ADAPTIVE SPACE-TIME TRANSMIT DIVERSITY FOR MIMO SYSTEMS

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Abstract

Adaptive space-time transmit diversity (ASTTD) is a scheme, which combines the ordinary STTD scheme (open loop transmit diversity) with information feedback from mobile terminals to adaptively adjust the transmit power at each transmit antenna. In comparison with the STTD system, the performance can be improved especially in slow fading channels. In this paper, the application of ASTTD to MIMO (multiple input multiple output) system is investigated through theoretical analysis and numerical simulations. The proposed scheme requires simpler feedback information compared with the closed loop transmit diversity schemes. Furthermore, this scheme can be included in the current 3GPP standard without any change of the air interface. The performances of ASTTD MIMO systems based on the 3GPP standard are also studied through the simulations.

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ABSTRACT

Adaptive space-time transmit diversity (ASTTD) is a scheme, which combines the ordinary STTD scheme (open loop transmit diversity) with information feedback from mobile terminals to adaptively adjust the transmit power at each transmit antenna. In comparison with the STTD system, the performance can be improved especially in slow fading channels. In this paper, the application of ASTTD to MIMO (multiple input multiple output) system is investigated through theoretical analysis and numerical simulations. The proposed scheme requires simpler feedback information compared with the closed loop transmit diversity schemes. Furthermore, this scheme can be included in the current 3GPP standard without any change of the air interface. The performances of ASTTD MIMO systems based on the 3GPP standard are also studied through the simulations.

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 codes [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 base stations 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.

Recently, adaptive STTD (ASTTD) scheme is proposed [4,5], which combines STTD with adaptive transmit power allocation in order to improve the performances of the STTD systems. In this paper, the application of ASTTD to MIMO (multiple input multiple output) systems is investigated through theoretical analysis and numerical simulations. The signal-to-noise ratio (SNR) performances are analyzed and compared with the ordinary STTD systems. The decoded BER (bit error rate) performances simulated based on the 3GPP W-CDMA standard are also presented in different system configurations and wireless channels. In comparison with the ordinary STTD scheme, the simulation results show that performance gains can be achieved for all simulated velocities, while the gains decrease as the number of receive antennas increases.

2. SYSTEM MODEL

Consider the STTD coded system in Fig.1(a), 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

$$|w_1|^2 + |w_2|^2 = 1 \tag{1}$$

The STTD encoder uses a space-time block code which

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*The author is also with Stevens Institute of Technology, Hoboken, NJ 07030 USA encodes two successive input data symbols $[X_1\ X_2]^T$ into a 2×2 output matrix [1]

$$\begin{bmatrix} X_1 & -X_2^* \\ X_2 & X_1^* \end{bmatrix} \tag{2}$$

where * denotes the complex conjugate operation and each row of the matrix is assigned to one transmit antenna. Assume there are N_r antenna elements at the receiver, as shown in Fig.1(b), the received signal r_i(n) and r_i(n+1) corresponding to the two successive received symbol intervals in one space-time coded block at the i^{th} receive antenna can be expressed as

$$\begin{array}{ccccccc}
\begin{bmatrix} r_1(n) \\ r_1^*(n+1) \\ r_2(n) \\ r_2^*(n+1) \\ \vdots \\ r_{N_r}(n) \\ r_{N_r}^*(n+1) \end{bmatrix} & = & \begin{bmatrix} w_1 h_{11} & w_2 h_{21} \\ w_2 h_{21}^* & -w_1 h_{11}^* \\ w_1 h_{12} & w_2 h_{22} \\ w_2 h_{22}^* & -w_1 h_{12}^* \\ \vdots & \vdots \\ w_1 h_{1N_r} & w_2 h_{2N_r} \\ w_2 h_{2N_r}^* & -w_1 h_{1N_r}^* \end{bmatrix} & \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} & + & \begin{bmatrix} v_1(n) \\ v_1^*(n+1) \\ v_2(n) \\ v_2^*(n+1) \\ \vdots \\ v_{N_r}(n) \\ v_{N_r}^*(n+1) \end{bmatrix} \\
\mathrm{r}(n) & = & \tilde{\mathrm{H}} & \mathrm{X} & + & \mathrm{v}(n)
\end{array} \tag{3}$$

where h_{ij} is the channel coefficient from *ith* transmit antenna to the *jth* receive antenna and $\boldsymbol{v}(n)$ is the additive white Gaussian noise sampled at time instant n with a standard deviation σ_v, which is assumed to be independent at all receive antenna elements. The channel coefficients, h_{ij}, are complex-valued, i.i.d. Rayleigh fading.

For the MIMO receiver shown in Fig.1(b), three stages of operations are conducted to detect the transmitted signals: combiner, STTD decoder, and interference cancellation. The received signals at all antenna elements are first combined, before fed into an ordinary STTD decoder. In a 2×1 STTD system, the transmitted signals are decoded by multiplying a 2×2 matrix G* with the two successive received symbols, where [1]

$$G^* = \begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix} \tag{4}$$

and h_i are the channel coefficients from the *ith* transmit antenna. Therefore, the output of the STTD decoder, $\tilde{\mathrm{r}}$, corresponding to the two successive transmitted symbols in one space-time coding block is given by

$$\begin{aligned} \tilde{\mathrm{r}}(n) &= \begin{bmatrix} \tilde{r}_1 \\ \tilde{r}_2 \end{bmatrix} = \mathrm{H}^* r(n) \\ &= \begin{bmatrix} h_{11}^* & h_{21} & h_{12}^* & h_{22} & \cdots & h_{1N_r}^* & h_{2N_r} \\ h_{21}^* & -h_{11} & h_{22}^* & -h_{12} & \cdots & h_{2N_r}^* & -h_{1N_r} \end{bmatrix} \mathrm{r}(n) \\ &= \begin{bmatrix} A & B \\ -B^* & A \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \tilde{\mathrm{v}}(n) \end{aligned} \tag{5}$$

where $A = w_1 \sum_{i=1}^{N_r} |h_{1i}|^2 + w_2 \sum_{i=1}^{N_r} |h_{2i}|^2$,

$$B = w_2 \sum_{i=1}^{N_r} h_{1i}^* h_{2i} - w_1 \sum_{i=1}^{N_r} h_{1i}^* h_{2i} \tag{6}$$

and

$$\tilde{\mathrm{v}}(n) = \mathrm{H}^* \mathrm{v}(n) = \begin{bmatrix} \sum_{i=1}^{N_r} h_{1i}^* v_i(n) + \sum_{i=1}^{N_r} h_{2i} v_i^*(n+1) \\ \sum_{i=1}^{N_r} h_{2i}^* v_i(n) - \sum_{i=1}^{N_r} h_{1i} v_i^*(n+1) \end{bmatrix} \tag{7}$$

The term B in Eq.(6) is an cross-interference due to unequal transmit weights applied at each transmit antenna. In a standard STTD system, there is no cross-interference after decoding, since $w_1 = w_2 = 1/\sqrt{2}$. To cancel the cross-interference term B in Eq.(6), an interference cancellation stage is introduced to maximize the SNR of the STTD decoded symbols. The output is given by

$$\begin{aligned} \begin{bmatrix} \hat{X}_1 \\ \hat{X}_2 \end{bmatrix} &= \begin{bmatrix} A & B \\ -B^* & A \end{bmatrix}^* \tilde{\mathrm{r}}(n) \\ &= \begin{bmatrix} |A|^2 + |B|^2 & 0 \\ 0 & |A|^2 + |B|^2 \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} A^* & -B \\ B^* & A \end{bmatrix} \tilde{\mathrm{v}}(n) \end{aligned} \tag{8}$$

where A and B are defined in Eq.(6). The conditional SNR of the output signal can be therefore computed by

$$\mathrm{SNR}\,|_{h_{ij}} = \frac{(|A|^2 + |B|^2) E_s}{\sigma_v^2 \sum_j \sum_i |h_{ij}|^2} \tag{9}$$

where E_s is the transmitted signal energy and σ_v^2 is the additive white noise power.

3. PERFORMANCE ANALYSIS

The output SNR in (9) 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. Since the term A in Eq.(6) contributes dominantly to the desired signal energy, one may maximize A in stead of maximizing the SNR in Eq.(9). We thus can find the optimum weight function by letting $dA/dw_1=0$ with the fixed power constraint in Eq.(1). We have

$$w_1 = \frac{1}{\sqrt{1+\left(\frac{\sum_{i=1}^{N_r}|h_{2i}|^2}{\sum_{i=1}^{N_r}|h_{1i}|^2}\right)^2}}$$

$$w_2 = \frac{1}{\sqrt{1+\left(\frac{\sum_{i=1}^{N_r}|h_{1i}|^2}{\sum_{i=1}^{N_r}|h_{2i}|^2}\right)^2}} \qquad (10)$$

It shows that only the ratio of the magnitude sum of the propagation channels is sufficient as feedback information for the transmitter to calculate the optimum transmit weight, which is simpler than the current closed loop techniques. It also implies that simpler feedback signaling is needed than the closed loop TXAA scheme. Rewrite Eq.(9), the conditional SNR is expressed by

$$\mathrm{SNR}|_{h_{ij}} = \frac{(|w_1|^2\sum_{i=1}^{N_r}|h_{1i}|^2+|w_2|^2\sum_{i=1}^{N_r}|h_{2i}|^2)E_s}{\sigma_v^2} \qquad (11)$$

Applying the transmit weights in (10) to (11), the output SNR becomes

$$\mathrm{SNR}|_{h_{ij}} = \frac{[(\sum_{i=1}^{N_r}|h_{1i}|^2)^3+(\sum_{i=1}^{N_r}|h_{2i}|^2)^3]E_s}{[(\sum_{i=1}^{N_r}|h_{1i}|^2)^2+(\sum_{i=1}^{N_r}|h_{1i}|^2)^2]\sigma_v^2} \qquad (12)$$

The average SNR can be further computed if the channel density function is available. Under the assumption that all propagation channels, h_{ij}'s, are i.i.d. Rayleigh fading channels with the probability density function

$$f(h_{ij}) = (h_{ij}/\sigma_0^2)e^{-h_{ij}^2/2\sigma_0^2} \qquad (13)$$

the average output SNR can be obtained by integrating the product of the joint density function and the SNR functions in (12). Consider three transmit antenna configurations: (2x1), (2x2) and (2x4), it follows that the performance gains are given by

$$\frac{SNR_{(2\times1)}}{SNR_{STTD}} \doteq 1.55\,dB\,,\ \frac{SNR_{(2\times2)}}{SNR_{STTD}} \doteq 0.8\,dB$$

$$\frac{SNR_{(2\times4)}}{SNR_{STTD}} \doteq 0.4\,dB \qquad (14)$$

where the SNR for STTD systems can be computed using the conditional SNR in Eq.(11) by letting $|w_1|^2=|w_2|^2=1/2$.

4. SIMULATIONS

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 with frame size being 246 symbols. 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.

Table 1. Simulation Parameters

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

Fig.2, 3 and 4 illustrate the decoded BER performances for different system configurations, (2,1), (2,2) and (2,4), at the velocities 3km/h and 30km/h, respectively. The gains of ASTTD over the STTD are around 1.2dB, 0.8dB and 0.4dB in with 1, 2 and 4 receive antennas, respectively, which is consistent with the conclusions in previous sections.

5. CONCLUSIONS

In this paper, the performances of the STTD with adaptive transmit weights for MIMO systems are studied via theoretical analysis and numerical simulations. It has been demonstrated that ASTTD is superior to STTD at different velocities with different receive antennas. However, the performance gains decrease when the number of receive antennas increases.

6. REFERENCES

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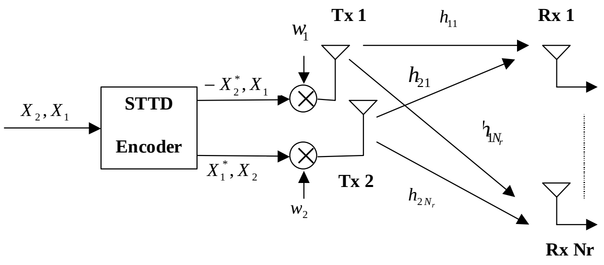

Figure 1(a) ASTTD system with Nr receive antennas.

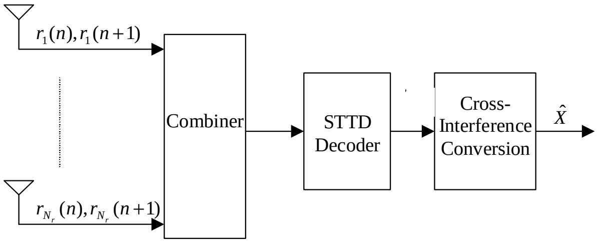

Figure 1(b) Receiver structure.

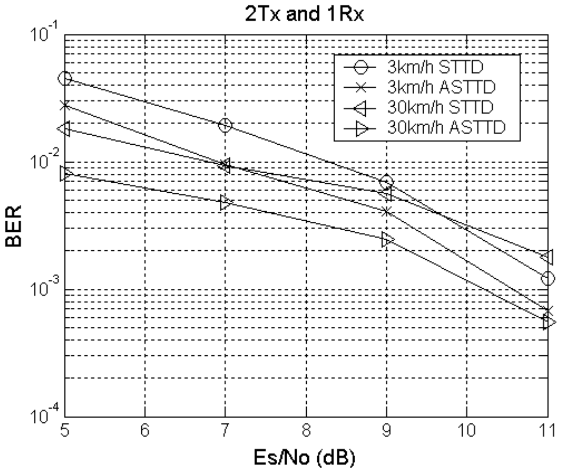

Figure 2. FER performance with 1Rx

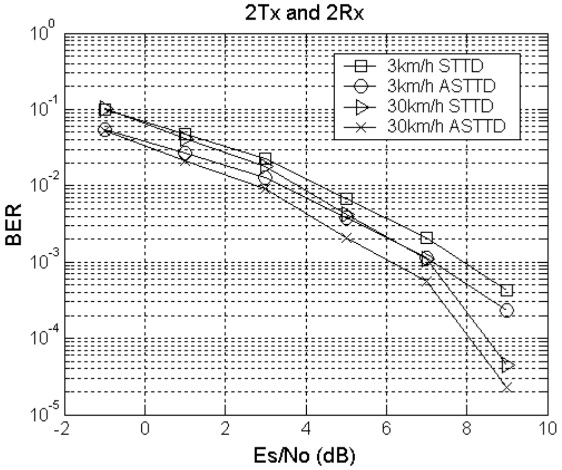

Figure 3. FER performance with 2Rx

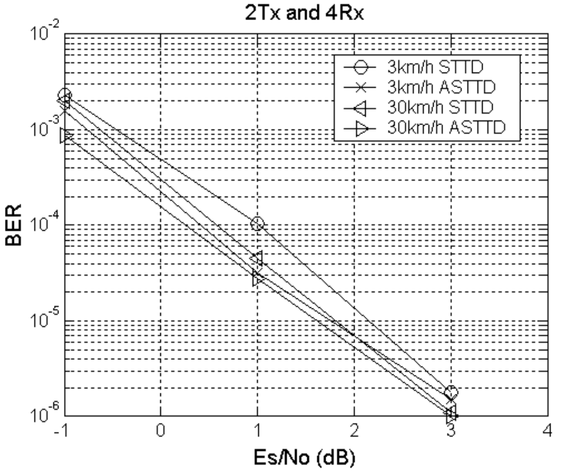

Figure 4. FER performance with 4Rx