Wireless Pers Commun (2013) 71:2937–2945
DOI 10.1007/s11277-012-0980-0

Robust Transmit Antenna Selection with Phase Feedback Over Correlated Fading Channels

Van-Bien Pham

Published online: 6 January 2013

Abstract A new transmit antenna selection (TAS) scheme with phase feedback for multiple-input multiple-output systems is proposed in this paper. This scheme allows two or more transmit antennas to simultaneously use one radio frequency chain. By grouping the transmit antennas according to their similarities in instantaneous channel coefficients into two subsets and treating each subset as a single antenna, both hardware complexity reduction and antenna array gain can be achieved. Compared with the transmit antenna selection combined with space-time block code (TAS/STBC) scheme, the proposed TAS scheme provides excellent robustness, in terms of symbol error rate performance, against spatially correlated fading channels. Moreover, the proposed TAS scheme need not use STBC encoder and decoder which used in the TAS/STBC schemes. Therefore, the proposed TAS scheme is simpler than the TAS/STBC schemes in practical hardware implementation.

Keywords Transmit antenna selection · Phase feedback · Space-time block code

1 Introduction

Multiple-input multiple-output (MIMO) systems provide significant enhancement on data rate and link reliability. This enhancement comes along with extra complexity, size and price in system hardware design, since each antenna port is required to connect with one radio frequency (RF) chain. Antenna selection techniques that can reduce the cost and attain many of the advantages of MIMO systems are of great interest [1]. Of the existing selection techniques, transmit antenna selection (TAS) is an important category. Using TAS, one antenna or a subset of the antennas is selected for transmission. It is shown in [2–4] that, in a TAS-based MIMO system, full diversity benefits can be retained as if all the transmit antennas were in use. Numerous TAS schemes combined with space-time coding have been proposed [2,3,5]. In particular, Gore et al. [2] proposed to combine TAS with space-time block code

V.-B. Pham (✉)
Faculty of Radio-Electronics, Le Quy Don Technical University, Hanoi, Vietnam
e-mail: bienngaxanh@gmail.com

(TAS/STBC) in which two out of all transmit antennas are selected to transmit data using Alamouti code [6]. It is worthwhile to point out that all the existing antenna selection schemes assume by default that there is a one-to-one mapping between the selected antennas and the available RF chains. In practice, due to insufficient antenna spacing or surrounding scatters, spatial correlation occurs between the path gains associated with different transmit-receive antenna pairs. Strong spatial correlation incurs substantial loss in channel capacity [7]. With transmit antenna correlation, as the degree of randomness to be exploited via antenna selection decreases, TAS/STBC schemes may not be as effective as when the transmit antennas are independent. In [8], Tao et al. proposed a TAS scheme with extended space-time block code (TAS/ESTBC) tailored for spatially correlated fading channels. In TAS/ESTBC scheme, the transmit antennas are selectively grouped into two subsets, each subset connecting with one RF chain. Alamouti code [6] is then applied on top of the two subsets as if each was a single antenna. The TAS/ESTBC scheme outperforms the TAS/STBC scheme in correlated channels, but performance is worse in uncorrelated channels.

This paper introduces a new TAS scheme tailored for the both spatially correlated and uncorrelated fading channels. This scheme allows two or more transmit antennas to simultaneously use a common RF chain and hence to transmit identical signals. The transmitter hardware cost is cheaper than that of existing TAS/STBC and TAS/ESTBC schemes due to avoiding STBC encoder and decoder in transceivers. An exemplary system with four transmit antennas is considered. We use ideal of the TAS/ESTBC scheme [8] where the antennas are selectively grouped into two subsets, each consisting of two antennas and connecting with one RF chain. However, instead of applying Alamouti code [6] on top of the two subsets as performed in the TAS/ESTBC scheme, we apply directly transmitted signal s to all antenna in the first subset and its rotated version $e^{\mathbf{j}\theta} s$ to all antenna in the second subset, where θ is feedback phase from receiver to transmitter and $\mathbf{j}^2 = -1$. The grouping criterion is to maximize the instantaneous received signal-to-noise ratio (SNR) for transmitted symbol, and correspondingly to minimize the probability of symbol error. Simulation results show that the proposed scheme can provide a SNR gain over the conventional TAS/STBC scheme [2] and the TAS/ESTBC scheme [8] up to 1dB (or 4.6 dB) and 1.6 dB (or 2.6 dB) in transmit uncorrelated (or correlated) fading channels.

The rest of this paper is organized as follows. In Sect. 2 presents the channel model and transmitter and receiver structures of the proposed TAS scheme. Performance comparison with existing schemes is carried out in Sect. 3. Conclusions are presented in Sect. 4.

2 The Proposed TAS Scheme

2.1 Channel Model

Consider to a narrow-band communication link with N_{T} transmit antennas (Tx) and N_R receive antennas (Rx), the channel is assumed to be frequency-nonselective Rayleigh fading. It remains approximately constant during a transmission frame but can vary from one frame to another. We further consider that the antennas at both communication sides are not necessarily placed sufficiently apart from each other so that spatial correlation may occur. To focus on the effect of transmit antenna correlation on the performance of transmit antenna selection, we adopt the "one-ring" channel model in [7, Fig. 1], where the transmitter is elevated and unobstructed, whereas the receiver is surrounded by local scatters. For this channel model, we let the antenna spacing at the receiver side be large enough that the fades associated with different receive antennas are independent, but those associated with different transmit

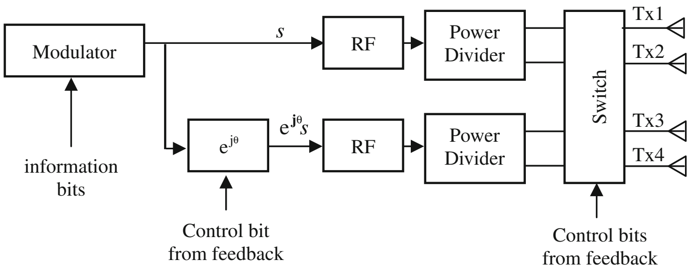

Fig. 1 Simplified transmit diagram of the proposed TAS scheme using two RF chains and four antennas

antennas are correlated. Mathematically, let $\boldsymbol{H}$ be the $N_R \times N_T$ channel matrix, of which the (n, m)-th element, $h_{n,m}$ is the channel coefficient for the path from the m-th transmit antenna to the n-th receive antenna. Then, the N_R rows of the channel matrix $\boldsymbol{H}$ can be modeled as independent and identically distributed (i.i.d.) complex Gaussian row vectors with covariance matrix $\boldsymbol{R}_T$. The (m, k)-th element of $\boldsymbol{R}_T$ is defined as $\boldsymbol{R}_T(m, k) = \mathrm{E}\left[h_{n,m}h^*_{n,k}\right]$, where notation $\mathrm{E}[\cdot]$ stands for expectation. Let $\boldsymbol{B}$ be a square root of the matrix $\boldsymbol{R}_T$ so that $\boldsymbol{B}\boldsymbol{B}^H = \boldsymbol{R}_T$, with the superscript H denoting conjugate transpose. The statistical properties of $\boldsymbol{H}$ are then identical to those of the product matrix $\tilde{\boldsymbol{H}}\boldsymbol{B}^{\mathrm{H}}$. Here, $\tilde{\boldsymbol{H}}$ is an $N_R \times N_T$ matrix with independent identically distributed complex Gaussian entries of zero mean and unit variance. We shall use this statistical equivalence to generate each channel realization in numerical analysis in Sect. 3. Note that this method has been widely used in [2,7] and [8].

2.2 The Proposed TAS Scheme

The transmitter architecture of the proposed scheme for $N_T = 4$ transmit antennas using two RF chains is depicted in Fig. 1. The modulated signal s is divided into two branches. The first branch is up-converted to a radio channel by the first RF chain. The second branch is passed a phase rotator $e^{j\theta}$. The output signal of the phase rotator $e^{j\theta}\,s$ is up-converted to a radio channel by the second RF chain. A typical RF chain consists of a digital-to-analog converter, a frequency up-converter and a power amplifier. The passband signal from each chain is then split into two sub-signals with the aid of a power divider. The mapping between the four transmit antennas and the four RF signal sub-signals is implemented in the switch unit. The receiver informs the transmitter of the switch setting and phase angle θ according to the latest channel state information through a feedback channel with limited capacity.

The *baseband equivalence* of the resulting passband signals transmitted on the four antennas within one symbol interval can be represented by

$$\boldsymbol{X} = \sqrt{\frac{E_s}{4}}\left[\, s \;\; s \;\; e^{j\theta}s \;\; e^{j\theta}s \,\right]^{\mathrm{T}} \tag{1}$$

with the superscript T denoting transpose.

In (1), s is independent complex-valued information symbol with unit average energy, and $E_s/4$ is the radiation power on each antenna. The factor 1/4 is to assure that the system total radiation power is independent of the number of transmit antennas and equal to E_s. The baseband received signals on the N_R receive antennas denoted by $N_R \times 1$ vectors $\boldsymbol{y}$ can thus be written as:

$$y = \sqrt{\frac{E_s}{4}} \boldsymbol{H} s + \boldsymbol{n} \tag{2}$$

where $\boldsymbol{n}$ is the complex additive white Gaussian noise vector with each entry being independent and having mean zero and variance N_0 and $\boldsymbol{H}$ is equivalent channel matrix

$$\boldsymbol{H} = \boldsymbol{h}_1 + \boldsymbol{h}_2 + \mathrm{e}^{\mathbf{j}\theta} \boldsymbol{h}_3 + \mathrm{e}^{j\theta} \boldsymbol{h}_4 \tag{3}$$

where, $\boldsymbol{h}_i = \left[h_{i,1} \; h_{i,2} \; \ldots \; h_{i,N_R} \right]^{\mathrm{T}}, i = 1, 2, 3, 4$. Thus, the instantaneous received SNR for symbol s is

$$\begin{aligned} \gamma &= \frac{\gamma_0}{4} \left\| \boldsymbol{h}_1 + \boldsymbol{h}_2 + \mathrm{e}^{\mathbf{j}\theta} \boldsymbol{h}_3 + \mathrm{e}^{\mathbf{j}\theta} \boldsymbol{h}_4 \right\|^2 \\ &= \frac{\gamma_0}{4} \left\{ \sum_{m=1}^{4} \|\boldsymbol{h}_m\|^2 + 2\mathrm{Re}\left(\boldsymbol{h}_1^{\mathrm{H}} \boldsymbol{h}_2 + \boldsymbol{h}_3^{\mathrm{H}} \boldsymbol{h}_4\right) + 2\mathrm{Re}\left[\mathrm{e}^{\mathbf{j}\theta}\left(\boldsymbol{h}_1^{\mathrm{H}} \boldsymbol{h}_3 + \boldsymbol{h}_1^{\mathrm{H}} \boldsymbol{h}_4 + \boldsymbol{h}_2^{\mathrm{H}} \boldsymbol{h}_3 + \boldsymbol{h}_2^{\mathrm{H}} \boldsymbol{h}_4\right)\right] \right\} \end{aligned} \tag{4}$$

In which $\gamma_0 \triangleq E_s/N_0$ is the system total transmit SNR, $\|\cdot\|^2$ represents the squared Euclidean norm, and Re $(\cdot)$ means the real part.

2.3 Feedback Bits Selection

Let $\hat{\boldsymbol{H}} = \hat{\boldsymbol{h}}_1 + \hat{\boldsymbol{h}}_2 + e^{j\theta} \hat{\boldsymbol{h}}_3 + e^{j\theta} \hat{\boldsymbol{h}}_4$ denote the effective channel matrix obtained by swapping the columns of the original channel matrix $\boldsymbol{H}$ according to the control bits from the feedback channel. Thus, the instantaneous received SNR for each symbol s is

$$\begin{aligned} \gamma = \frac{\gamma_0}{4} \Bigg\{ & \sum_{m=1}^{4} \|\boldsymbol{h}_m\|^2 + 2\mathrm{Re}\left(\hat{\boldsymbol{h}}_1^{\mathrm{H}} \hat{\boldsymbol{h}}_2 + \hat{\boldsymbol{h}}_3^{\mathrm{H}} \hat{\boldsymbol{h}}_4\right) \\ & + 2\mathrm{Re}\left(\mathrm{e}^{\mathbf{j}\theta}\left(\hat{\boldsymbol{h}}_1^{\mathrm{H}} \hat{\boldsymbol{h}}_3 + \hat{\boldsymbol{h}}_1^{\mathrm{H}} \hat{\boldsymbol{h}}_4 + \hat{\boldsymbol{h}}_2^{\mathrm{H}} \hat{\boldsymbol{h}}_3 + \hat{\boldsymbol{h}}_2^{\mathrm{H}} \hat{\boldsymbol{h}}_4\right)\right) \Bigg\} \end{aligned} \tag{5}$$

To minimize the instantaneous probability of symbol error for a given channel realization $\boldsymbol{H}$, we need to maximize the received SNR γ in (5). Firstly, we should choose a swapping $\left\{\hat{\boldsymbol{h}}_1, \hat{\boldsymbol{h}}_2, \hat{\boldsymbol{h}}_3, \hat{\boldsymbol{h}}_4\right\}$ that produces the largest value of Re $\left(\hat{\boldsymbol{h}}_1^{\mathrm{H}} \hat{\boldsymbol{h}}_2 + \hat{\boldsymbol{h}}_3^{\mathrm{H}} \hat{\boldsymbol{h}}_4\right)$. Then, in order to obtain maximum value of $2\mathrm{Re}\left(\mathrm{e}^{\mathbf{j}\theta}\left(\hat{\boldsymbol{h}}_1^{\mathrm{H}} \boldsymbol{h}_3 + \hat{\boldsymbol{h}}_1^{\mathrm{H}} \hat{\boldsymbol{h}}_4 + \hat{\boldsymbol{h}}_2^{\mathrm{H}} \hat{\boldsymbol{h}}_3 + \hat{\boldsymbol{h}}_2^{\mathrm{H}} \hat{\boldsymbol{h}}_4\right)\right)$, $\mathrm{e}^{\mathbf{j}\theta}$ should satisfy the exact channel phase rotation as follows.

$$\mathrm{e}^{\mathbf{j}\theta}\left(\hat{\boldsymbol{h}}_1^{\mathrm{H}} \boldsymbol{h}_3 + \hat{\boldsymbol{h}}_1^{\mathrm{H}} \hat{\boldsymbol{h}}_4 + \hat{\boldsymbol{h}}_2^{\mathrm{H}} \hat{\boldsymbol{h}}_3 + \hat{\boldsymbol{h}}_2^{\mathrm{H}} \hat{\boldsymbol{h}}_4\right) = \left|\hat{\boldsymbol{h}}_1^{\mathrm{H}} \hat{\boldsymbol{h}}_3 + \hat{\boldsymbol{h}}_1^{\mathrm{H}} \hat{\boldsymbol{h}}_4 + \hat{\boldsymbol{h}}_2^{\mathrm{H}} \hat{\boldsymbol{h}}_3 + \hat{\boldsymbol{h}}_2^{\mathrm{H}} \hat{\boldsymbol{h}}_4\right| \tag{6}$$

$$\theta = k\pi - \angle\left(\hat{\boldsymbol{h}}_1^{\mathrm{H}} \hat{\boldsymbol{h}}_3 + \hat{\boldsymbol{h}}_1^{\mathrm{H}} \hat{\boldsymbol{h}}_4 + \hat{\boldsymbol{h}}_2^{\mathrm{H}} \hat{\boldsymbol{h}}_3 + \hat{\boldsymbol{h}}_2^{\mathrm{H}} \hat{\boldsymbol{h}}_4\right); k \in \mathrm{Z} \tag{7}$$

In practical wireless communication systems, the number of feedback bits is required to be as small as possible. The reason is that large bits for exact channel phase feedback cause overhead in the receiver. Due to this practical limitation, the phase information θ to be fed back needs to be quantized, we propose here a 1-bit feedback based on the two choices of $\theta, \theta = 0$ or π, according to the following criterion:

$$\theta = \begin{cases} 0; & \text{if}\,\mathrm{Re}\left(\hat{\boldsymbol{h}}_1^{\mathrm{H}} \hat{\boldsymbol{h}}_3 + \hat{\boldsymbol{h}}_1^{\mathrm{H}} \hat{\boldsymbol{h}}_4 + \hat{\boldsymbol{h}}_2^{\mathrm{H}} \hat{\boldsymbol{h}}_3 + \hat{\boldsymbol{h}}_2^{\mathrm{H}} \hat{\boldsymbol{h}}_4\right) > 0 \\ \pi; & \text{otherwise} \end{cases} \tag{8}$$

3 Performance Comparisons

In this section we illustrate the performance of the proposed TAS scheme by comparing it with the TAS/STBC scheme [2] and the TAS/ESTBC scheme [8] in the number of feedback bits required, average received SNR gain and symbol error rate (SER) performance.

3.1 Feedback Bits

The number of information bits needed on the feedback path is also different for the different TAS schemes. In the TAS/ESTBC scheme [8], the legitimate antenna subset grouping methods include $\{(\boldsymbol{h}_1, \boldsymbol{h}_2), (\boldsymbol{h}_3, \boldsymbol{h}_4)\}$, $\{(\boldsymbol{h}_1, \boldsymbol{h}_3), (\boldsymbol{h}_2, \boldsymbol{h}_4)\}$, and $\{(\boldsymbol{h}_1, \boldsymbol{h}_4), (\boldsymbol{h}_3, \boldsymbol{h}_2)\}$. Thus, the feedback information required is 2 bits. In the TAS/STBC scheme [2], the total number of ways of selecting two out of the four transmit antennas is 6, which requires 3 feedback bits. In the proposed TAS scheme, it is required 2 feedback bits for swapping $\left\{\hat{\boldsymbol{h}}_1, \hat{\boldsymbol{h}}_2, \hat{\boldsymbol{h}}_3, \hat{\boldsymbol{h}}_4\right\}$ that produces the largest value of $\mathrm{Re}\left(\hat{\boldsymbol{h}}_1^{\mathrm{H}}\hat{\boldsymbol{h}}_2 + \hat{\boldsymbol{h}}_3^{\mathrm{H}}\hat{\boldsymbol{h}}_4\right)$ and 1 feedback bit for choosing phase angle θ (0 or π). Thus, the proposed TAS scheme requires 3 feedback bits. Clearly, the proposed TAS scheme and the TAS/STBC scheme [2] require the same number of feedback bits. And the proposed TAS scheme requires only one more bit in the feedback path than that of the TAS/ESTBC scheme [8] does.

3.2 Average SNR Gain

Recall that the baseband transmitted codeword in TAS/STBC scheme [2] using the same total radiation power E_s as in the proposed scheme can be described by the matrix.

$$\boldsymbol{G} = \sqrt{\frac{E_s}{2}} \begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix} \tag{9}$$

The instantaneous received SNR of each symbol after detection is given by

$$\gamma_{2/4} = \frac{\gamma_0}{2}\left\{\|\boldsymbol{h}_{1\max}\|^2 + \|\boldsymbol{h}_{2\max}\|^2\right\} \tag{10}$$

where $\boldsymbol{h}_{1\max}$ and $\boldsymbol{h}_{2\max}$ are the two columns of the channel matrix $\boldsymbol{H}$ with the largest Euclidean norms, and the subscript in $\gamma_{2/4}$ indicates a 2-out-of-4 transmit antenna selection. The quantity γ_0 in (10) is defined in the same way as in (4).

Recall that the baseband transmitted codeword in the TAS/ESTBC scheme [8] using the same total radiation power E_s as in the proposed scheme can be described by the matrix.

$$\boldsymbol{G} = \sqrt{\frac{E_s}{4}} \begin{bmatrix} s_1 & -s_2^* \\ s_1 & -s_2^* \\ s_2 & s_1^* \\ s_2 & s_1^* \end{bmatrix} \tag{11}$$

The instantaneous received SNR of each symbol after detection is given by

$$\gamma_{22} = \frac{\gamma_0}{4}\left\{\sum_{m=1}^{4}\|\boldsymbol{h}_m\|^2 + 2\mathrm{Re}\left(\hat{\boldsymbol{h}}_1^{\mathrm{H}}\hat{\boldsymbol{h}}_2 + \hat{\boldsymbol{h}}_3^{\mathrm{H}}\hat{\boldsymbol{h}}_4\right)\right\} \tag{12}$$

In the extreme case where $\{\boldsymbol{h}_m\}$ are fully correlated and $\boldsymbol{h}_m = \boldsymbol{h}, \forall m$, one can have $\bar{\gamma} = 4\gamma_0\|\boldsymbol{h}\|^2$, $\bar{\gamma}_{2/4} = \gamma_0\|\boldsymbol{h}\|^2$ and $\bar{\gamma}_{22} = 2\gamma_0\|\boldsymbol{h}\|^2$. Hence, the average received SNR of the

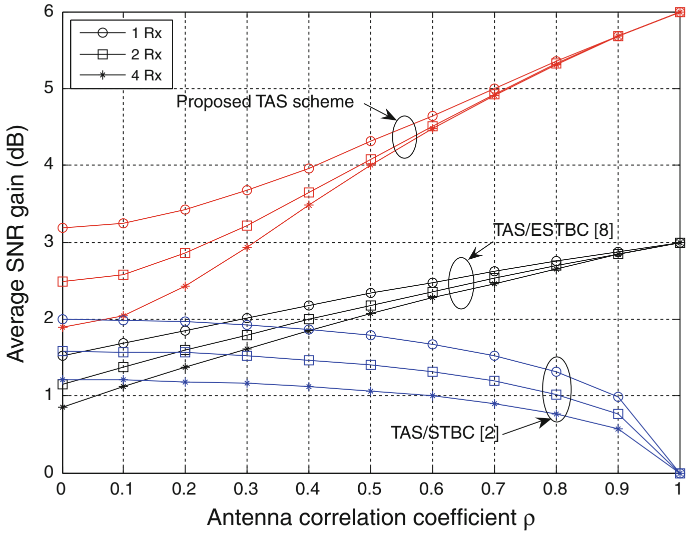

Fig. 2 Average received SNR gain comparison

proposed TAS scheme $\bar{\gamma}$ is 6 and 3 dB higher than that of TAS/STBC scheme $\bar{\gamma}_{2/4}$ [2] and the TAS/ESTBC scheme $\bar{\gamma}_{22}$ [8], respectively.

In the general case where the transmit antennas are arbitrarily correlated, it is difficult to evaluate the probability density functions of γ, $\gamma_{2/4}$ and γ_{22}. Thus, we resort to numerical methods for computing all γ, $\gamma_{2/4}$ and γ_{22} via simulation. For simplicity, it is assumed that an evenly correlated channel where the correlation coefficient between any pair of transmit antennas is the same and denoted as ρ. Let $g = 10\log_{10}\left(\frac{\bar{\gamma}}{\gamma_0 N_{\mathrm{R}}}\right)$, $g_{2/4} = 10\log_{10}\left(\frac{\bar{\gamma}_{2/4}}{\gamma_0 N_{\mathrm{R}}}\right)$ and $g_{22} = 10\log_{10}\left(\frac{\bar{\gamma}_{22}}{\gamma_0 N_{\mathrm{R}}}\right)$ denote the gain in average received SNR of the proposed TAS scheme, the TAS/STBC scheme [2] and the TAS/ESTBC scheme [8], respectively. Figure 2 shows the gains at different values of ρ and N_R. Each gain value is obtained by averaging over 10^5 independent channel realizations. It is observed that at arbitrarily transmit antenna correlation, the gain of the proposed TAS scheme is always higher than that of the TAS/STBC scheme [2] and the TAS/ESTBC scheme [8]. This implies that our scheme is more beneficial than the TAS/STBC scheme [2] and the TAS/ESTBC scheme [8] over both spatially correlated and uncorrelated fading channels. From Fig. 2 one can also observe that, as the correlation factor ρ increases the gap between g, $g_{2/4}$ and g_{22} also increases. Thus, it can be expected that the SER performance gain of the proposed TAS scheme over the TAS/STBC scheme [2] and the TAS/ESTBC scheme [8] should be higher when high correlated channels, but will always be upper bounded by 6 and 3 dB, respectively.

3.3 SER Performance

The above analysis based on the average received SNR serves as a good performance indicator, but is not sufficient for the comparison of average probability of error. In this subsection we provide simulation results to compare the symbol error rate between the proposed TAS scheme, the TAS/ESTBC scheme [8] and the TAS/STBC scheme [2]. In order to make clearly

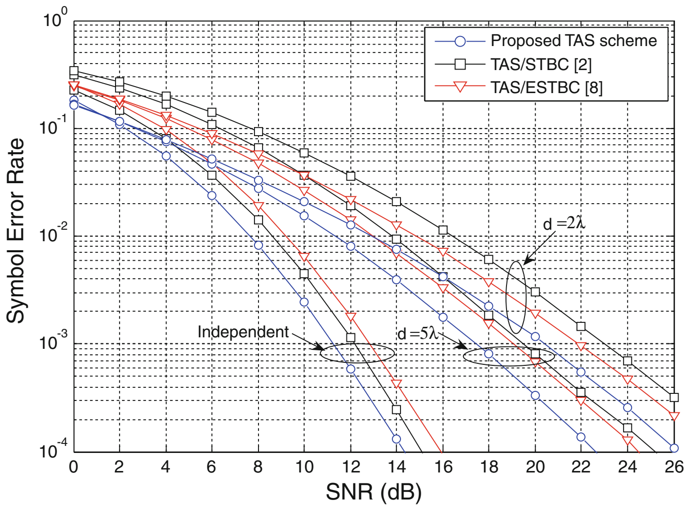

Fig. 3 Comparison of the SER performance with one receive antenna and 4QAM modulation

performance comparison, simulation parameters are chosen the same simulation parameters in [8].

The communication link follows the "one-ring" model and is equipped with a linear array consisting of N_T equally spaced antennas at the transmitter and with N_R or independent antennas at the receiver. It is assumed that the angle of departure is perpendicular to the transmit antenna array and that the angle spread (denoted by Δ) is small. Thus, by using the results in [7], the spatial correlation between the m-th and k-th transmit antennas can be approximated by $\boldsymbol{R}_T(m, k) = J_0(2\pi\Delta\,|m-k|\,d/\lambda)$, where λ is the carrier wavelength, d is the spacing between two adjacent antenna elements and $J_0(\cdot)$ is the zeroth-order Bessel function of the first kind. In our simulation, we fix the angle spread Δ to 0.6 degree and let the antenna spacing d vary. Here, simulation parameters.

Figures 3 and 4 illustrate the symbol error rate results with 4QAM modulation at various values of d using 1 receive antenna and 2 receive antennas, respectively. The total transmit SNR per symbol is defined as γ_0.

From Figs. 3 and 4, we can have several observations. Firstly, in the independent channels, the performance of the proposed TAS scheme is about 1dB (or 0.5 dB) and 1.6 dB (or 1.2 dB) better than that of the TAS/STBC scheme [2] and the TAS/ESTBC scheme [8] for one (or two) receive antenna. Secondly, as the transmit antenna correlation increases, by decreasing the antenna spacing d, the proposed TAS scheme becomes superior to the TAS/STBC scheme [2] and the TAS/ESTBC scheme [8]. Moreover, the performance improvement using two receive antennas is larger than the gain using one receive antenna. In particular, using two receive antennas, the proposed TAS scheme has an improvement of about 4.6 and 2.6 dB over the TAS/STBC scheme [2] and the TAS/ESTBC scheme [8] at all SNR regions can be observed when $d = 2\lambda$. On the other hand, an improvement of 5.6 and 2.94 dB in average received SNR is seen from Fig. 2 for $\rho = 0.96$ (which corresponds to the smallest antenna correlation coefficient at $d = 2\lambda$). We can see that the performance trend of the symbol error rate results matches very well with the comparison on average received SNRs, but the gains predicted in Fig. 2 are slightly optimistic. These results further confirm the benefits of using the proposed TAS scheme in both spatially correlated and uncorrelated fading channels.

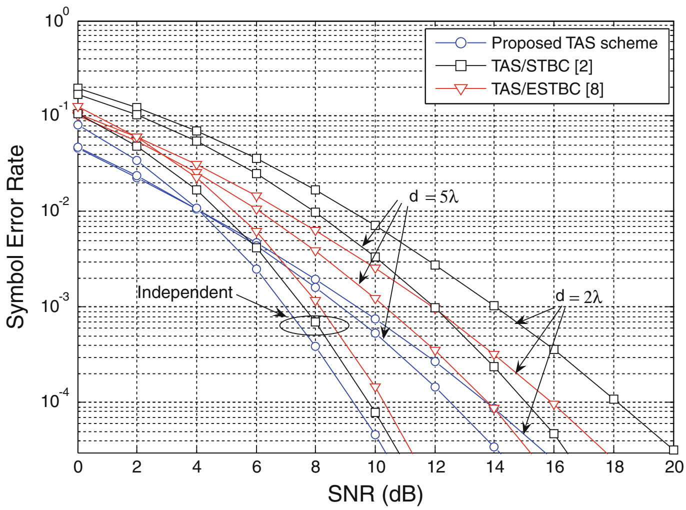

Fig. 4 Comparison of the SER performance with two receive antenna and 4QAM modulation

Notice: In [8], authors demonstrated that the TAS/ESTBC scheme is the best among related works [11–16] and it is only worse than the TAS/STBC scheme [2] under independent channel conditional. Therefore the results only are checked for references [2,8], but not be checked for compliance with other papers from literature.

4 Conclusions

A new TAS scheme with phase feedback for four transmit antennas was proposed. By grouping the transmit antennas according to their similarities in instantaneous channel coefficients into two subsets and treating each subset as a single antenna, both hardware complexity reduction and antenna array gain can be achieved. By combination of phase feedback and swapping transmit antennas between two subsets the proposed TAS scheme achieves better error performance than the existing TAS/STBC schemes over both spatially uncorrelated and correlated fading channels. Moreover, the proposed TAS scheme also is simpler than the existing TAS/STBC schemes in practical implementation due to avoiding STBC encoder and decoder in transceiver. For systems with more than four transmit antennas our scheme can be easily applied by grouping more antennas in each subset, as long as high transmit antenna correlation is present.

References

1. Sanayei, S., & Nosratinia, A. (2004). Antenna selection in MIMO systems. *IEEE Communications Magazine*, *42*(10), 68–72.
2. Gore, D. A., & Paulraj, A. J. (2002). MIMO antenna subset selection with space-time coding. *IEEE Transactions on Signal Processing*, *50*(10), 2580–2588.
3. Chen, Z., Yuan, J., Vucetic, B., & Zhou, Z. (2003). Performance of Alamouti scheme with transmit antenna selection. *IET Electronics Letters*, *39*(3), 1666–1668.
4. Thoen, S., Perre, L., Gyselinckx, B., & Engels, M. (2001). Performance analysis of combined transmit-SC/receive-MRC. *IEEE Transactions on Communications*, *49*(1), 5–8.

5. Chen, Z., Vucetic, B., & Yuan, J. (2003). Space time trellis codes with transmit antenna selection. *IET Electronics Letters*, *39*(11), 854–855.
6. Alamouti, S. M. (1998). A simple transmit diversity technique for wireless communication. *IEEE Journal on Select Areas in Communication*, *16*(8), 1451–1458.
7. Shiu, D. S., Foschini, G. J., Gans, M. J., & Kahn, J. M. (2000). Fading correlation and its effect on the capacity of multielement antenna systems. *IEEE Transactions on Communications*, *48*(3), 502–513.
8. Tao, M., Li, Q., & Garg, H. K. (2007). Extended space-time block coding with transmit antenna selection over correlated fading channels. *IEEE Transactions on Communications*, *6*(9), 3137–3141.
9. Liang, Y. (2010). MIMO systems with transmit antenna selection and power allocation over correlated channels. *Wireless Personal Communications*, *55*(2), 225–235.
10. Ahmet, Y., & Oguz, K. (2011). Performance of transmit antenna selection and maximal-ratio combining in dual hop amplify-and-forward relay network over Nakagami-*m* fading channels. Wireless Personal Communications, published online.
11. Tang, J., Zhang, X., & Du, Q. (2005). Alamouti scheme with joint antenna selection and power allocation over Rayleigh fading channels in wireless networks. *Proceedings of IEEE Globecom*, 6.
12. Chen, Z., Vucetic, B., & Yuan, J. (2005). Asymptotic performance of space-time block codes with imperfect transmit antenna selection. *IEEE Electronics Letter*, *41*(9), 538–540.
13. Machado, R., & Uchoa-Filho, B. F. (2004). Space-time block coding with hybrid transmit antenna/code slection. *Proceedings of IEEE International Conference on Communication*, *2*, 819–822.
14. Mukkavilli, K. K., Sabharwal, A., Erkip, E., & Aazhang, B. (2003). On beamforming with finite rate feedback in multiple antenna systems. *IEEE Transactions on Information Theory*, *49*, 2562–2579.
15. Heath, R. W., & Paulraj, A. J. (1998). A simple scheme for transmit diversity using partial channel feedback. *Proceedings of 32nd Asilomar Conference on Signals, Systems, and Computers*, *2*, 1073–1078.
16. Akhtar, J., & Gesbert, D. (2004). Extending orthogonal block codes with partial feedback. *IEEE Transactions on Wireless Commununications*, *3*(6), 1959–1962.

Author Biography

Van-Bien Pham received his B.S. and M.S. degrees in electronic engineering from Le Quy Don Technical University, Hanoi, Vietnam in 2002 and 2005, and his Ph.D. degree in information and communication engineering from Nanjing University of Science and Technology, Nanjing, China in June 2012. Now, he is a lecturer at Faculty of Radio-Electronics, Le Quy Don Technical University, Hanoi, Vietnam. His research interests include wireless communication, cognitive radio, multiple-antenna systems and space-time coding.