

# Space-time trellis codes with transmit antenna selection

Zhuo Chen, B. Vucetic and Jinhong Yuan

A scheme combining transmit antenna selection (TAS) and space-time trellis code (STTC), which is referred to as the TAS/STTC scheme, is considered. In this scheme, two transmit antennas, which maximise the signal-to-noise ratio (SNR) at the receiver, are chosen to transmit the baseline STTCs designed for two transmit antennas. It is shown by simulation that, similar to two other transmit antenna selection schemes investigated previously by the authors, this scheme also achieves a full diversity order as if all the transmit antennas were used. In addition, this scheme has a fixed low decoding complexity no matter how high the diversity order. Unlike the traditional STTC, this scheme does not have the requirement for minimum memory order to achieve a full diversity order.

*Introduction:* Transmit diversity has become a focus of extensive research due to the advantage of transferring complexity from the receiver to the transmitter. Among all the transmit diversity schemes, space-time trellis codes (STTCs) [1] are of particular interest because they can provide not only a full diversity order but also coding gain. At the mobile set, we normally have only one or two antennas. Therefore, to achieve a high diversity order, more than two transmit antennas have to be employed and the corresponding STTCs have to be designed. However, this is not an easy task and STTCs are designed for up to four transmit antennas in [2] and up to six antennas in [3]. As discussed in [1], the memory order has to be very large for STTCs for a large number of transmit antennas to achieve a full diversity order. For example, 64 and 1024 states is the minimum memory requirement for a 4-PSK STTC with four and six transmit antennas, respectively, not to mention higher constellation. This also makes the maximum likelihood decoding at the mobile very complicated.

It has been shown in several recent papers that transmit antenna selection is a good approach to achieving a high diversity order while maintaining low decoding complexity at the receiver. In [4] and [5], a scheme combining transmit antenna selection and maximal-ratio combining (the TAS/MRC scheme) is studied. In this scheme a single transmit antenna, which maximises the SNR at the receiver, is chosen for uncoded transmission and MRC is performed at the receiver. Another scheme combining transmit antenna selection and the space-time block code (STBC) (in particular the Alamouti scheme [6]) was investigated in [7] and [8], in which two transmit antennas, which maximise the SNR at the receiver, are chosen to transmit the Alamouti scheme at any time. It was referred to as the TAS/STBC scheme. The analytical bit error rate (BER) of these two schemes for binary phase-shift keying (BPSK) were presented in [5], [8] and [9]. It was shown by the BER expressions and simulation that these two schemes asymptotically achieve a full diversity order as if all the transmit antennas were used. A comparison between the two schemes is detailed in [9].

Heuristically, to address the issue of difficulty of STTC design and decoding complexity for large number of transmit antennas, we consider the combination of transmit antenna selection and existing STTCs designed for two transmit antennas. The two transmit antennas which maximise the SNR at the receiver are chosen out of all the available transmit antennas and the baseline STTCs for two transmit antennas are employed for transmission. We refer to it as the TAS/STTC scheme.

*System and channel model:* We consider an  $(n_T, n_R)$  wireless link in a quasi-static flat Rayleigh fading environment with  $n_T$  antennas at the transmitter and  $n_R$  antennas at the receiver. Let  $\mathbf{H}$  denote the  $n_R \times n_T$  channel matrix. Its entries are the fading coefficients  $h_{ij}$ ,  $1 \leq i \leq n_R$ ,  $1 \leq j \leq n_T$ , which are modelled as independent samples of complex Gaussian random variables with a zero mean and the variance of 0.5 per dimension. It is assumed that the channel state information (CSI) is perfectly available at the receiver side and partially known at the transmitter side. If at any time,  $N$  ( $N \leq n_T$ ) transmit antennas are chosen and activated for transmission and all the other transmit antennas are silent we refer to it as an  $(n_T, N; n_R)$  system. In this Letter, we only consider the  $(n_T, 2; n_R)$  case for the TAS/STTC scheme.

*Performance:* In this Section, we illustrate by simulation the performance of the TAS/STTC schemes. In the simulation, each frame

consists of 130  $M$ -PSK ( $M=4$  or 8) information symbols. The performance curves are plotted against SNR, the signal-to-noise ratio at each receive antenna. A quasi-static flat Rayleigh fading channel is assumed. All performance comparisons are carried out at a frame error rate (FER) of  $10^{-3}$ .

Fig. 1 compares the performance of the TAS/STTC scheme with the four-state 4-PSK TSC code [1] as the baseline code. A single receive antenna is assumed. It clearly shows that with two transmit antennas chosen from three, four and six antennas, a diversity order three, four and six has been asymptotically achieved, respectively, as if all the transmit antennas were used. For reference, the baseline TSC code without antenna selection is also presented. Note that all the four curves in Fig. 1 have the same low decoding complexity. Also note that the four-PSK STTC designed by the traditional way that achieves a full diversity order 6 should have at least 1024 states.

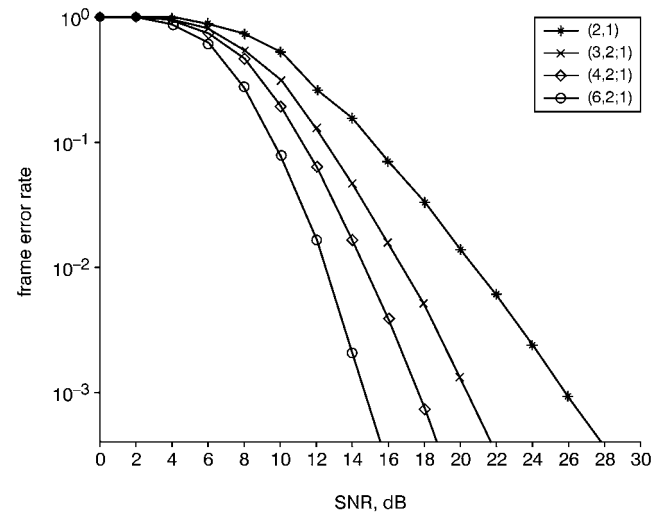


Fig. 1 Performance comparison of four-state 4-PSK TSC code with and without transmit antenna selection, a single receive antenna

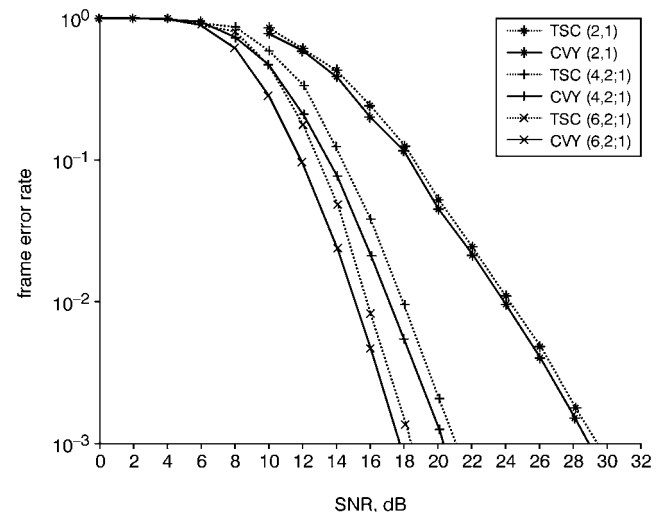


Fig. 2 Performance comparison of eight-state 8-PSK STTCs with and without transmit antenna selection, a single receive antenna

Fig. 2 shows the performance comparison between the eight-state 8-PSK TSC code [1] and CVY code ([10], Table 1) with and without transmit antenna selection. A single receive antenna is assumed. Without antenna selection, both codes achieve an asymptotic diversity order 2 and the CVY code is 0.4 dB superior to the TSC code. With two chosen from four available transmit antennas, both codes asymptotically achieve a diversity order 4 and the CVY code is superior by 0.7 dB. With two chosen from six available antennas, both codes achieve an asymptotic diversity order 6 and the CVY code is 0.6 dB superior. Note that the 8-PSK STTC designed by the traditional way for six transmit antennas which achieves a full diversity order 6 should

have at least  $2^{15} = 32\,768$  states, which makes the code design nearly impossible and decoding very complicated.

Fig. 3 compares the performance of the four-state 4-PSK TSC code [1] and BBH code [11] with two receive antennas. Without transmit antenna selection, both codes have an asymptotic diversity order 4 and the BBH code is superior by 0.7 dB. With two to be chosen from four available transmit antennas, both codes achieve an asymptotic diversity order 8 and the BBH code is also 0.7 dB superior.

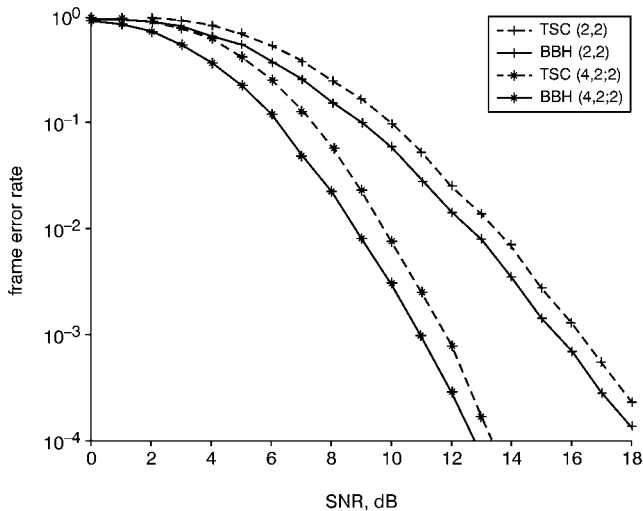


Fig. 3 Performance comparison between four-state 4-PSK TSC and BBH codes with and without transmit antenna selection, two receive antennas

From the above simulation results, we show that the  $(n_T, 2; n_R)$  TAS/STTC schemes can achieve a full diversity order  $n_T n_R$ , as if all the transmit antennas were used although at any time only two transmit antennas are activated. This conclusion is the same as that for the TAS/MRC and TAS/STBC schemes, which has been proven in [5] and [8] analytically based on the exact BER expressions. Currently the theoretic performance analysis of the TAS/STTC scheme is under investigation.

The TAS/STTC scheme has a small decoding complexity at the receiver and a full diversity order can be achieved even with the baseline STTC of small memory order, as long as the baseline STTC has a full diversity order. No particular code design is involved when the diversity order is to be increased. We simply increase the number of transmit antennas to be chosen from accordingly.

*Feedback information:* In the TAS/STTC scheme, the feedback link has to be provided. For the  $(n_T, 2; n_R)$  case, the transmitter only needs to know which two transmit antennas will be chosen and activated when the channel parameter changes. The feedback information, which is determined at the receiver side, is an  $n_T \times 1$  binary vector with weight 2. The position of the two binary 1s in the vector denotes the index of the two transmit antennas which are chosen for transmission. For a system working in a quasi-static flat fading channel at a high data rate, the feedback transmission rate is relatively low and affordable.

*Conclusion:* A scheme combining transmit antenna selection and STTC has been investigated. The STTCs designed for two transmit antennas are used as the baseline codes. It is shown by simulation that this scheme achieves a full diversity order as if all the transmit antennas were used. This conclusion is the same as that for the TAS/MRC and TAS/STBC schemes. This scheme provides a new paradigm for the STTC design for a large number of transmit antennas and can achieve a full diversity order regardless of the memory order of the baseline STTC, as long as the baseline STTC has a full diversity order.

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