Adaptive Transmit Weights for Performance Enhancement in Space-Time Transmit Diversity Systems

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ABSTRACT

Space-time transmit diversity (STTD) is an open loop multi-antenna transmission method adopted in 3G standard. This technique uses the space-time block code at the basestation to combat deep channel fading. In order to enhance the STTD system performance, adaptive algorithms were proposed in which the corresponding information can be fed back to adjust the transmit weights. In this paper, the performances of STTD with various transmit weights and receiver structures are investigated via theoretical analysis and numerical simulations. And their respective compatibility and implementation complexity are pointed out.

1. INTRODUCTION

Transmit diversity is one of the key contributing technologies in defining 3G systems. By transmitting the downlink signal through multiple, widely spaced transmit antennas, the signals emanating from them can be assumed to undergo independent fading. Therefore, poor performance due to prolonged deep fading under low mobility conditions can be improved, which leads to an increase in the downlink capacity.

Transmit diversity methods fall into two classes: open loop and closed loop. Space-time transmit diversity (STTD) is an open loop technique in which the symbols are modulated using space-time block code [1] and the two encoded symbol streams are transmitted through two antennas simultaneously. Due to its simplicity of implementation and achievable diversity gains, the STTD scheme is accepted by 3G wireless standard. Transmit adaptive array (TXAA) is a closed loop transmit diversity technique included in 3G wireless standard, in which the mobile users feedback the estimated optimal transmit weights to the basestations such that the received power at the desired mobile user is maximized. Depending on the different modes of operation, the amplitude and/or phase of the transmit weights are adaptively adjusted based on the channel conditions. The simulation results show that the STTD is robust at higher velocities, while TXAA provides the biggest benefits at the lower velocities [2][3]. A mixture of open and closed loop diversity technique could be, therefore, entertained to combat both fast and slow fading.

In this paper, a scheme combining the standard STTD with adaptive transmit power allocation is studied in order to improve the performance of the standard STTD systems. The signal-to-noise ratio (SNR) performances of two receiver structures, namely ASTTD (adaptive STTD) [4] and eigen-STTD [5], combined with two feedback methods are analyzed and compared with the ordinary STTD systems. The decoded BER performances simulated based on the 3GPP W-CDMA standard are also presented in different wireless environments. In comparison with the ordinary STTD scheme, the simulation results show that around 1.2dB SNR gain can be achieved for all simulated velocities.

2. SYSTEM MODEL

Consider the STTD coded system in Fig.1, in which the transmitter combines the STTD encoder with the adaptive weights of transmitted signals together. The transmit weights, w_1 and w_2, are selected based on the feedbacks from the receiver under the fixed power constraint

$$|w_1|^2 + |w_2|^2 = 1 \qquad (1)$$

The STTD encoder uses a space-time block code which encodes two successive input data symbols $[X_1\ X_2]^T$ into a 2×2 output matrix [1]

$$\begin{bmatrix} X_1 & -X_2^* \\ X_2 & X_1^* \end{bmatrix} \qquad (2)$$

where * denotes complex conjugate operation and each row of the matrix is assigned to one transmit antenna. Assume there is one antenna element at the receiver, as shown in Fig.1, the received signal r_1(n) and r_2(n) corresponding to the two successive received symbol intervals in one space-time coded block can be expressed as

$$\begin{array}{ccccccc} \begin{bmatrix} r_1(n) \\ r_2(n) \end{bmatrix} & = & \begin{bmatrix} w_1 X_1 & w_2 X_2 \\ -w_1 X_2^* & w_2 X_1^* \end{bmatrix} & \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} & + & \begin{bmatrix} v_1(n) \\ v_2(n) \end{bmatrix} & (3) \\ \mathrm{r}(n) & = & X & \underline{h} & + & v(n) & \end{array}$$

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*The author is also with Stevens Institute of Technology, Hoboken, NJ 07030 USA where h_j is the channel coefficient from *ith* transmit antenna to the receive antenna and $v(n)$ is the additive white Gaussian noise sampled at time instant n with a standard deviation σ_v. The channel coefficients, h_1 and h_2, are complex-valued, i.i.d. Rayleigh fading.

3. PERFORMANCE ANALYSIS

Figs.2 shows two receiver structures for the STTD systems with adaptive transmit weights, namely ASTTD and eigen-STTD. In this section, the SNRs at the receiver outputs are computed and analyzed. The ASTTD receiver, as shown in Fig.2a, consists two stages of operation: ordinary STTD decoding and cross-interference cancellation. Consider the received signal $r(n)$ in (3), the output of the ordinary STTD decoder can be expressed as

$$\begin{aligned} z_1 &= h_1^* r_1 + h_2 r_2^* = AX_1 - BX_2 + C_1 \\ z_2 &= h_1^* r_2 - h_2 r_1^* = -AX_2^* - BX_1^* + C_2 \end{aligned} \tag{4}$$

where

$$\begin{aligned} A &= (w_1 |h_1|^2 + w_2^* |h_2|^2) \\ B &= (w_1^* - w_2) h_1^* h_2 \\ C_1 &= h_1^* v_1 + h_2 v_2^*; \quad C_2 = h_1^* v_2 - h_2 v_1^* \end{aligned} \tag{5}$$

The term B in (5) is a cross-interference caused by the unequal transmit weights at transmitters. In order to cancel this term, a linear operation can be introduced and given by [4]

$$\begin{aligned} \hat{X}_1 &= A^* z_1 - B z_2^* = (|A|^2 + |B|^2) X_1 + (A^* C_1 - B C_2^*) \\ \hat{X}_2 &= -B^* z_1 - A z_2^* = (|A|^2 + |B|^2) X_2 - (A C_2^* + B^* C_1) \end{aligned} \tag{6}$$

Therefore, the conditional output SNR of the decoded symbol can be computed from (6) as

$$\mathrm{SNR}|_{h_1 h_2} = \frac{(|h_1|^2 |w_1|^2 + |h_2|^2 |w_2|^2) E_s}{\sigma_v^2} \tag{7}$$

where Es is the symbol power and σ_v^2 is the noise power. From (6), it is straightforward to see that the ASTTD receiver is backward compatible with the ordinary STTD, in which $w_1=w_2$. In fact, under the fixed transmit power constraint, the output SNR for ordinary STTD systems can be obtained from (7) as

$$\mathrm{SNR}|_{h_1 h_2} = \frac{(|h_1|^2 + |h_2|^2) E_s}{2\sigma_v^2} \tag{8}$$

Similar to the ASTTD receiver, the eigen-STTD receiver, as shown in Fig.2(b), has two processing blocks to estimate the transmitted symbols. In the first stage, the received signal is linearly combined with the transmit weights and given by [5]

$$\begin{aligned} z_1 &= w_1^* r_1 + w_2 r_2^* = DX_1 - QX_2 + M_1 \\ z_2 &= w_1^* r_2 - w_2 r_1^* = -DX_2^* - QX_1^* + M_2 \end{aligned} \tag{9}$$

where

$$\begin{aligned} D &= (h_1 |w_1|^2 + h_2^* |w_2|^2) \\ Q &= (h_1^* - h_2) w_1^* w_2 \\ M_1 &= w_1^* v_1 + w_2 v_2^*; \quad \mathrm{M}_2 = w_1^* v_2 - w_2 v_1^* \end{aligned} \tag{10}$$

Following the same operation in the ASTTD scheme, the output of the eigen-STTD receiver can be shown as

$$\begin{aligned} \hat{X}_1 &= D^* z_1 - Q z_2^* = (|D|^2 + |Q|^2) X_1 + (D^* M_1 - Q M_2^*) \\ \hat{X}_2 &= -Q^* z_1 - D z_2^* = (|D|^2 + |Q|^2) X_2 - (D M_2^* + Q^* M_1) \end{aligned} \tag{11}$$

From (11), the conditional SNR at the eigen-STTD receiver output is given by

$$\mathrm{SNR}|_{h_1 h_2} = \frac{(|h_1|^2 |w_1|^2 + |h_2|^2 |w_2|^2) E_s}{\sigma_v^2} \tag{12}$$

It is easily seen that the eigen-STTD receiver is not backward compatible with the ordinary STTD. However, compared with the SNR for ASTTD in (7), the eigen-STTD has the same performance as ASTTD if the same transmit weights are selected. Therefore, the selection of the transmit weights is the key factor in determining the receiver performances.

4. TRANSMIT WEIGHT SELCTION

The output SNR in (7) can be maximized under the fixed transmit power constraint in (1) in order to find the optimum transmit weights. However, it is rather difficult to find a solution. In this section, two alternatives to calculate the transmit weights are analyzed and compared under Rayleigh fading assumption.

Method 1:

Instead of maximizing the SNR in (7), the term A in (5) is maximized to find the optimum transmit weights, since it contributes dominantly to the desired signal energy in (6) [4]. By letting $dA/dw_1=0$ with respect to the constraint in (1) and the constraint of real values, the optimum transmit weights are given by

$$w_1 = \frac{1}{\sqrt{1+(|h_2|/|h_1|)^4}} \; ; \; w_2 = \frac{1}{\sqrt{1+(|h_1|/|h_2|)^4}} \qquad (13)$$

It shows that only the amplitude ratio of the propagation channels is needed as feedback information to calculate the transmit weights. It also implies that simpler feedback signaling is needed than the closed loop TXAA scheme. Applying the transmit weights in (13) to (7), the SNR of ASTTD with feedback 1 can be obtained by

$$\mathrm{SNR}\,|_{h_1h_2} = \frac{(|h_1|^6+|h_2|^6)E_s}{(|h_1|^4+|h_2|^4)\sigma_v^2} \qquad (14)$$

Method 2:

The principal eigenvector corresponding to the maximum eigenvalue of the channel correlation matrix can be adopted for transmit weights, which maximizes the received SNR at the receiver's front end. The channel correlation matrix *R* is defined by

$$R = \underline{h}\underline{h}^H \; ; \; \underline{h} = (h_1, h_2)^T \qquad (15)$$

In this case, the SNR of the eigen-STTD receiver in (12) can be rewritten as

$$\mathrm{SNR}\,|_{h_1h_2} = \frac{(|h_1|^4+|h_2|^4)E_s}{(|h_1|^2+|h_2|^2)\sigma_v^2} \qquad (16)$$

In comparison with the SNR of ASTTD in (14), it is straightforward to show that

$$\frac{(|h_1|^4+|h_2|^4)}{(|h_1|^2+|h_2|^2)} - \frac{(|h_1|^6+|h_2|^6)}{(|h_1|^4+|h_2|^4)} \le 0 \qquad (17)$$

Clearly, the SNR of eigen-STTD cannot be greater than the SNR of ASTTD. Since the eigen-STTD receiver is not backward compatible with the ordinary STTD, it will be much beneficial if the ASTTD receiver together with the amplitude ratio weight selection is adopted. The average SNR can be further computed if the channel density function is available. Under the assumptions that both propagation channels, h_1 and h_2, are i.i.d. Rayleigh fading channels with the probability density function

$$f(h_i) = (h_i/\sigma_0^2)e^{-h_i^2/2\sigma_0^2} \qquad (18)$$

the average output SNR of STTD, ASTTD and eigen-STTD can be obtained by integrating the product of the joint density function and the SNR functions in (8), (14) and (16), respectively. It follows that the performance gains are given by

$$\frac{SNR_{ASTTD}}{SNR_{STTD}} = 1.55dB \; ; \; \frac{SNR_{eigen-STTD}}{SNR_{STTD}} = 1.25dB \qquad (19)$$

$$\frac{SNR_{ASTTD}}{SNR_{eigen-STTD}} = 0.3dB$$

5. SIMULATION

Link level simulation based on the 3GPP W-CDMA standard is conducted to compare the performances of different methods. The main simulation parameters are listed in Table 1. In the simulations, the total power transmitted from the basestation is normalized and denoted by I_{or} with a fraction of the power, E_c/I_{or}, allocated to the desired mobile. The value of geometry, defined as the ratio of I_{or} to I_{oc}, where I_{oc} is the interference power from other cells, is specified and the decoded bit error rate (BER) is computed. Then the received signal is the output of the channels driven by the transmitted signals plus interference from other cells and thermal noise. The last two terms can be modeled as zero-mean additive white Gaussian noise. In addition, it is assumed that the transmit weights are ideally fed back to the transmitter every 2 ms. Here, perfect channel estimation is also assumed.

Carrier frequency	2GHz
Spreading factor	16
Number of multicodes	10
Frame length	2ms
CPICH power	10% total
Ec/Ior	80%
Ior/Ioc	variable
Channel coding	Turbo, rate=1/2
Fading model	One path Rayleigh
Correlation model	i.i.d.
Channel estimation	perfect
Modulation	QPSK
Feedback	ideal

Table 1. Simulation Parameters

Fig.3 and 4 illustrate the decoded BER performances for different methods at the velocities 20km/h and 120km/h, respectively. Four methods are considered: open loop STTD, eigen-STTD with feedback method 2, ASTTD with feedback 1 (ASTTD1) and feedback 2 (ASTTD2). The gains of ASTTD1 over the open STTD are around 1.2dB in both cases at BER=10^{-3}, as shown in Fig.3 and 4. The ASTTD1 also outperforms eigen-STTD by 0.3-0.5dB at BER=10^{-3}. It is noted that the ASTTD2 has no significant performance difference in comparison with the eigen-STTD, which is consistent with the conclusions in section 2.

5. CONCLUSIONS

In this paper, the performances of the STTD with adaptive transmit weights are studied via theoretical analysis and numerical simulations. It has been demonstrated that both ASTTD and eigen-STTD receivers have the same output SNR if the same transmit weights are selected. It can be seen that the ASTTD receiver combined with amplitude ratio feedback outperforms the other methods.

6. REFERENCES

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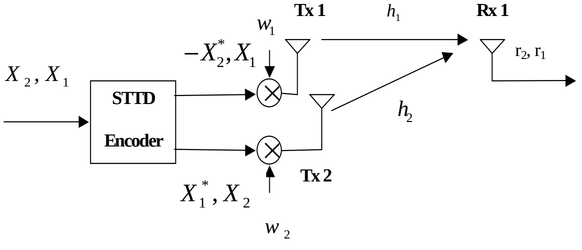

Fig. 1. a STTD system with adaptive transmit weights

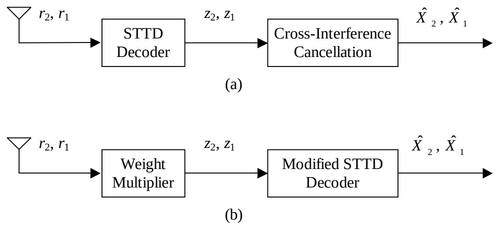

Fig.2. two receiver structures (a) ASTTD (b) eigen-STTD

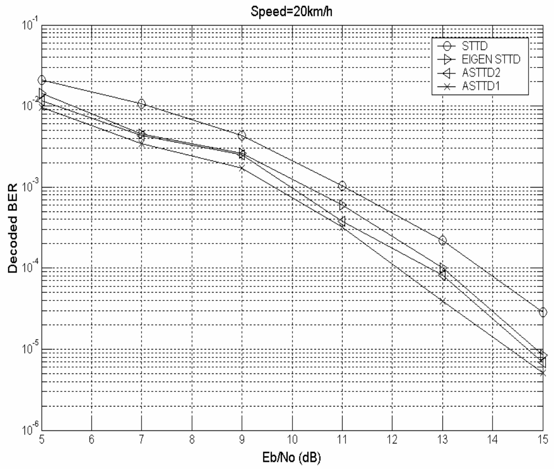

Fig.3 decoded bit error rate at 20km/h

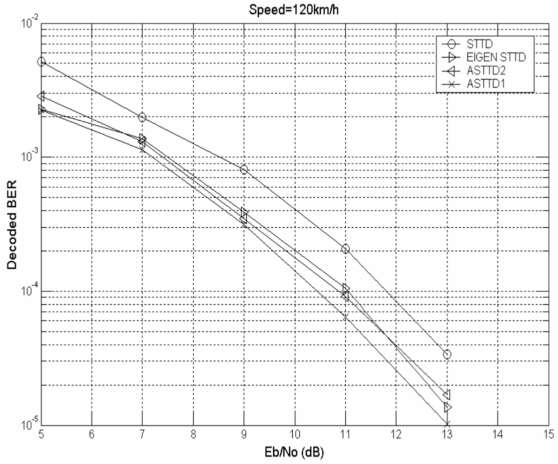

Fig.4 decoded bit error rate at 120km/h