

공간변조 기법을 위한 새로운 PAPR 감쇄 방법

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New PAPR Reduction Method for Spatial Modulation

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ABSTRACT

In this paper, a new peak-to-average power ratio (PAPR) reduction method for spatial modulation(SM) is presented. By using the matrix with all non-zero elements to precode the signals before transmitting, the transmit power is scattered over all transmit antennas for achieving the goal of PAPR reduction. If this matrix is also an unitary matrix, the distribution of transmit power over transmit antennas will be uniform and it also could retain the characteristic of avoiding inter channel interference (ICI) due to the orthogonality of unitary matrix. In case of a non-ideal amplifier, the proposed method can produce a considerable improvement that increases with a number of transmit antennas in performance. Furthermore, the new scheme achieves an identical performance with conventional one in the case of ideal amplifier.

Key Words : Peak-to-average power ratio, spatial modulation, maximum likelihood, unitary matrix

I. Introduction

Multiple-input multiple-output (MIMO) systems are well-known as their improvements in capacity and reliability of communication. For instance, space time block code (STBC)^[1-4] and spatial multiplexing [5-6] are very attractive for above two advantages. However, the STBC cannot retain the orthogonality when transmit antenna number is larger than two. For spatial multiplexing, the inter-channel interference(ICI) produced by transmitting parallel symbol over all antennas at the same time is difficult to remove.

Spatial modulation (SM)^[7-10] is a fresh spatial multiplexing MIMO technique, which possesses both the spatial gain of STBC and the multiplexing gain

of spatial multiplexing simultaneously. The most remarkable advantages of SM are the elimination of ICI and low decoding complexity due to activating only one transmit antenna at each symbol time. However, it is possible to reduce the peak-to-average power ratio (PAPR) of SM to a lower level, so that the performance of SM could be improved in the case of non-ideal amplifier. Therefore, in this paper, we propose a new method to reduce the PAPR of SM, which is inserting a non-zero unitary precoder in SM for distributing the transmit power over all transmit antennas uniformly.

Organization: Section II introduces the conventional SM model and optimal detection. In Section III, we propose a PAPR reduced scheme for SM and detection method based on SM optimal

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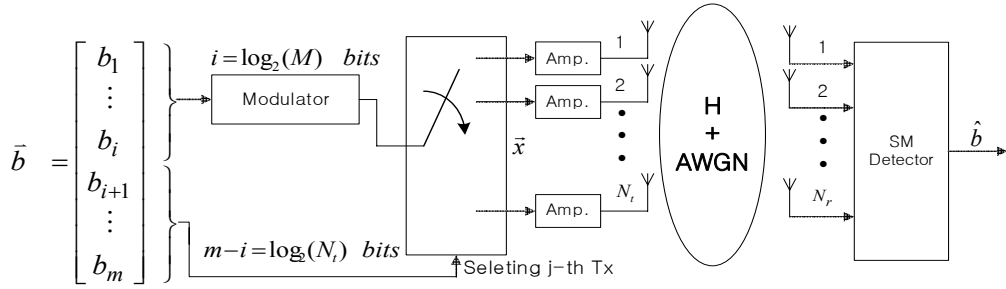


Fig. 1. Conventional SM scheme

detector. Simulation results are presented in Section IV, and conclusion is in Section V.

II. Conventional SM Scheme

The conventional SM scheme is shown in Fig. 1, which consists of N_t transmit antennas and N_r receive antennas.

Firstly, an input bit vector $\vec{b} = [b_1 b_2 \dots b_m]^T$ of length $m = \log_2(M \cdot N_t)$ is splitted into two parts, $\log_2(N_t)$ and $\log_2(M)$ bits, where M denotes a constellation size. The first $\log_2(M)$ bits are modulated as x_q and then transmitted through the j -th antenna which is selected by the next $\log_2(N_t)$ bits. Hence a resulting spatial modulated vector can be expressed as $\vec{x}_{j,q} = [0 \dots x_q \dots 0]^T$ with only j -th non-zero element of x_q , where q denotes the index of constellation.

Obviously, by selecting a single transmit antenna, a group of additional information bits is conveyed over spatial dimension. In general, the number of antenna selection bits depends on the number of transmit antenna, which is expressed as $\log_2(N_t)$. And these increased bits are mapped into antenna selection according to the following Table 1.

Table 1. Antenna selection rule for $N_t = 4$

Mapped bits	Active antenna index
00	1
01	2
11	3
10	4

Under assumptions of an ideal amplifier and i.i.d. $N_r \times N_t$ MIMO fading channels, a received signal vector \vec{y} of length N_r is given as

$$\vec{y} = \vec{H}x_{j,q} + \vec{n} \quad (1)$$

where \vec{H} and \vec{n} are a channel matrix of size $N_r \times N_t$ and a noise vector of length N_r , respectively, with $\vec{H} \sim CN(0, 1/2)$ and $\vec{n} \sim CN(0, \sigma^2/2)$: $CN(\mu, \sigma^2)$ is complex Gaussian PDF of real and imaginary parts with mean and variance σ^2 .

In the following, the optimal detection method based on ML principle is proposed in [9]. In case of the equally likely channel inputs, the algorithm is given as

$$[\hat{j}, \hat{q}] = \underset{j, q}{\operatorname{argmin}} \|\vec{h}_{j,q}\|^2 - 2\operatorname{Re}[(\vec{y})^H \vec{h}_{j,q}] \quad (2)$$

where j denotes the index of active transmit antenna and q denotes the q -th symbol of M-ary constellation. \vec{h}_j represents the j -th column of channel \vec{H} . The following notation is used throughout this paper. $\|\cdot\|$ and $(\cdot)^H$ are used for Frobenius norm of a matrix or vector and conjugate transpose, respectively. $(\cdot)^T$ is used for transpose and $\operatorname{Re}(\cdot)$ denotes the real part of complex number.

III. New SM Scheme

The typical feature of the original SM scheme of

Fig. 1 is activating only one transmit antenna at each symbol time epoch. Hence from this operation, we can easily conjecture that the scheme has higher PAPR with a given average transmit power, which may incur severely degraded performance in case of a non-ideal amplifier. Therefore we will design a new SM scheme that has lower PAPR compared to the original one without any loss of performance in an ideal amplifier.

For this goal, a hypothetical transformation of SM model is introduced firstly in Fig 2. In order to make the characteristics of SM not vary with our proposed operation, we add a precoder that consists of an identical matrix before transmit antenna since both the situations with and without the identity precoder are completely the same in mathematics. Then we can rewrite (1) by simply inserting an $N_t \times N_t$ identity matrix I_{N_t} between H and \vec{x} , given as

$$\vec{y} = \mathbf{H} \mathbf{I}_{N_t} \vec{x}_{j,q} + \vec{n}. \quad (3)$$

It is obvious that formula (1) and (3) are equivalent in mathematics, thus the performance will not change. However, the mapping object is changed from antenna index to column of the identical matrix I_{N_t} . The mapping rule is shown in Table 2.

By comparing (1) and (3), we can see that selecting an j -th antenna depicted in Fig. 1 can be interpreted as selecting a j -th orthogonal unit vector of I_{N_t} as shown in Fig 2. Following this way, it is feasible to adopt the unitary matrix U of size $N_t \times N_t$ instead of I_{N_t} as shown in Fig. 3 for achieving the goal of the PAPR reduction without any loss of performance, since the unitary matrix

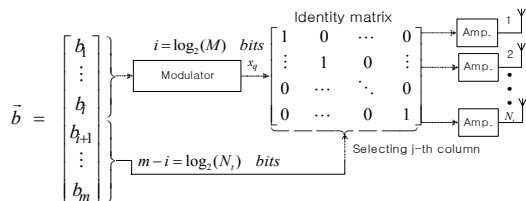


Fig. 2. Conventional SM transmitter

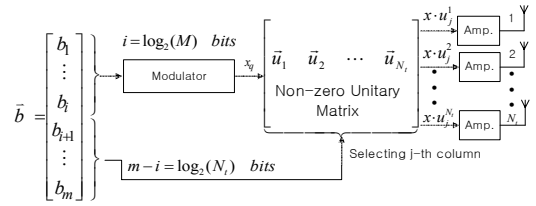


Fig. 3. New SM transmitter

Table 2. Column selection rule for $N_t = 4$.

Mapped bits	Selected column
00	$[1\ 0\ 0\ 0]^T$
01	$[0\ 1\ 0\ 0]^T$
11	$[0\ 0\ 1\ 0]^T$
10	$[0\ 0\ 0\ 1]^T$

with all non-zero elements can scatter the concentrated power into every element uniformly. Then, the received signal from new SM transmitter can be obtained as

$$\vec{y} = \mathbf{H} \mathbf{U} \vec{x}_{j,q} + \vec{n}. \quad (4)$$

Obviously, (3) and (4) have identical performance in the case of ideal amplifier since HU in (4) has identical distribution with H due to the orthogonality of U . Meanwhile, the new scheme in (4) needs not transmit a modulated signal only through an single antenna any more, which means the possibility of reducing the PAPR by distributing the transmitted power over all of antennas.

For a special case of $N_t = 2^k$ with a positive integer k , we assume that the total transmit power per symbol duration is given as 1. The probability of activating each antenna in each symbol duration is close to $1/N_t$ in the case of a large number of experiments, so the average power of SM signal is nearly fixed at $1/N_t$. Then, the PAPR could be reduced to $1/N_t$ times of that in original scheme of Fig. 1 by scattering the transmit power over all transmit antennas when we guarantee that the average power of signal is not changed by this operation. In other words, the PAPR decreases

$10\log_{10}N_t dB$ compared to conventional SM. Thus the new scheme may be more effective as increasing the number of transmit antenna.

Here, a typical non-zero unitary matrix Hadamard matrix[11] is exploited for precoder matrix, and it can be iteratively generated as

$$W_2 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}, W_{2^k} = \begin{bmatrix} W_{2^{k-1}} & W_{2^{k-1}} \\ W_{2^{k-1}} & -W_{2^{k-1}} \end{bmatrix}, U_{2^k} = \frac{1}{\sqrt{2^k}} W_{2^k} \quad (5)$$

where $1 \leq k \in N$ (N is natural number). And the mapping table for new scheme is shown in Table 3.

Since the unitary matrix possesses the orthogonality, the distribution of HU should be identical with channel H and the ICI could also be completely removed in receiver. Therefore, the optimal detector what mentioned in Section II can be also applied to new scheme with a little alteration. It is obvious that the HU can be regarded as a new formed channel G that possesses identical distribution with original channel matrix H because of the orthogonality of unitary matrix and characteristic of channel H . Thus, the formula (4) is changed as

$$\vec{y} = \vec{G}x_{j,q} + \vec{n}. \quad (6)$$

Then, the optimal detection based on ML principle for new scheme can be written as

$$[\hat{j}, \hat{q}] = \operatorname{argmin} \|\vec{g}_j x_q\|^2 - 2\operatorname{Re}(\vec{y}^* \vec{g}_j x_q) \quad (7)$$

where \vec{g}_j is the j -th column of matrix G . Because the distribution of G is identical to H , the new scheme enjoys identical performance with conventional scheme in ideal amplifier.

Table 3. Mapping rule for New scheme ($N_t = 4$).

Mapped bits	selected column
00	$[1 \ 1 \ 1 \ 1]^T$
01	$[1 \ -1 \ 1 \ -1]^T$
11	$[1 \ 1 \ -1 \ -1]^T$
10	$[1 \ -1 \ -1 \ 1]^T$

IV. Simulation Results

In this section, the simulation results for the new scheme are given and compared to those of the conventional one for the various values of input backoff (IBO). As models for non-ideal amplifier, we use a simple clipping calculation given as [12],

$$s = \begin{cases} |A_s|e^{j\theta}, & \text{if } |x| > A_s \\ |x|e^{j\theta}, & \text{if } |x| < A_s \end{cases} \quad (8)$$

where A_s is the saturation value of the non-ideal amplifier, and s is output signal.

Moreover, the definitions of IBO and PAPR is shown as follows,

$$IBO = 10\log_{10} \frac{A_s^2}{P_i} \quad (9)$$

$$PAPR = 10\log_{10} \frac{P_{peak}}{P_i} \quad (10)$$

where A_s^2 is the amplifier input saturation power, P_i is the average input power, and P_{peak} denotes the signal peak power. Obviously, when P_{peak} is larger than A_s^2 , the exceeding power will be clipped by amplifier. It indicates that the effect of reducing 3dB PAPR value is identical to the case of increasing 3dB IBO value.

Firstly, the CCDF of PAPR is presented in Fig 4. It can be observed that the new scheme achieves a 3dB PAPR reduction compared to conventional SM in the case of $N_t = 2$. For $N_t = 4$, the new scheme could provide 6dB PAPR reduction compared to conventional SM. It accords with what mentioned before, the new scheme could provide $10\log_{10}N_t dB$ PAPR reduction over conventional SM.

Next, we show a waveform comparison with $N_t = 4$ in Fig. 5. As shown in the figure, the waveform is transmitted from one antenna in conventional or new transmitter, and the waveform of conventional scheme does not exist during some symbol durations. It means that in these symbol

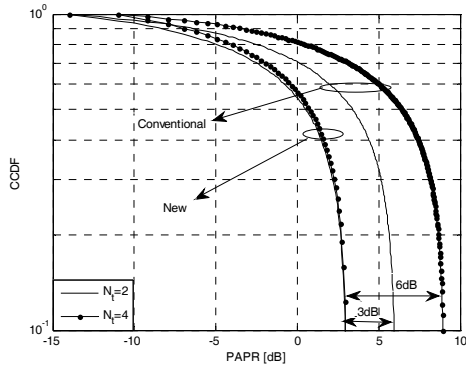


Fig. 4. The CCDF of PAPR for 4QAM

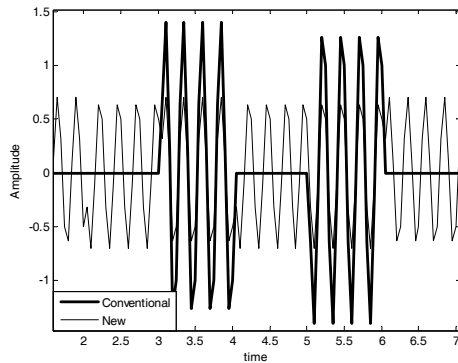


Fig. 5. Time waveform for 4-QAM and $N_t = 4$

durations, this transmit antenna is not selected for conveying information. In a single symbol duration, if we uniformly divide the power originally distributed to single selected antenna into four parts and distribute them to all transmit antennas, the power of each antenna will decrease to 1/4 of original one. Certainly, the peak power is also reduced to 1/4 of original as shown in the Fig 5.

As shown in Fig 6, the average BER performance is presented with different modulation, 4-QAM, 16-QAM and 64-QAM in the case of IBO = infinite, in which the amplifier can be interpreted as an ideal amplifier. In the figure, the new scheme is shown to be according with our conjecture, which is enjoying an identical performance with conventional one. It is well known that the signal clipping only occurs in case of IBO less than PAPR.

Hence, For $N_t = 2$ curves shown in Fig 7, the new scheme in case of IBO = 3dB has almost identical performance with the convention one in

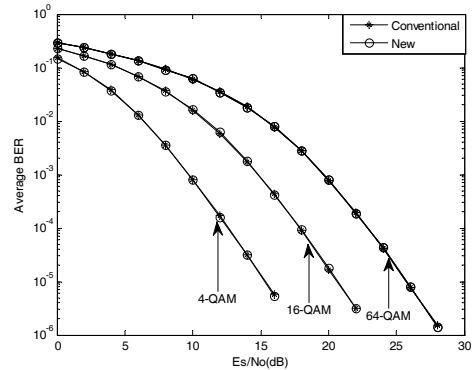


Fig. 6. Average BERs in ideal Amp. for $N_t = 4, N_r = 4$

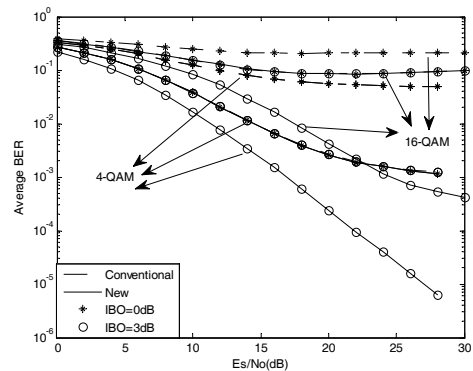


Fig. 7. Average BERs in non-ideal Amp. for $N_t = 2, N_r = 2$

case of IBO = 6dB, since the PAPR decreases to $1/N_t$ times as that of the conventional scheme. For $N_t = 4$ curves in Fig 8, the performance of the new scheme in case of IBO = 0dB is nearly the same to conventional one in case of IBO = 6dB. For $N_t = 8$ curves in Fig 9, the new scheme obtains a 9dB gain due to the Hadamard precoder. Hence, in conclusion, the proposed method can reduce $10\log_{10}N_t$ dB for PAPR value of SM.

At fact, as the transmit antenna number increases, the transmit power will be more concentrated. As shown in above figures, the $N_t = 4$ case suffers more distortion than the $N_t = 2$ case in conventional scheme. On the other hand, the new scheme should obtain more prominent improved performance, as the number of transmit antennas is larger.

The PAPR reduction in new scheme above is based on the multiple antennas transmission. Thus, the new scheme has a disadvantage that needs

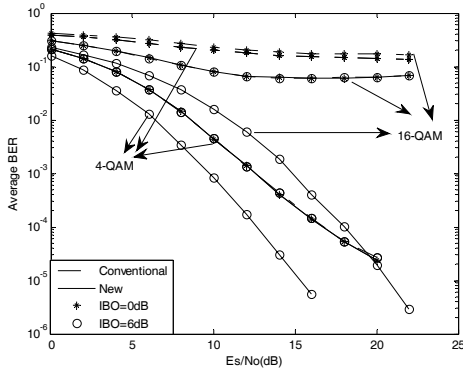


Fig. 8. Average BERs in non-ideal Amp. for $N_t = 4, N_r = 4$

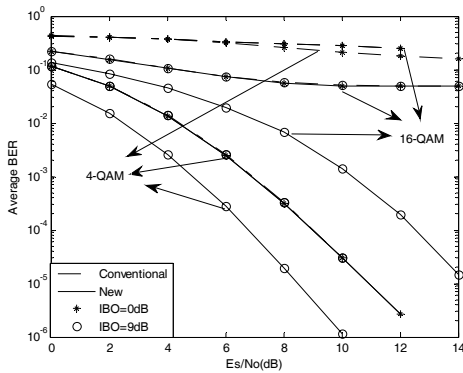


Fig. 9. Average BERs in non-ideal Amp. for $N_t = 8, N_r = 8$

multiple RF chains, while the conventional scheme only requires one RF active chain. However, the new scheme could use cheaper RF chains with small linear range than conventional one due to PAPR. On the other hand, some new SM scheme [13-14] could achieve a higher data rate at the cost of single antenna transmission or single RF chain.

V. Conclusion

In this paper, we uniformly scattered the power originally focused on single antenna into all transmit antennas by means of a non-zero unitary matrix so that achieved the goal of reducing peak power or PAPR without any loss of performance. Obviously, the single antenna transmission is changed to multiple antennas transmission by the proposed method, and the enhancement of new scheme is achieved by distributing the power over all antennas.

The new scheme retains the key advantage of avoiding ICI due to the orthogonality of unitary matrix, but the synchronization of multiple active antennas is required to eliminate the inter-symbol interference (ISI) caused by multiple antennas transmission. Furthermore, the simulation results also show that, as the number of transmit antennas increases, the effect of reducing PAPR can be more obvious. In detail, the proposed method can reduce $10\log_{10}N_t dB$ PAPR value.

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