OFDM-CDMA 시스템에서 새로운 PAPR 감쇄기법

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New Peak-to-Average Power Ratio Reduction Scheme for an OFDM-CDMA System

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ABSTRACT

A very simple and effective peak power reduction scheme for a downlink OFDM-CDMA system is proposed using the relationship between peak-to-average power ratio (PAPR) and out-of-phase autocorrelation. Since power spectrum and autocorrelation function are Fourier transform pair, the PAPR property of the sequences can be estimated by the out-of-phase autocorrelation function of the spreading sequences. Thus, by scrambling the spread data in the frequency domain, we can reduce the sidelobe energy of autocorrelation, and at last, suppress PAPR in the proposed OFDM-CDMA system.

I. Introduction

Recently, as the needs to transmit high data rate in a mobile environment increase, several types of code division and orthogonal frequency division multiplexing (OFDM) based multiple access schemes have drawn a lot of attention in the field of wireless multimedia communications, since they have a strong immunity to multipath fading without employing an elaborate adaptive equalization.

However, OFDM signals have relatively large PAPR values, which introduce severe limits on their applications and experience nonlinear distortion. A number of methods have been proposed for PAPR reduction of OFDM signals. Ochiai [2] proposed an adaptive scheme utilizing Walsh-Hadamard code and Golay complementary code for downlink OFDM-CDMA system. Müller [3] optimized weights of partial transmit sequences to minimize PAPR. And a lot of schemes were considered in several papers. But their techniques are too complex to implement and have large delay time.

In this paper, therefore, we will propose a simple technique to reduce PAPR. Since the autocorrelation functions of the sequences and their power spectrums are Fourier transform pair, the PAPR property of the sequences may be estimated by the out-of-phase autocorrelation function of the sequences. If this assumption is true, we can suppress the PAPR values by reducing the sidelobe energy of the autocorrelation function of the sequences. In [4], Schnell suggested simplified method of reducing the sidelobe energy of the autocorrelation function. Scrambling the spread signals in the downlink of the DS-CDMA system makes it possible to reduce orthogonal spreading sequences' out-of-phase autocorrelation values. Based on this philosophy, we adopt the *frequency domain scrambling* (FDS) method in the downlink of OFDM-CDMA system to reduce the sidelobe energy of the auto-

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correlation and finally suppress PAPR of transmission signal. This system block is shown in Fig. 1.

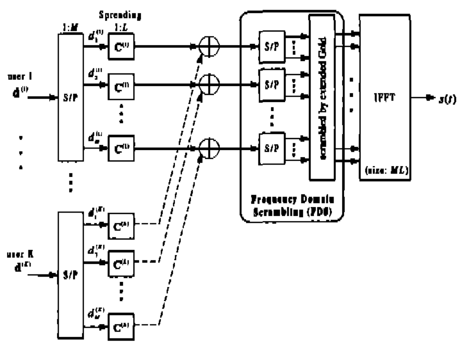

Fig. 1 Proposed downlink OFDM-CDMA system block

This paper is organized as follows: Section II introduces the proposed downlink OFDM-CDMA system model, which is considered all through this paper. Two basic properties of orthogonal spreading sequences, PAPR property and out-of -phase autocorrelation, are studied in Section III. In Section IV, we show the simulation results. Finally, in Section V, conclusion remarks are given.

II. Proposed OFDM-CDMA System Model

Various types of OFDM-CDMA have been proposed [1], and the system discussed here is similar to the MC-CDMA model in [1], which spreads the data stream by spreading sequences in the frequency domain. Since orthogonal sequence sets can cancel the crosscorrelation, they are preferred as the spreading sequences and have no multiple access interference (MAI) factor over an AWGN channel.

The system model of downlink OFDM-CDMA is given in Fig. 1, where $d^{(l)}=[d_1^{(l)}, d_2^{(l)}, \ldots, d_M^{(l)}]$ denotes M data symbols of lth user, $l=1, 2, \ldots, L$. After serial-to-parallel conversion, each symbol is spread by the user-specific spreading sequence $c^{(l)}=[c_1^{(l)}, c_2^{(l)}, \ldots, c_L^{(l)}]$. Assuming K active users, the spread data symbols of K users are summed and then second serial-to-parallel conversions are executed. After that conversion, total N branches are scrambled by extended Gold sequences, $g=[g_{1,1}, g_{1,2}, \ldots, g_{1,L}, g_{2,1}, \ldots, g_{m,l}, \ldots, g_{M,L}]$, in the frequency domain and then they are modulated by inverse Fast Fourier Transform (IFFT) of size $N=M\cdot L$. Baseband transmission signal for one OFDM-CDMA symbol in $0\le t< T_s$ can be written as

$$s(t)=\sum_{m=1}^{M}\sum_{l=1}^{L}\sum_{k=1}^{K} d_m^{(k)} c_l^{(k)} g_{m,l} e^{j2\pi(M(l-1)+(m-1))t/T_s} = \sum_{n=0}^{N-1}\sum_{k=1}^{K} d_m^{(k)} c_l^{(k)} g_{m,l} e^{j2\pi nt/T_s}, \quad (1)$$

where T_s is an OFDM-CDMA symbol period, and for convenience, $n\equiv M(l-1)+(m-1)$. In our discussion, the guard interval and the influence of intersymbol interference (ISI) are excepted, since our interest is on the PAPR property of the signal.

III. Orthogonal Sequence Sets

In this section, we deal with two basic properties of orthogonal sequence sets, PAPR property and sidelobe energy of the auto-correlation function. For the spreading sequences, $c^{(k)}$, Walsh- Hadamard sequences and Golay complementary sequences will be considered.

An orthogonal set of Walsh-Hadamard sequences can be recursively generated by

$$H_{2N}^W=\frac{1}{\sqrt{2}}\begin{bmatrix} H_N^W & H_N^W \\ H_N^W & -H_N^W \end{bmatrix},\ H_2^W=\frac{1}{\sqrt{2}}\begin{bmatrix} + & + \\ + & - \end{bmatrix}. \quad (2)$$

In a similar manner, we can obtain Golay complementary sequences as follows:

$$H_{2N}^C=\frac{1}{\sqrt{2}}\begin{bmatrix} H_N^C & \overline{H_N^C} \\ H_N^C & -\overline{H_N^C} \end{bmatrix},\ H_2^C=\frac{1}{\sqrt{2}}\begin{bmatrix} + & + \\ + & - \end{bmatrix}, \quad (3)$$

where $\overline{H_N^C}$ is composed of H_N^C of which the right half columns are reversed, e.g., if $H_N^C=[A_N\ B_N]$ where A_N and B_N are $N\times N/2$ matrices, then $\overline{H_N^C}=[A_N\ -B_N]$. It readily be shown that

$$H_N^C \cdot H_N^{C^T} = I_N, \quad (4)$$

where I_N denotes the $N \times N$ identity matrix, thus the matrix given above is orthogonal [7].

1. PAPR Property of Sequences

PAPR of transmission signal, $s(t)$, is defined as follows:

$$\lambda = \max |s(t)|^2 / \frac{1}{T_s} \int_0^{T_s} |s(t)|^2 dt, \quad (5)$$

where T_s is an OFDM symbol period. When the number of active users are 4, PAPR property of two orthogonal sequence sets is as shown in Fig. 2.

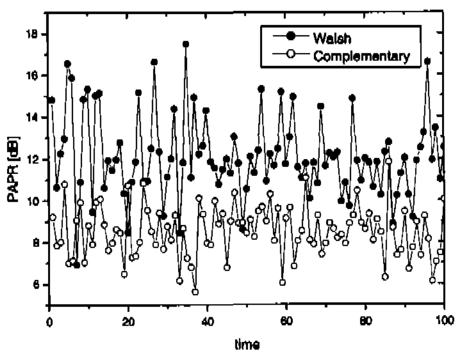

Fig. 2 PAPR property of OFDM-CDMA with orthogonal sequences of length L=16

Fig. 2 shows that Golay complementary sequences have better performance from the viewpoint of PAPR property. And this figure also means that Golay complementary sequences have stronger immunity to nonlinear distortion.

From our assumption, in the next subsection, we turn our viewpoint to the autocorrelation function of two orthogonal spreading sequence sets.

2. Autocorrelation Property of Sequences

The aperiodic autocorrelation function [8] of a real-valued sequence $x(k)$ of length L is denoted by

$$\Phi_x(l) = \begin{cases} \sum_{k=0}^{L-1-l} x(k) \cdot x(k+l) & 0 \le l \le L-1 \\ \sum_{k=0}^{L-1+l} x(k-l) \cdot x(k) & 1-L \le l < 0 \end{cases} \quad (6)$$

Then the even and odd autocorrelation function is

$$\Theta_x(l) = \Phi_x(l) \pm \Phi_x(l-L), \quad (7)$$

respectively. And second moment of the out-of-phase autocorrelation function is as follows:

$$\Theta_x^2 = \sum_{l=1}^{L-1} \left(\frac{\Theta_x(l)}{L} \right)^2. \quad (8)$$

First, we evaluated the out-of-phase autocorrelation of two orthogonal sequences, Walsh-Hadamard and Golay complementary sequences with length, L=16. Their correlation property and second moments are shown in Fig. 3, and Fig. 4, respectively.

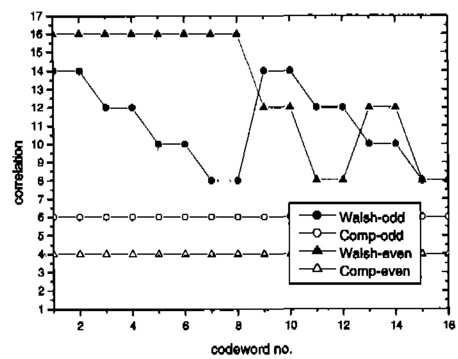

Fig. 3 Out-of-phase autocorrelation property of Walsh-Hadamard and Golay complementary sequences

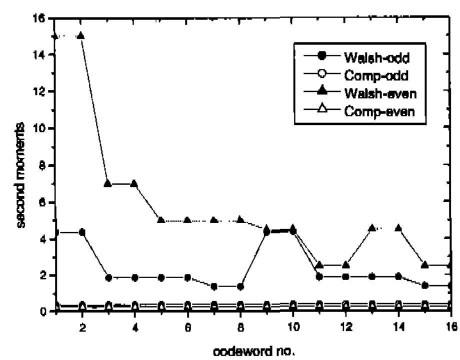

Fig. 4 Second moments for two orthogonal sequences

Golay complementary sequences have smaller sidelobe energy of autocorrelation and second moments than Walsh-Hadamard sequences. This property is same as PAPR property of two orthogonal sequence sets mentioned in [2]. From Fig. 3, 4 and results in [2], we can say that if the sidelobe has small values, then the PAPR of the sequence is also small. In conclusion, our assumption that the PAPR property of the sequences may be estimated by the sidelobe of the autocorrelation function of the sequences is somewhat available. So we will suppress PAPR by reducing sidelobe energy, and *frequency domain scrambling* (FDS) method will be adopted for this reducing work.

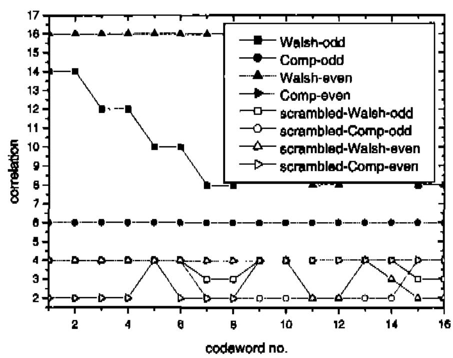

Fig. 5 Out-of-phase autocorrelation of two orthogonal sequences and their scrambled version

Scrambling both Walsh-Hadamard and Golay complementary sequences based on proved assumption, then both even and odd out-of-phase autocorrelation function and second moments described above have small values as shown in Fig. 5 and Fig. 6, respectively.

In Fig. 5 and 6, as forecasted, out-of-phase autocorrelation and second moment of scrambled orthogonal sequences have better properties than sequences without scrambling, and these small out-of-phase autocorrelation values will derive good PAPR property. Especially, from Fig. 5 and 6, we can say that Golay complementary sequence set may have best PAPR property. In the next section, actual PAPR values are computed by simulation.

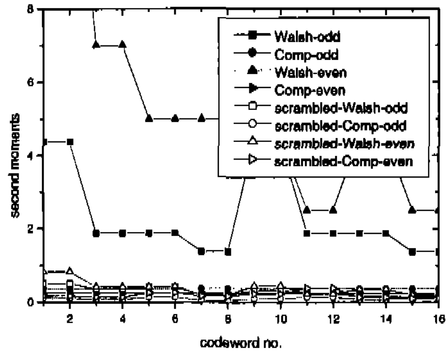

Fig. 6 Second moments for two orthogonal sequences and their scrambled version

Ⅳ. Simulation Results

Based on the proposed method, computer simulations have been carried out. Extended Gold sequence with length 128 is adopted and orthogonal sequences with length 16 are randomly selected in either Walsh-Hadamard or Golay complementary sequence sets and spread each user's data. Data in each user block is paralleled into 8 branches (1/8 serial-to-parallel conversion).

When the number of active users is 4, PAPR property of each sequences is given in Fig. 7. Golay complementary sequence adopted FDS shows somewhat better performance, and comparing with Fig. 2 represented in same scale, two scrambled versions show much better performance, about 3~4 dB.

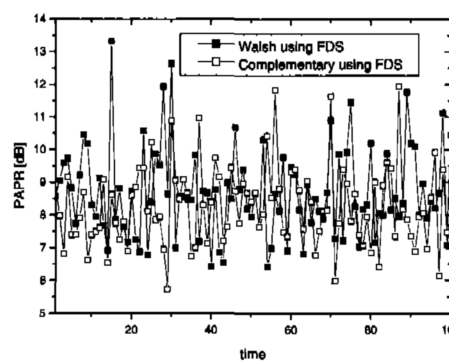

Fig. 7 PAPR property of proposed OFDM-CDMA system using FDS scheme with orthogonal sequences of length $L=16$.

For more reliable result, in Fig. 8, probabilities that an OFDM-CDMA symbol with 8 active users exceeds specific PAPR λ_0 are shown. Walsh-Hadamard code sets PAPR properties are improved greatly by adopting FDS scheme, and Golay complementary code set's PAPR values are also dropped a little. FDS-adopted Walsh-Hadamard codes have lower PAPR values than Golay complementary codes without FDS. In conclusion, FDS-adopted Golay complementary codes show the best performance on the whole.

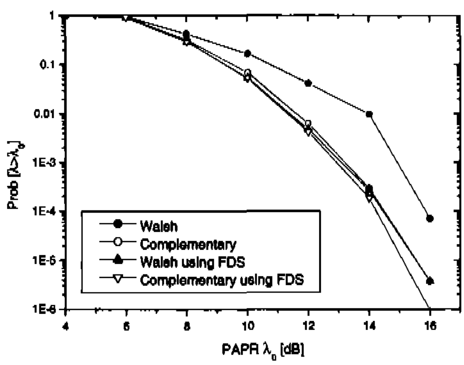

Fig. 8 Probability that an OFDM-CDMA symbol exceeds specific PAPR λ_0

V. Conclusions

We have considered the out-of-phase autocorrelation of orthogonal spreading sequences and the PAPR property in their downlink OFDM-CDMA system and demonstrated the performance of proposed FDS scheme. In the case of Golay complementary sequences, relatively small improvement was derived when the proposed scheme was adopted, however, scrambled case of Walsh-Hadamard sequences introduced very large improvement, and in the sequel, scrambled case of the Golay complementary sequences shows the best performance. In conclusion, since scrambling, prior to IFFT modulation, randomizes the regular patterns of spread signals, it can suppress the peak power of IFFT output signal. Therefore, we can say that the proposed FDS scheme is much simpler effective PAPR reduction method than other PAPR suppression scheme and it may be able to mitigate the nonlinear distortion of the multicarrier signals as well as OFDM-CDMA signals.

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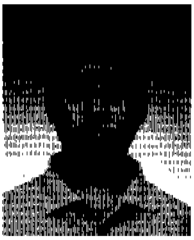

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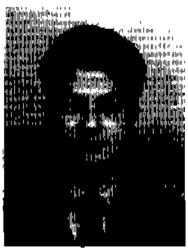

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