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A Modified Pre-Coding Technology for PAPR Reduction in V-OFDMsystem

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Abstract: The Vector Orthogonal Frequency Division Multiplexing (V-OFDM) system is a generalized version of the conventional Orthogonal Frequency Division Multiplexing (OFDM) system,and also hasthe disadvantage of highin the peak-to-average power ratio (PAPR). However, most technologies used in OFDM cannot be appliedto a V-OFDM system directlybecause of existingdifference between the OFDM and V-OFDM systems.After further research on the characteristics of V-OFDM system, a modifying pre-coding technology is proposed for PAPR reduction in V-OFDM system, where power of each vector block (VB) is assigned to V-OFDMblock for PAPR reduction.The simulation results show that the modified pre-coding technologycanreduce PAPR more effectivelyand has a 1 dB gain on signal noise ratio (SNR) when the bit error rate(BER) reached 10^{-3} in the case of$M = 4$ (M represents thelengthof VBs) in V-OFDM system.So the modified pre-coding technology isan attractive solution to the high PAPR of V-OFDM system.

Keywords: Vector Orthogonal Frequency Division Multiplexing (V-OFDM); modified pre-coding technology; PAPR.

Introduction

Single antenna V-OFDM is a generalization of OFDM technology [1-2], where the traditional OFDM scalar channel and symbols are transformed into vector channel and OFDM VBs, and a certain numbers ofcyclic prefix is inserted to each VB.Through the choice of system parameters, V-OFDM technology can make tradeoff between computational complexity and the spectrum utilization efficiency [3].

As a generalization of OFDM, V-OFDM is a multi-carrier orthogonal modulation technology, andalso has the disadvantageof high PAPR.So it is important and necessary to researchhow to reduce PAPRin the V-OFDM system.In OFDM system, the study on PAPR reduction has been relatively mature. In general, the methods can be divided into three categories: distortion technology, coding technology, and non-distortion technologytoreduce the PAPR of the OFDM system[4-9]. However, so far there is no the research on reduce PAPR in the V-OFDM is found. Coding technology has been applied in many systems for itsperfect performance[10]. Reference[10] proposed a pre-coding technologyto reduce PAPR in OFDM system, where the power of each modulated symbol is distributed over the OFDM block. Anovel signal-to-leakage–and-noise-ratio (SLNR) pre-coding algorithm, whichhas the advantage of numerical stability and lower computational complexity, was proposed utilizing Fukunaga-Koontz (FK) transform in Multiple-Input-Multiple-Output (MIMO) systems [11]. References [12] proposed an encoding-pre distortion method in OFDM visible light communications (VLC-OFDM) system for PAPR reduction of VLC-OFDM system.However, the coding technology is only suitable for the situation wherethe number of subcarriers is less. Coding efficiency will decrease with the increment ofnumber of sub-carriers.The concept of subcarrier is substituted for VB in V-OFDM system [13], where fewer subcarriers are needed than OFDM system.

In this paper, we propose a modified pre-coding technology to reduce the PAPR in V-OFDM systems, where precoding consists of multiplying blocking (transform modulated date into a matrix) of each V-OFDM block by a precoding matrix before V-OFDM modulation (IFFT per

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column) and transmission. Simulation results show that the modified pre-coding technology can reduce the PAPR of V-OFDM system more effectively.

This paper is organized as follows. In Section II, the V-OFDM system model is introduced. In Section III, we describethe PAPRand modified pre-coding technology in V-OFDM system. The performance of modified pre-coding technology is analyzed in Section IV. In Section V, some conclusions are given.

V-OFDM system model

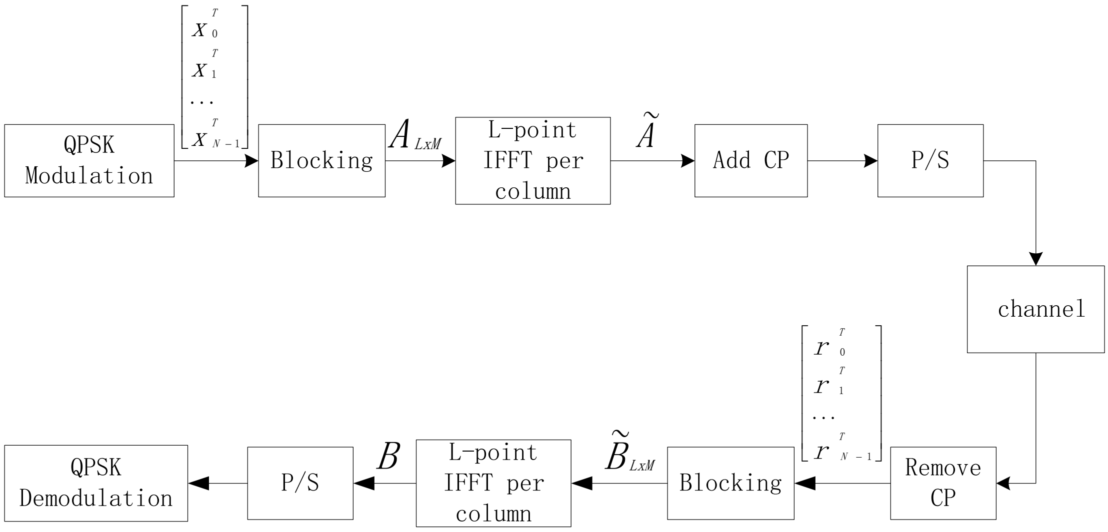

Figure 1.V-OFDM system model.

The V-OFDM system is a generalized version of the conventional OFDM system. The V-OFDM system model is depicted in Figure 1, where the modulated symbols are processed block by block. Different from conventional OFDM,V-OFDM further divides the length N block into L VBs, where each VB has size M .Assume that there are $N = LM$ modulated symbols in one block, and denoted by$x = [x_0, x_1, \dots, x_{N-1}]^T$. At the transmitter, V-OFDM is to transform the traditional OFDMsymbols intoOFDM VBs, where thel-th row$x_l$is modulation symbol vector of the l-th VB in V-OFDM, $x_l$can be expressed as.

$$x_l = \left[x_{lM}, x_{lM+1}, \dots, x_{(l+1)M-1}\right]^T \qquad (1)$$

The transmitter transforms the modulated symbols vector $x = [x_0, x_1, \dots, x_{N-1}]^T$into a $L \times M$ matrix A, and performs L-point IFFT on per column of A and obtains a new matrix$\tilde{A}$. Then, the relationship between the m-thcolumn of$\tilde{A}$, denoted by$\widetilde{x_m}$, and $x_l$can be expressed as.

$$\widetilde{x_m} = \frac{1}{L}\sum_{l=0}^{L-1} x_l \exp\left(\mathrm{j}\frac{2\pi ml}{L}\right), m = 0,1,\dots,M-1, l = 0,1,\dots,L-1 \qquad (2)$$

The last P column vectors of $\tilde{A}$ are chosen as the cyclic prefix vectors. In order to avoid inter-block interference, the CP lengthP should larger than the maximum delay of the channel. After adding CP, the time domain signal is sent out serially by parallel-to-serial (P/S) transformation.

At the receiver, after removing CP, denote the received symbol vector by$r = [r_0, r_1, \dots, r_{N-1}]^T$, where thel-th row$r_l$ is received symbol vector of the l-th VB in V-OFDM,$r_l$can be expressed as.

$$r_l = \left[r_{lM}, r_{lM+1}, \dots, r_{(l+1)M-1}\right]^T \qquad (3)$$

The received symbol vector $r = [r_0, r_1, \dots, r_{N-1}]^T$is transformed into a $L \times M$ matrix$\tilde{B}$, and takeL-point FFT over per column of$\tilde{B}$. Then, the relationship between the

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m-th column of $\widetilde{r_m}$, denoted by $\widetilde{r_m}$, and r_l can be expressed as.

$$\widetilde{r_m} = \frac{1}{L}\sum_{l=0}^{L-1} r_l \exp\left(\mathrm{j}\frac{2\pi ml}{L}\right), m = 0,1,\dots,M-1, l = 0,1,\dots,L-1 \quad (4)$$

The relationship given by the reference [1] between the received symbol vectors r_l of V-OFDM andmodulation symbol vector x_l can be expressed as.

$$r_l = H_l x_l + W_l \quad (5)$$

Where, H_l is a channel matrix of thel-th vector sub-channel W_l is the noise vector of thel-th vector sub-channel, whose entries are independent and identically distributed (i.i.d) and $\mathrm{CN}(0,\sigma^2)$. No interference between each vector channel. The equivalent channel matrix H_l is given by.

$$H_l = (U_l)^H \overline{H_l}(U_l) \quad (6)$$

By the further deduce of the reference [4].

$$r_l = H_l x_l + W_l = (U_l)^H \overline{H_l}(U_l)x_l + (U_l)^H \overline{W_l} \quad (7)$$

Where, $\overline{W_l} = \left[W_l, W_{l+L}, \dots, W_{l+(M-1)L}\right]^T$ is the additive white Gaussian noise vector,

$\overline{H_l} = diag\left(H_l, H_{l+L}, \dots, H_{l+(M-1)L}\right)$ is $\mathrm{M}\times\mathrm{M}$ diagonal matrix, U_l is an $\mathrm{M}\times\mathrm{M}$ unitary matrix ,whose entry in the s-th row(s=0,1,…,M-1) and m -th (m=0,1,…,M-1) column equals $[U_l]_{s,m} = \frac{1}{\sqrt{M}} exp\left\{-j\frac{2\pi}{N}m(l+sL)\right\}$.

The formula (7) connects the V-OFDM system and traditional OFDM system.

Modified Pre-Coding Technology to Reduce the PAPR of V-OFDM System

PAPR Problem of in V-OFDM Systems

V-OFDM can be regarded as a general vectorization of OFDM, for which the concept of subcarrier is substituted for VB. Different from OFDM, V-OFDM divides the length N block into L VBs, where each VB has size M.Assuming the modulation symbol vector of V-OFDM system is $[x_0, x_1, \dots, x_{N-1}]^{\mathrm{T}}$. Instead of doing N-point IFFT as in OFDM, V-OFDM does L-point IFFTover VBs. Assuming the signal before IFFT transform is a frequency domain signal x_l, x(t) is a time domain signal obtained after IFFT transform in the V-OFDM system. x(t)can be written as.

$$\mathrm{x(t)} = \frac{1}{\sqrt{L}}\sum_0^{L-1} x_l e^{j\frac{2\pi lt}{L}} \; , \; l = 0,1,\dots L-1 \quad (8)$$

Where, t represents the index number of sub-carrier,L is the number of VB.

PAPR of V-OFDM is the ratio of maximum peak power to the average power. It can be written as.

$$\mathrm{PAPR(dB)} = \frac{P_{peak}}{P_{average}} = 10log_{10}\frac{\max\limits_{0\le t\le L-1}[|x(t)|]^2}{E[|x(t)|^2]} \quad (9)$$

Where, $E[|\mathrm{x(t)}|^2]$ is the mathematical expectation of V-OFDM signal power. PAPR of V-OFDM signal is a random variable.

Complimentary Cumulative Distribution Function(CCDF) is the most commonly usedmethod as a measure of the PAPR reduction, and it represents the probability that the PAPR of VBs is larger than a certain thresholdz. It is defined as.

$$\mathrm{CCDF} = \mathrm{P}(PAPR > z) = 1 - [1 - exp(-z)]^L \quad (10)$$

Where zrepresents the threshold value of PAPR,L denotes the number of VB,the CCDF is a key performance indicator to measure a technology for PAPRreduction.

Modified Pre-Coding Technology

Pre-codingtechnology is a processing method of reducing the PAPR of V-OFDM systems without distorting the signal. The data-sequence mapping changes the phase and amplitude distribution of original data, then the data is modulated and transmitted after pre-coding. Figure 2illustrates the block diagram of the V-OFDM transmission system with precoder.

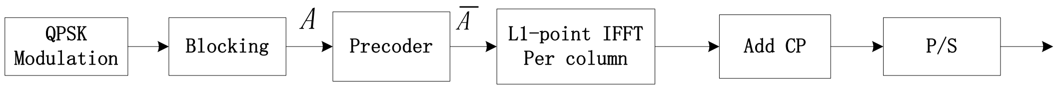

Figure 2. Transmitter block diagram of the modified pre-codingtechnologyV-OFDM.

Pre-coding is a signal preprocessing technique. The pre-coder is applied between blocking and performing L1-point inverse fast Fourier transform (IFFT). The process can be considered as the frequency domain data transformation. References[10] proposed a pre-coding technique which had been used in OFDM system. Pre-coder is a $N1 \times N$ Precoding matrix, Where N is the number of subcarriers. $N1 = N + N_P$, N1 is the total number of subcarriers, $N_P$is the extension size, and$N_P \in (0, N)$. The pre-codingtechniquemust be modified before being applied in V-OFDM systems because of existing differences between OFDM and V-OFDM systems. A modifying pre-coding technologybased on the characteristics of V-OFDM system is proposed, and the explanationis as follows.Pre-coder is a $L1 \times L$pre-coding matrix, where lies the number of VB, and L1 is the total number of VB.$L1 \times L$ Pre-coding matrix can be written as.

$$P = \begin{bmatrix} p_{0,0} & p_{0,1} & p_{0,2} & \cdots & p_{0,L-1} \\ p_{1,0} & p_{1,1} & p_{1,2} & \cdots & p_{1,L-1} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ p_{L1-1,0} & p_{L1-1,1} & p_{L1-1,2} & \cdots & p_{L1-1,L-1} \end{bmatrix} \quad (11)$$

Assume that $L1 = L + Lp$, where L1 is the total number of VB,Lpis the extension size, and $Lp \in (0, L)$, $P_{a,b}$is the first b-th VB, value of the first a-th sampling points separately.

In addition, the pre-coding matrix must satisfy$P'P = t$, where t is the $L \times L$ identity matrix, P' is the conjugate transpose matrix of pre-coding matrix P.
According to the above pre-coding matrix (11), where the elements of the matrix P are defined as follows

$$P_{a,0} = \begin{cases} \frac{(-1)^a}{\sqrt{L}} sin\left(\frac{a\pi}{2L_P}\right) & 0 \le a \le L_P \\ \frac{(-1)^a}{\sqrt{L}} & L_P \le a \le L \\ \frac{(-1)^a}{\sqrt{L}} cos\left(\frac{(a-L)\pi}{2L_P}\right) & L \le a \le L1-1 \end{cases} \quad (12)$$

WhereL1is the total number of VB. To evaluate the relationship between L and L_P in PAPR reduction, we defineβas an expansion factor.

$$\beta = \frac{(L1-L)}{L} = L_p/L \quad (13)$$

Then, the element $P_{a,b}$ of pre-coding matrix can be expressed as.

$$P_{a,b} = P_{a,0} e^{-j2\pi\frac{ab}{L-1}} (14)$$

Therefore, pre-coder and$\bar{A}$can be represented as

$$\bar{A} = PA = \begin{bmatrix} p_{0,0} & p_{0,1} & p_{0,2} & \cdots & p_{0,M-1} \\ p_{1,0} & p_{1,1} & p_{1,2} & \cdots & p_{1,M-1} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ p_{L1-1,0} & p_{L1-1,1} & p_{L1-1,2} & \cdots & p_{L1-1,M-1} \end{bmatrix}$$
(15)

The mathematical model shows that the modified pre-coding technologycan be applied to theV-OFDM system to expand the original signal. Through theredistribution of data power from LtoL1, the phase distribution of each sampling point of the original V-OFDM symbol is changed to reduce PAPR.

Simulation Results and Analysis

In this section, we perform simulations to validate the modified pre-coding technology, where the QPSK modulation scheme with gray mapping is employed. In the simulation, we assume that the V-OFDM symbol length is N=128, the CP length is P=12, and the channel with additive white Gaussian noise channel is employed. We use CCDF of PAPR to show the PAPR performance of V-OFDM system. Under the same condition of PAPR, smaller probability of PAPR shows better performance of PAPR reduction.

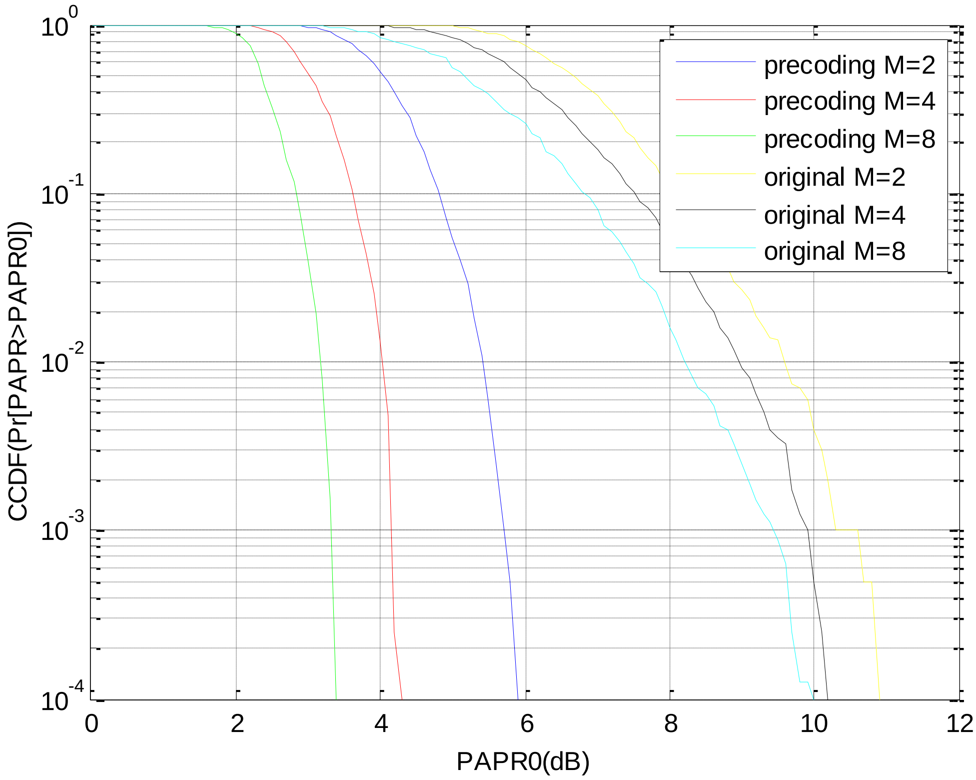

Figure 3. CCDF of the PAPR of modifiedpre-codingV-OFDM system andoriginalV–OFDM system at different M.

Figure3compares CCDF of the PAPR of modified pre-coding V-OFDM system and original V-OFDM system at different M. The length of VBs, M, varies among 2,4and8 with the IFFT length of L adjusted to keep $N = LM$. Compared with the PAPR of original V-OFDM, the PAPR of improved pre-codingV-OFDM can be reduced almost to 5.9dB at $CCDF = 10^{-4}$ with $M = 2$and$\beta = 8/64$, with 5dB down. Compared with the PAPR of original V-OFDM, the PAPR ofmodified pre-codingV-OFDM can be reduced almost to 4.3dB at $CCDF = 10^{-4}$ with $M = 4$ and$\beta = 8/32$, with 6dB down. Compared with original V-OFDM, modified pre-codingV-OFDM can be reduced almost to 3.4dB at $CCDF = 10^{-4}$ with $M = 8$ and$\beta = 8/16$, with 6.5dB down. We can see from the Figure3, While M increases from 2 to 8, L decreases from 64 to 16, the PAPR of the modified pre-coding V-OFDM system and original V-OFDM system are decreased rapidly. The PAPR of modified pre-coding V-OFDM system reduce with the increase of β.

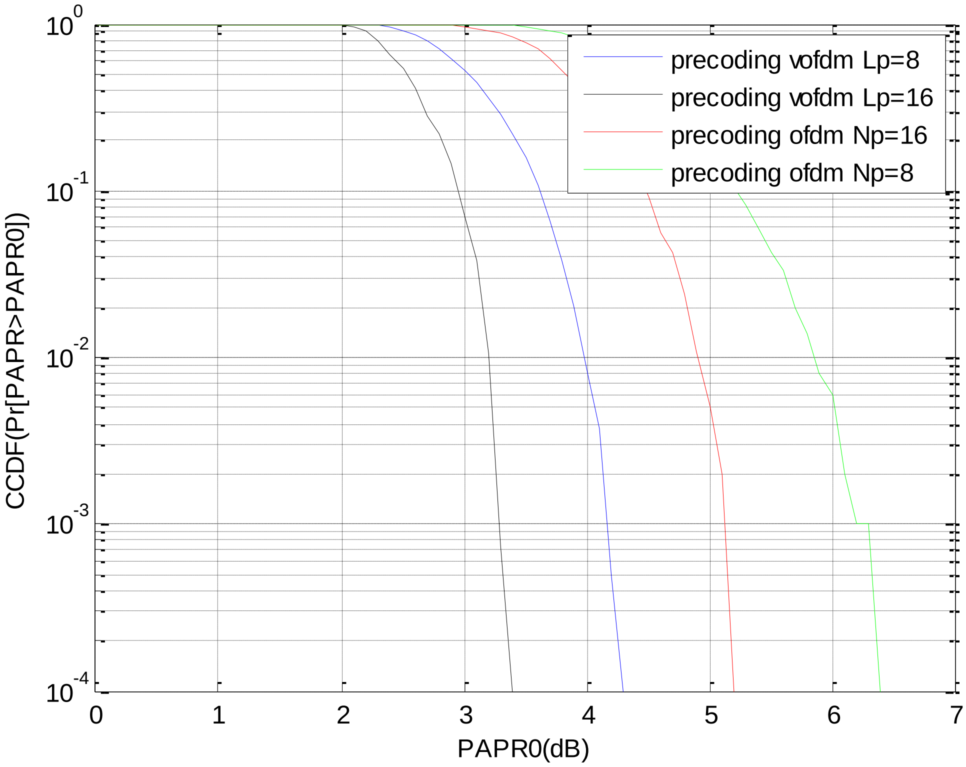

Figure4.CCDF of the PAPR of modified pre-coding V-OFDM system andpre-codingOFDM system at different $L_p$andN_p.

Figure 4compares CCDF of the PAPR of modified pre-coding V-OFDM system and pre-coding V-OFDM system at different L_p and N_p. A total of N=128 subcarriers are considered in OFDM system.

The relationship given by the reference [10] between N_P and N can be expressed as $\beta 1 = \frac{(N1-N)}{N} = N_p/N$.Compared with pre-codingOFDMsystem at$N_p = 8$ with β1=8/128, modified pre-codingV-OFDMsystem can be reduced almost to 4.3dB at $CCDF = 10^{-4}$ with $M = 4$ and$L_p = 8$, β=8/32, with 2.1dB down. Compared with pre-codingOFDMsystem at$N_p = 16$ with β1=16/128modified pre-codingV-OFDMsystem can be reduced almost to 3.4dB at $CCDF = 10^{-4}$ with $M = 4$ and $L_p = 8$, β=16/32, with 1.8dB down. We can see from the Figure 4,in the case of$M = 4$, the PAPR of modified pre-coding V-OFDM system would reducewith the increasing ofL_p. The PAPR of pre-coding OFDM system would reducewith the increasing ofN_p.Under the same condition ofextension size, the modified pre-coding V-OFDM has a better PAPR performance than pre-coding OFDM systems.

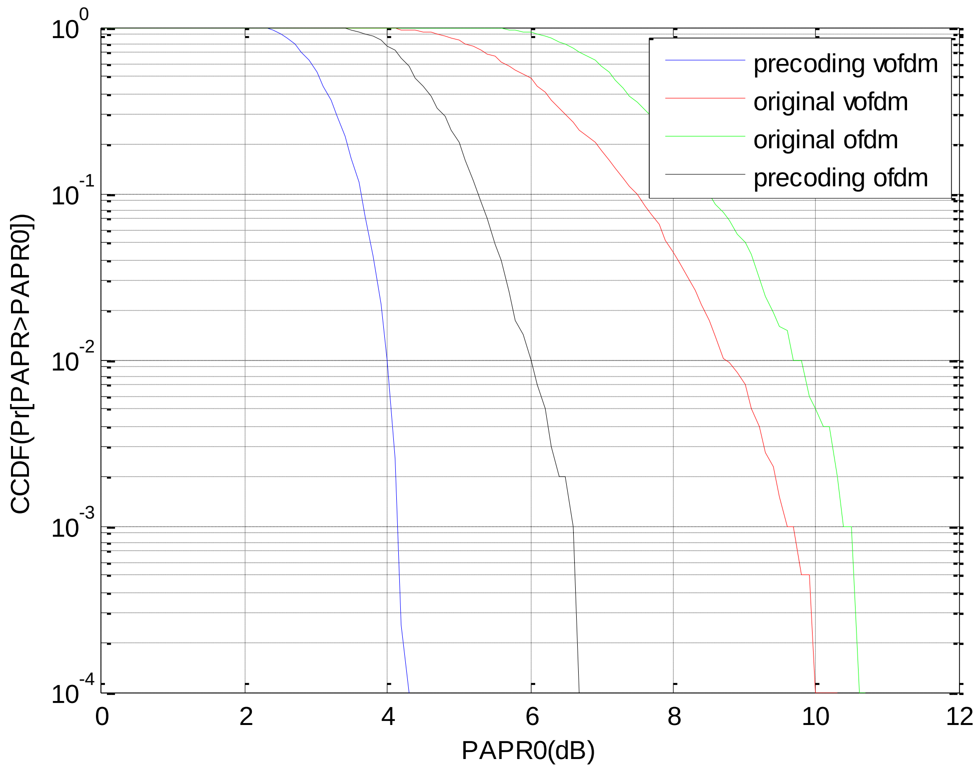

Figure5. CCDF of the PAPR Comparison between Modified pre-coding V-OFDM、original V-OFDM、 pre-coding OFDM and Original OFDM Systems.

Figure 5 compares CCDF of the PAPR of modified pre-coding V-OFDM、original V-OFDM、pre-coding OFDM and original OFDM system. Compared with original V-OFDM system, modified pre-codingV-OFDM system can be reduced almost to 4.3dB at CCDF = 10^{-4} with M = 4 and$\beta = 8/32$, with 5.7dB down. Compared with original OFDM system, modified pre-codingV-OFDM system can be reduced almost to 4.3dB at CCDF = 10^{-4} with M = 4 and$\beta = 8/32$, with 6.3dB down. Compared with pre-codingOFDMsystem at β1=8/128, modified pre-coding VOFDMsystem can be reduced almost to 4.3dB at CCDF = $10^{-4}$with M = 4 and$\beta = 8/32$, with 2.4dB down. We can see from the Figure 5, the modified pre-coding technologycan be appliedto a V-OFDM system directly, and reduce the PAPR of V-OFDM systemat M = 4 and$\beta = 8/32$. The modified pre-coding V-OFDM has a better PAPR performance than the originalV-OFDM, pre-coding OFDM and original OFDM systems.

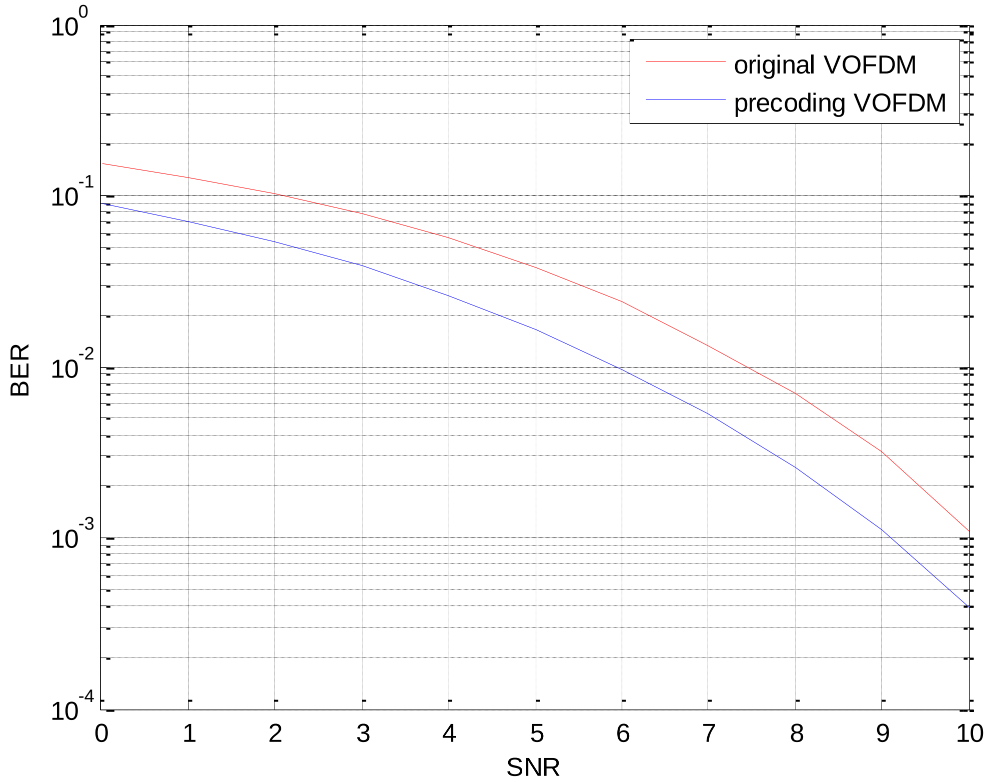

Figure6. BER comparison between Modified Pre-Coding V-OFDM and Original V-OFDM.

Figure 6compares the BER of modified pre-coding V-OFDM system and original V-OFDM system. Over an additive white Gaussian noise (AWGN) channel, comparing with theoriginal V-OFDM system, the modified pre-coding V-OFDM system has a 1 dB gain on signal noise ratio (SNR) when the bit error rate(BER) reached 10^{-3} in the case of $M = 4$ .We cansee from the Figure 6, the BER performance of the modified pre-coding V-OFDM system is better than the original V-OFDM system.

Simulate results show that the PAPR of V-OFDM system reduce with the increase of M. In the case of M = 4, the modified pre-coding V-OFDM have better PAPR performance than the pre-coding OFDM and original OFDM systems. The modified pre-coding V-OFDM system has a 1 dB gain on signal noise ratio (SNR) when the bit error rate(BER) reached 10^{-3} in the case of M = 4. In a word, the modified pre-coding technology is a good solution to the PAPR reduction of V-OFDM system.

Conclusion

Wepropose a modified pre-coding technique to reduce the PAPR of V-OFDM system.The proposed technique is based on signal pre-coding, where blocking of each V-OFDM block is multiplied by a precoding matrix before V-OFDM modulationand transmission.This technology is data-independent and, thus, does not require new processing and optimization for each transmitted V-OFDM block. The

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