Block-Ordered STBC MIMO-OFDM combined with Eigen-beamformer and Ad-hoc Power Allocation

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1. Introduction

Regardless of the numerous affirmative features on the usage of MIMO-OFDM systems, the correlation between MIMO fading channels, one of the major destructive causes, brings out performance degradation. Here, the correlation across fading parameters exhibits the degree of coherence in long-term fading characteristics experienced at each subchannel between a certain pair of transmit and receive antennas. This impairment may diminish a diversity gain as well as its capacity, and no further enhancement could be expected even though more number of antennas are involved[1]-[2]. Also, provided that the received multiple substreams produce more-or-less the same SINRs(Signal-to-Interference plus Noise), it is hard to assign the appropriate order of decoding, This occurs the unwanted error propagation on the way of successive signal separation. To overcome above difficulties, this paper proposes the usage of the transmit and receive eigen-beamformer together with sub-optimal ad-hoc transmit power allocation in time domain.

2. Parametric MIMO Channel Modeling

The MIMO channel is constituted with $M_r \times M_t$ distinct propagation paths in pairs of M_t transmit and M_r receive antennas. Assuming that the distance between transmit and receive antennas is far enough, two spatial covariance matrices denoted $\mathbf{R}_t$ and $\mathbf{R}_r$ are designated in the geometric configuration of antenna array. Each element in the spatial covariance matrix corresponds to the mutual correlation across corresponding fading parameters. Clearly, it can be noticed that both covariance matrices are Hermitian Toeplitz, and its diagonal terms are unity. According to [3], the MIMO channel can represented as the following:

$$\mathbf{H} = \mathbf{R}_r^{1/2} \cdot \mathbf{G} \cdot \mathbf{R}_t^{T/2} \qquad (1)$$

where the matrix $\mathbf{G}$ of size $M_r \times M_t$ is comprised of identically and independently distributed (i.i.d.) complex Gaussian random variables having zero mean and unit variance. And in (1), $\mathbf{R}_t^{1/2}$ and $\mathbf{R}_r^{1/2}$ are half decomposed matrices expressed in terms of matrices composed of relevant eigenvectors and root squared eigenvalues, i.e.,

$$\mathbf{R}_r^{1/2} = \mathbf{Q}_r \cdot \mathbf{\Lambda}_r^{1/2} \text{ and } \mathbf{R}_t^{1/2} = \mathbf{Q}_t \cdot \mathbf{\Lambda}_t^{1/2} \qquad (2)$$

where $\mathbf{Q}_t$ and $\mathbf{Q}_r$ are the collections of eigenvectors relevant to $\mathbf{R}_t$ and $\mathbf{R}_r$ respectively, and diagonal matrices $\mathbf{\Lambda}_t$ and $\mathbf{\Lambda}_r$ are comprised of corresponding eigenvalues.

3. Principles of JBSTBC MIMO-OFDM Scheme with Employing Block-Ordered Successive Decoding

Figure 1(a) depicts the generic structure of proposed JBSTBC MIMO-OFDM transmitter where the single symbol stream is demultiplexed into $N(=M_t/2)$ substreams, then those are STBC-OFDM encoded in pairwise, respectively, output streams are performed Inverse Fast Fourier Transform (IFFT) as FFT points and conveyed into the block of transmit eigen-beamformer. Figure 1(b) shows

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the structure of JBSTBC receiver comprised of a bank of receive eigen-beamformers, a MRC block and a series of block-ordered successive STBC decoders.

Let us denote $\mathbf{w}_i$, $i=1,\cdots,M_t$, as transmit eigen-beamformer weight vectors, $\mathbf{X}=[X_1 \ \cdots \ X_{M_t}]^T$ as the output vector of N^{th} subsymbol of one frame in frequency domain to the STBC-OFDM encoder. $\mathbf{x}=[x_1 \ \cdots \ x_{M_t}]^T$ as the sample carried on k^{th} subcarrier of OFDM symbol in time domain after IFFT and $\mathbf{t}=[t_1 \ \cdots \ t_{M_t}]^T$ as the beamformed vector for the sample carried on k^{th} subcarrier of OFDM symbol at front end .Here, the signal vector $\mathbf{t}$ to be transmitted can be expressed in a form of weighted linear combination as the following:

$$\mathbf{t}=\mathbf{w}_1x_1+\mathbf{w}_2x_2+\cdots+\mathbf{w}_{M_t}x_{M_t}=\mathbf{W}\mathbf{x} \tag{3}$$

where the matrix $\mathbf{W}$ of size $M_t \times M_t$ is the collection of eigen-beamformer weight vectors.

The received vector $\mathbf{r}=[r_1 \ \cdots \ r_{M_r}]^T$ can be expressed as

$$\mathbf{r}=\mathbf{H}(l)*\mathbf{t}+\mathbf{n} \quad = \mathbf{R}_r^{1/2}\cdot\mathbf{G}(l)\ \cdot\mathbf{\Lambda}_t^{1/2}*\mathbf{x}+\mathbf{n} \tag{4}$$

where $\mathbf{H}(l)\equiv\sum_{l=0}^{L-1}H(t-l)$, $\mathbf{G}(l)\equiv\sum_{l=0}^{L-1}G(t-l)$ and superscript $*$ means the convolution.

Referring to the receiver structure in Fig. 1(b) the vector after the receive beamforming process is denoted by $\mathbf{z}=[\mathbf{z}_1 \ \cdots \ \mathbf{z}_{M_r}]^T$, whose explicit expression is

$$\mathbf{z}\triangleq[\mathbf{v}_1^H\cdot\mathbf{r} \quad \mathbf{v}_2^H\cdot\mathbf{r} \quad \cdots \quad \mathbf{v}_{M_r}^H\cdot\mathbf{r}]^T=\tilde{\mathbf{G}}(l)*\mathbf{x}+\tilde{\mathbf{n}} \tag{5}$$

where $\tilde{\mathbf{G}}(l)=\Lambda_r^{1/2}\cdot\mathbf{G}(l)\cdot\Lambda_t^{1/2}$ and $\tilde{\mathbf{n}}=\mathbf{Q}_r^H\cdot\mathbf{n}$ are the modified subchannel of MIMO-OFDM and noise vector, respectively. With the usage of transmit and receive eigen-beamformers, the original matrix channel $\mathbf{H}(l)$ is altered to $\tilde{\mathbf{G}}(l)$ whose input and output are $\mathbf{x}$ and $\mathbf{z}$, respectively. Here, (5) can be represented as N^{th} subsymbol of one frame in frequency domain before IFFT, i.e.,

$$\mathbf{Z}=\tilde{\mathbf{G}}\cdot\mathbf{X}+\tilde{\mathbf{N}} \tag{6}$$

where $\tilde{\mathbf{G}}$ denotes N^{th} subchannel of frequency response correspond with channel matrix.

Consecutive frames $F_{i,1}$ and $F_{i,2}$, component of symbols as the number of FFT Points, are input to the i^{th} STBC-OFDM encoder, Assuming that the channel experiences frequency selective slow fading, the sample carried on N^{th} subcarrier denoted as $Z_q(0)$ and $Z_q(1)$ received at the q^{th} antenna over a certain two-frame period can be expressed as the following:

$$\begin{bmatrix} Z_q(0) \\ Z_q(1) \end{bmatrix}=\sum_{k=1}^{M_t/2}\begin{bmatrix} S_{k,1}/\sqrt{2} & -S_{k,2}^*/\sqrt{2} \\ S_{k,2}/\sqrt{2} & S_{k,1}^*/\sqrt{2} \end{bmatrix}\cdot\begin{bmatrix} \tilde{G}_{q,2k-1} \\ \tilde{G}_{q,2k} \end{bmatrix}+\begin{bmatrix} \tilde{N}_q(0) \\ \tilde{N}_q(1) \end{bmatrix} \tag{7}$$

where, $\tilde{G}_{i,j}$, namely the $(i,j)^{th}$ component of N^{th} subchannel $\tilde{\mathbf{G}}$, is assumed to be *quasi-static*} over two frame period. To make further progress, rewriting Eqn. (7) in vector notation gives rise to

$$\mathbf{Z}_q=\sum_{k=1}^{M_t/2}\tilde{\mathbf{G}}_{q,k}\cdot\mathbf{X}_k+\tilde{\mathbf{N}}_q \tag{8}$$

where, $\mathbf{Z}_q\equiv[Z_q(0) \quad Z_q^*(1)]^T$, $\mathbf{X}_k\equiv[S_{k,1}/\sqrt{2} \quad S_{k,2}^*/\sqrt{2}]^T$ and $\tilde{\mathbf{G}}_{q,k}\equiv\begin{bmatrix} \tilde{G}_{q,2k-1} & -\tilde{G}_{q,2k} \\ \tilde{G}_{q,2k}^* & \tilde{G}_{q,2k-1}^* \end{bmatrix}$ (9)

In order to perform decoding with using (7)-(9), the following relationship can be constructed.

$$\mathbf{Y}=\mathbf{\Theta}\cdot\mathbf{U}+\boldsymbol{\eta} \tag{10}$$

where, $\mathbf{Y}=[\mathbf{Z}_1^T \ \cdots \ \mathbf{Z}_{M_r}^T]^T$, $\mathbf{\Theta}=[\tilde{\mathbf{G}}_1 \ \cdots \ \tilde{\mathbf{G}}_{M_t/2}]$, $\mathbf{U}=[\mathbf{X}_1^T \ \cdots \ \mathbf{X}_{M_t/2}^T]^T$, $\boldsymbol{\eta}=[\tilde{\mathbf{N}}_1^T \ \cdots \ \tilde{\mathbf{N}}_{M_r}^T]^T$ (11)

and $\tilde{\mathbf{G}}_k=[\tilde{\mathbf{G}}_{1,k}^T \quad \tilde{\mathbf{G}}_{2,k}^T \quad \cdots \quad \tilde{\mathbf{G}}_{M_r,k}^T]^T$ (12)

As a first step for generating decision statistics along the process of block-ordered JBSTBC-MIMO-OFDM decoding, MRC is preceded on received vector $\mathbf{Y}$ with the usage of matrix $\mathbf{\Theta}$. As a result,

$$\boldsymbol{\beta}=\mathbf{\Theta}^H\cdot\mathbf{Y}=\mathbf{A}\cdot\mathbf{U}+\boldsymbol{\xi} \tag{13}$$

where $\beta\equiv[\beta_1^T \ \cdots \ \beta_{M_t/2}^T]^T$ with $\beta_i\equiv[\beta_1^T \ \cdots \ \beta_{M_t/2}^T]^T$ represents a vector of decision statistics for a series blocks of subsymbols. And $\boldsymbol{\xi}\equiv\mathbf{\Theta}^H\cdot\boldsymbol{\eta}$ is the noise vector, and the square matrix $\mathbf{A}=\mathbf{\Theta}^H\cdot\mathbf{\Theta}$ of size $M_t\times M_t$ is denoted as the "characteristic matrix". With using (13) the decision statistics $\hat{\mathbf{X}}_k$ for the k^{th} transmitted block of subsymbols turns out to be

$$\hat{\mathbf{X}}_k \triangleq \boldsymbol{\beta}_k = \tilde{\mathbf{G}}_k^H \tilde{\mathbf{G}}_k \mathbf{X}_k + \sum_{l=1\&l\neq j}^{Mt/2} \tilde{\mathbf{G}}_k^H \tilde{\mathbf{G}}_l \mathbf{X}_l + \boldsymbol{\xi}_k \tag{14}$$

Here a block SINR denoted by $SINR_k$ for symbol vector $\mathbf{X}_k$ can be explicitly represented by $P_{k,S}/(P_{k,I}+P_{k,N})$. where $P_{k,S}$, $P_{k,I}$ and $P_{k,N}$ are signal, interference and noise powers associated with the wanted k^{th} block of subsymbol vector $\mathbf{X}_k$, respectively. the iterative STBC-OFDM decoding process can be performed in block-wise incorporated with sorting out the order of decoding by inspecting $SINR_k$'s for every subsymbol blocks.

4. Ad-hoc Power Allocation Based on The Proposed Power Discrimination Function (PDF)

At the receiver, Eigenvalues of transmit covariance matrix becomes almost unity, which this situation implies a lack of deviation among received SINRs, such that the signal separation conducted during the block-ordered STBC decoding process becomes corrupted due to the strong coexistence of inter-substream interferences.

To mitigate this problem, a transmitter structure with applying an ad-hoc power allocation scheme on the basis of the proposed PDF. Here, the PDF is an eigenvalue of transmit spatial covariance matrix and output is an extra weighting value. The proposed PDF used for ad-hoc power allocation is expressed as a function of eigenvalue λ_i^t, i.e., for $i=1,\cdots,M_t$

$$\tilde{c}_i = c(\lambda_i^{Tx})/\rho = (M_t/\rho)\cdot[1-\exp((\alpha\lambda_i^{Tx})^{CO/ESR})] \tag{15}$$

where $\alpha = \ln(1-1/M_t)$ and $\rho = \sqrt{\sum_{i=1}^{M_t} c^2(\lambda_i^{Tx})/M_t}$ is the normalization factor used preserve the total transmit power. The principal parameters designated in (15) are ``ESR(Eigenvalue Spread Ratio)" calculated from the eigenvalues of transmit covariance matrix and ``CO(Curve Order) " selected by considering degree of power discrimination.

5. Simulation Results And Performance Analysis

In this section illustrates BER curves of the proposed method for a fixed signal constellation. In simulations, the relevant parameters together with eigenvalues of specifically constructed transmit spatial covariance matrices is prescribed in Table 1. observing the eigenvalues of spatial covariance matrix for Case #1, it can be stated that there exists strong correlations among fading channels from multiple transmit antennas to a certain receive antenna. On the other hand, the depth of correlation is relatively weak for Case #4. receive spatial covariance matrices, $\mathbf{R}_r$ is prescribed in PAS *Uniform*, Topology 0.5λ, AS $360°$ and AOA $0°$. Figure 2 (in dotted lines) shows the results representing the BER behaviours with respect to given E_b/N_0's. Clearly, it is worthwhile to mention that as increasing the depth of correlation between fading channels the BER performance degrades due to the loss of diversity gain. Figure 2 (in solid lines) shows the BER behaviours resulting from block-ordered STBC-OFDM decorder combined with joint eigen-beamformer without involving the proposed ad-hoc power allocation scheme. For the cases when the depth of fading correlation is relatively strong (``Case #1" and ``Case #2"), plausible performances could be obtained. However, in the existence of low correlations (``Case #3" and ``Case #4"), there is a little performance improvement regardless of employing eigen-beamformers. This is due to the fact that spatial channels are already somewhat uncorrelated, so that it could expect no further enhancement of diversity gain. Moreover, since the SINRs corresponding to multiple blocks of symbols are more or less the same, the error occurs along the execution of successive signal separation attributed to strong coexistence of substream interferences. It is necessary to employ the ad-hoc transmit power allocation so as to enforce received SINRs diversified on purpose. Figures 3 shows BER curves resulting from applying the proposed JBSTBC-MIMO-OFDM combined with the ad-hoc power allocation scheme. As shown in Fig.3, the proposed method (in solid lines) with the curve order of 5 in PDF outperforms the conventional one (in dotted lines) in presence of both low correlated channels.

6. Conclusion

This paper proposed a novel MIMO-OFDM transmission scheme designated as JBSTBC comprised of transmit and receive eigen-beamformers, space-time block encoder and block-ordered decoder. Along the recovery of multiple sub-streams at receiver, a series of successive signal separations incorporated with simple MRC are conducted based on predetermined block order of detection. Moreover, when fading channels are weakly correlated, a performance degradation could be encountered due to the imperfect signal separation. In order to circumvent this problem the ad-hoc power allocation technique was proposed, which is parameterized in terms of the eigenvalue spread ratio corresponding to transmit spatial covariance matrix and a priori assigned curve order. The amount of transmit power readjustment is computed for each substream to be transmitted on the basis of the proposed PDF. The contribution of ad-hoc power allocation to signal separation is concrete, since the discrimination among SINRs associated with substreams could be enhanced.

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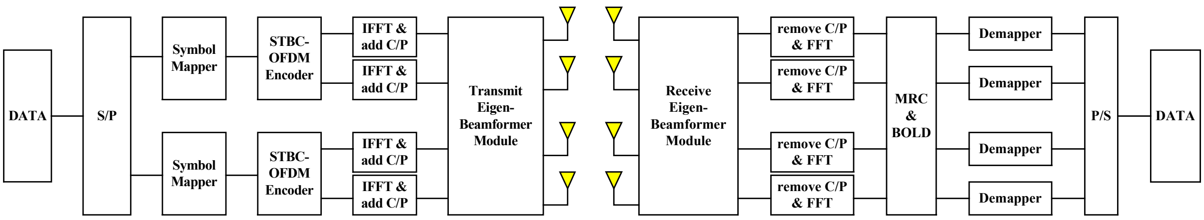
TABLE 1 Parameter For Transmit Spatial Covariance Matrices [4]

	Case #1	Case #2	Case #3	Case #4
PAS	Laplacian	Laplacian	Laplacian	Laplacian
Topology	0.5λ	0.5λ	4λ	4λ
AS	10°	15°	10°	15°
AoD	22.5°	31°	50°	–20°



(a) Structure of Transmitter (b) Structure of Receiver

Fig.1 Block diagrams of JBSTBC MIMO-OFDM transmitter and receiver

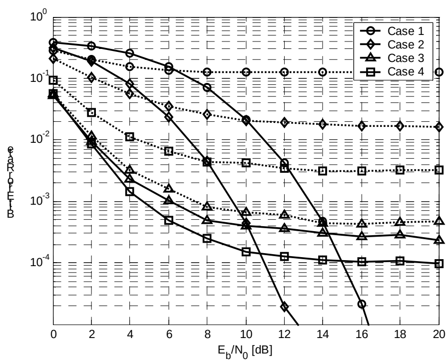


Fig.2 Effect of Eigen-beamformer

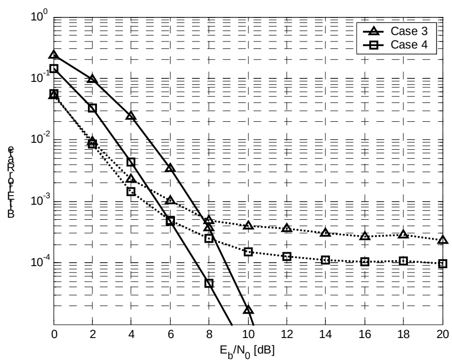


Fig.3 Effect of ad-hoc power allocation