Hindawi Publishing Corporation
International Journal of Antennas and Propagation
Volume 2013, Article ID 718482, 5 pages
http://dx.doi.org/10.1155/2013/718482

Research Article

Power Scaling for Spatial Modulation with Limited Feedback

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Received 8 February 2013; Revised 6 May 2013; Accepted 8 May 2013

Academic Editor: Feifei Gao

Spatial modulation (SM) is a recently developed multiple-input multiple-output (MIMO) technique which offers a new tradeoff between spatial diversity and spectrum efficiency, by introducing the indices of transmit antennas as a means of information modulation. Due to the special structure of SM-MIMO, in the receiver, maximum likelihood (ML) detector can be combined with low complexity. For further improving the system performance with limited feedback, in this paper, a novel power scaling spatial modulation (PS-SM) scheme is proposed. The main idea is based on the introduction of scaling factor (SF) for weighting the modulated symbols on each transmit antenna of SM, so as to enlarge the minimal Euclidean distance of modulated constellations and improve the system performance. Simulation results show that the proposed PS-SM outperforms the conventional adaptive spatial modulation (ASM) with the same feedback amount and similar computational complexity.

1. Introduction

Spatial modulation (SM) [1] is a recently proposed multiple-input multiple-output (MIMO) transmission technique, in which the index of the transmit antenna is utilized for information modulation in the spatial domain. The main advantages of SM-MIMO can be described as follows. Firstly, only one transmit antenna is active on each time slot so that strict time synchronization is saved. Secondly, SM-MIMO can be used for any number of receive antennas so that it adapts to downlink communications on an unbalanced MIMO channels in which the number of transmit antennas is much larger than that of receive antennas. Finally, SM-MIMO can offer a new balance between spectrum efficiency and spatial diversity compared to the conventional MIMO techniques [2, 3].

For detecting the SM-MIMO signals at the receiver side, maximum likelihood (ML) algorithm was suggested in [4] to achieve the optimal performance, which also gives a performance bound of the SM-MIMO system. For controlling the computational complexity of ML detection while approaching the performance bound, in current research, a series of near-ML detectors has been proposed [5–7] to make a tradeoff between complexity and performance.

Traditional SM-MIMO cannot exceed the ML performance bound. In this case, for further improving the system performance, in recent research, limited feedback was considered for link adapted SM-MIMO. However, these techniques have their disadvantages. For example, adaptive SM (ASM) was firstly proposed in [8] to select the modulation styles according to the channel information. In ASM, the transmission rate of each data frame is not fixed, which is not good for system design. And error propagation may happen in low-SNR domain due to the wrong demodulation for any single data symbol. Furthermore, a combination of adaptive spatial modulation and antenna section scheme is proposed in [9] to enhance the performance. However, it inherits the drawbacks of ASM, and the introduction of additional antennas will introduce extra implementation cost and channel estimation complexity.

This paper considers another aspect as adaptive power scaling for SM-MIMO with limited feedback. A novel power scaling spatial modulation (PS-SM) scheme is proposed, based on the introduction of scaling factor (SF) for weighting the modulated symbols and enlarging the minimum Euclidean distance of the transmit signals. As a result the proposed method can effectively improve the system performance. We will show that the proposed PS-SM outperforms the conventional adaptive spatial modulation (ASM) with the same feedback. In this case, PS-SM can be an alternative scheme to ASM schemes by overcoming their disadvantages.

Furthermore, the enlarging of the minimum distance could lead to an improvement of equivalent transmit power. In this paper, a power attenuation factor is introduced to keep the minimal transmit power for improving the energy efficiency.

The rest of the paper is organized as follows. In Section 2, the basic structure of SM-MIMO and main idea of adaptive schemes are summarized. The proposed PS-SM scheme is described in Section 3. In Section 4, bit-error rate (BER) performance of PS-SM and conventional schemes are disclosed by simulation results. Finally, conclusions are given in Section 5.

2. Conventional SM and Adaptive Scheme

Assume an SM-MIMO [1] with N transmit and M receive antennas. The information bits vector $\mathbf{b}$, with length L, can be divided into two parts as $\log_2 N$ and $\log_2 P$ (P is the size of QAM constellation) bits, as $L = \log_2 NP$. Then the bit information vector $\mathbf{b}$ is mapped into transmit vector $\mathbf{x} = [0, \ldots, x_n^p, \ldots, 0]$ with length N, in which there is only one nonzero element x_n^p, where n is the index of transmit antennas with $n \in [1, 2, \ldots, N]$ and p is the index of QAM constellation with $p \in [1, 2, \ldots, P]$. Let $\mathbf{H}$ be the $M \times N$ MIMO channel matrix. Then the receive vector $\mathbf{y}$, with length M, can be written as

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{n} = \mathbf{h}_n x_n^p + \mathbf{n}, \tag{1}$$

where $\mathbf{h}_n$ represents the nth column of $\mathbf{H}$ and $\mathbf{n}$ is AWGN noise with variance of σ^2.

For optimal ML detector [4], the estimated SM-MIMO symbol is given by

$$\hat{\mathbf{x}} = \arg\min_{\mathbf{x}\in\Lambda} \left\|\mathbf{y} - \mathbf{H}\mathbf{x}\right\|_F^2, \tag{2}$$

where $\hat{\mathbf{x}}$ denotes the estimated transmit symbol vector, Λ is the set of all possible transmit symbols, and $\|\cdot\|_F$ represents the Frobenius norm of the vector.

The performance bound of ML detection is decided by the minimal Euclidean distance $d_{\min}$, defined as [8]

$$d_{\min} = \min_{\substack{\mathbf{x}_i,\mathbf{x}_j\in\Lambda,\\ \mathbf{x}_i\neq\mathbf{x}_j}} \left\|\mathbf{H}\left(\mathbf{x}_i - \mathbf{x}_j\right)\right\|_F. \tag{3}$$

In general, the minimal Euclidean distance $d_{\min}$ is determined by the transmit vector $\mathbf{x}$ and channel matrix $\mathbf{H}$ for conventional SM. In ASM [8, 9], the modulation styles for each antenna can be selected to offer extra freedom for generating a larger $d_{\min}$. However, ASM schemes suffer from a nonconstant data rate when different antennas employ different modulation styles. For instance, for an SM-MIMO with 2 transmit antennas, if the first and second antennas separately select BPSK and QPSK, the data rate may be variable between 2 and 3 bits/slot. Furthermore, in the receiver side, if the antenna index is estimated incorrectly, the number of the received bits will differ from that of original transmission, which will cause consecutive errors.

3. Power Scaling Spatial Modulation

For avoiding the drawback of ASM schemes, in this paper, a novel power scaling spatial modulation scheme is proposed. The system block is shown in Figure 1. Firstly, the information bits are divided into two parts to modulate the digital constellations and the active transmit antenna index. Then at each time instant one active transmit antenna is selected with a scaling factor (SF) $w_{n,k}$, $n = 1, 2, \ldots, N$, $k = 1, 2, \ldots, K$, for weighting the modulated symbols, where $w_{n,k} \in (0, 1]$ and K is the total number of candidate SF groups. In this case, the transmit SM symbol can be expressed as $\mathbf{x} = [0, \ldots, w_{n,k}x_n^p, \ldots, 0]$. For normalizing the transmit power, let $\sum_{n=1}^N w_{n,k}^2 = N$. According to (1) and (3), in PS-SM, the minimal Euclidean distance is a function of k, given and further computed as

$$\begin{aligned}
d_{\min}(k) &= \min_{u\neq v \text{ or } i\neq j} \left\|w_{i,k}x_i^u\mathbf{h}_i - w_{j,k}x_j^v\mathbf{h}_j\right\|_F \\
&= \min_{u\neq v \text{ or } i\neq j} \left\|\begin{pmatrix} w_{i,k}x_i^u h_{1,i} \\ w_{i,k}x_i^u h_{2,i} \\ \vdots \\ w_{i,k}x_i^u h_{M,i}\end{pmatrix} - \begin{pmatrix} w_{j,k}x_j^v h_{1,j} \\ w_{j,k}x_j^v h_{2,j} \\ \vdots \\ w_{j,k}x_j^v h_{M,j}\end{pmatrix}\right\|_F \\
&= \min_{u\neq v \text{ or } i\neq j} \sqrt{x_i^u w_{i,k} m_1 + x_j^v w_{j,k} m_2 - 2\Re\left(x_i^u x_j^{v*} w_{i,k} w_{j,k} m_3\right)}
\end{aligned} \tag{4}$$

with

$$\begin{aligned}
m_1 &= \left|h_{1,i}^2\right|^2 + \left|h_{2,i}^2\right|^2 + \cdots + \left|h_{M,i}^2\right|^2 = \left\langle \mathbf{h}_i, \mathbf{h}_i\right\rangle, \\
m_2 &= \left|h_{1,j}^2\right|^2 + \left|h_{2,j}^2\right|^2 + \cdots + \left|h_{M,j}^2\right|^2 = \left\langle \mathbf{h}_j, \mathbf{h}_j\right\rangle, \\
m_3 &= h_{1,i}h_{1,j}^* + h_{2,i}h_{2,j}^* + \cdots + h_{M,i}h_{M,j}^* = \left\langle \mathbf{h}_i, \mathbf{h}_j\right\rangle,
\end{aligned} \tag{5}$$

where $\Re(\cdot)$ denotes the real part of the input and m_1, m_2, m_3 are the inner products of the columns of the channel matrix and can be reused for reducing the calculation complexity. Comparing (4) to the processing of [8], it is shown that the proposed PS-SM scheme has similar computational complexity as ASM.

From every possible set of SF candidates as $w_{n,k}$, $k = 1, 2, \ldots, K$, there is one minimal Euclidean distance $d_{\min}(k)$. Then the optimal value of $d_{\min}(k_{\text{opt}})$, which is defined as the maximal value of $d_{\min}(k)$, is expressed as

$$k_{\text{opt}} = \arg\max\left\{d_{\min}(k)\right\}, \quad k = 1, \ldots, K. \tag{6}$$

The only limitations for the selection of SF are given as $w_{n,k} \in (0, 1]$ and $\sum_{n=1}^N w_{n,k}^2 = N$. For example, we target a 2×2 PS-SM-MIMO transmission system with the scaling factors obeying uniform distribution, which is generated in Table 1, as $w_{n,k} \in \{\sqrt{0.333}, \sqrt{0.667}, \sqrt{1, 1.333}, \sqrt{1.667}\}$. With limited feedback, the proposed PS-SM algorithm presets the same candidate SF sets at both transceiver sides. And the selected

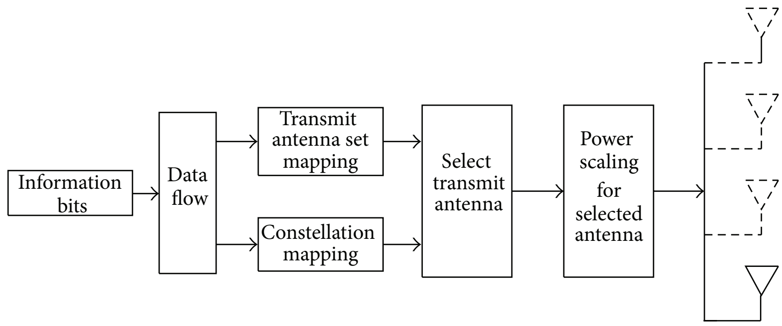

Figure 1: Block diagram of proposed power scaling SM-MIMO system.

Table 1: An SF generation example for 2 × 2 PS-SM.

Index	SF for Tx1	SF for Tx2
1	$\sqrt{0.333}$	$\sqrt{1.667}$
2	$\sqrt{0.667}$	$\sqrt{1.333}$
3	1	1
4	$\sqrt{1.333}$	$\sqrt{0.667}$
5	$\sqrt{1.667}$	$\sqrt{0.333}$

index of the optimal candidate will be delivered to the transmitter.

Figure 2 gives the complementary cumulative distribution functions (CCDF) of the minimum Euclidean distance for a 4 × 2 PS-SM-MIMO and conventional SM-MIMO. It is shown that with the introduction of scaling factor, the minimum Euclidean distance can be enlarged effectively. Moreover, with the increase in feedback amount, the increase in minimum Euclidean distance is more considerable. In this case, the system performance will be effectively improved. The following simulation results will show the benefit of PS-SM to system performance. In this case, the proposed PS-SM is an alternative scheme by overcoming the disadvantage of traditional ASM.

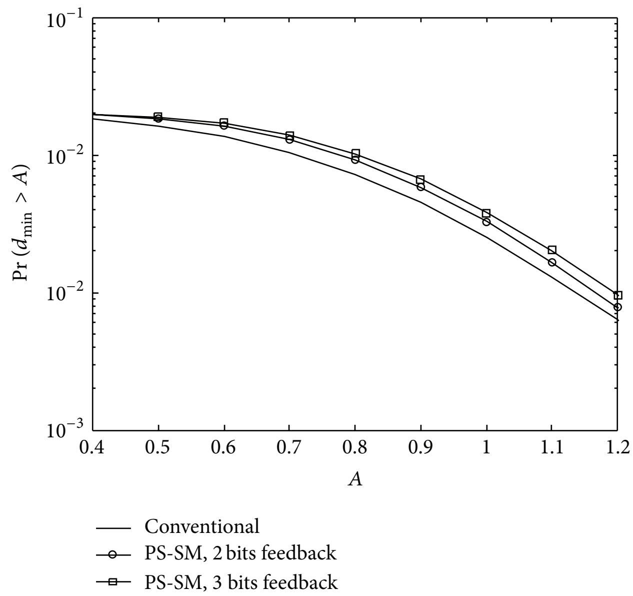

Figure 2: The distribution of minimal Euclidean distance for conventional and proposed methods.

4. Simulation Results

Computer simulation is performed for comparing the system performance of conventional SM, ASM, and PS-SM. We consider an SM-MIMO system with 2 and 4 transmit antennas and QPSK modulation under Rayleigh flat fading channel, so the transmission data rate is 3 and 4 bits per symbol, respectively. The number of receive antennas is 2. Assume that the channel information of Rayleigh flat fading channel is perfectly estimated at the receiver side.

Figure 3 gives the system performance of 2×2 SM-MIMO system. Both ASM, and PS-SM schemes are with 5 candidates for a fair comparison. Firstly, with limited feedback, both ASM and PS-SM outperform conventional SM. For example, at BER of 10^{-3}, there is a 1.7 dB SNR gap between ASM and conventional SM. Furthermore, with the same amount of candidate adaptive sets, the proposed PS-SM outperforms ASM. More specifically, at BER of 10^{-3}, 0.9 dB SNR gain can be achieved by the proposed PS-SM scheme.

Figure 4 shows the comparison of system performance of PS-SM with different amounts of feedback as 1, 2, and 3 bits in which 2, 4, and 8 candidate SF sets are assumed, respectively. The system is with 4 × 2 transceiver configuration and QPSK modulation. It is shown that the performance of PS-SM improves with the increase in the number of feedback bits which is related to the number of factor candidates. At a BER of 10^{-3}, there are 2.5 dB, 3.8 dB, and 4.4 dB performance gains in PS-SM with 1-bit, 2-bit, and 3-bit feedback, respectively. In this case, a feedback of 2 bits gives a better tradeoff between feedback amount and system performance.

Since PS-SM can effectively enlarge the minimum Euclidean distance, the equivalent transmit power is also enlarged. In this part, we consider a tradeoff between system performance and energy-efficient minimum power transmission (Figure 5). A power attenuation factor is introduced to normalize the enlarged minimum Euclidean distance to original SM. In this case, we keep the same system performance to traditional SM while minimizing the transmit power for improving the energy efficiency. A PS-SM with different

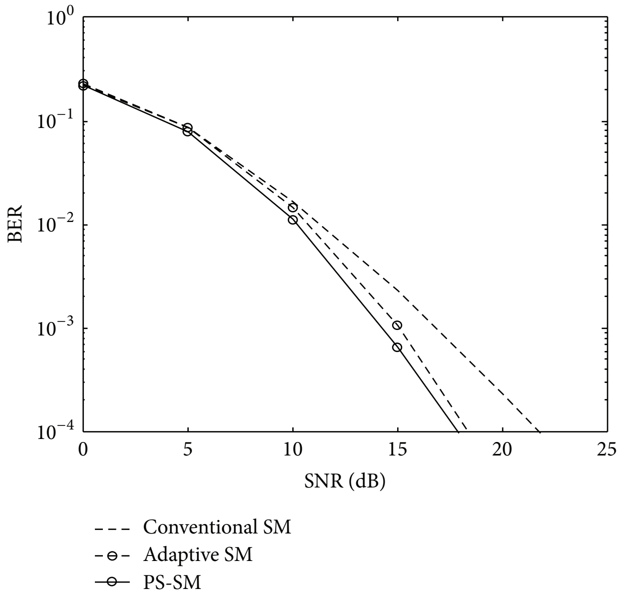

Figure 3: Performance comparison of SM, ASM, and PS-SM on 2×2 MIMO channels.

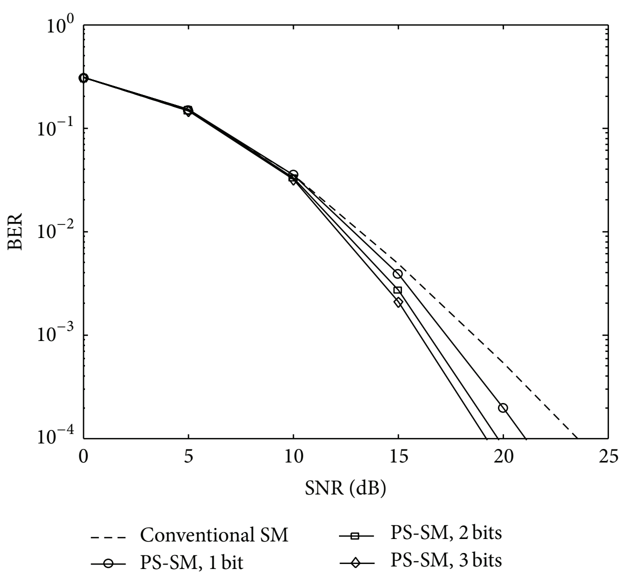

Figure 4: Performance of PS-SM with different feedback amounts on 4 × 2 MIMO channels.

amounts of feedback as 1, 2, and 3 bits in which 2, 4, and 8 candidate SF sets are assumed, respectively. The system is with 4 × 2 transceiver configuration and QPSK modulation. A PS-SM with different amounts of feedbacks as 1, 2, and 3 bits are assumed, with 2, 4, and 8 candidates SF sets respectively. Furthermore, energy saving of 0.4 dB, 1.5 dB, and 2.2 dB is achieved with feedback amounts of 1, 2, and 3 bits, respectively.

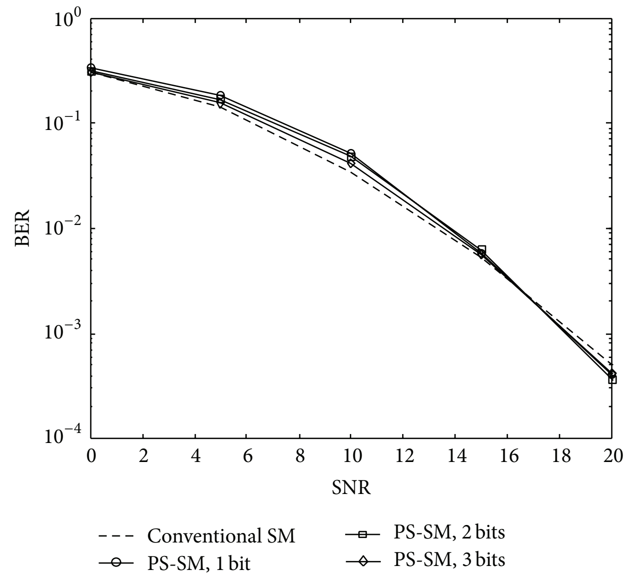

Figure 5: Performance of PS-SM with minimum transmit power.

5. Conclusions

For overcoming the disadvantages of original ASM schemes, a novel power scaling spatial modulation scheme was proposed as an alternative adaptive SM-MIMO scheme with limited feedback. In PS-SM, multiple candidate scaling factor sets are introduced for weighting the modulated symbols on each transmit antenna, so as to enlarge the minimal Euclidean distance and improve the system performance. Simulation results showed that the proposed PS-SM outperforms ASM schemes with the same feedback amount on similar computational complexity.

Acknowledgments

This work was supported in part by the National Science Foundation of China under Grant no. 61101101, the National High-Tech R&D Program of China ("863" Project under Grant no. 2011AA01A105), and the Foundation Project of National Key Laboratory of Science and Technology on Communications under Grant 9140C020404110C0201.

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