PAPR Reduction Scheme for MISO and MIMO OFDM Systems with Limited Feedback

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Abstract: - For multiple-input single-output (MISO) and multiple-input multiple output (MIMO) beamforming (BF) orthogonal frequency division multiplexing (OFDM) systems employing cluster-based codebook index feedback (CCIF), a new peak-to-average power ratio (PAPR) reduction method is proposed. In the proposed method, a dummy signal is generated in null space of the channel and superimposed on the original signal to reduce the PAPR. First, we modify the conventional method to apply to the MISO/MIMO OFDM system with CCIF based BF. From the observation that the conventional method will severely degrade the bit error rate (BER) performance, weight functions for the dummy signal across the subcarriers are proposed. The proposed weight functions are found by both nonlinear optimal and simple suboptimal manners. Through simulation results, it is shown that the proposed scheme can make the BER loss be negligible at the expense of some loss in PAPR reduction gain.

Key-Words: - OFDM, MIMO, PAPR reduction, transmit beamforming, limited feedback.

1 Introduction

Orthogonal frequency division multiplexing (OFDM) is a transmission technique used widely in wideband wireless communications. One of the well-known drawbacks of OFDM-based transmission is the high peak to average power ratio (PAPR) owing to the superposition of the signals from many subcarriers. High PAPR leads to low power efficiency of a power amplifier and hence to a bulky amplifier design [2-5]. In order to reduce the PAPR of OFDM signal, various techniques have been proposed and they can be categorized into two types: rate-lossless method and rate-loss method. Some examples for the former are active constellation extension (ACE) [6], tone injection (TI) [7], and pilot-based schemes [8], [9]. The latter include partial transmit sequence (PTS) [10], selected mapping (SLM) [11], and tone reservation (TR) [12]. Rate-lossless method reduces PAPR without sacrificing data rate by modifying the data subcarriers or utilizing the pilot subcarriers. On the contrary, rate-loss method requires additional resources to reduce PAPR or to send side information to the receiver.

Since those methods are originally developed for single-input single-output (SISO) systems, careful attention should be taken to apply to multiple transmit antenna systems whether they can be separately applied to each transmit antenna. Especially for spatial precoding or beamforming (BF), the methods in [6], [7], [10], and [11] need to be modified to trade off the bit error rate (BER) and PAPR performance and all pilot based schemes cannot be applied to multiple transmit antenna systems. For [10] and [11], if those methods are applied to each transmit antenna, optimal BF weights cannot be used and therefore, receiver performance will be degraded even though maximal gain of PAPR reduction can be achieved. On the other hand, if the same PAPR reduction method as [9] is applied to all transmit antennas, optimal BF weights can be used but PAPR reduction gain is reduced. For [6] and [7], it is impossible to apply the same PAPR reduction method to all transmit antennas because of the difficulty of finding a common solution over all transmit antennas. Also, per-antenna based application of the methods in [6] and [7] will degrade BER performance because intentionally added signals for PAPR reduction will distort received signals. Pilot-based schemes cannot be applied to multiple-input multiple-output (MIMO) systems because of the difference in frame structure between SISO and MIMO systems. Even though [12] can be used for MIMO systems without degrading BER and PAPR performances, it causes the loss of the transmission rate.

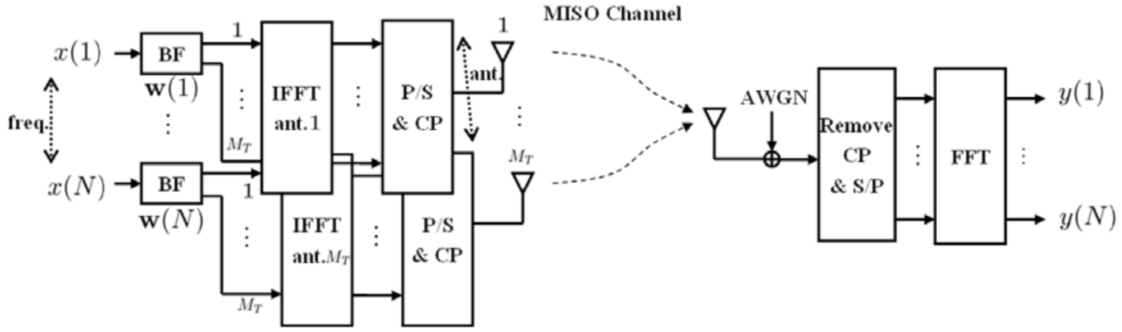

Fig. 1. MISO OFDM system with beamforming.

Recently, Thomas et al. has proposed a rate-lossless PAPR reduction technique for MIMO OFDM system with BF by using the spatial null space of channel matrix [1]. This method generates a dummy signal in the null space of the channel. The dummy signal has time-domain peaks at the same position but opposite direction as the peaks of original signal. The dummy signal and original signal are summed up and then, transmitted. Compared with the rate-loss methods that require data resource or side information, this method is rate-lossless because dummy signal used for PAPR reduction is based on redundant resource, i.e., null space of channel matrix. However, since the method in [1] assumes the perfect knowledge of the channel state information at the transmitter (CSIT) to calculate the null space of the channel, the amount of the feedback information could be very large for a system where the uplink and downlink channels are not reciprocal each other. One common way to reduce the feedback information is grouping the several neighboring subcarriers (called cluster) and sending one representative index of the BF codebook for each cluster [13].

In this paper, we consider BF OFDM system employing the cluster-based codebook index feedback (CCIF). It is shown that the null space of the channel vector/matrix can be calculated from the BF vector. Since the codebook-based BF vector inherently has a codebook quantization error, the deviation between the ideal and codebook-based vectors could be very large at certain subcarriers. As a consequence, the dummy signal introduced in [1] is not completely cancelled out by the channel and it causes some interference at the receiver. This interference degrades the BER performance severely. In order to solve this problem, we assume that the codebook index represents the BF vector for the center subcarrier within a cluster and propose a weight function for the subcarriers within a cluster through both nonlinear optimization method and suboptimal method. Those weight functions provide a trade-off between BER performance and the amount of PAPR reduction. Simulation results show that the proposed scheme reduces PAPR significantly with negligible degradation of the BER performance by choosing the weight function appropriately.

The rest of this paper is organized as follows. Section 2 explains the system model and the conventional PAPR reduction method given in [1]. The OFDM system with CCIF based BF is introduced in Section 3 and the proposed PAPR reduction method is described in Section 4. Section 5 shows simulation results and Section 6 concludes this paper.

2 System Model and Conventional PAPR Reduction Scheme

2.1 System model

Fig. 1 shows a multiple-input single-output (MISO) OFDM system with BF when there are M_T transmit antennas and N subcarriers. In the figure, P/S and CP mean parallel-to-serial converter and cyclic prefix, respectively. At the k-th subcarrier ($1 \le k \le N$), a transmit symbol vector $\mathbf{s}(k)$ of length M_T is obtained by multiplying input symbol $x(k)$ with a BF vector $\mathbf{w}(k) = [w_1(k), w_2(k), \cdots, w_{M_T}(k)]^T$. The transmit symbols for all subcarriers and antennas can be written as $\mathbf{S} = [\mathbf{s}(1), \mathbf{s}(2), \cdots, \mathbf{s}(N)]^T = [\mathbf{s}_1, \mathbf{s}_2, \cdots, \mathbf{s}_{M_T}]$ of size $N \times M_T$ where the m-th column of $\mathbf{S}$, $\mathbf{s}_m$, is the frequency-domain OFDM symbol to be transmitted at the m-th transmit antenna. Time-domain transmit signal at each antenna is obtained by multiplying $\mathbf{s}_m$ with the N-point inverse fast Fourier transform

(FFT) matrix $\mathbf{Q}^H$ where $[\mathbf{Q}]_{p,q} = 1/\sqrt{N} e^{j2\pi pq/N}$, $1 \le p, q \le N$. In this MISO OFDM system with BF, we define the PAPR as the maximum PAPR among all M_T transmit antennas[1]:

$$\text{PAPR} = \max_{1 \le m \le M_T} \frac{\| \mathbf{Q}^H \mathbf{s}_m \|^2}{E[\| \mathbf{Q}^H \mathbf{s}_m \|_F^2] / (NM_T)}. \quad (1)$$

If we denote a frequency-domain MISO channel vector for the k-th subcarrier by $\mathbf{h}(k) = [h_1(k), \cdots, h_{M_T}(k)]^T$, the frequency-domain received signal at the subcarrier k can be written as

$$y(k) = \mathbf{h}(k)^T \mathbf{w}(k) x(k) + n(k), \quad (2)$$

where $n(k)$ is an additive white Gaussian noise (AWGN) at the subcarrier k.

2.2 Conventional null space based PAPR reduction method

Conventional PAPR reduction method given in [1] utilizes the null space of the channel vector to reduce the PAPR. In this method, a time-domain signal is generated from the difference between the original signal and its clipped version with a certain threshold. Then, the generated signal is projected onto the null space of the channel vector and the projected signal is called dummy signal. The transmit signal is obtained by subtracting the dummy signal from the original signal and it is similar to the clipped signal. Note that the dummy signal will disappear while traveling through the channel because it is orthogonal to the channel vector. Therefore, the received signal is the same as in the conventional MISO OFDM system without PAPR reduction scheme. The dummy signal is updated by the iteration in order to reduce the PAPR under the desired value. This procedure given in [1] can be summarized as follows:

Step 1: $j = 0$ where j is the number of iteration.
Initialize $\mathbf{S}^{(j)} = \mathbf{S}$

Step 2: $j = j + 1$
Calculate the time-domain signal $\tilde{\mathbf{S}}^{(j)} = \mathbf{Q}^H \mathbf{S}^{(j)}$ where $\mathbf{Q}^H$ is the IFFT matrix.

Step 3: Generate $\tilde{\mathbf{C}}^{(j)}$ as follows [1]:

$$[\tilde{\mathbf{C}}^{(j)}]_{k,m_T} = \begin{cases} 0, & |[\tilde{\mathbf{S}}^{(j)}]_{k,m_T}| \le A \\ (|[\tilde{\mathbf{S}}^{(j)}]_{k,m_T}| - A) e^{j\angle[\tilde{\mathbf{S}}^{(j)}]_{k,m_T}}, & |[\tilde{\mathbf{S}}^{(j)}]_{k,m_T}| > A, \end{cases}$$

$$, \ 1 \le k \le N, \ 1 \le m_T \le M_T \quad (3)$$

where $[\mathbf{B}]_{k,m}$ is the (k,m)–element of a matrix $\mathbf{B}$. The matrix $\tilde{\mathbf{C}}^{(j)}$ is a time-domain signal obtained by subtracting a magnitude limit A from the original signal, $\tilde{\mathbf{S}}^{(j)}$, at the j-th iteration.

Step 4: Calculate $\mathbf{C}^{(j)} = \mathbf{Q}\tilde{\mathbf{C}}^{(j)}$, where $\mathbf{Q}$ is the FFT matrix. Let $\mathbf{c}^{(j)}(k)$ be the transposed vector of the k-th row of $\mathbf{C}^{(j)}$, which is an M_T-dimensional vector. At each subcarrier, $\mathbf{c}^{(j)}(k)$ is projected onto the null space of the channel vector and then, it is subtracted from the original signal as follows:

$$\mathbf{s}^{(j+1)}(k) = \mathbf{s}^{(j)}(k) - \mathbf{P}(k)\mathbf{c}^{(j)}(k), \quad (4)$$

where $\mathbf{P}(k)$ is the projection matrix given by [14]

$$\mathbf{P}(k) = \mathbf{I} - \mathbf{h}(k)^* (\mathbf{h}(k)^T \mathbf{h}(k)^*)^{-1} \mathbf{h}(k)^T. \quad (5)$$

Step 5: Return to Step 2 and continue the operations iteratively until the desired peak reduction is achieved or the number of iteration is equal to its maximum value.

After J iterations, transmit symbol vector at the k-th subcarrier is represented by

$$\mathbf{s}(k) = \mathbf{w}(k)x(k) - \mathbf{P}(k) \sum_{j=1}^{J} \mathbf{c}^{(j)}(k), \quad (6)$$

where the second term in the right-hand side of (6) is dummy signal. We note that the dummy signal is completely removed during the transmission through the channel because the channel vector $\mathbf{h}(k)$ and $\mathbf{P}(k)$ is orthogonal, *i.e.*, $\mathbf{h}(k)^T \mathbf{P}(k) = 0$.

3 MISO OFDM system with CCIF based BF

[1] MIMO OFDM has the same expression on the PAPR as MISO OFDM.

The conventional PAPR reduction method given in [1] assumes perfect CSIT to calculate $\mathbf{P}(k)$ in (5). In this case, it is easy to see from (2) that non-codebook based BF vector which maximizes an effective channel gain is given by $\mathbf{w}(k) = \mathbf{h}(k)^*$ and the projection matrix is obtained using the BF vector as follows:

$$\mathbf{P}(k) = \mathbf{I} - \mathbf{w}(k)(\mathbf{w}(k)^H \mathbf{w}(k))^{-1} \mathbf{w}(k)^H \qquad (7)$$

For the perfect CSIT, however, a large amount of feedback information needs to be reported from the receiver to the transmitter when the uplink and downlink channels are not reciprocal. In order to reduce the amount of the feedback information, we consider CCIF based BF for MISO OFDM system. Furthermore, we consider subcarrier-group based feedback where neighboring subcarriers are grouped (this group is called cluster.) and the receiver feedbacks only one representative codebook index for each cluster. The representative codebook index is one for the center subcarrier of a cluster. In this way, the amount of feedback information is significantly reduced [13].

Suppose that a cluster is composed of the neighboring B subcarriers, then the number of clusters is $L = N/B$. The projection matrix for the l-th cluster is given by [14]

$$\overline{\mathbf{P}}_l(k) = \mathbf{I} - \overline{\mathbf{w}}_l(\overline{\mathbf{w}}_l^H \overline{\mathbf{w}}_l)^{-1} \overline{\mathbf{w}}_l^H, \quad (l-1)B+1 \le k \le lB. \; (8)$$

where $\overline{\mathbf{w}}_l$ is the BF vector for the l-th cluster. Note that the projection matrix is the same for all the subcarriers within a cluster.

Once the projection matrix is obtained at each cluster, the rest procedures for PAPR reduction are the same as in [1] (refer to Section 2.2). Therefore, the amount of PAPR reduction may not be much different between the perfect CSIT based and the CCIF based BF systems.

Let us consider the detection performance at a receiver. The received signal at the subcarrier k within the l-th cluster can be written as

$$y_l(k) = \mathbf{h}(k)^T \overline{\mathbf{w}}_l x(k) - \mathbf{h}(k)^T \overline{\mathbf{P}}_l(k) \sum_{j=1}^{J} \mathbf{c}_l^{(j)}(k) + n(k),$$
$$(l-1)B+1 \le k \le lB. \qquad (9)$$

Due to the quantization error inherent in codebook, the BF vector $\overline{\mathbf{w}}_l$ obtained from the codebook will be different from the ideal BF vector

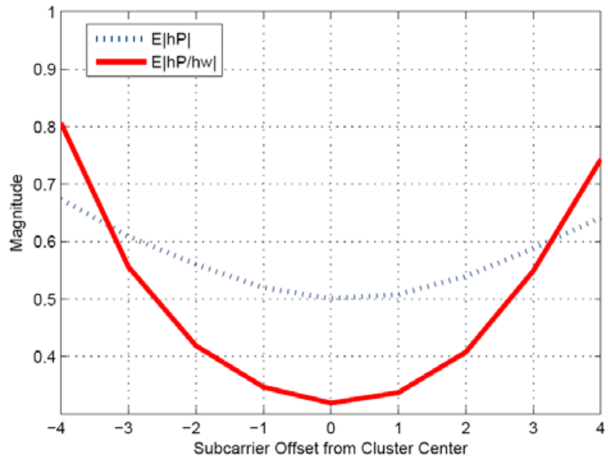

Fig. 2. Effective channel gain (dotted line) and PEGR (solid line) in a cluster ($B = 8$) for MISO OFDM system with CCIF based BF when ETSI/BRAN channel E model with $M_T = 4$ and $M_R = 1$ is used.

and we can regard this difference as the BF error. Furthermore, it is obvious that the deviation between the two BF vectors will become larger at the edge of the cluster. The BF error can have negative impacts on the detection performance at the receiver in two ways. First, the effective channel gain $|\mathbf{h}^T \overline{\mathbf{w}}_l|$ will be reduced. Second, the dummy signal which is the second term at the right hand side of (9) will not disappear because the projection matrix $\overline{\mathbf{P}}(k)$ is no longer exactly orthogonal to the channel vector. To see the degradation in detail, we introduce projection error to effective channel gain ratio (PEGR) which is the magnitude ratio of the projection error, $|\mathbf{h}(k)^T \overline{\mathbf{P}}(k)|$, to the effective channel gain, $|\mathbf{h}(k)^T \overline{\mathbf{w}}_l|$ and the PEGR is given by

$$\text{PEGR}_k = \frac{|\mathbf{h}(k)^T \overline{\mathbf{P}}_l|}{|\mathbf{h}(k)^T \overline{\mathbf{w}}_l|}, \quad (l-1)B+1 \le k \le lB. \qquad (10)$$

If the BF vector and projection matrix are ideal, the PEGR will become zero. As the deviation between the actual BF vector and the ideal one is getting larger, the PEGR will be increased. This phenomenon is shown in Fig. 2 where ETSI/BRAN channel model E [15] with $M_T = 4$, $M_R = 1$, and $N = 64$ is used. The root mean square (RMS) delay of this channel model is 500 ns. In this figure, we assumed that the channel impulse responses from different transmit antennas are independent each other. We can observe that on the average, the

PEGR is getting larger as the subcarrier index becomes more far away from the center of the cluster.

4 Proposed PAPR reduction method for OFDM system with CCIF based BF

In this section, first we propose a new PAPR reduction scheme for MISO OFDM system and then, extend it to MIMO OFDM system.

4.1 PAPR reduction method for MISO OFDM system

In practice, the detection performance at the receiver is more important than PAPR reduction at the transmitter. Therefore, based on the observation in Fig. 2, we propose frequency-dependent weight $g_l(k)$ to reduce the PAPR at the transmitter and to minimize the degradation of the receiver performance caused by null space based PAPR reduction operation. For the subcarrier k within the l-th cluster, the transmitted signal with the proposed weight is represented as

$$\mathbf{s}_l(k) = \bar{\mathbf{w}}_l x(k) - g_l(k)\bar{\mathbf{P}}_l(k)\sum_{j=1}^{J} \mathbf{c}^{(j)}(k), \quad (l-1)B+1 \le k \le lB. \tag{11}$$

By designing the weight $g_l(k)$ appropriately, the PEGR shown in Fig. 2 can be equalized over all subcarriers and thus, the degradation of the detection performance can be made negligible.

First, we propose an optimal weight design method to minimize the mean square error and then, a simple suboptimal method to reduce the computational complexity.

If we define $\mathbf{g} = [g_1(1),\cdots,g_1(B),\cdots g_L(1),\cdots,g_L(B)]^T$, a proposed nonlinear optimization problem for obtaining the optimal weight vector is given by

$$\mathbf{g}_{\text{opt}} = \arg\min_{\mathbf{g}} \sum_{k=1}^{N} \varepsilon(k) \quad \text{s.t.} \quad \mathbf{1}^T\mathbf{g} = \alpha, \tag{12}$$

where $\varepsilon(k)$ is the mean square error (MSE) between the received signal and the ideal one denoted by

$$\varepsilon(k) = E_n[\left|\frac{\mathbf{h}(k)^T\bar{\mathbf{P}}}{\mathbf{h}(k)^T\bar{\mathbf{w}}}\sum_{j=1}^{J} g_l(k)c^{(j)}(k) - \frac{n(k)}{\mathbf{h}(k)^T\bar{\mathbf{w}}}\right|^2]. \tag{13}$$

If (12) has no constraint, the optimal weight vector $\mathbf{g}_{\text{opt}}$ will be $\mathbf{0}$, i.e., a trivial solution. In order to avoid the trivial solution, we introduce a constraint on the sum of the weights in (12).

If we choose a small value for α, the power of the dummy signal which is the second term of the right-hand side in (12) will become small. Therefore, the PAPR reduction gain will become small while the degradation of the detection performance at the receiver will be small. On the other hand, if we choose a large value for α, the PAPR reduction gain will become high at the expense of the loss of the detection performance at the receiver. Therefore, α should be selected appropriately to obtain a trade-off between the PAPR reduction performance at the transmitter and the degradation of the detection performance at the receiver.

Since the optimization problem in (12) includes nonlinear operations such as clipping, it is difficult to find a closed-form solution. Hence, the optimal solution is found by resorting to the numerical method. Specifically, the problem in (12) is rewritten as

$$\mathbf{g}_{\text{opt}} = \arg\min_{\mathbf{g}} E_{\mathbf{H}}\left\{E_{\mathbf{x}}\left[\sum_{k=1}^{N} MSE(k)\,|\,\mathbf{x}\right] \,\Big|\, \mathbf{H}\right\}, \quad \text{s.t.} \quad \mathbf{1}^T\mathbf{g} = \alpha \tag{14}$$

where

$$\mathbf{x} = [x(1), x(2), \cdots, x(N)]^T, \quad \mathbf{H} = [\mathbf{h}(1), \mathbf{h}(2), \cdots, \mathbf{h}(N)]^T.$$

The detailed procedure to find the solution using the numerical method is summarized as follows:

Step 1) For a randomly generated MISO channel matrix $\mathbf{H}$, find the optimal solutions [2] that satisfy (14) over 200 samples of random input vector $\mathbf{x}$.

Step 2) Since (14) is not a convex problem, the solution obtained in Step 1 could be a local optimum. Therefore, the solutions are found for 20 randomly generated initial values and the solution causing the minimum MSE is chosen as an optimal solution.

Step 3) Repeat Step 1 and 2 over 200 randomly generated $\mathbf{H}$ s.

[2] To find the solution in (14), the function 'fmincon' in the optimization toolbox of MATLAB is used.

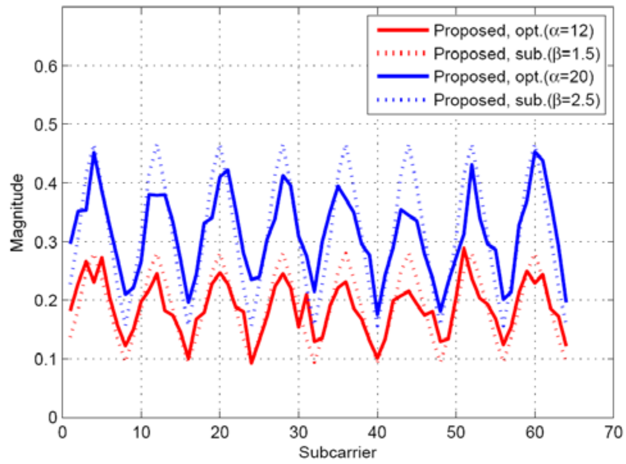

Fig. 3. Proposed optimal weights (solid line) and suboptimal weights (dotted line).

Step 4) Obtain the optimal solution $\mathbf{g}_{\text{opt}}$ by averaging the total 40,000 solutions.

Next, we propose a suboptimum method for reducing the computational complexity. In order to equalize the PEGR, the inverse of PEGR can be considered as the desired weight by intuition as follows:

$$g_l(k) = \frac{\beta}{\text{PEGR}(k)}, \quad (15)$$

where β is a positive constant controlling total power of the dummy signal similarly to α in (12).

4.2 Extension to MIMO OFDM system

The null space based PAPR reduction method for MIMO OFDM system with BF is very similar to that for MISO OFDM system with BF. The PAPR reduction scheme proposed for MISO OFDM system can be directly applied to the MIMO OFDM system except that the MIMO channel matrix is used in the projection matrix instead of the MISO channel matrix.

Suppose that the transmitter and the receiver have M_T and M_R antennas, respectively. If $\mathbf{H}(k)$ is the $M_R \times M_T$ channel matrix at the *k*-th subcarrier, the columns of the right singular matrix of $\mathbf{H}(k)$ corresponding to nonzero eigenvalues from the optimal BF matrix $\mathbf{W}(k)$. The projection matrix orthogonal to the channel matrix is given by [14]

$$\mathbf{P}(k) = \mathbf{I} - \mathbf{W}(k)\{\mathbf{W}(k)^H \mathbf{W}(k)\}^{-1}\mathbf{W}(k)^H. \quad (16)$$

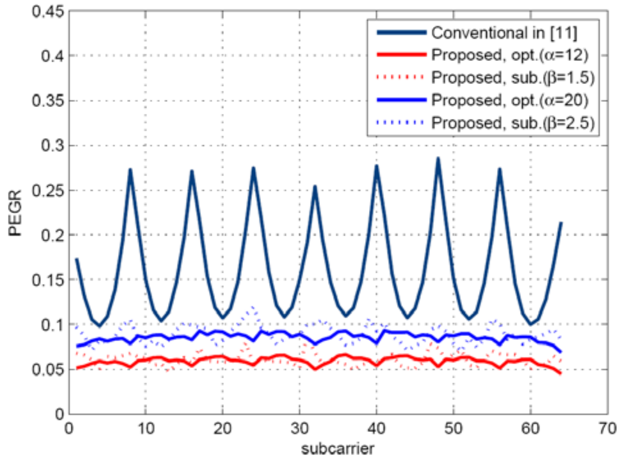

Fig. 4. PEGR of MISO OFDM system with CCIF based BF when ETSI/BRAN channel E model with $M_T = 4$ and $M_R = 1$.

If we define the singular value decomposition of $\mathbf{H}(k)$ as $\mathbf{H}(k) = \mathbf{U}(k)\mathbf{\Sigma}(k)\mathbf{V}^H(k)$ where $\mathbf{U}(k)$ and $\mathbf{V}^H(k)$ denote the left and right singular matrices, respectively, and $\mathbf{\Sigma}(k)$ is a diagonal matrix, the BF matrix $\mathbf{W}(k)$ is composed of the columns of $\mathbf{V}(k)$ and the projection matrix in (16) holds $\mathbf{H}(k)^T\mathbf{P}(k) = \mathbf{0}$. The procedures to generate the dummy signal and to find the weight vector $\mathbf{g}$ are the same as the MISO OFDM case. Here, we note that the sufficient condition for the null space to exist is $M_T > M_R$. If this condition is not satisfied, the null space may not exist.

4 Simulation results

In order to evaluate the BER and PAPR performance of the proposed methods, we have performed computer simulation over 10^5 Monte Carlo trials. The system parameters are as follows: $M_T = 4$ and $M_R = 1$ for MISO system, $M_R = 2$ for MIMO, $N = 64$, and $B = 8$. The transmitted data are encoded by rate 1/2 convolutional code, and modulated by quadrature phase shift keying (QPSK). The oversampling ratio is 4. For the channel model, ETSI/BRAN Channel Model E in [15] is employed and the channels from different transmit antennas are generated independently. The channel is assumed to be quasi-static, *i.e.*, the channel is time-invariant within an OFDM symbol period but varies independently between symbols. The noise is complex additive white Gaussian random variable with zero mean. For the detection of the transmitted

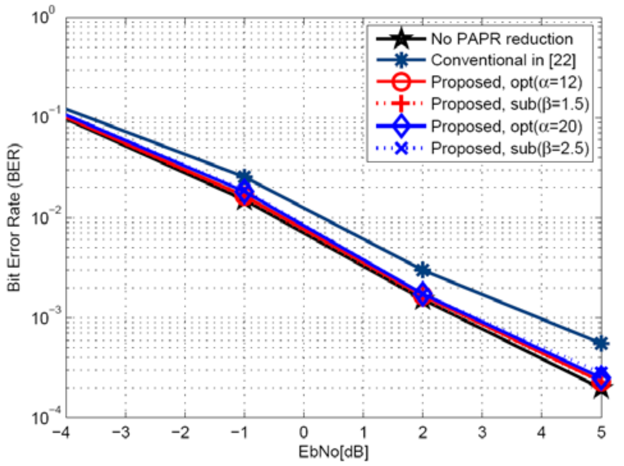

Fig. 5. BER performance of MISO OFDM system with CCIF based BF.

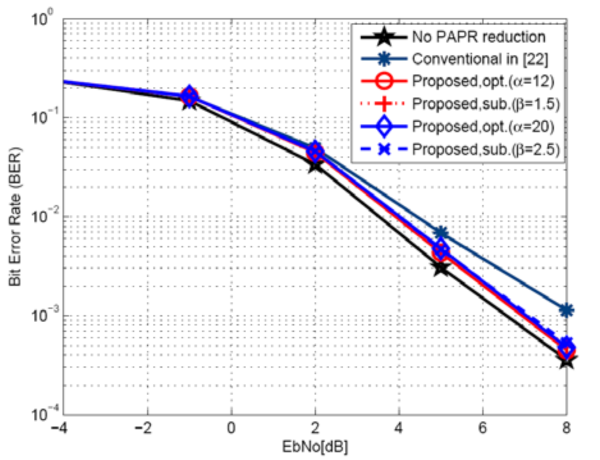

Fig. 7. BER performance of MIMO OFDM system with CCIF based BF when $M_T = 4$ and $M_R = 2$.

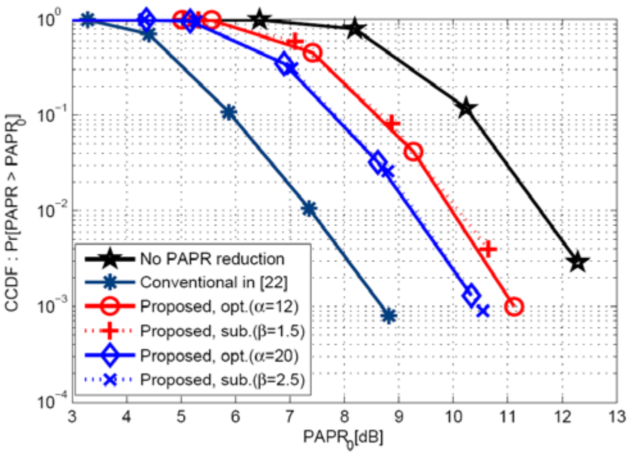

Fig. 6. PAPR performance of MISO OFDM system with CCIF based BF.

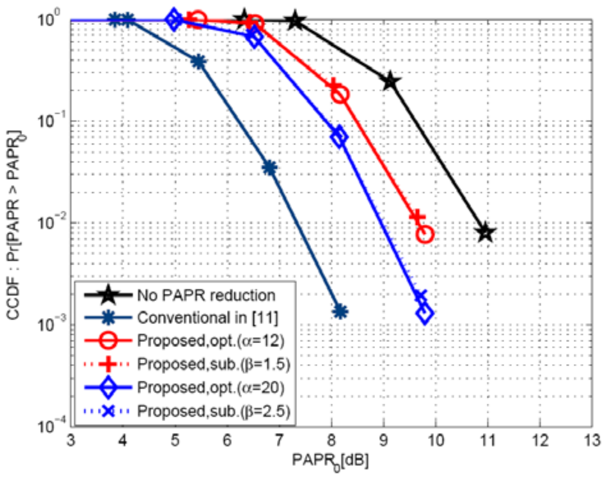

Fig. 8. PAPR performance of MIMO OFDM system with CCIF based BF when $M_T = 4$ and $M_R = 2$.

symbols, zero-forcing equalization is employed, *i.e.*, at the receiver, the received signal is divided by the channel coefficient at each subcarrier. For the BF codebook, 4 bit codebook for MISO system and 6 bit for MIMO system are used [16]. It is assumed that the feedback channel has no time delay and no transmission error. The PAPR performance is examined through the complementary cumulative distribution function (CCDF) defined as [16]

$$CCDF(PAPR_o) = \Pr(PAPR > PAPR_o) . \quad (17)$$

Fig. 3 shows the optimum weights given in (12) for $\alpha = 12$ and 20, and the suboptimum weights given in (15) for $\beta = 1.5$ and 2.5 in case of MISO OFDM system. Fig. 4 represents the PEGR after applying the proposed weights. It is observed that the PEGR is equalized over all subcarriers. Also, it is shown that by varying α in (12) and β in (15), the total amount of PEGR can be controlled.

Figs. 5 and 6 show the BER and PAPR performances for MISO OFDM system, respectively. By applying the conventional method in [1], a significant BER loss about 1.5dB at $BER = 10^{-3}$ is observed while the PAPR is reduced by 3.5dB at $CCDF = 10^{-2}$. In contrast, the proposed methods mitigate the BER loss at the expense of the sacrifice of the PAPR reduction gain. The suboptimum weights $\beta = 1.5$ and 2.5 provide almost the same performance as the optimum weights $\alpha = 12$ and 20, respectively.

Figs. 7 and 8 show the BER and PAPR performances when the proposed techniques are applied to MIMO OFDM system. It is observed that the behavior is quite similar to the MISO OFDM case. The proposed methods relieve the BER loss significantly while providing less PAPR reduction performance than the conventional method.

Through the simulation results, it is confirmed that the proposed weights can significantly reduce the BER loss at the expense of the small degradation of the PAPR reduction performance when the null space based PAPR reduction technique is used for OFDM system with CCIF based BF.

4 Conclusion

A new PAPR reduction method was proposed for MISO/MIMO OFDM systems with the limited feedback based BF. In the proposed scheme, frequency domain weights are introduced to mitigate the BER performance loss at the receiver caused by the inaccuracy of the BF weight vector and projection matrix in CCIF based BF system. Simulation results showed that the proposed method has better BER performance than the conventional method at the expense of the small PAPR performance degradation

5 Acknowledgement

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