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Abstract

In this paper, we propose a new iterative approach to compensate the nonlinearity and clipping noise in multi-input multi-output orthogonal frequency division multiplexing (MIMO-OFDM) system with nonlinear channel. The proposed approach consists of two stages. Firstly a decision aided method is proposed to eliminate the nonlinearity introduced by high power transmit amplifier (HPA). Then this improved decision observations are employed to achieve the clipping noise compensation. The effectiveness of the proposed approach has been verified by computer simulations.

Keywords

Decision, Aided, Joint, Compensation, Clipping, Noise, Nonlinearity, for, MIMO, OFDM, Systems

Disciplines

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Decision Aided Joint Compensation of Clipping Noise and Nonlinearity for MIMO-OFDM Systems

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*Abstract—**In this paper, we propose a new iterative approach to compensate the nonlinearity and clipping noise in multi-input multi-output orthogonal frequency division multiplexing (MIMO-OFDM) system with nonlinear channel. The proposed approach consists of two stages. Firstly a decision aided method is proposed to eliminate the nonlinearity introduced by high power transmit amplifier (HPA). Then this improved decision observations are employed to achieve the clipping noise compensation. The effectiveness of the proposed approach has been verified by computer simulations.***

*Key words-- **MIMO, OFDM, peak average power ratio, nonlinearity***

I. INTRODUCTION

MIMO-OFDM is a promising technology to increase the capacity in frequency selective fading channels. By using space-time coding, MIMO-OFDM can achieve transmit diversity and power gain over spatially un-coded systems without sacrificing the bandwidth. One of the most frequently used encoding method is the space-time block codes (STBC). However, similar to the OFDM system, the MIMO-OFDM system also suffers from the drawback of high peak-to-average-power-ratio (PAPR). If the linear dynamic range of the high power amplifiers (HPAs) is not large enough, the HPAs will work in nonlinear region, and the bit error rate (BER) performance will be degraded.

A straight forward way to solve the problem is to reduce the PAPR, for which many approaches have been proposed. Among them, Clipping of high amplitude peaks is a simple and effective way to reduce PAPR [1]. However, peak clipping causes distortion of the transmitted signal, modeled as clipping noise [3], which also degrades the system performance. In order to mitigate the clipping noise in OFDM systems, a decision aided reconstruction (DAR) method has been proposed in [2].

Compared to that of OFDM systems, the decision observations of MIMO-OFDM receiver are more accurate due to the space-time diversity, and hence the DAR method in [2] can be used for MIMO-OFDM systems with better performance. However, in [2] it is assumed that after clipping HPAs work in linear region, which is not what happens in practice. In fact nonlinearity still exists with high power transmit amplifier (HPA) even after the clipping, and in this case the clipping noise compensation technique in [2] will not work well.

In this paper we propose a scheme to solve the above mentioned problem for MIMO-OFDM systems. Compared to existing approaches, such as [2], the proposed scheme considers both the HPA nonlinearity and clipping noise and tries solve the two issues at the same time. In particular, a decision aided algorithm is firstly employed to cancel the nonlinearity in the received symbols and then decision-based clipping noise compensation is applied to the output of the first stage. This processing can be repeated for several times in order to yield better performance.

The rest of the paper is organized as follows. Section 2 gives a brief description of the problem and the approach proposed in [2]. Then Section 3 presents the new method for both nonlinear elimination and clipping noise compensation. Numerical results are presented in Section 4. Finally, Section 5 concludes the paper.

II. PROBLEM STATEMENT

Figure 1 shows the block diagram of MIMO-OFDM transmitter with clipping operation and HPA.

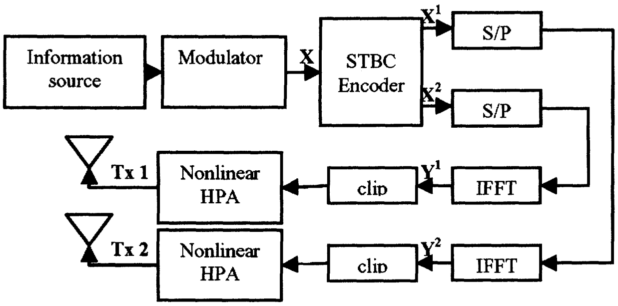

Figure 1 Transmit Block Diagram of STBC-OFDM

Let us assume that an *M*-ary modulation scheme is used. The Alamouti space-time block coding STBC encoder takes a block of two modulated symbols $\mathbf{x}_1$ and $\mathbf{x}_2$ in each encoding operation according to a code matrix given by

$$X = \begin{bmatrix} \mathbf{x}_1 & -\mathbf{x}_2^* \\ \mathbf{x}_2 & \mathbf{x}_1^* \end{bmatrix} \qquad (1)$$

where $\mathbf{x}_t = \begin{bmatrix} x_{t,1} & x_{t,2} & \cdots & x_{t,N} \end{bmatrix}^T$, t=1,2 is the data symbol (N sub-carriers) at time t. The symbols are transformed to time domain by N points IFFT and then clipped for PAPR reduction. Finally, the signals are amplified by the HPA and then transmitted by antennas.

The clipping operation for OFDM systems is described as follows. The amplitude of the time domain signal samples are limited by a threshold A. Let $\bar{\mathbf{s}}_n$ be a clipped time sample with the phase left unchanged. Then

$$\bar{\mathbf{s}}_n = \begin{cases} |s_n| & if \ |s_n| \le A \\ A & if \ |s_n| > A \end{cases} \qquad (2)$$

It was shown in [3] that the clipped signal $\{\bar{s}_n\}$ can be modeled as the aggregate of an attenuated signal component and clipping noise $\{d_n\}$

$$\bar{s}_n = \alpha s_n + d_n \qquad n = 0,1,\cdots,N-1 \qquad (3)$$

where the attenuation α is a function of the clipping ratio γ, defined as $\gamma = A/\sqrt{P_{in}}$, with P_{in} the average signal power before clipping

$$\alpha = 1 - e^{-\gamma^2} + \frac{\sqrt{\pi}}{2} erfc(\gamma) \qquad (4)$$

Formula (3) can be expressed in frequency domain as

$$\bar{C}_k = \alpha C_k + D_k \qquad k = 0,1,\cdots,N-1 \qquad (5)$$

The main idea of the clipping noise cancellation scheme for OFDM systems proposed in [2] is to recreate the clipping process at the receiver using detected symbols, then estimate and cancel the frequency domain clipping noise caused by it. The receiver works in an iterative manner.

This scheme can be used for MIMO-OFDM with little modification. Since the decision observations of MIMO-OFDM receiver are more accurate due to the space-time diversity, better results could be expected.

However, this scheme does not consider the nonlinearity introduced by HPA, which can be significant if the HPA works in the nonlinear region. As can be seen by the numerical computation in Section 4, the performance of the clipping noise compensation by using the technique proposed in [2] with modification for MIMO-OFDM systems will degrade a lot when the nonlinearity exists.

III. THE PROPOSED APPROACH

In order to solve the problem mentioned above, we propose a scheme depicted in Figure 2.

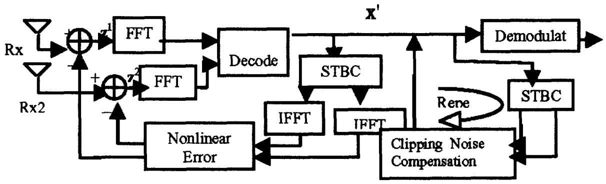

Figure 2 Block diagram of nonlinearity and clipping noise

We use decision-based algorithms for both nonlinearity elimination and clipping noise compensation. Assume that signal at the output of transmitter HPA are:

$$\mathbf{y}^i_{out} = \mathbf{y}^i + R^i \qquad (6)$$

where i=1,2 and y^i is the symbol input to ith HPA and R^i is the distorted term [4]. The received signal can be expressed as

$$\mathbf{y}^i_{rec} = \sum_{j=1}^{N_T} (\mathbf{y}^j \otimes \mathbf{h}^{j,i} + R^j \otimes \mathbf{h}^{j,i}) \qquad (7)$$

where $\mathbf{h}^{j,i}$ is the channel response from transmit antenna j to receive antenna i, N_T is the number of transmit antennas and " $\otimes$ " is convolution. Then the decision observations $\hat{\mathbf{X}}$ can be obtained from these received signals by the decoder. The main idea of the proposed nonlinearity cancellation scheme is to use a nonlinear system which yields replica of the nonlinear distortion components, that is, the second term in (7), and then use the replica to cancel the nonlinear distortion components in the received symbols. The outputs after this nonlinear distortion are as follows:

$$\mathbf{z}^i = \mathbf{y}^i_{rec} - \sum_{j=1}^{N_T} \hat{R}^j \otimes \mathbf{h}^{j,i} \qquad (8)$$

where $\hat{R}^j$ is the nonlinear component replica which can be reconstructed by using the same HPA modeling as formula (5) with decision observations

$$\hat{R}^j = (\hat{\mathbf{y}}^j)_{out} - \hat{\mathbf{y}}^i \qquad (9)$$

where $(\hat{\mathbf{y}}^j)_{out}$ is the output of HPA modeling when the input is $\hat{\mathbf{y}}^j$ and $\hat{\mathbf{y}}^j$ can be obtained from the decision observations $\hat{\mathbf{X}}$ by doing the same processing of STBC and IFFT as in the transmission side.

After the nonlinearity is removed (because of the clipping noise, this nonlinearity mitigation is rather rough), the signal $\mathbf{z}^i$ is then used to regenerate the clipped signals at the receiver by passing z^i through the same clipping process as at the transmitter. Denote regenerated clipped samples in frequency domain by G_k^i. Similar to (5), these clipped signals can be represented as the sum of an attenuated non-clipped signal αZ_k^i and the clipping noise $\hat{D}_k$,

$$G_k^i = \alpha Z_k^i + \hat{D}_k^i \qquad k = 0,1,\cdots,N-1 \qquad (10)$$

Since and are observable and can be computed from (4), the clipping noise can be estimated as

$$\hat{D}_k^i = G_k^i - \alpha Z_k^i \qquad k = 0,1,\cdots,N-1 \qquad (11)$$

The estimated clipping noise terms $\hat{D}_k^i$ are subtracted from the current decision observation $\hat{X}_k$ (after nonlinearity mitigation) to obtain the refined channel observation for the next iteration

$$\hat{T}_k = \hat{X}_k - \sum_{j=1}^{N_T} \hat{D}_k^j \otimes H_k^{j,i} \qquad (12)$$

With the algorithms described above, both nonlinearity and clipping noise will be reduced. However, a single round of application of the above algorithms is not enough as nonlinearity may still exist. In practice, the proposed scheme should be applied for a few iterations until satisfactory performance is achieved. Our simulations show that as the iteration proceeds, the estimation of the nonlinearity and clipping noise components is found to become increasingly accurate and the receiver performance is improved.

IV. NUMERICAL RESULTS

Computer simulations are performed to test the performance of the proposed approach. The parameters used in our simulations are as follows: the system has two transmitting and receiving antennas and has 128 OFDM sub-carriers. The channels are of Rayleigh fading. Modulation is 16QAM. The high power amplifier at the transmitter RF stage has been modeled as a non-linear circuit with the amplitude characteristic:

$$A_{out} = \frac{A_{in}}{\left(1 + \left(\frac{A_{in}}{A_0}\right)^{2p}\right)^{\frac{1}{2p}}} \qquad (13)$$

where A_{in} and A_{out} are the amplitudes at the input and at the output of an amplifier, respectively, $A0$ is the maximum (saturation) amplitude at its output, while p is the so-called *Rapp's parameter*. A good approximation of the AM/AM characteristics of existing amplifiers is obtained with the parameter p in the range of 2 to 3 [6]. For large values of p the model converges to an amplifier that is perfectly linear until it reaches its saturation level. For our simulations we have chosen p=2. The saturation level is described by the *IBO* (*Input Backoff*) parameter, which is defined as:

$$IBO = 10\log\frac{A_0^2}{A_{av}^2} \qquad (14)$$

where A_{av} is the signal amplitude having the power equal to the average OFDM signal power.

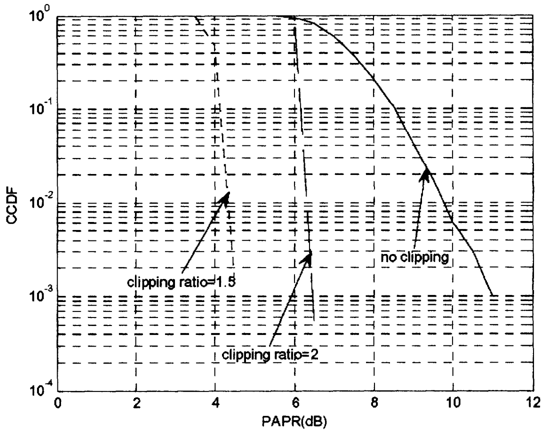

Figure 3 PAPR performances of clipping operation

The resultant complementary cdf (CCDF) is shown in Fig. 3 in the case of γ=2 and γ=1.5. Also shown in the figure is the complementary cdf of the PAPR without clipping. It is observed that compared to that without clipping, the clipping yields significantly lower PAPR.

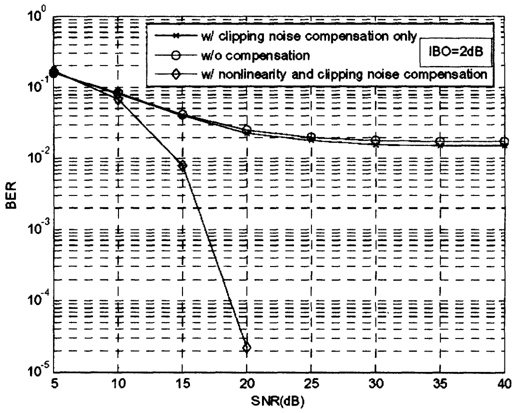

Figure 4 BER performances versus SNR when IBO=2dB and γ =2

Figure 4 shows the BER performances versus signal noise ratio (SNR) for 16QAM when IBO=2dB and clipping ratio γ=2 with comparison to that of a receiver without any compensation, and to a receiver with clipping noise compensation only. We can see that since the nonlinearity is very strong, so the BER performance without clipping noise and nonlinearity compensation is very poor. If we use clipping noise compensation only, the results is only a little bit better but still not good. However if we use the joint method of nonlinearity and clipping noise compensation, the results will be improved greatly.

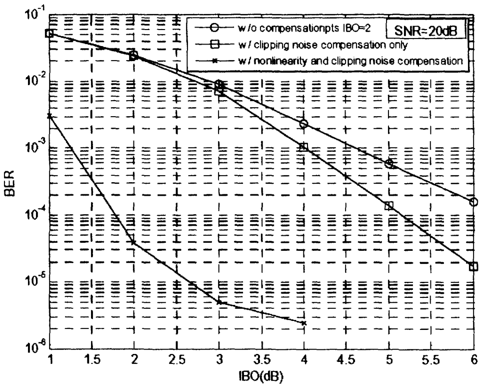

Figure 5 BER performances versus IBO when SNR=20dB and γ=2

Figure 5 presents the BER performances versus IBO for 16QAM when SNR=20dB and clipping ratio γ=2. It can be observed that the IBO performance of the compensated signals can be improved about 3.5dB at BER=10^{-5}.

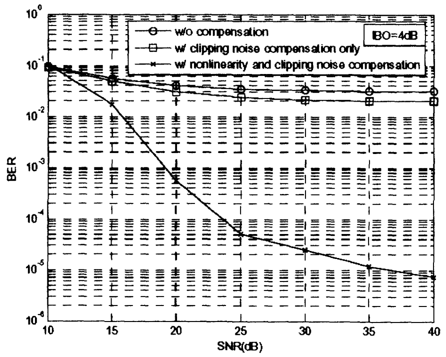

Figure 5 BER performances versus SNR when IBO=4dB and γ=1.5

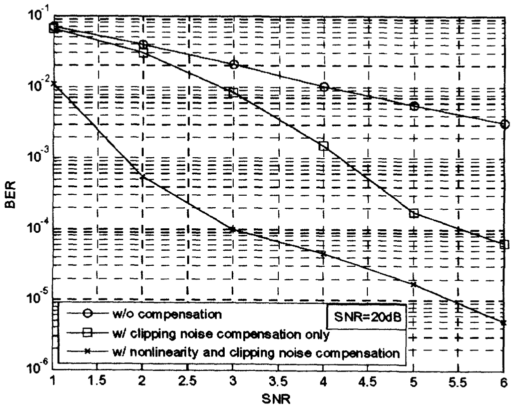

Figure 6 BER performances versus IBO when SNR=25dB and γ=1.5

Figure 5 and figure 6 show the BER performance versus *SNR* when IBO=4dB and BER performances versus IBO when SNR=20dB, respectively, for the clipping ratio γ=1.5. From these figures, we can draw almost the same conclusions with γ=2 cases.

V. CONCLUSIONS

In this paper, we propose new scheme that combines nonlinearity elimination and clipping noise compensation for MIMO-OFDM systems when severe nonlinearity exists in the HPAs. The proposed scheme consists of two stages of decision-aided processing, one for nonlinearity elimination and the other clipping noise reduction. Our numerical evaluation shows that the BER performance can be significantly improved by proposed technique.

One problem associated with the approach is that the nonlinearity model is assumed to be known which may not be true in practice, and deviation of the model will result in degrade of the performance. In fact more work should be done regarding the modeling of the HPA nonlinearity, which may be an issue for further research.

VI. REFERENCES

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