Performance of quasi-orthogonal space-time code with antenna selection

B. Badic, P. Fuxjaeger and H. Weinrichter

The performance of a quasi-orthogonal space-time block code with antenna selection is considered. Transmit antenna selection as well as receive antenna selection is studied. A new selection rule is proposed that minimises the average bit error ratio and achieves full diversity even if only a simple zero-forcing receiver is used.

Introduction: The performance of a wireless system can be significantly improved by using multiple antenna elements at the transmitter and/or at the receiver side. The major problems of such systems are high cost and complexity due to more than one RF chain at both link ends. A promising technique to reduce this overhead is to allow the transmitter and/or the receiver to select the optimum antenna subset according to some optimisation criterion [1, 2].

In this Letter we study antenna selection at the transmitter and at the receiver combined with quasi-orthogonal space-time block codes (QSTBCs) for four transmit antennas. The main goal is to improve the bit error ratio (BER) performance of the QSTBC using a simple linear decoding algorithm by an additional channel dependent antenna selection scheme. We propose an optimum selection criteria for a zero-forcing (ZF) receiver and show that using the best antenna subset we can achieve a significantly higher diversity order compared to transmission over a fixed set of antennas.

Transmission scheme with QSTBCs: We consider coded transmission over $n_t = 4$ out of N_t transmit antennas and $n_r = 1$ out of N_r receive antennas. This transmission is described by $\mathbf{y} = \mathbf{Sh} + \mathbf{v}$, where $\mathbf{y}$ is the (4×1) vector of signals received at the single receive antenna in four successive time slots, $\mathbf{S}$ is the QSTBC code matrix [3, 4]:

$$\mathbf{S} = \begin{pmatrix} s_1 & s_2 & s_3 & s_4 \\ s_2^* & -s_1^* & s_4^* & -s_3^* \\ s_3^* & s_4^* & -s_1^* & -s_2^* \\ s_4 & -s_3 & -s_2 & s_1 \end{pmatrix} \qquad (1)$$

$\mathbf{h}$ is the $(n_t \times 1)$ channel vector and $\mathbf{v}$ is the (4×1) complex Gaussian noise vector. By complex conjugation of the second and third element of $\mathbf{y}$, as already described in [4], the input/output relation can be reformulated as $\tilde{\mathbf{y}} = \mathbf{H}_v \mathrm{s} + \tilde{\mathbf{v}}$, where $\mathbf{H}_v$ is an equivalent (4×4) virtual channel matrix consisting of elements taken from the original (4×1) MISO channel vector $\mathbf{h}$ (including some conjugate versions of the original channel coefficients) [4]. The non-orthogonality of the QSTBCs becomes obvious when matched filtering of $\tilde{\mathbf{y}}$ with $\mathbf{H}_v^H$ is applied at the receiver resulting only in a partial decoupling of the data transmission, described by $\mathbf{r} = \mathbf{H}_v^H \mathbf{H} \mathrm{s} + \mathbf{H}_v^H \tilde{\mathbf{v}}$, where the resulting equivalent (4×4) Grammian channel matrix $\mathbf{G}$ results in

$$\mathbf{G} = \mathbf{H}_v^H \mathbf{H}_v = \mathbf{H}_v \mathbf{H}_v^H = h^2 \begin{bmatrix} 1 & 0 & 0 & X \\ 0 & 1 & -X & 0 \\ 0 & -X & 1 & 0 \\ X & 0 & 0 & 1 \end{bmatrix} \qquad (2)$$

$h^2 = |h_1|^2 + |h_2|^2 + |h_3|^2 + |h_4|^2$ characterises the total channel gain and indicates a fourfold diversity. X can be interpreted as a channel dependent interference parameter, given by $X = 2\mathrm{Re}(h_1 h_4^* - h_2 h_3^*)/h^2$. It is well known that $\mathbf{G}$ should approximate a scaled identity-matrix as far as possible to achieve ideal data stream decoupling. This means X should be as small as possible. In fact, the scaling-factor h^2 as well as the interference parameter X determines the BER performance [4, 5]. Therefore, the optimum selection strategy has to take into account both these values.

Optimal antenna selection: First, only transmit antenna selection is considered. The channel coefficients are modelled as zero mean i.i.d complex Gaussian random variables with unit variance and are assumed to be invariant during a frame length of 2048 4QAM data symbols. We assume that at the transmitter $N_t \geq 4$ antennas are available and at the receiver only $n_r = 1$ antenna is used. We further assume that the receiver has perfect channel knowledge, gained by estimating the channel coefficients during training periods. The transmitter selects only four out of N_t transmit antennas at the beginning of a new frame, transmitting the QSTBC over this subset of transmit antennas. The selection goal is to transmit over the optimum antenna subset. The receiver evaluates this subset due to his channel knowledge and informs the transmitter about the optimum subset via a given number of feedback bits per frame. In the case of receive antenna selection only, we assume that the receiver knows the exact same channel characteristics. In the case of receive antenna selection we assume that on the receiver side $N_r \geq 1$ antennas are available, but only the 'best' receive antenna is used for processing the received data. Obviously no channel feedback to the transmitter is necessary in the case of receive antenna selection.

To find an optimum transmit selection criterion we optimise the performance of the system after decoding. On the receiver side, after matched filtering, we consider a simple zero-forcing receiver, described by the channel inversion: $\hat{\mathbf{y}} = (\mathbf{H}_v^H \mathbf{H}_v)^{-1} \mathbf{r}$. It is well known that a linear ZF receiver suffers from noise enhancement and diversity loss. The BER performance of the ZF receiver applied to QSTBC transmission is given by [4]:

$$\mathrm{BER}_{\mathrm{ZF}} = \frac{1}{2} \mathrm{erfc} \sqrt{\left(\frac{h^2 (1 - X^2)}{\sigma_v^2} \right)} \qquad (3)$$

Therefore our antenna subset selection criterion aims to maximise the term $h^2(1 - X^2)$, which means that the receiver selects those transmit or receive antennas that maximise $h^2(1 - X^2)$. This criterion trades off a maximisation of the channel gain h^2 and a minimisation of the channel dependent interference parameter X. We have compared this criterion to several other selection rules and found that this optimisation criterion leads to the best BER performance over the whole SNR range.

Simulation results: We have simulated the BER against E_b/N_0 using 4QAM symbols leading to an information rate of 2 bits/channel use. In the case of transmit antenna selection we simulated MISO systems with $4 \leq N_t \leq 7$ and $n_r = 1$. In the case of receive antenna selection we simulated MIMO systems with $n_t = 4$ and $1 \leq N_r \leq 6$.

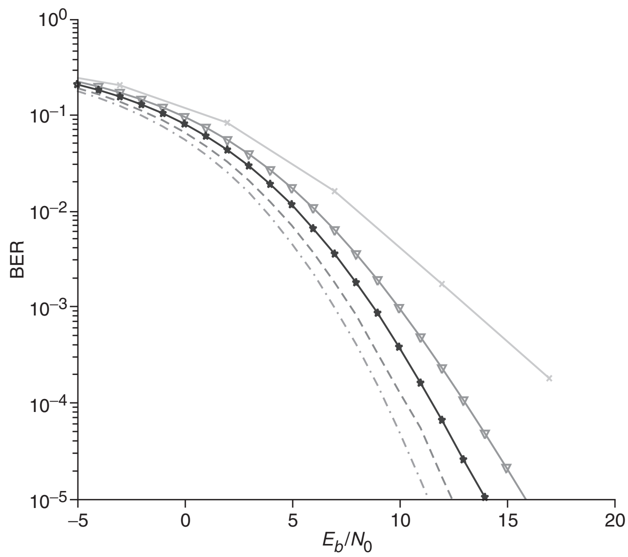

Fig. 1 *Transmit antenna selection*

—+— no antenna selection
—▽— ideal 4-path diversity (no antenna selection)
—*— 4 of 5 transmit antennas
– – – 4 of 6 transmit antennas
–·–· 4 of 7 transmit antennas

Fig. 1 shows our simulation results for the transmit antenna selection. In the case of transmit antenna selection, both coding gain and diversity gain are strongly improved, increasing the number of available transmit antennas. For a $\mathrm{BER} = 10^{-3}$ and $N_t = 5$, the coding gain is about 3 dB compared to $N_t = 4$. Increasing the number of available transmit antennas further, the additional coding gain decreases to about 1 dB per additional transmit antenna. Fig. 2 shows the simulation results for receive antenna selection. Diversity order increases with the number of available receive antennas and additional coding gain can be achieved with each additional receive antenna. However, the additional coding gain becomes smaller when N_r increases further. For instance, at a $\mathrm{BER} = 10^{-3}$, increasing the number of receive antennas from one to two we achieve an SNR gain of about 4 dB, whereas only an additional gain of about 1 dB is achieved in the case if one receive antenna is selected out of three available receive antennas.

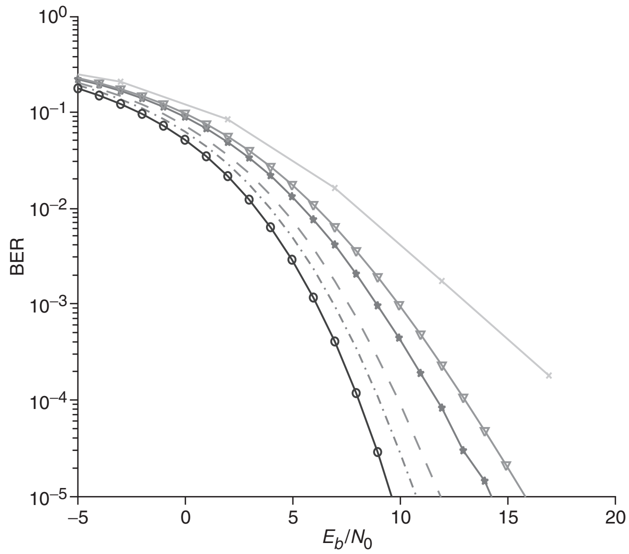

Fig. 2 *Receive antenna selection*

—+— no antenna selection
—▽— ideal 4-path diversity (no antenna selection)
—*— 1 of 2 receive antennas
– – – 1 of 3 receive antennas
– · – · 1 of 4 receive antennas
—○— 1 of 5 receive antennas

Conclusions: We have analysed and simulated the performance of an MIMO system using jointly a quasi-orthogonal space-time code and antenna selection. We found an efficient selection criterion that gives additional diversity and coding gain and therefore significantly enhances system performance even in the case of a simple ZF receiver. Antenna selection is a promising low-cost technique that improves the performance of the QSTBC substantially.

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