Transmit Eigen-Beamformer with Space-Time Block Code for MISO Wireless Communication Systems

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Abstract: This paper introduces the downlink Eigen-beamformer with Space-Time Block Code (STBC) [1,2] employed on the MISO (Multiple Input Multiple Output) systems. The proposed scheme is acquired both transmit diversity gain from STBC and beamforming gain from Eigen-beamformer. In general, it is well described that the diversity gain be maximized when channel parameters associated to fingers are mutually independent. Major role of utilizing Eigen-beamformer is to enforce channel parameters being uncorrelated. According to this, the proposed STBC combined with Eigen-beamformer on the downlink significantly improves its performance under the spatially correlated channel. Simulation results are accomplished under three distinct channel conditioned with varying the degree of their correlations. The result indicates that our proposed scheme is good performance in spatially correlated channel.

1. Introduction

The STBC has been known as one of promising transmit diversity methods for MISO systems, and its superior performance has been confirmed throughout many papers [1,2]. In order to enhance the capability of mitigating the effects of fading, it is well known that channels between transmit antennas and single receiving antenna are expected to be uncorrelated as possible as it can. In [3], considering the flat fading channel in macro cell environment, it could not guarantee to experience these uncorrelateness. Thus channels between Tx antennas and Rx antenna are frequently showing coherent fading characteristics in realistic case. This results in the performance degradation due to the coherent deep fading. To overcome this problem, recently the Eigen-beamformer (EBF) technique has been introduced [4], its major role is to enforce fading channels being mutually uncorrelated. Here a series of transmit beamformer weight vectors for the EBF have the form of a linear combination of eigenvectors associated to the spatial correlation matrix along the multiple transmit antennas. It is worth while to mention that these EBFs produce the uncorrelateness between MISO channels in average sense [3,4].

*This paper introduces the Eigen-beamformer with Space-*Time Block Code (STBC) on the downlink transmission, which is acquired both transmit diversity gain form STBC and beamforming gain from Eigen-beamformer. And its performance is evaluated under the three distinct channel conditions by varying the degree of spatial correlation between MISO channels.

The rest of this paper is organized as follows. In Section 2, the MISO wireless channel model is introduced. In Section 3, we present the principles of the proposed Transmit Eigen-Beamformer with STBC (TEBS). In Section 4, the superior performance of the proposed scheme will be verified by showing the simulation results. Section 5 contains the conclusions.

2. MISO Channel Model for TEBS

In this paper, we consider two subarrays for transmit beamforming in order to obey the backward compatibility of the conventional STBC. The vector channel between each transmit subarray consisting of M antenna elements and single receiving antenna is configured by the M distinct fading parameters. The rays invoked from the downlink transmission are spread over certain angle spread. And its geometrical interpretation can be obtained from the wave interaction between the Tx antennas and Rx antenna. The long-term spatial covariance matrix is purely characterized on the basis of this geometric situation relevant to certain angle of departure (AoD) profile which is represented by

$$\mathbf{R} = \sum_{r=0}^{N_{ray}} \mathbf{a}(\theta_r)\mathbf{a}^H(\theta_r), \tag{1}$$

where N_{ray} is number of rays, $\mathbf{a}(\theta_r)$ is the M -dimensional directional vector to a signal impinging from azimuth direction θ_r of the r -th ray. In general, the directional vector is expressed in terms of distance of adjacent antenna sensors and departure angle of rays. It can be defined as

$$\mathbf{a}(\theta_r) = [1 \quad \exp(-j\mu) \quad \cdots \quad \exp(-j(M-1)\mu)], \tag{2}$$

In (2), considering the sensor distance d in each subarray and the carrier wavelength λ,

$$\mu = \frac{2\pi}{\lambda} d \sin(\theta_r). \tag{3}$$

Throughout this paper, a uniform linear array (ULA) is presumed to be utilized for each subarray.

It can be easily noticed from (1), the spatial covariance matrix has a hermitian Toeplitz structure indicating that the mutual correlation between neighbored antenna elements is identical [6]. The channel covariance matrix **R** in (1) is decomposed into eigenvectors and eigenvalues by eigen analysis as the following

$$\mathbf{R} = \mathbf{Q}\boldsymbol{\Sigma}\mathbf{Q}^H \tag{4}$$

where $\mathbf{Q}$ is the matrix which is composed with eigenvectors, and $\boldsymbol{\Sigma}$ is a diagonal matrix whose diagonal elements are eigenvalues corresponding to the spatial correlation matrix. Here the vector channel between multiple transmit antennas of subarray and single receiving antenna can be modeled as

$$\mathbf{h} = [h_1 \quad h_2 \quad \cdots \quad h_M]^T = \mathbf{Q}\boldsymbol{\Sigma}^{1/2}\mathbf{g}, \tag{5}$$

In (5), $\mathbf{g}$ is a vector of M independent zero-mean complex Gaussian samples with having unit variance. If Rx and Tx is located relatively far apart and the height of Tx antenna is high enough, the spatial covariance matrix among Tx subarray antennas is determined by directional vector of rays associated to each spatially resolvable multipath as shown in (1). Moreover provided that the distance between two subarrays in Tx part is moderate, and the profiles of AODs corresponding to both subarray would be identical. Hence, with the help of (5), two distinct vector channels can be expressed as follows;

$$\begin{aligned} \mathbf{h}_1 &= [h_{11} \quad h_{12} \quad \cdots \quad h_{1M}]^T = \mathbf{Q}\boldsymbol{\Sigma}^{1/2}\mathbf{g}_1 \\ \mathbf{h}_2 &= [h_{21} \quad h_{22} \quad \cdots \quad h_{2M}]^T = \mathbf{Q}\boldsymbol{\Sigma}^{1/2}\mathbf{g}_2 \end{aligned} \tag{6}$$

where $\mathbf{h}_i$, $i = 1,2$ is the channel vector constituted from the fading parameters between i-th antenna subarray and receiving antenna, h_{ij} is the fading channel parameter between j-th sensor in i-th antenna subarray and receiving antenna. And in (6) $\mathbf{g}_i = [g_{i,1} \quad g_{i,2} \quad \cdots \quad g_{i,M}]^T$ is an i.i.d Gaussian random variable vector about ith subarray. Utilizing (6), it can be noticed that channel covariance matrix for both subarray turn out to be the same as pre-defined spatial covariance matrix.

3. Principles of proposed TEBS

Figure 1 depicts the structure of TEBS for transmission having the two subarray and four antennas in each subarray. For the convenience, the number of antennas for each subarray is prefixed as four. As shown in Fig 1, STBC encoded signals are transmitted through two identical Eigen-beamforming (EBF) blocks associated to subarrays respectively. Here, the beamforming weight vector is a linearly combined of eigenvectors updated from the spatial covariance matrix of subarray on Tx side which is equivalent to the channel correlation matrix. Due to the fact that the correlations between adjacent antennas are strongly dependent on the AOD profile and the antenna distances, as the angle spread (AS) is larger and distance between adjacent antennas is narrower, the degree of correlation gets higher.

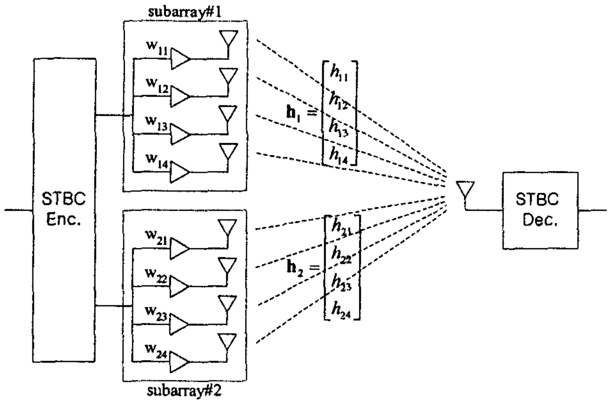

Figure 1. Model of the proposed TEBS system

Since the geometrical interaction of wave propagation between two Tx subarrays and single Rx antenna are the same, the beamforming weight vectors for both subarrays are the same such as

$$\mathbf{w} = \frac{1}{\zeta}\sum_{j=1}^{M}\sqrt{\lambda_j}\,\mathbf{q}_j = \sum_{j=1}^{M}\tilde{\mathbf{w}}^{(j)} \tag{7}$$

where $\mathbf{w}$ is the EBF weight vector which is a linear combination of eigenvectors $\{\mathbf{q}_j\}_{j=1}^M$ weighted by the squre-roots of eigenvalues. In (7), for the weight normalization, $\zeta = \sqrt{\lambda_1 + \lambda_2 + \cdots + \lambda_M}$ is the normalization factor which makes the l_2-norm of EBF weight vector being unity for later performance comparison. Without considering the propagation delay and background additive noise, two distinct symbol sequences, i.e., s_1, s_2, are generated from the STBC encoder, then transmitted over MISO flat fading channel via each subarray EBF.

To see the effect of using EBF, provided that the symbol s is transmitted through the SISO (Single-Input Single-Output) system with having antenna array at Tx side, the received symbol r at receiver from each subarray can be represented as

$$r = \left(\sum_{j=1}^{M}\tilde{\mathbf{w}}^{(j)H}\cdot\mathbf{h}\right)\cdot s = \left(\sum_{j=1}^{M} f_j\right)\cdot s \quad , \quad i = 1,2. \tag{8}$$

Here in (8) $\{f_i\}_{i=1}^M$ are the newly generated fading parameters, and $\mathbf{h}$ is the vector channel for the antenna array to receiver. Consequently, the performance of whole system depends on the characteristic of new fading parameter $f_i = \tilde{\mathbf{w}}^{(j)H}\cdot\mathbf{h}$. Furthermore, to mitigate against the fading effect, those parameters are expected to be mutually independent as possible as they are. The following

Eqn. (9) shows that newly generated fading parameters are totally uncorrelated with each other, i.e. for $m \neq n$,

$$E\{f_m f_n^*\} = E\{\tilde{\mathbf{w}}^{(m)H}\mathbf{h}\ \mathbf{h}^H \tilde{\mathbf{w}}^{(n)}\} = \tilde{\mathbf{w}}^{(m)H}\left\{\sum_{k=1}^{M}\lambda_k \mathbf{q}_k \mathbf{q}_k^H\right\}\tilde{\mathbf{w}}^{(n)} = 0 \quad (9)$$

The result in (9) is originated from the orthonormal property between two distinct weight vectors $\tilde{\mathbf{w}}^{(m)}$ and $\tilde{\mathbf{w}}^{(n)}$, since these are scaled eigenvectors.

Similarly based on the structure of TEBS as shown in Fig. 1, the received signal through two subarrays during two consecutive symbol periods $[0,2T]$ are respectively given by

$$\begin{aligned} r_1 &= s_1\gamma_1 + s_2\gamma_2 + n_1 \\ r_2 &= -s_2^*\gamma_1 + s_1^*\gamma_2 + n_2 \end{aligned} \quad (10)$$

where T is a symbol interval, s_i is the symbol from i-th subarray. $\{n_k\}_{k=1}^2$ are complex AWGN. And $\{\gamma_k\}_{k=1}^2$ are the equivalent fading channel parameters corresponding to subarray k respectively. Here the equivalent channel parameter can be written as

$$\gamma_i = \mathbf{w}^H \mathbf{h}_i . \quad (11)$$

Here in (11), the weight vector for both subarray is the form of weighted linear combination of eigenvectors corresponding to the spatial covariance matrix. With the help of (8) and (9), it could be mentioned that the equivalent channel parameters in (11) are the sum of independent random variables.

The receiver retrieves the transmitted symbol by using soft decision via linearly combining the received signals weighted by equivalent channel parameters over the two consecutive symbol period, i.e.,

$$\begin{aligned} \hat{s}_1 &= r_1\gamma_1^* + r_2^*\gamma_2 \\ &= \left(|\gamma_1|^2 + |\gamma_2|^2\right)\cdot s_1 + \eta_1 , \\ \hat{s}_2 &= r_1\gamma_2^* - r_2^*\gamma_1 \\ &= \left(|\gamma_1|^2 + |\gamma_2|^2\right)\cdot s_2 + \eta_2 \end{aligned} \quad (12)$$

The terms within parenthesis in (12) represent the resulting gain of STBC. Since the newly generated channel parameters $\{\gamma_i\}_{i=1}^2$ are constructed by i.i.d complex Gaussian random variables, the gain can be maximized in average sense. As a result, output SNR (Signal to Noise Ratio) of the proposed TEBS system turns out to be

$$SNR = \frac{1}{2}\frac{|\gamma_1|^2 + |\gamma_2|^2}{\sigma_n^2} . \quad (13)$$

4. Simulation results

In this section, the performance of proposed TEBS method using two subarrays composed of four antennas is verified on the basis of several prescribed spatial covariance matrices. For the sake of comparison, the performances in BER of the conventional STBC without using subarray, the transmit uniform-weighting beamforming STBC (TUBS) method with weights for each subarray whose values are $1/2$ and the proposed TEBS are shown together. To show the performance variations under the different degree of correlation environment, three channel models are exploited as described in [5]. The following descriptions are explaining predetermined channel situations for the simulation.

Case 1: Uncorrelated channel:

In this case the spatial covariance matrix for each subarray is given as the identity matrix. This means that there is no mutual correlation between channels associated to different Tx antennas along the subarray.

Case 2: Weakly correlated channel:

In this case, the degree of correlation is moderate. The antenna spacing is set to be 4 times to the carrier wavelength, and there exists single multipath whose AoD=50 degree and AS=10 degree [5]. The spatial covariance matrix is shown in Table 1.

Case 3: Heavily correlated channel:

In this case, the degree of correlation is high. The antenna spacing is set to be 0.5 times to the carrier wavelength, and other parameters such as AoD and AS are the same as in Case 2. The spatial covariance matrix is shown in Table 1.

Table 1. Channel covariance matrices for simulations

Cov. Mat.		Case 1	Case 2	Case 3
$\begin{bmatrix} 1 & a & b & c \\ a^* & 1 & a & b \\ b^* & a^* & 1 & a \\ c^* & b^* & a^* & 1 \end{bmatrix}$	a	0	$0.1669 + 0.0944j$	$-0.6821 + 0.6512j$
	b	0	$0.0370 + 0.0499j$	$0.0673 - 0.8081j$
	c	0	$0.0092 + 0.0220j$	$0.3773 + 0.5411j$

Figure 2 shows the BER performances of three distinct systems under the predefined channel condition as in case 1. As mentioned, the channel parameters between each antenna along the subarray and the receiver are mutually uncorrelated. In this case, as shown in Fig. 2, the performances associated to three distinct methods are identical such that the proposed TEBS method does not show the performance improvement rather than the conventional STBC. According to the explanation in section 3, this result is surely predictable since the EBF employed in our proposed method could not give any superiority in uncorrelated channel situation.

In Fig. 3, the proposed TEBS method along with the TUBS method using the uniform weighting vector shows the performance improvement under the weakly correlated channel environment. In this case, since the channel parameters experiences the correlation each other such that this correlation can be removed by adopting EBF at the transmitter. But still the degree of correlateness is not severe the performance of our proposed scheme is not dominant. Finally in heavily correlated channel situation, our proposed TEBS outperform the other methods as shown in Figure 4. This result is quite reasonable due to the inherent effects of the EBF for transmit beamformer. The Tx power gain of proposed method is about to 5dB compared with that of the conventional STBC.

4. Conclusions

This paper introduced the TEBS method which employs EBF as the transmit beamformer and STBC as the transmit diversity for MISO systems. The advantage of utilizing EBF is originated from the capability of decorrelating the channel parameters experienced in MISO flat fading channel. This paper verifies the performance improvement of the proposed TEBS method in either weakly or strongly correlated channel situations. From the sake of backward compatibility, our proposed scheme can be employed in the current 3G mobile communication systems with promising performance enhancements.

Acknowledgement

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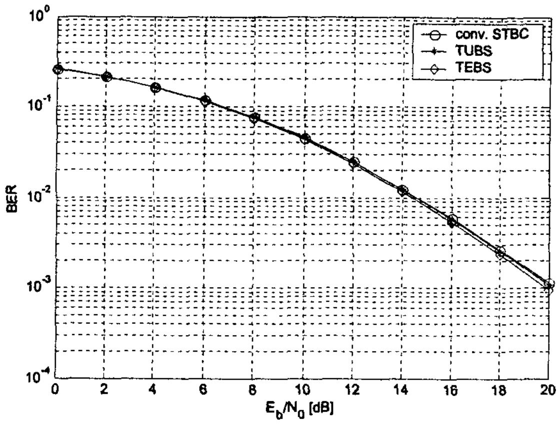

Figure 2. Spatially uncorrelated channel

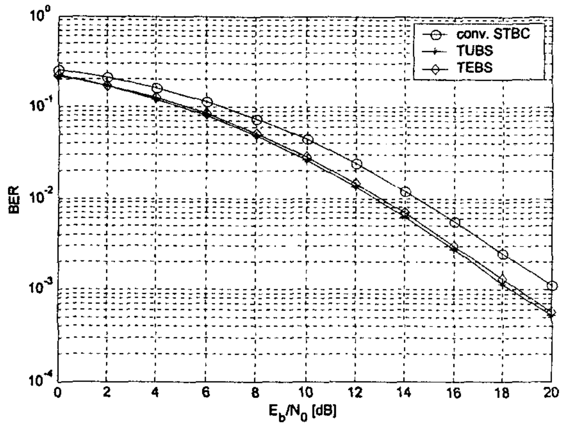

Figure 3. Spatially weakly correlated channel

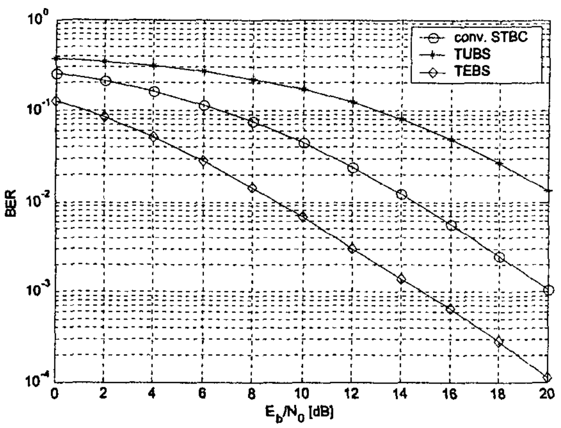

Figure 4. Spatially heavily correlated channel