmatrix} 0 & \frac{1}{2} & \frac{1}{8} & \ldots\ldots & \frac{1}{2(K-1)^2} \\ \frac{1}{2} & 0 & \frac{1}{2} & \ldots\ldots & \frac{1}{2(K-2)^2} \\ \frac{1}{8} & \frac{1}{2} & 0 & \ldots\ldots & \frac{1}{2(K-3)^2} \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ \frac{1}{2(K-1)^2} & \frac{1}{2(K-2)^2} & \frac{1}{2(K-3)^2} & \ldots\ldots & 0 \end{bmatrix}$$

Table 1: lists the optimum weights, for corresponding $g(c_K)$ and performance gain, according to the above results. From the table, the value of $g(c_K)$ is close to the limit when K=4.

K	c_k	$-g\ (c_k)$	Gain (dB)
1	1	0	0
2	0.7071,-0.7.71	0.5000	4.066
3	-0.4775,0.7376,-0.4775	0.6474	6.719
4	-0.3501,0.6144 -0.6144,0.3501	0.7137	8.786
		0.8225	------

Table 1: Optimum weights, for corresponding *g(c)* and performance gain

Here in this study used PRC coding technique for grouping (say) the signal. After that these grouped symbol transmit over the cannel using OFDM technique. We can calculate the value by the following procedure

Let,

$c_k = [0.707 - 0.707]$ from the Table 1.

$$R_k = \begin{bmatrix} 0 & \frac{1}{2} \\ \frac{1}{2} & 0 \end{bmatrix}$$

again,

$$I(c_N, fT_s) \approx g(c_N)$$

so that,

$$[0.707 \quad -0.707]\begin{bmatrix} 0 & \frac{1}{2} \\ \frac{1}{2} & 0 \end{bmatrix}\begin{bmatrix} 0.707 \\ -0.707 \end{bmatrix}$$

$$= [0.707 \quad -0.707]\left[\frac{1}{2\sqrt{2}} - \frac{1}{2\sqrt{2}}\right]$$

$$= -\frac{1}{4} - \frac{1}{4} = -\frac{1}{2} = -0.5$$

similarly for

$c_k = [-0.4775 \quad 0.7376 \quad -0.4775]$

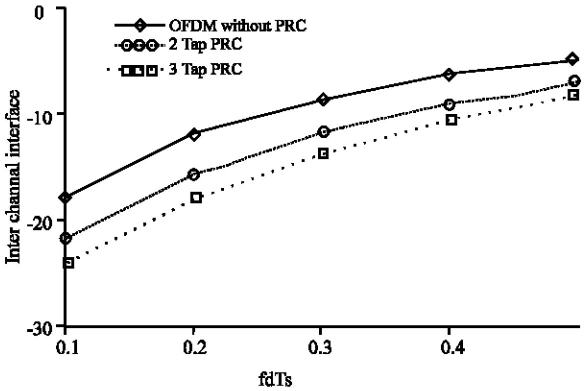

Fig .3: Comparison of the ICI power due to the Doppler frequency shift.

$$R_N = \begin{bmatrix} 0 & \frac{1}{2} & \frac{1}{8} \\ \frac{1}{2} & 0 & \frac{1}{2} \\ \frac{1}{8} & \frac{1}{2} & 0 \end{bmatrix}$$

for c_k= [-0.3501 0.6144 -0.6144 0.3501]

$$R_N = \begin{bmatrix} 0 & \frac{1}{2} & \frac{1}{8} & \frac{1}{18} \\ \frac{1}{2} & 0 & \frac{1}{2} & \frac{1}{8} \\ \frac{1}{8} & \frac{1}{2} & 0 & \frac{1}{2} \\ \frac{1}{18} & \frac{1}{8} & \frac{1}{2} & 0 \end{bmatrix}$$

$$g(c_N) \approx -07137$$

At the end of the example we can reach into a simple decision that the investigated result in frequency domains PRC to reduce the ICI caused by time variation of wireless channels.

CONCLUSIONS

In this study we investigate frequency domain PRC to reduce the ICI caused by the time variation of the wireless channels. The optimum weights for PRC that minimize the ICI power are obtained. The simulation result shows that PRC effectively reduce the error floor caused by Doppler frequency shift or carrier offset.

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