Reducing Peak Transmission Power of OFDM System Using Signal Partition Technique

Yingxin Zhao, Yue Wu and Hong Wu

***Abstract*—A new spread spectrum Orthogonal-Frequency-Division-Multiplexing (OFDM) system using a novel signal partition method is proposed. The time domain signals after Inversion-Fast-Fourier-Transform (IFFT) are divided into one continuous segment and several discrete segments and sent out after interleaving. At the receiving end, a unique demodulation method called partial signal restoration is further proposed. Simulation results show that the proposed system, with low computation complexity, can significantly increase the BER performance while the peak transmission power can be reduced obviously.**

***Index Terms*—OFDM, PAPR, Spread spectrum, Signal partition**

I. INTRODUCTION

One of the major drawbacks of Orthogonal-Frequency-Division-Multiplexing (OFDM) systems is that the OFDM signal exhibits high peak power [1-3]. When the peak power lies in the saturation region of the power amplifier, the output signal would suffer from nonlinear distortion, leading to spectrum spreading, in-band distortion and intermodulation interference across the OFDM subcarriers [4-6], which severely degrade the bit error rate (BER) performance at the receiving end. Great efforts have been made to reduce the peak power[7], such as partial transmit sequences (PTS) algorithm [8-11] and selected mapping (SLM) algorithm [12-14]. Saberian and Tewfik [15] proposed a spectrum-spreading based OFDM system by using a sigma-delta modulator for UWB communication, where the peak to average power ratio (PAPR) of this system equals one, while the spectral efficiency was also reduced as expense due to the quantization noise of the sigma-delta converter. In this paper, we propose a new spread spectrum OFDM system using a novel signal partition method, which we call mixed signal partition. The time domain signals after Inversion-Fast-Fourier- Transform (IFFT) are divided into one continuous segment and several discrete segments and sent out after interleaving. At the receiving end, we further propose a unique demodulation method, partial signal restoration, to demodulate the discrete segments. The restored discrete data, together with the continuous segment, are further deinterleaved and combined. Simulation results show that the proposed system improves the BER performance and reduces the peak transmission power with low computation complexity. This paper is organized as follows: The proposed OFDM system is introduced in Section Ⅱ. The simulation results are presented and discussed in Section Ⅲ. Section Ⅳ concludes this paper.

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II. MIXED SIGNAL PARTITION TECHNIQUE

A. Mixed Signal Partition of the Signals

The block diagram of the proposed system is show in Fig.1. Different from the conventional OFDM system, we add a signal partition and interleaving module after the IFFT process at the transmitter, and a deinterleaving and signal combination module at the receiver. For illustration, the signal partition and interleaving at the transmitter side would be first introduced.

Specifically, the real parts x_i and the imaginary parts y_i of the time domain signals from N point IFFT are separated and clipped so that the amplitude of each part of the signal is under a certain level CL , where the clipping level CL is determined by the BER degradation tolerance. After clipping, x_i and y_i are partitioned into K segments, where K is a positive integer. For illustration, let us take the real part, i.e., x_i as an example. Denote $x_{i1}, x_{i2}, ..., x_{iK}$ as the K segments divided from real part x_i , where $i = 0,1,..., N-1$. When $K = 1$, it is the same as the conventional OFDM.

When $K = 2$, the rules of partition can be written as:

$$\begin{array}{lll} x_{i1} = a, & x_{i2} = CL - a. & \text{if } x_i > CL \\ x_{i1} = a, & x_{i2} = x_i - a. & \text{if } a < x_i \le CL \\ x_{i1} = 0, & x_{i2} = x_i. & \text{if } -a \le x_i \le a \\ x_{i1} = -a, & x_{i2} = x_i + a. & \text{if } -CL \le x_i < -a \\ x_{i1} = -a, & x_{i2} = a - CL. & \text{if } x_i < -CL \end{array} \quad (1)$$

where a is a positive real number , $a \le CL/2$.

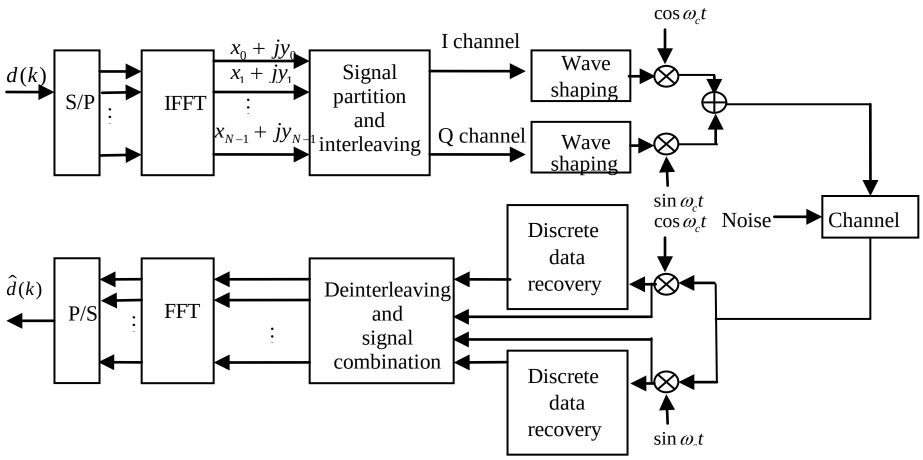

Fig.1 Block diagram of the system

When $K \geq 3$, the rules of partition can be written as:

$x_{i1} = a,\ x_{i2} = a, \cdots,\ x_{i\,K-1} = a,\ x_{ik} = CL - (K-1)a.$
if $x_i > CL$

$x_{i1} = a,\ x_{i2} = a, \cdots,\ x_{i\,K-1} = a,\ x_{iK} = x_i - (K-1)a.$
if $(K-1)a < x_i \leq CL$

$x_{i1} = a, \cdots, x_{i\,n-1} = a,\ x_{in} = 0, \cdots, x_{i\,K-1} = 0,\ x_{iK} = x_i - (n-1)a.$
if $(n\text{-}1)a < x_i \leq na, n = 2, 3, \cdots, K-1$

$x_{i1} = 0,\ x_{i2} = 0, \cdots, x_{i\,K-1} = 0,\ x_{iK} = x_i.$ (2)
if $-a < x_i \leq a$

$x_{i1} = -a, \cdots, x_{i\,n-1} = -a, x_{in} = 0, \cdots, x_{i\,K-1} = 0, x_{iK} = x_i + (n-1)a.$
if $-na \leq x_i \leq -(n-1)a, n = 2, 3, \cdots, K-1$

$x_{i1} = -a,\ x_{i2} = -a, \cdots,\ x_{i\,K-1} = -a,\ x_{iK} = x_i + (K-1)a.$
if $-CL < x_i \leq -(K-1)a$

$x_{i1} = -a,\ x_{i2} = -a, \cdots,\ x_{i\,K-1} = -a,\ x_{iK} = (K-1)a - CL.$
if $x_i < -CL$

The imaginary parts y_i can also be partitioned according to (1-2). The peak power of the partitioned signals is closely related to the selection of a. It is obvious that the peak power can be minimized when $a = CL / K$.

From (1) and (2), we can observe that the signals are partitioned into one segment with continuous values and $K-1$ segments with discrete values, which is known as mixed signal partition.

In fact, the partition here can be interpreted as quantization, where the discrete segments correspond to the quantum level and the continuous segment corresponds to the quantizing error.

B. Method of Interleaving

After the signal partition, we order the sequences of the partitioned signals as $x_{01}, x_{11}, ..., x_{N-1,1}, x_{02}, x_{12}, ..., x_{N-1,2}, ..., x_K, x_{1K}, ..., x_{N-1,K}$ in I channel and $y_{01}, y_{11}, ..., y_{N-1,1}, y_{02}, y_{12}, ..., y_{N-1,2}, ..., y_{0K}, y_{1K}, ..., y_{N-1,K}$ in Q channel. This order is determined by the properties of Discrete Fourier Transform (DFT).

C. Example

To illustrate our proposed method, we would like take the Quadrature Amplitude Modulation (QAM) signals as an example. Suppose that we have four QAM signal, $1-j, -1+j, -1-j, 1+j$. After a 4 point IFFT, we get four time domain data, $0,\ \frac{1}{2}(1+j),\ j,\ \frac{1}{2}(1-j)$.

Setting $CL = 0.9$, $a = 0.225$, we get following data:

$x_0 = \{0, 0, 0, 0\}$ $y_0 = \{0, 0, 0, 0\}$

$x_1 = \{a, a, 0, 0.05\}$ $y_1 = \{a, a, 0, 0.05\}$

$x_2 = \{0, 0, 0, 0\}$ $y_2 = \{a, a, a, 0.225\}$

$x_3 = \{a, a, 0, 0.05\}$ $y_3 = \{-a, -a, 0, -0.05\}$

After interleaving, the I channel signal is:
$\{0, a, 0, a, 0, a, 0, a, 0, 0, 0, 0, 0, 0.05, 0, 0.05\}$
and Q channel signal is :
$\{0, a, a, -a, 0, a, a, -a, 0, 0, a, 0, 0, 0.05, 0.225, -0.05\}$.

D. Receiver Structure

According to the property of the signal, we propose a unique demodulation method, called partial signal restoration (PSR). The I/Q channel signals are separated after synchronization. The received signals corresponding to the discrete segments are estimated and detected, and finally restored to $\hat{a}$, 0 or $-\hat{a}$. Together with received continuous segment, the restored data are deinterleaved and combined. After FFT and data recovery, the original data can be obtained. Note that although the channel noise is removed from the received discrete segments, the performance may be degraded by the decision errors.

E. Average Power, PAPR and Processing Gain

If $f(x)$ is an even probability distribution function of x_i or y_i, the total average power of two segments partition will be:

$$P_{tot} = 4\int_0^a x^2 f(x)dx + 4\int_a^{CL} [(x-a)^2 + a^2] f(x)dx + 4\int_{CL}^{\infty} [(CL-a)^2 + a^2] f(x)dx \quad (3)$$

When $K \ge 3$,

$$\begin{aligned} P_{tot} &= 4\int_0^a x^2 f(x)dx \\ &+ 4\sum_{n=1}^{K-2}\int_{na}^{(n+1)a} [(x-na)^2 + na^2] f(x)dx \\ &+ 4\int_{(K-1)a}^{CL} \{[(x-(K-1)a]^2 + (K-1)a^2] f(x)dx \\ &+ 4\int_{CL}^{\infty} \{[CL-(K-1)a]^2 + (K-1)a^2] f(x)dx \end{aligned} \quad (4)$$

Because the clipping is carried out at x_i or y_i individually, the average power is slightly less than that under ordinary clipping.

According to the Centre Limit Theorem, $f(x)$ converges to the normal distribution when N is large.

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{x^2}{2\sigma^2}} \quad (5)$$

where σ is the standard deviation of x_i or y_i.

The processing gain of spread spectrum here could be written as:

$$\begin{aligned} &\text{Processing Gain} \\ &= 10\log \frac{\text{the average power of the original signal}}{\text{the total average power of K parts}} \\ &= 10\log \frac{2\sigma^2}{P_{tot}} \end{aligned} \quad (6)$$

The Peak to Average Power Ratio (PAPR) is mainly determined by the clipping level. Partition reduces not only peak power, but also average power. The value a should be properly selected to decrease the PAPR. The PAPR after partition is given by

$$PAPR = \frac{2[CL-(K-1)a]^2}{P_{tot}/K} \quad (7)$$

For example, when $N = 64, CL = 2\sigma, a = \sigma$ and $K = 2$, calculated P_{tot} is $1.243\sigma^2$, PAPR is 5.08dB and Processing Gain is 2.07dB.

III. Results of Computer Simulation

In our simulation, the input signals to IFFT are QPSK and 16QAM. At first, the CL levels were set by experiment. The levels are selected as 2σ for QPSK input and 2.6σ for 16QAM input, because the two clipping levels cause little BER degradation.

Fig.2 shows the simulation results of the BER performance of QPSK input with 2 segments partition. The curve labeled without PSR is also plotted for comparison. We can see from Fig. 2 that the BER curve without PSR is 2dB worse than our proposed method, which verified our analysis on the processing gain. By comparing the curve with PSR and the curve clipping, we can see from Fig.2 that the SNR improvement is 3.65dB at 10^{-4} BER. The PAPR resulted from clipping is 6.02dB and that after partition is 5.08dB. Therefore, a 4.59dB reduction of the transmitter peak power can be achieved.

Fig.3 is shows the BER performance of QPSK input with 4 segments partition. SNR improvement is 5.65dB. The PAPR after partition is 2.85dB. So the transmitter peak power is reduced by 8.82dB.

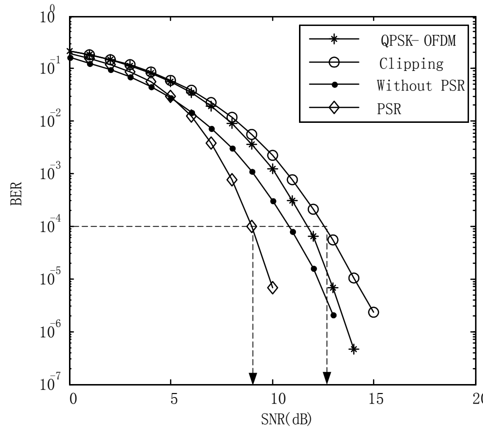

Fig.2 BER performance of QPSK-OFDM system with $K = 2, a = \sigma, N = 64$ and $CL = 2\sigma$ in AWGN channel

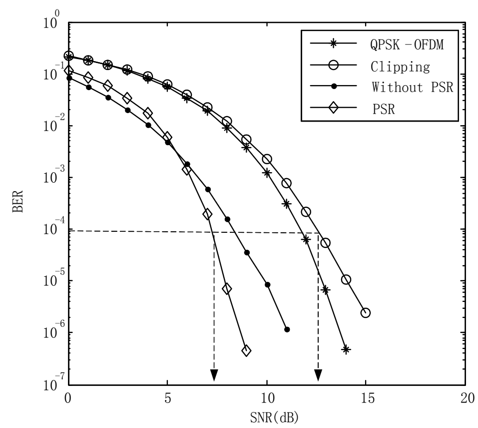

Fig.3 BER performance of QPSK-OFDM system with $K = 4, a = 0.5\sigma, N = 64$ and $CL = 2\sigma$ in AWGN channel

Fig.4 is the BER performance of 16QAM input with 2 segments partition. The SNR improvement is 4.2dB at 10^{-4} BER. The PAPR of clipping is 8.30dB and that after partition is 7.48dB. So the reduction of the peak power is 5.02dB.

Fig.5 is the BER performance of 16QAM input with 4 segments partition. The calculated processing gain is 3.5dB. This is shown by the curve labeled without PSR. The calculated PAPR values are 8.30dB and 5.78dB for clipping and partition respectively. At 10^{-4} BER, the SNR improvement is 9.35dB. So the peak transmission power is reduced by 11.87dB.

Table Ⅰ summarizes the results of peak power reduction after partition. We can see the peak transmission power can be significantly reduced by our proposed method. The results with maximum 11.87dB reduction are very significant.

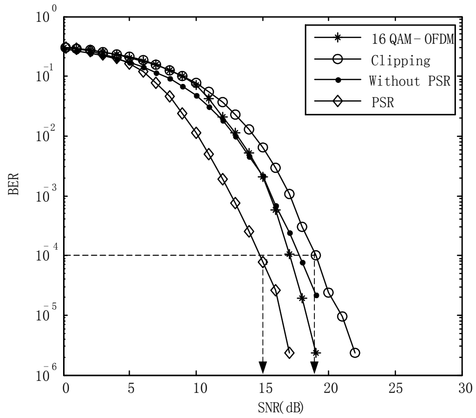

Fig.4 BER performance of 16QAM-OFDM with $K=2, a=1.3\sigma, N=32$ and $CL=2.6\sigma$ in AWGN channel

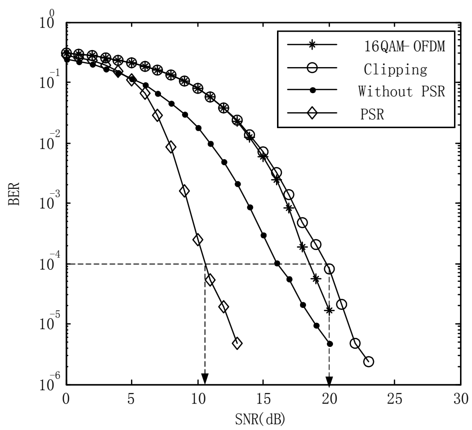

Fig.5 BER performance of 16QAM-OFDM with $K=4, a=0.65\sigma, N=32$ and $CL=2.6\sigma$ in AWGN channel

TABLE Ⅰ
TRANSMITTER PEAK POWER REDUCTION

Combination	Peak power reduction(dB)
QPSK, $K=2$	4.59
QPSK, $K=4$	8.82
16QAM, $K=2$	5.02
16QAM, $K=4$	11.87

The comparison of the three combinations with the same bandwidth is further plotted in Fig.6. 128 point BPSK input, 64 point QPSK input at $K=2$, and 32 point 16QAM input at $K=4$ are used in simulation. Table Ⅱ lists the results. Comparing with BPSK input, we can see that the peak transmission power of QPSK input and $K=2$ decreases 1.44dB at 10^{-4} BER.

Fig.7 is a comparison of the BER performance with 64-tone sigma-delta method in AWGN channel. The interpolation factor L is 4 in 64-tone sigma-delta method. The parameters of the spread spectrum method are $K=4, a=0.5\sigma, CL=2\sigma$ .The original signal is $N=64$, QPSK-OFDM and the bandwidth expansion of the two methods is the same. Table Ⅲ lists the comparison results. We can see that at BER=10^{-2}, the needed average power of 64-tone sigma delta is 6.8dB higher than the proposed spread spectrum method. And although the PAPR of 64-tone sigma delta is 0dB, the peak power is still 1.54dB higher than the later.

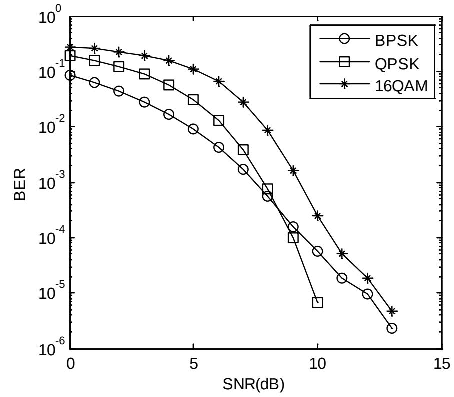

Fig.6 Comparison of BER performance of BPSK with $CL=2\sigma$, QPSK with $CL=2\sigma, K=2, a=\sigma$, 16QAM-OFDM with $CL=2.6\sigma, K=4, a=0.65\sigma$ in AWGN channel

TABLE Ⅱ
COMPARISON OF THE THREE COMBINATIONS

Combination	Point number of IFFT and FFT	S/N(dB) at 10^{-4} BER	PAPR (dB)	Relative peak power (dB)
BPSK, $CL=2\sigma$	128	9.45	6.02	0
QPSK, $CL=2\sigma$ $K=2, a=\sigma$	64	8.95	5.08	-1.44
16QAM, $CL=2.6\sigma$ $K=4, a=0.65\sigma$	32	10.65	5.78	0.96

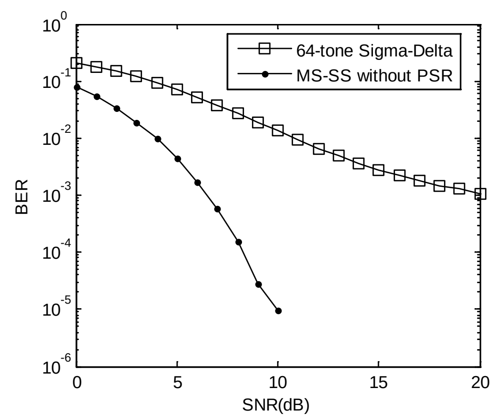

Fig.7 Comparison of BER performance of sigma-delta method with $N=64, L=4$ and spread spectrum method with $N=64, K=4, a=0.5\sigma, CL=2\sigma$ in AWGN channel

TABLE Ⅲ
COMPARISON RESULTS OF THE TWO METHODS

Method	S/N(dB) at 10^{-2} BER	PAPR (dB)	Relative peak power(dB)
64-tone Sigma-delta	10.7	0	0
Mixed Signal Spread Spectrum	3.9	4.56	-1.54

IV. Conclusion

To reduce the peak transmission power of an OFDM system, a mixed signal partition technique is proposed. Simulation results verify that the proposed OFDM system can significantly improve the system performance. For instance, the mixed signal partition will increase S/N by an amount equal to processing gain. The BER performance is further reduced by the PSR method. The peak transmission power can be significantly reduced by our proposed method.

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