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Antenna Selection for MIMO Systems in Correlated Channels with diversity technique

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Abstract—In recent years, due to the increasing demand of the data transmission rate, a lot of research based on Multiple-Input Multiple-Output (MIMO) system is established. MIMO systems can increase the system capacity and improve transmission reliability. However, the multiple RF chains associated with multiple antennas are costly in terms of size, power and hardware. Antenna selection techniques have been applied in MIMO system design to reduce the system complexity and cost. In this paper, we consider two schemes of antenna selection in correlated Rayleigh channels i.e. the maximal ratio transmission and Orthogonal Space-Time Block Code technique. The simulation results illustrate that; the new antenna selection scheme can obtain performance close to the optimum selection with low computational complexity.

Index Terms—Antenna selection, receiver diversity, transmit diversity, multiple-input multiple-output (MIMO) systems, multiple-antenna communications, Correlated channels, space-time coding, wireless communications.

I. INTRODUCTION

Recent results have demonstrated that multiple-input multiple-output (MIMO) systems, which employ multiple antennas at both transmitter and receiver, can significantly increase system capacity and improve performance of wireless communication channel as shown by Telatar [1], Foschini and Gans [2] and Khalighi [3]. However, the deployment of multiple antennas would require the implementation of multiple RF chains with separate modulator (demodulator) chain at the transmitter (receiver) that consists of analog to digital converters (A/D and D/A) that are typically expensive. With this motivation, antenna selection (AS) has been introduced recently as a means to alleviate this complexity while exploiting the diversity provided by adaptively choosing the signals from a subset of available antenna elements [4]-[5]. In this case only the best set of antennas is used but gives almost the same capacity as the conventional systems, as the remaining antennas are not employed, thus the number of required RF chains are reduced.

It is also well known that these systems are subject to severe multipath fading which can seriously degrade the bit error rate (BER) performance. One of the common methods used in wireless communication to combat multipath fading is the antenna diversity technique. Diversity at the receive side,

referred to as diversity combining which skillfully combines multiple replicas of the received signal is a classical and powerful technique to combat multipath impairments. The widely used signal processing techniques in diversity systems are the maximal ratio combining (MRC), equal gain combining (EGC) and the selection combining (SC) algorithms. MRC provides the best improvement in system performance, followed by the equal gain combining and then by selection combining. We will limit our study to MRC and SC algorithms. In MRC systems, the signals from the received antenna elements are weighted with the weights being proportional to the power in each branch such that the signal-to-noise ratio (SNR) of their sum is maximized. However, with MRC, most of the system complexity concentrates at the receiver side. To achieve a high diversity order, a large number of receive antennas with the same number of RF chains have to be deployed at the small size mobile set, which is normally impractical. To decrease the receiver complexity in terms of the number of RF chains, a simple suboptimal combining scheme was proposed, it refers to selection combining (SC). In SC systems, the output is the branch with the highest signal-to-noise ratio or power. The SC has been extended to the case where the signals on more than one receive antenna with the largest instantaneous SNR are combined, this scheme is referred to as hybrid selection/maximal-ratio combining (HS/MRC) [5]. However, HS/MRC scheme only decreases the number of RF chains but cannot decrease the number of antennas physically deployed at the mobile set for the downlink transmission. Therefore, a transmit antenna selection scheme in which MRC is used at the receiver is investigated. This scheme is referred to as transmit antenna selection/maximal-ratio combining (TAS/MRC) scheme, where a single transmit antenna which maximizes the SNR at the output of the maximal-ratio combiner, is chosen for transmission. This system has been discussed in [6], [7] where a BER expression for the uncorrelated Rayleigh channel with BPSK is given.

In addition, with a limited number of antennas allowed in the small mobile set, we can obtain a high diversity order if space-time code technique is used at the base station that deploy multiple antennas. It's referred to as transmit diversity. In recent years, several space-time coding schemes have been

developed. For example, a simple transmit diversity scheme proposed by Alamouti [8]; and space-time block codes (STBC) developed by Tarokh [9], which are essentially a generalization of the Alamouti's scheme. For Orthogonal STBC, beside their diversity advantage, they provide decoding simplicity since transmitted symbols are separately decoded by means of linear processing. Alamouti's scheme for two transmit antennas is the unique orthogonal space-time block code for complex channel symbols which provides both full diversity and full rate. However, employing more than two transmit antennas impose some constraints of physical limitation of wireless devices.

To overcome these problems, while utilizing the advantage of using multiple antennas, several papers have appeared recently in the literature in which the notion of antenna selection was introduced. In this paper, we investigate in terms of concept and principles of Transmit Antenna Selection with MRC (TAS/MRC) and Antenna Selection with OSTBC (AS/OSTBC) in correlated channel with QPSK constellation. It can provide a reference for the optimum performance that a system can obtain using both transmit and receive diversity. The paper is organized as follows. Section II establishes the system model. In section III, the TAS/MRC and AS/OSTBC is presented which are followed by some simulation results and discussions in section IV. Conclusions are given in section V.

II. SYSTEM MODEL

Let us consider a narrowband MIMO communication system with N_T antennas at the transmitter side and N_R antennas at the receiver side. After antenna selection, K transmit and L receive antennas are used ($K \leq N_T, L \leq N_R$). The received signals can be written as:

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{n} \quad (1)$$

where $\mathbf{x} = [x_1, x_2, \dots, x_{N_T}]^T$ denotes the transmitted vector, in which are symbols drawn from possibly different constellations, $\mathbf{y} = [y_1, y_2, \dots, y_{N_R}]^T$ denotes the received vector and $\mathbf{n} = [n_1, n_2, \dots, n_{N_R}]^T$ is a complex additive white Gaussian noise (AWGN) vector with covariance $E\{\mathbf{nn}^H\} = N_0 I_{N_R}$, N_0 is the power spectral density of the AWGN at each receive antenna and I_{N_R} denotes the $N_R \times N_R$ identity matrix. We normalize the constellation energy such that $E\{\mathbf{x}^H \mathbf{x}\} = E_S$, where E_S is the total transmit energy. If the antenna elements are closely spaced, and/or the angular spread of the multipath components is small, then the entries of channel matrix are correlated. The $N_R \times N_T$ channel matrix is given below:

$$\mathbf{H} = \mathbf{R}_{\mathbf{R}_x}^{1/2} \mathbf{H}_w \mathbf{R}_{\mathbf{T}_x}^{1/2} = \begin{bmatrix} h_{11} & \cdots & h_{1N_T} \\ \vdots & \ddots & \vdots \\ h_{N_R 1} & \cdots & h_{N_R N_T} \end{bmatrix} \quad (2)$$

Where $\mathbf{R}_{\mathbf{R}_x} = \mathbf{R}_{\mathbf{R}_x}^{1/2} (\mathbf{R}_{\mathbf{R}_x}^{1/2})^H$ and $\mathbf{R}_{\mathbf{T}_x} = \mathbf{R}_{\mathbf{T}_x}^{1/2} (\mathbf{R}_{\mathbf{T}_x}^{1/2})^H$ are the $N_R \times N_R$ receive and $N_T \times N_T$ transmit correlation matrices, respectively. $\mathbf{R}_{\mathbf{R}_x}^{1/2}$ and $\mathbf{R}_{\mathbf{T}_x}^{1/2}$ indicate the square-root decomposition of $\mathbf{R}_{\mathbf{R}_x}$ and $\mathbf{R}_{\mathbf{T}_x}$. $[\cdot]^H$ denotes the conjugate transpose operation. And \mathbf{H}_w is a matrix whose elements

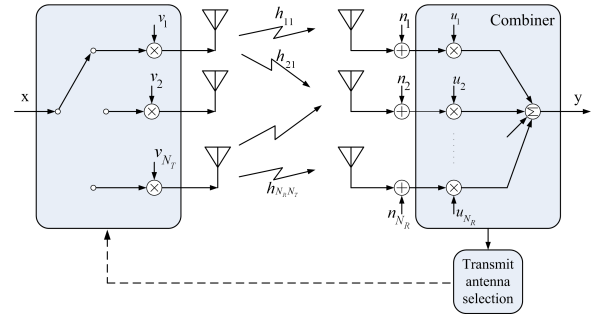


Fig. 1. Transmit antenna selection with MRC

are independent and identically distributed (i.i.d) complex Gaussian random variables with zero mean and unit variance. \mathbf{R} is the correlation control matrix, which can be generated by kronecking the transmit correlation matrix $\mathbf{R}_{\mathbf{T}_x}$ and the receive correlation matrix $\mathbf{R}_{\mathbf{R}_x}$; \otimes designates the Kronecker product.

$$\mathbf{R} = \mathbf{R}_{\mathbf{T}_x} \otimes \mathbf{R}_{\mathbf{R}_x} \quad (3)$$

with

$$\mathbf{R}_{\mathbf{T}_x} (\mathbf{R}_{\mathbf{R}_x}) = \begin{pmatrix} 1 & \rho_{12} & \cdots & \rho_{1N_T} \\ \rho_{21} & 1 & \cdots & \rho_{2N_T} \\ \vdots & \vdots & 1 & \vdots \\ \rho_{N_T 1} & \rho_{N_T 2} & \cdots & 1 \end{pmatrix} \quad (4)$$

where ρ_{ij} indicates the transmit correlation coefficient (or receive correlation coefficient) between the i th transmit (or receive) antenna and the j th transmit (or receive) antenna. The calculation of ρ_{ij} can be found in [10]. Shiu in [11], approximates ρ_{ij} by using the Bessel function $\rho_{ij} \approx J_0(\Delta \frac{2\pi}{\lambda} d(i, j))$ in which Δ is the angle spread, λ is the wavelength, and $d(i, j)$ is the distance from object i to object j , and $J_0(x)$ is the Bessel function of the first kind of the *zeroth* order.

III. OPTIMAL ANTENNA SUBSET SELECTION

In this section, we will investigate three configuration schemes: MRC with Transmit Antenna Selection (TAS), OSTBC with RAS and TAS, respectively. we assume that 1) the channel state information (CSI) is exactly known at the receiver and at the transmitter, the selection is available at the receiver or transmitter, and it is based on the instantaneous signal-to-noise ratio (SNR) at each receive antenna; 2) perfect knowledge of the channel correlation matrices at both transmitter and receiver sides; and 3) in the latter case, the receiver would feed back the choice of the active transmit antennas to the transmitter. If K transmit antennas and L receive antennas are chosen and all the other antennas are inactivated, we refer to it as $(N_T, K; N_R, L)$ system. We may also use $(N_T, K; N_R)$ and $(N_T; N_R, L)$ to denote a system with antenna selection only at the transmitter side or at the receiver side, respectively.

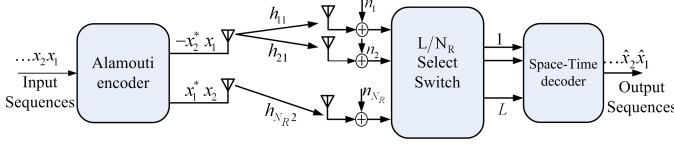


Fig. 2. Alamouti selection scheme

A. transmit antenna selection with MRC

In this paper, we consider a $(N_T, K = 1; N_R)$ TAS/MRC system with correlated channel, which is illustrated in Fig.1. The entries of channel matrix \mathbf{H} are the correlation coefficients $h_{i,j}$, $1 \leq i \leq N_R$, $1 \leq j \leq N_T$ and can be written as

$$\mathbf{H} = [\mathbf{h}_1 \quad \mathbf{h}_2 \quad \cdots \quad \mathbf{h}_{N_T}] \quad (5)$$

where $\mathbf{h}_j = [h_{1j} \quad h_{2j} \quad \cdots \quad h_{N_R j}]^T$ is a $N_R \times 1$ vector which is the j th column of \mathbf{H} , is used to denote the channel between the single selected transmit antenna and N_R receive antennas. The single selected transmit antenna, denoted by I , and is determined through the Frobenius norm by

$$I = \arg \max_{1 \leq j \leq N_T} \left\{ \gamma(j) = \frac{E_s}{N_T N_0} \sum_{i=1}^{N_R} |h_{i,j}|^2 \right\} \quad (6)$$

where $\gamma(j)$ denotes the instantaneous SNR of the output of the MRC combiner when using transmit antenna j . Through a feedback channel, the value of I is available to the transmitter. It's well known that the output SNR of a maximal-ratio combiner, also referred to as post-processing SNR, is the sum of the SNRs at different receive antennas. Therefore, the selection criterion in (6) is equivalent to maximizing the instantaneous post-processing SNR.

We rearrange the output SNRs $\gamma(j)$, $1 \leq j \leq N_T$, in descending order of magnitude and denote them by $\gamma(p)$, where $1 \leq p \leq N_T$ and $\gamma(1) \geq \gamma(2) \geq \cdots \geq \gamma(N_T)$. According to (6) the transmit antenna corresponding to the first order statistic, $\gamma(1)$, will be selected for transmission.

B. Antenna selection with OSTBC

In this antenna selection, Alamouti transmit diversity scheme is proposed in [8]. This OSTBC uses 2 transmit antennas and one receive antenna simultaneously. During the first symbol period, x_1 and x_2 are transmitted via the first and the second antenna respectively. While the next symbol cycle, $-x_2^*$ and x_1^* are emitted respectively. The received signals, y_1 and y_2 for two considered time intervals are then obtained:

$$\begin{bmatrix} y_1 & y_2 \end{bmatrix} = \begin{bmatrix} h_1 & h_2 \end{bmatrix} \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix} + \begin{bmatrix} n_1 & n_2 \end{bmatrix} \quad (7)$$

This is equivalent to form:

$$\mathbf{y} = \begin{bmatrix} y_1 \\ y_2^* \end{bmatrix} = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix} = \mathbf{H}_V \mathbf{x} + \mathbf{N} \quad (8)$$

Where we introduced the so called Equivalent Virtual Channel Matrix (EVCVM) \mathbf{H}_V and the rows and columns of the virtual channel matrix are strictly orthogonal:

$$\mathbf{H}_V \mathbf{H}_V^H = \mathbf{H}_V^H \mathbf{H}_V = (|h_1|^2 + |h_2|^2) \mathbf{I}_2 = \|\mathbf{H}\|^2 \mathbf{I}_2 \quad (9)$$

For this advantage, decoding with maximum-likelihood (ML) can be obtained simply by multiplying the receive vector with Hermitian of \mathbf{H}_V

$$\tilde{\mathbf{x}} = \mathbf{H}_V^H \mathbf{y} = \|\mathbf{H}\|^2 \mathbf{x} + \tilde{\mathbf{n}} \quad (10)$$

1) Receive antenna selection with OSTBC (RAS/OSTBC):

In this section, we will investigate the schemes combining receive antenna selection (RAS) with OSTBC; where the transmitter employs the Alamouti code with $N_T = 2$ transmit antennas.

At any time, only L out of N_R receive antennas are chosen and activated for reception. All the transmit antennas are used without selection for transmission.

The channel matrix \mathbf{H} defined by (2) is transformed as follows: $\mathbf{H} = [\mathbf{h}_1, \mathbf{h}_2, \dots, \mathbf{h}_{N_R}]^T$ where $\mathbf{h}_i = [h_{i1} \quad h_{i2}]$ is a 1×2 vector which is the i th row of \mathbf{H} , referred to the channel between two transmit antennas and the i th receive antenna. $\|\mathbf{h}_i\|^2$ denotes the squared Frobenius norm of the i th row. We should choose L rows of the channel matrix \mathbf{H} with the L first largest norms $\|\mathbf{h}_i\|^2$. We denote $\gamma(i) = \frac{E_s}{N_T N_0} \|\mathbf{h}_i\|^2$, $1 \leq i \leq N_R$ as the SNR output when receive antenna i is used.

We rearrange the $\gamma(i)$ in descending order of magnitude and denote them by $\gamma(p)$, where $1 \leq p \leq N_R$ and $\gamma(1) \geq \gamma(2) \geq \cdots \geq \gamma(N_R)$. It's so clear that L receive antennas corresponding to the N_T first order statistic will be selected for transmission. Using a feedback channel, the information of L selected receive antennas is available to the transmitter in order to construct the code matrix.

In the following case, Alamouti STBC transmission system that employs $L \geq 1$ receive antennas, while keeping the transmission procedure identical to the precedent case, the signals from the multiple receive antennas are maximum ratio combined by constructing an appropriate virtual channel matrix.

Starting with the virtual channel matrix \mathbf{H}_V in (8), and referring that it's the first sub-matrix

$$\mathbf{H}_{V,n} = \begin{bmatrix} h_{n1} & h_{n2} \\ h_{n2}^* & -h_{n1}^* \end{bmatrix}, \quad 1 \leq n \leq L \quad (11)$$

Stacking those 2×2 matrices on top of each other finally yields the correct virtual channel for the Alamouti transmission scheme with L receive antennas.

$$\mathbf{H}_V = \begin{bmatrix} h_{11} & h_{12}^* & \cdots & h_{L1} & h_{L2}^* \\ h_{12} & -h_{11}^* & \cdots & h_{L2} & -h_{L1}^* \end{bmatrix}^T \quad (12)$$

Again, the input-output relation is always given by (8). The subsequent processing steps are completely analog to the single antenna case since: $\mathbf{H}_V \mathbf{H}_V^H = \|\mathbf{H}\|^2 \mathbf{I}_2$. Finally, the decoded symbol vector is determined by $\tilde{\mathbf{x}} = \|\mathbf{H}\|^2 \mathbf{x} + \tilde{\mathbf{n}}$.

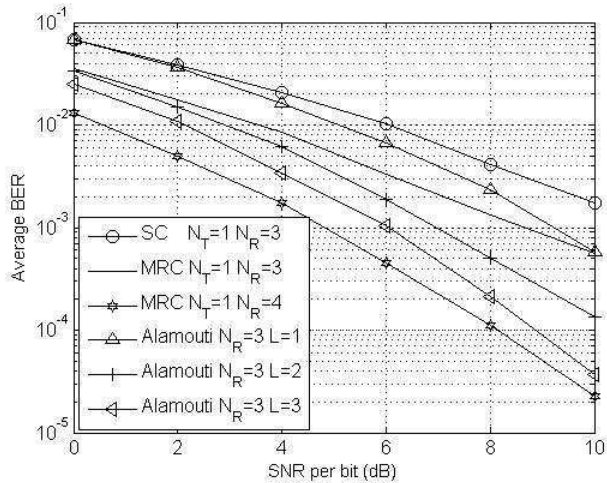


Fig. 3. BER performance of SC, MRC, Alamouti selection schemes at receive side, with $\Delta = 30^\circ$, $d = 0.75\lambda$

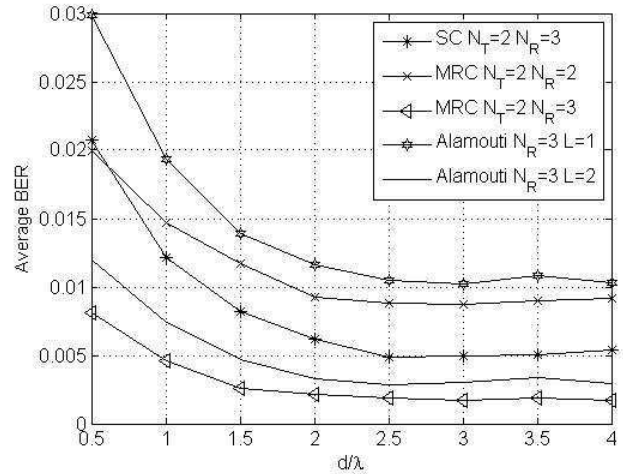


Fig. 5. Correlated channel effect over antenna selection, with $\Delta = 10^\circ$ and $NSR=4dB$.

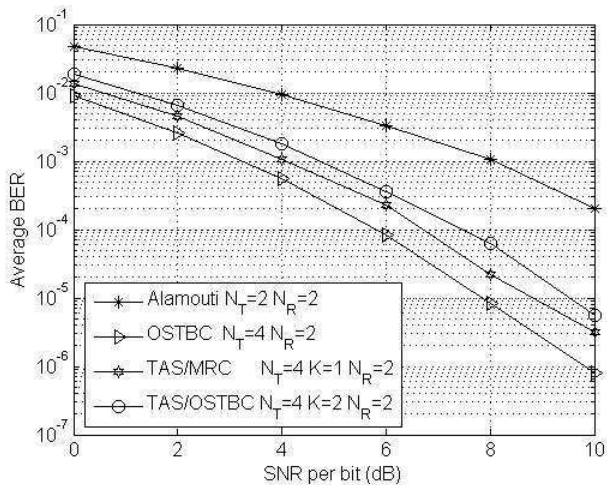


Fig. 4. BER performance of TAS/MRC, TAS/OSTBC selection schemes at transmit side, with $\Delta = 30^\circ$, $d = 0.75\lambda$

2) Transmit antenna selection with OSTBC (TAS/OSTBC):

In this section, the $(N_T, 2; N_R)$ scheme with Alamouti code can also be considered. At any time, only two out of N_T antennas are chosen for transmitting. The principle of the TAS/OSTBC is basically same as that of the RAS/OSTBC. It is clear that the optimal transmit antenna subset is the two columns of the channel matrix \mathbf{H} with the first largest and second largest norms, denoting as $\|\mathbf{h}_{cp}\|^2$ and $\|\mathbf{h}_{cq}\|^2$, respectively. And then the p th and q th transmit antennas will be selected for transmission.

IV. SIMULATION RESULTS

In this section, the performances of the mentioned methods are analyzed. The correlated channel and QPSK modulation are carried out. In this section, the performances of the mentioned methods are analyzed. The correlated channel and QPSK modulation are carried out. Fig.3 shows the perfor-

mance of all schemes: SC, MRC and RAS with Alamouti. Note that Alamouti (2;3,3) scheme is the traditional scheme without antenna selection. However, with the same diversity order, MRC can always provide better performance than SC and Alamouti schemes. Here, we assume the same scenario, in which we choose $d/\lambda = 0.75$ and the angle spread is $\Delta = 30^\circ$. In Fig.4 we compare the performance of the (2;2) Alamouti scheme without antenna selection, the (4,2;2) TAS/OSTBC and (4;2) OSTBC; and in which, we assume the same afore-scenario. We can see that TAS/MRC can make better performance than TAS/OSTBC; because with TAS/MRC, we select only one transmit antenna, therefore, there isn't the correlation at the transmit side. However, the performance of both schemes is close; TAS/MRC is 0.7dB superior to the OSTBC and loses around 0.7dB compared with TAS/OSTBC. Fig.4 clearly demonstrates the advantage of TAS/MRC and TAS/OSTBC relative to conventional STBC in term of SNR, in particular, we have extra benefits for TAS/OSTBC scheme compared with Alamouti scheme. Fig.5 shows the influence of distance between the antennas at the receive side over BER performance of schemes; in which we assume that $\Delta = 10^\circ$ and $NSR=4dB$. It can be exactly shown that the more the channel is correlated (d/λ is small), the worse the BER performance, and the performance get better with a higher distance d/λ .

V. CONCLUSION

In this paper, some antenna selection schemes, referred as TAS/MRC, TAS/OSTBC and RAS/OSTBC schemes were proposed over spatially correlated MIMO channel with QPSK modulation. Compared with the well known HS/MRC scheme (TAS/MRC), or with the conventional orthogonal space-time block code with full antennas at the both transmit and receive side, these schemes can dramatically reduce the system hardware complexity at the mobile set and antenna array gain can be achieved. However, the transmit antenna selection based on

the instantaneous CSI may cause the performance degradation due to the limited feedback channel bandwidth, otherwise, with TAS/OSTBC and RAS/OSTBC which make the decoding algorithm at the mobile set complex. Simulation shows that the TAS/MRC scheme outperforms the TAS/OSTBC of the same diversity order with the same number of receive antennas.

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