Group Selection for Transmit Beamforming Systems Combined with V-BLAST over Correlated Fading Channels

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1. Introduction

In the rich scattering environment, the multiple-input multiple-output (MIMO) antenna systems is well known to promise higher data rates with reliable link quality by several literatures [1],[2]. However, the beamforming system which exploits antenna correlation and concentrates the antenna beam on the desired direction has a barrier to combine with some kinds of MIMO technologies such as Vertical Bell laboratories layered space-time (V-BLAST)[1] and Space time coding (STC)[2].

Due to the completely different of antenna deployment between the beamforming system(half times wavelength of the carrier) and MIMO technologies(10 times wavelength of the carrier), there is a contradiction to combine two systems together. However, several studies have proposed modified beamforming structures to achieve the diversity gain of STC or the multiplexing gain of BLAST system [4],[5]. In [4], a new beamforming structure is suggested in order to obtain the diversity gain by optimizing a cost function of the beamforming weight vector. While in [5], by the antenna grouping, spatial multiplexing gain is achieved in beamforming structure.

In this paper, we propose a new transmit beamforming system combined with V-BLAST using antenna selection considering the hardware cost of the transmitter. The radio frequency (RF) chains which make hardware cost and complexity of devices dominantly increase are alleviated by antenna selection. Additionally, it is known that selecting the best subset of antennas gives the improvement of diversity gain without the loss of spectral efficiency [6], [7]. To exploit these advantages of antenna selection, we divide transmit multiple antennas into several groups which consist of transmit antenna arrays (TAA) and derive optimum beamforming weight vectors from two distinct selection strategies which are to maximize received signal-to-noise ratio(SNR) and mutual information(MI) respectively. The simulation results show that proposed system obtains additional diversity gain while maintains the same capacity of V-BLAST system without group selection.

This paper is organized as follows. The system model of a novel transmit beamforming combined with V-BLAST is presented in section 2. Section 3 describes our overall transmit strategies and how to evaluate beamforming weight vectors in each scenario. Then, the simulation results are followed in Section 4. Finally, the paper is concluded in section 5.

2. System Model

Fig. 1. shows the proposed transmit beamforming combined with V-BLAST system. First, it divides $N_G N_t$ antennas into N_G groups to form virtual $N_G \times N_r$ V-BLAST system with the N_r received antennas. We assume that antenna correlations among N_G groups at the transmitter and among N_r receive antennas are negligible but N_t antennas of each group are fully correlated. Next, in the proposed scheme, N_{GS} groups out of N_G are selected for actual data transmission and transmit different data streams like V-BLAST system. However, N_t correlated antennas of each group send same symbols to make directional

beam. Then, we can model the received signal as follows:

$$\begin{aligned}\mathbf{y} &= \mathbf{H}\tilde{\mathbf{x}} + \mathbf{n} \\ &= \begin{bmatrix} \mathbf{H}_1 & \dots & \mathbf{H}_{N_{GS}} \end{bmatrix} \begin{bmatrix} \mathbf{w}_1 x_1 \\ \vdots \\ \mathbf{w}_{N_{GS}} x_{N_{GS}} \end{bmatrix} + \mathbf{n} \\ &= \sum_{i=1}^{N_{GS}} \mathbf{H}_i \mathbf{w}_i x_i + \mathbf{n}\end{aligned} \tag{1}$$

where $\mathbf{H} \in C^{N_r \times (N_t N_{GS})}$ is the channel fading matrix which consists of sub-channel matrix $[\mathbf{H}_1 \dots \mathbf{H}_{N_{GS}}]$. The sub-channel matrix $\mathbf{H}_i \in C^{N_r \times N_t}$ is a channel of i-th group and modeled as $\mathbf{H}_i = \mathbf{R}_r^{1/2} \mathbf{H}_\omega \mathbf{R}_t^{1/2}$ where $\mathbf{R}_t$ and $\mathbf{R}_r$ are covariance matrices of the transmit and receive antennas respectively. The receive covariance matrix is replaced by $\mathbf{I}_{N_r \times N_r}$ according to our assumption, and the transmit covariance matrix follows the widely used one in [5]. $N_r \times N_t$ random matrix $\mathbf{H}_\omega$ is independent and identically distributed (i.i.d) circular symmetric Gaussian matrix. The transmit symbol vector $\tilde{\mathbf{x}}$ consists of beamforming weight vector $\mathbf{w}_i \in C^{N_t}$ ($\|\mathbf{w}_i\|_2^2 = N_t$), $i = 1, 2, ..., N_{GS}$ in the i-th group and modulated data symbol vector $\mathbf{x}$. The random noise vector $\mathbf{n} \in C^{N_r}$ is complex Gaussian with zero-mean and noise variance $\frac{N_0}{2} \mathbf{I}_{N_r \times N_r}$.

3. Group Selection Criteria

In this section, the ways to select N_{GS} groups out of N_G and to find optimum beamforming weight vectors are proposed under the perfect channel state information at both sides of tranceiver. We derive those by two criteria: One is to maximize the received SNR, and the other is to maximize MI. In both schemes, all combinations of the N_{GS} groups are evaluated the received SNR or the MI to choose the best groups among N_G candidates. Finally, the combinations of the groups which corresponds with the maximum value are used in the actual transmission. The follow subsections describe details about two selection criteria with some equations.

3. 1 The maximization of the received SNR criterion

In this criterion, all combinations of the N_{GS} groups among N_G groups are evaluated based on the received SNR. The groups which have the biggest received SNR are selected for actual data transmission. Assuming that transmit signal x_i's are independent, the received SNR of all possible combinations of groups is

$$SNR_j = \sum_{i=1}^{N_{GS}} \frac{\mathbf{w}_i^H \mathbf{H}_i^H \mathbf{H}_i \mathbf{w}_i E_s}{N_{GS} N_0/2}, \; j \in C_{N_{GS}}^{N_G} \tag{2}$$

where E_s is the energy per symbol. The channel covariance matrix $\mathbf{H}_i^H \mathbf{H}_i$ is positive definite hermitian matrix due to the transmit antenna covariance matrix.

By the Spectral Theorem [8], equation (3) is the maximum received SNR when vector $\mathbf{w}_i$ is the eigenvector associated with the maximum eigenvalue of the channel covariance matrix. The maximum SNR is shown by

$$SNR_j = \frac{N_t \sum_{i=1}^{N_{GS}} \lambda_i E_s}{N_{GS} N_0/2} \tag{3}$$

where λ_i is the maximum eigenvalue of $\mathbf{H}_i^H \mathbf{H}_i$. Using this equation, the possible combination of all groups yields the N_{GS} groups.

3. 2 The maximization of the MI criterion

In this criterion, N_{GS} of combinative groups among N_G groups are evaluated by mutual information. Finally selected groups have the biggest MI among all sort of cases.

The MI is given by

$$C_j = \ln\det\left(\mathbf{I}_{N_r\times N_r} + \frac{SNR}{N_{GS}N_t}\sum_{i=1}^{N_{GS}}\mathbf{H}_i\mathbf{w}_i\mathbf{w}_i^H\mathbf{H}_i^H\right), j\in C_{N_{GS}}^{N_G} \tag{4}$$

where det($\mathbf{X}$) is determinant of $\mathbf{X}$. The Natural logarithm is omitted to calculate C_j because it is monotonically increasing function. Using Jacobi's formula $\det(\mathbf{I}+\mathbf{X}) \cong 1 + \mathrm{tr}(\mathbf{X})$ where tr(($\mathbf{X}$)) is a trace of $\mathbf{X}$, the approximated MI can be represented

$$\begin{aligned}&\det\left(\mathbf{I}_{Nr\times Nr} + \tfrac{SNR}{N_{GS}N_t}\sum_{i=i}^{N_{GS}}\mathbf{H}_i\mathbf{w}_i\mathbf{w}_i^H\mathbf{H}_i^H\right)\\ &\cong 1 + \mathrm{tr}\left(\tfrac{SNR}{N_{GS}N_t}\sum_{i=i}^{N_{GS}}\mathbf{H}_i\mathbf{w}_i\mathbf{w}_i^H\mathbf{H}_i^H\right)\\ &= 1 + \tfrac{SNR}{N_{GS}N_t}\sum_{i=i}^{N_{GS}}\mathbf{w}_i^H\mathbf{H}_i^H\mathbf{H}_i\mathbf{w}_i\end{aligned} \tag{5}$$

In equation (5), $\mathbf{H}_i^H\mathbf{H}_i$ is the positive definite hermitian matrix. Therefore, we can achieve the maximum MI with the optimized beamforming weight vectors by taking the eigenvector of the maximum eigenvalue.

4. Simulation Results and Discussion

The performance of the group selection for transmit beamforming systems combined with V-BLAST is demonstrated by the Monte-Carlo simulation. We consider a downlink transmission system with 2 selected groups and 2 receive antennas. Each group uses 2-element ULA. The channel is assumed quasi-static Rayleigh flat fading and the correlation coefficient ρ is set to 0.3 and 0.8 as the low and high spatially correlated cases respectively. We compare our proposed scheme (GS max SNR or GS max MI) with transmit beamforming systems combined with V-BLAST without group selection (BF+V-BLAST w/o GS) and conventional V-BLAST in terms of bit error rates (BER) vs. SNR.

Fig. 2 (a) shows that proposed scheme with SNR criterion has the SNR gain compared with BF+V-BLAST w/o GS about 3dB at a BER of 10^{-3} when the channel is high correlated and 1dB when the channel is low correlated compared with BF+V-BLAST w/o GS. In case of MI criterion, the superiority of proposed scheme is more prominent due to the diversity gain which is defined as the slope of the BER-SNR curve. For example, at a BER of 10^{-3}, the maximization of the MI obtains about 4dB power gain compared with BF+V-BLAST w/o GS regardless of channel correlation coefficient.

In the second simulation, we measure the diversity order of proposed scheme as the number of the candidate groups are increased. Fig. 2 (b) shows that the improvement of diversity order is observed only in maximization of MI criterion case.

5. Conclusions

In this paper, we propose a new transmit beamforming system combined with V-BLAST adopting the group selection which contributes saving the hardware cost of RF chains. Two group selection criteria are derived and optimum beamforming weight vectors of each case are found. Simulation results show that the proposed scheme provides a significant enhancement in the BER performance compared with the conventional V-BLAST and transmit beamforming systems. Moreover, we conform that additional diversity gain can be achieved when the MI criterion is used. In conclusion, the proposed scheme obtain the diversity gain and the beamforming gain simultaneously with the same number of the RF chains of conventional V-BLAST system while holding the spectral efficiency.

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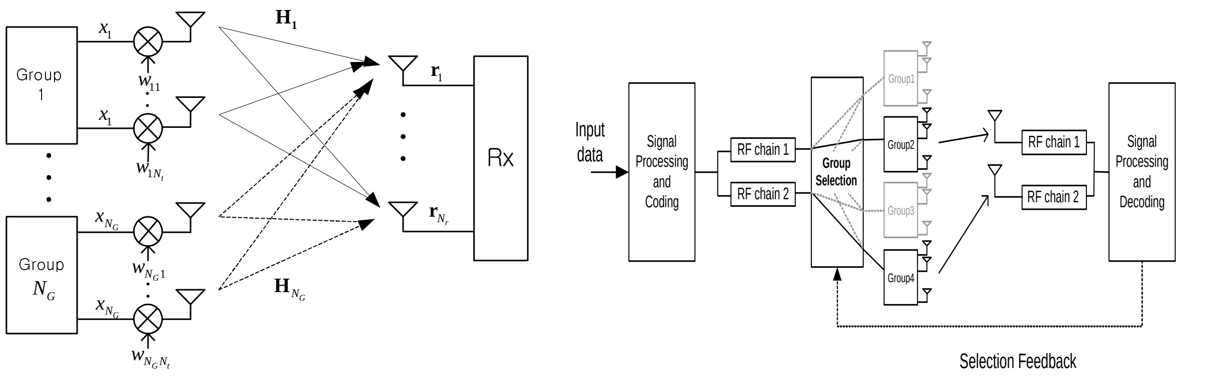
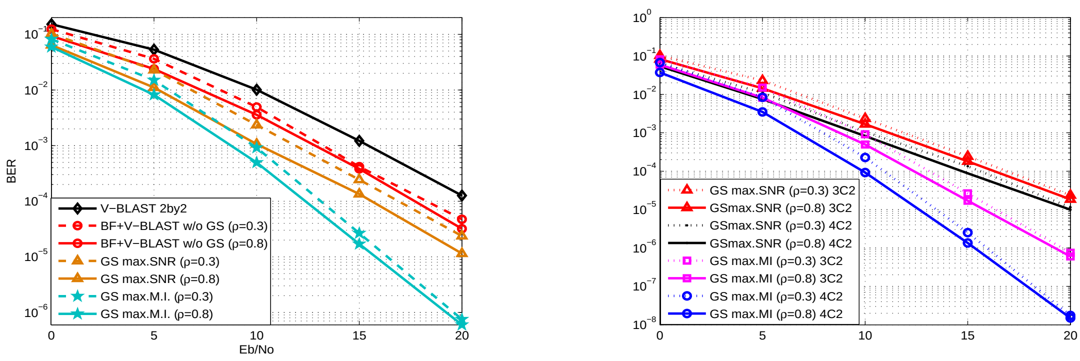


(a) (b)

Figure 1: (a) Block diagram for the combined scheme of the beamforming and V-BLAST (b) Transmit antenna group selection (N_G = 4, N_{GS} = 2, N_r = 2)



(a) (b)

Figure 2: Simulation results for QPSK with ML decoding in the low/high correlation channels(N_{GS} = N_r = 2, η = 4bps/Hz) (a) BER performance comparison of proposed schemes(GS) vs. conventional V-BLAST (b) Diversity gain comparison of two group selection criterion

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