MIMO-OFDM에서 PAPR 저감 및 사전 왜곡기에 의한 HPA의 전력 효율 개선

Improvement of Power Efficiency of HPA by the PAPR Reduction and Predistorter in MIMO-OFDM

NGO THI THU TRANG*, 한태영*, 김 남**

충북대학교 정보통신공학과*, 충북대학교 정보통신공학과 컴퓨터정보통신연구소**

NGO THI THU TRANG(nttrang@osp.chungbuk.ac.kr)*,
Tae-Young Han(tyhan67@osp.chungbuk.ac.kr)*, Nam Kim(namkim@cbucc.chungbuk.ac.kr)**

요약

본 논문에서는 SLM(selective mapping)과 PTS(partial transmit sequence) 방식을 이용한 STBC MIMO-OFDM(space-time block code multi-input multi-output orthorgonal frequency division multiplexing) 시스템의 PAPR(peak-to-average power ratio) 성능을 분석한다. MIMO-OFDM 시스템에서 SLM과 PTS 방식은 비선형왜곡을 줄이고 비선형 HPA(high power amplifier)의 전력효율을 개선하기위해 사용된다. 시뮬레이션 결과에서는 QPSK를 사용한 기존의 MIMO-OFDM 시스템과 비교하였을때, SLM의 PAPR이 3.5dB 정도 줄어드는 동안 PTS는 5dB 정도 감소되는 결과를 볼 수 있다. 또한, HPA의 앞단에 사전왜곡기의 유무에 따른 MIMO-OFDM 시스템의 BER 성능을 분석해 본 결과 사전 왜곡기를 사용하였을 때 선형 증폭기에 근접하기 위해서 SLM 방식에서 6dB IBO(input backoff)가 요구되고 PTS 방식에서는 4dB가 요구됨을 확인하였다. PAPR을 개선하는 방식을 사용하지 않으면 8dB의 IBO가 필요하다.

■ 중심어 : | 고출력 증폭기 | MIMO-OFDM | PAPR | 전력 효율 |

Abstract

In this paper, we evaluate the peak-to-average power ratio (PAPR) performance in a space-time block code (STBC) multi-input multi-output orthogonal frequency division multiplexing (MIMO-OFDM) system using selected mapping (SLM) and partial transmit sequences (PTS) approaches. SLM and PTS methods are used to decrease the nonlinear distortion and to improve the power efficiency of the nonlinear high power amplifier(HPA) in the MIMO-OFDM system. In simulation result, when compared with the existing MIMO-OFDM system using QPSK, the PTS method reduces the PAPR about 5 dB while the SLM method can reduce about 3.5 dB. Also, we find the BER performance of the MIMO-OFDM system with and without the predistorter in front of the HPA. When the predistorter is used, the input back-off (IBO) of 4 dB is required in the PTS method, and IBO of 6 dB in the SLM method to closely conform to the linear amplifier. If the method of improving the PAPR is not used, the value of IBO of 8 dB is required.

■ keyword : | HPA | MIMO-OFDM | PAPR | Power Efficiency |

I. Introduction

MIMO-OFDM(multi-input multi-output orthogonal frequency division multiplexing) is one of the promising technologies to improve the spectral efficiency, enhance the system capacity, and mitigate the inter-symbol interference in the fourth broadband wireless communication system. The MIMO-OFDM system takes advantage of both OFDM technology and the spatial diversity that is obtained by spatially separated antennas. In spite of a lot of advantages, some drawbacks become apparent when using OFDM in transmission system. The main limitation is the high peak-to-average power ratio(PAPR) of the transmitted signals[1][2]. Thus, the nonlinear distortion that leads to the out-of-band emission and the in-band distortion is caused by a high power amplifier(HPA). The nonlinear distortion degrades the transmission quality and makes the spectrum be expanded excessively. The out-of-band emission results in the interference to the adjacent channels in that system's band and the interference to the other systems using the adjacent frequency band(ACI: adjacent channel interference).

Therefore, it is necessary to combat against the nonlinearity of HPA and to improve the power efficiency of HPA. This problem is also common to the multi-carrier transmission system [3] [4]. Outputs of this system have very high PAPR. More expensive power amplifier with a high linearity over a wide dynamic range is required to transmit the high PAPR signal without distortion. The impact of amplifier nonlinearity is investigated since the efficiency of high power amplifier depends on the PAPR[5]. Consequently, making a signal with low PAPR is the main concern to decrease the HPA nonlinearity and to improve the power efficiency of HPA.

To solve this serious problem, many methods have been proposed, for examples; clipping method, pre-coding method, SLM and PTS, etc.[6][7][8]. Clipping method is to clip the peak above a certain prescribed level. The merit of this clipping method is that PAPR can be easily reduced. But the BER performance becomes very worse due to the clip noise. Pre-coding is another important method for PAPR reduction. The information data is coded in the pre-coding block to reduce the PAPR. However, the code rate becomes lower than 1 so that the redundant bits or extra bandwidth are required. Furthermore, this method may restrict the number of parallel branches. Selected mapping(SLM) and partial transmit sequences(PTS) methods may be classified into the phase control scheme to suppress the high peak, which has originally been studied in the OFDM communication system. In the SLM method, a signal of the lowest PAPR is selected from a set of several signals containing the same information data. In the PTS method, the lowest PAPR signal is made by optimally phase combining the signal subblocks. They are very flexible schemes and give a good performance on the PAPR reduction without any signal degradation. Moreover, both techniques require much system complexity and computational burden because of the complex optimization procedure.

In this paper, we address the PAPR performance of space-time block coded(STBC) MIMO-OFDM systems using the SLM and PTS schemes. These methods are used to decrease the nonlinear distortion and improve the HPA power efficiency. The PAPR reduction is represented with the

simulation results when QPSK is used as a modulation, which takes the form of complementary cumulative distribution function (CCDF). Besides, we find the BER performance of MIMO-OFDM system with and without the predistorter in front of the nonlinear HPA. The results of BER performance tell that the predistorter can improve the bit error rate performance in all the cases of the conventional MIMO-OFDM using PTS or SLM method.

This paper is organized as follows. Section 2 provides a description of the MIMO-OFDM system model and PAPR equation. Section 3 describes the PAPR reduction methods. Section 4 provides the simulation results and the conclusion is given in section 5.

II. System model and PAPR

The MIMO-OFDM system using M transmit antennas and K subcarriers is considered. In Fig.1, we take the 2-input and 2-output MIMO-OFDM system as an example to illustrate the considered system
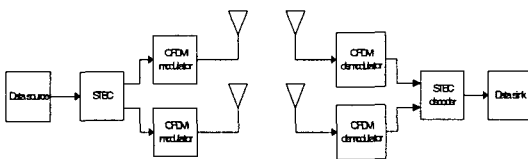

Fig. 1. MIMO-OFDM model

In the case of two transmit antennas [9], the K-dimentional OFDM symbol transmitted from antenna 1 is denoted by C_1 and from antenna 2 by C_2. During the next symbol period, $-C_2^H$ and C_1^H are transmitted from antenna 1 and 2,

respectively, where $(\cdot)^H$ denotes Hermitian transpose. In the time domain, the transmitted OFDM signal at the i-th transmit antenna is given by

$$c_i = F^H C_i \qquad (1)$$

where $c_i = [c_{i,0}, c_{i,1}, , c_{i,K-1}]^T$ is the discrete-time representation and F denotes a $K \times K$ FFT matrix. The PAPR of the transmitted OFDM signal of Eq. (1) is defined as

$$PAPR = \frac{\max\limits_{1 \leq k \leq K} |c_{i,k}|^2}{E\left[|c_{i,k}|^2\right]} \qquad (2)$$

where $E[\cdot]$ denotes the expected value. Applying the central limit theorem when assuming that K is sufficiently large, the time-domain samples $c_{i,k}$ are approximately zero-mean complex Gaussian distributed[10]. Then, the complementary cumulative distribution function (CCDF) of the PAPR of an OFDM signal for a given PAPR level, $PAPR_0$, is the probability that the PAPR of a randomly generated K-OFDM symbol exceeds the given threshold of $PAPR_0$, which can be expressed as[7]

$$\text{Prob}\left[PAPR > PAPR_0\right] = 1 - \left(1 - e^{-PAPR_0}\right)^K \qquad (3)$$

III. PAPR reduction methods

Since the high PAPR in the MIMO-OFDM system is the same problem as the OFDM system, we can use the selected mapping (SLM) and partial transmit sequence (PTS) schemes that are classified into the phase control scheme to suppress the high peak. In the SLM method, the number of U sequences, which is statistically independent and differently changed, are generated from the same information by multiplying the data vector C with the phase rotation vector b. Then,

the sequence of the lowest peak amplitude is selected to transmit. In the PTS method, the data vector is partitioned into Vdisjoint subblocks, which are combined with the phase rotation vector to minimize PAPR.

1. Selected Mapping(SLM)

In the MIMO-OFDM system, the SLM approach can be applied to each transmit antenna independently. In this method, a set of U vectors, which is statistically independent but fixed K-dimensional, must be defined to increase the number of alternate transmit sequences. The U phase rotation vectors can be represented as $\underline{b}^{(i)} =$ $(b_1^{(i)}, b_2^{(i)},..., b_K^{(i)})$ with $b_k^{(i)} = e^{j\varphi_k^{(i)}}$, $\varphi_k^{(i)} \in$ [0, 2), i = [1,U], k = [1,K]. The data sequence $\underline{C}$ = $(C_1, C_2,..., C_K)$ is rotated in phase by multiplying carrier-wise with the U vectors $\underline{b}^{(i)}$. Thus, we obtain U copy blocks of the data sequence with the same information as

$$S^{(i)} = \sum_{k=1}^{K} C_k b_k^{(i)} \quad , \qquad 1 \le i \le U \qquad (4)$$

TThe symbol of the lowest PAPR, denoted as $\overset{:}{\chi}$, chosen from the different U $S^{(i)}$symbols is transmitted. So, the complementary cumulative distribution function that $\overset{:}{\chi}$ exceeds $PAPR_0$ is approximated as

$$\mathrm{Prob}\left[\overset{:}{\chi} > PAPR_0\right] = \left(1-\left(1-e^{-PAPR_0}\right)^K\right)^U$$

Because of the selected assignment of binary data to the transmit signal, this principle is called a selected mapping.

The side information about the rotation can be transmitted in the embedded type into the data or in another channel. This requires much system complexity and computational burden.

2. Partial Transmit Sequences(PTS)

In the PTS method, the data sequence C must be partitioned into the V disjoint, fixed K-dimension subblocks or clusters that are combined to minimize the PAPR. There are three kinds of partitioning methods; adjacent, random and interleaved method. Partitioning C into V disjoint subblocks $\{C^{(j)}, j = 1, 2,..., V\}$and setting to zero in another subblocks can be presented as

$$C = \sum_{j=1}^{V} C^{(j)}$$

We introduce the phase rotation vector $\underline{b} = (b^{(1)}, b^{(2)},..., b^{(V)})$ chosen to minimize the peak value. The choice of $b^{(j)}$ $\{\pm1,\pm j\}$ is very important for the PAPR reduction. Each partitioned subblock is controlled in phase by multiplying the subblock with the corresponding rotation vector.

The objective is to optimally combine the V clusters

$$S = \sum_{j=1}^{V} b^{(j)} C^{(j)} \qquad (5)$$

In the time-domain

$$s = \sum_{j=1}^{V} b^{(j)} c^{(j)} \qquad (6)$$

where $c^{(j)}$, the IFFT of $C^{(j)}$, is called the partial transmit sequence. The signal s has lower PAPR than the original signal thanks to the optimization procedure. And the rotation vector $\underline{b}$ will be transmitted with the data signal as the side information.

3. HPA and Predistorter

In this paper, the predistorter may be combined into the high power amplifier (HPA) in the MIMO-OFDM system after the peak value of MIMO-OFDM signal is reduced. There are two types of HPA, traveling wave tube amplifier

(TWTA) and solid state power amplifier (SSPA).

The amplitude and phase characteristics of these two amplifiers are given by

$$A_{TWTA}(|s(t)|) = \frac{A_{in}^2 |s(t)|}{|s(t)|^2 + A_{in}^2}$$ (7)

$$\phi_{TWTA}(|s(t)|) = \frac{\pi}{3} \frac{|s(t)^2|}{|s(t)^2| + A_{in}^2}$$ (8)

$$A_{SSPA}(|s(t)|) = \frac{|s(t)|}{\left(1 + \left(\frac{|s(t)|}{A_{out}}\right)^{2p}\right)^{\frac{1}{2p}}}$$ (9)

$$\phi_{SSPA}(|s(t)|) = 0$$ (10)

where A_{in} is the input saturation voltage, A_{out} is the output saturation voltage, p is the Raff's coefficient to control the smoothness of the transition from the linear region to the saturation region, $|s(t)|$ is the amplitude of the input signal. A_{TWTA} and A_{SSPA} are the amplitude characteristics of TWTA and SSPA, respectively. Here, we investigate the application of PTS and SLM methods with the SSPA. From the above equations (Eq. 8, Eq. 9, Eq. 10, Eq. 11), we see that the SSPA has only the AM/AM distortion, while the TWTA has both AM/AM and AM/PA distortions. In our following simulation, the input back-off (IBO) is set to determine the saturation amplitude of the HPA.

Although both PAPR reduction methods of SLM and PTS can reduce the peak power, it is not enough to suppress the out-of-band emission. The predistorter should be used to limit the spectral regrowth. The predistorter is a linearization method in which the input signals are conversely predistorted before the HPA. Through the predistorter and the nonlinear HPA, the overall characteristics can be linearized.
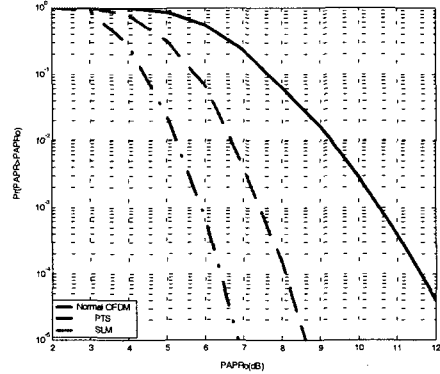
IV. Simulation results and discussion

Fig. 2. CCDFs of PTS, SLM and Normal MIMO-OFDM

In the simulation, the parameters are set as follows:

Size of IFFT: K = 64

Modulation format: QPSK

Channel: AWGN

Amplifier: SSPA with Rapp's coefficient, p = 2

Input back-off (IBO): 4, 6 and 8 dB

The number of subblocks in PTS method: V = 4

The number of copy blocks in SLM method: U = 4

The simulation results show the PAPR reduction by

SLM and PTS methods in Fig. 2. The PTS method is better than the SLM method, and the CCDF of the PTS technique is the best result. Compared with the original MIMO-OFDM, the PAPR of the PTS method can be reduced by about 5dB at the PAPR of probability of 10^{-4}. Meanwhile, at the same value of probability, the PAPR of the PTS method is only smaller than the SLM method about 1.5 dB. These results make a good effect on the BER performance. After

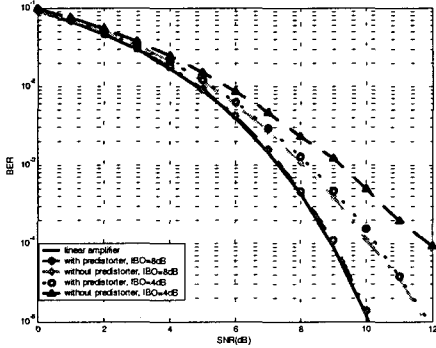reducing PAPR by PTS and SLM methods, the data goes into the SSPA with and without the predistortor.

Fig. 3. BER performance of conventional MIMO-OFDM with predistorter

The BER performance is shown for the conventional MIMO-OFDM system with and without the predistorter in Fig. 3. In this figure, the more input back-off (IBO) is, the better BER performance and the poorer HPA power efficiency are. The predistorter gives a good improvement in the BER performance. As shown in Fig. 3, with 4 dB IBO to meet the BER of 10^{-4}, the conventional MIMO-OFDM system plus the predistorter can achieve 1.7 dB SNR gain compared with this system without the predistorter. Meanwhile, at the same BER and the value of 8 dB IBO, the difference between them is about 1 dB. Consequently, it is clear that in case of using the predistorter with 8 dB IBO, the BER performance closely matches to the linear amplifier.

In this paper, we assume that there is no error in the side information (SI) at the receiver. The results in Fig. 4 are given by the SLM method when combined with and without the predistorter.
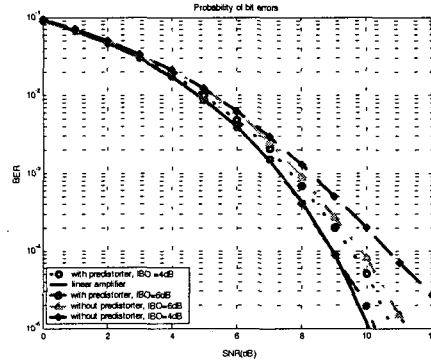

Fig. 4. MIMO-OFDM using SLM method with predistorter
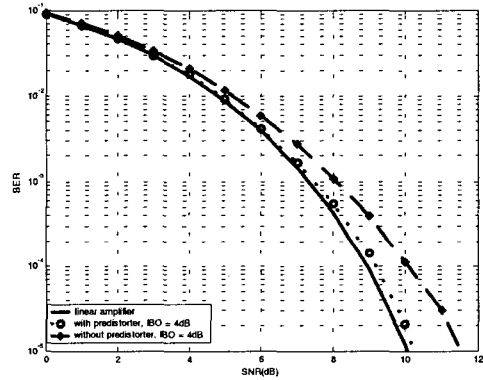

Fig. 5. MIMO-OFDM using PTS method with predistorter

The predistorter operates more effectively in the SLM method than in the original MIMO-OFDM system. With the IBO of 4 dB and without the predistorter, 10.7 dB SNR is required to meet the BER of 10^{-4}, while with the predistorter 9.5 dB SNR is required. With 6 dB IBO, the difference between them is about 1 dB SNR. Moreover, we can easily see that with the predistorter and IBO of 6 dB, the BER curve really matches to the ideal linear amplifier. In Fig. 4, the simulation results show that with 4 dB IBO plus the predistorter, the

system using the SLM method requires 9.5 dB SNR while the conventional system needs 10.3 dB SNR to obtain the BER of 10^{-4}. In Fig. 5, it is shown that in the PTS method only 4 dB IBO is required to get the same performance as the curve of linear amplifier when the predistorter is used.
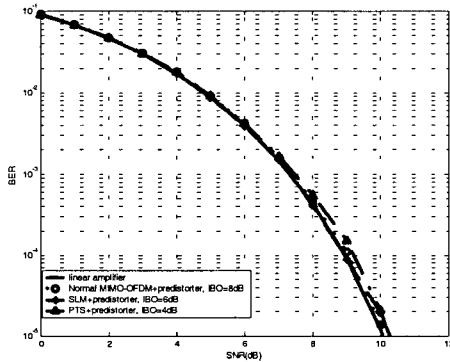

Fig. 6. Comparison of BER curves

The BER curves of the original MIMO-OFDM system and PTS and SLM methods are shown in Fig. 6. It is clear that by using PTS and SLM methods, the MIMO-OFDM system can reduce PAPR to decrease the nonlinear distortion and improve the HPA power efficiency. And the PTS method is better than SLM method in reducing the PAPR. From the BER performances in Fig. 3, Fig. 4, Fig. 5 and Fig. 6, it can be observed that to closely match to the linear amplifier, the PTS method plus the predistorter requires 4dB IBO, the SLM method with the predistorter needs 6 dB while the original MIMO-OFDM system using the predistorter requires 8 dB. Consequently, combining the predistorter with the HPA and using the PAPR reduction methods of SLM and PTS, we can design the signal of low PAPR, decrease the HPA nonlinearity and improve the power efficiency of HPA as well.

V. Conclusion

We have studied two methods of SLM and PTS to improve the power efficiency by reducing the peak of the MIMO-OFDM signals. By these methods, PAPR is reduced in the viewpoint of the CCDFs, where the PTS method is better than the SLM method about 1.5 dB at the PAPR probability of 10^{-4}. The BER performance of the MIMO-OFDM system is investigated when HPA is combined with and without the predistorter. The predistorter can improve the BER performance, especially with small input back-off values. From the simulation results, it is shown that the necessary input back-off is only 4 dB for the PTS method including the predistorter and 6 dB for the SLM method including the predistorter to closely match to the linear amplifier. On the contrary, the original MIMO-OFDM system needs 8 dB IBO without any nonlinear countermeasure.

참 고 문 헌

[1] S. B. Weinstein and P. M. Ebert, "Data transmission by frequency-division multiplexing using the discrete fourier transform," IEEE Trans. Comm. Techno., Vol. COM-19, No. 5, pp. 628-634, 1971.

[2] "Special issue on multicarrier communications," Wireless Personal Commun., Vol. 2, No. 1, 1996.

[3] A. E. Jones and T. A. Wilkinson, "Block coding scheme for reduction of peak to mean envelope power ratio multicarrier transmission schemes," IEEE Elect. Lett., Vol. 30, No. 25, pp. 2098-2099, 1994.

[4] K. G. Paterson, "Generalized Reed-Muller codes and power control in OFDM modulation," IEEE Trans. Inform. Theory, Vol. 46, No. 1, pp. 104-120, 2000.

[5] N. Guo and L. B. Milsten, "The impact of nonlinear amplification on multi-code CDMA system," Proceeding of IEEE ICC, pp. 1034- 1038, 2000.

[6] X. Li and L. J. Cimini Jr., "Effects of clipping and filtering on the performance of OFDM," IEEE Commun. Lett., Vol. 2, No. 5, pp. 131-133. 1998.

[7] R. W. Bauml, R. F. H. Fisher and J. B. Huber, "Reducing the peak-to-average power ratio of multicarrier modulation by selective mapping," Electron. Lett., Vol. 32, No. 22, pp. 2056-2057, 1996.

[8] L. J. Cimini Fr. and N. R. Sollenberger, "Peak-to-average power ratio reduction of an OFDM signal using partial transmit sequences," IEEE Commu. Lett., Vol. 4, No. 3, pp. 86-88, 2000.

[9] S. M. Alamouti, "A simple transmitter diversity scheme for wireless communications," IEEE J. Select. Areas Commun., Vol. 16, pp. 1451-1458, 1998.

[10] J. G. Proakis, Digital Communications, McGraw - Hill Inc., 1989.

저 자 소 개

NGO THI THU TRANG   준회원

- 2002년 : Vietnam National University, Hanoi(공학사)
- 2002년~2004년: 충북대학교 정보통신공학과 석사과정 수료
  <관심분야> : OFDM, PAPR, nonlinear HPA

한 태 영(Tae-Young Han)   정회원

- 1988년 : 연세대학교 전자공학과(공학석사)
- 2004년 : 충북대학교 정보통신공학과 박사과정 수료
  <관심분야> : UWB, OFDM

김 남(Nam Kim)   정회원

- 1981년 : 연세대학교 전자공학과 (공학사)
- 1983년 : 연세대학교 전자공학과 (공학석사)
- 1988년 : 연세대학교 전자공학과 (공학박사)
- 1992년~1993년 : 미 Stanford 대학 방문교수
- 2000년~2001년 : 미 California Technology Institude 방문교수
- 1989년~현재 : 충북대학교 전기전자컴퓨터공학부 교수, 컴퓨터정보통신연구소
  <관심분야> : 디지털 이동통신, 이동통신, 무선시스템, 전자파해석, EMI/EMI, Diffractive Optics, WDM Optical Filter & DEMUX Optical Memory, Holography Application