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Enhancement of CSI (Channel State Information) performance using Diversity Techniques

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ABSTRACT*: Receiver diversity is used to combat the adverse effect of fading. However in general, it is not possible to install multiple antennas at the receiver. Therefore, it is important to exploit diversity at the transmitter also. To do this, MISO (Multiple Input Single Output) and MIMO (Multiple Input Multiple Output) systems are considered in Transmit Beam forming (TB) technique and Space Time Block Coding (STBC) technique. In TB technique, CSI is available at both transmitter and receiver. Based on CSI at transmitter, maximum Eigen mode transmission is used to maximize the received SNR (Signal to Noise Ratio). It provides diversity gain along with antenna array gain also. Apart from it, it reduces delay spread by eliminating the echoes created by distant objects. By focusing power in one direction, it improves interference from other users. In STBC techniques, CSI is required only at the receiver not at transmitter. It provides full diversity gain. However, it is not possible to exploit antenna array gain. There is a loss of code rate for multiple antennas. However, Alamouti has proposed a transmission scheme with two transmit antennas, using which diversity gain of order two can be achieved without losing data rate.*

Keywords*: CSI, MISO, MIMO, STBC, TB, Transmit-Receive Diversity.*

I. INTRODUCTION

To combat the effect of fading in different detection schemes, different diversity techniques are used. Precisely in diversity, multiple copies of input symbols have been received via independent channels at the receiver. Receiver diversity is considered to reduce the effect of fading. However, it is not always possible to install multiple antennas at the receiver. Therefore it is important to consider the transmitter diversity also. To do this, MISO (Multiple Input Single Output) and MIMO (Multiple Input Multiple Output) systems are considered in Transmit Beam forming (TB) technique and Space Time Block Coding (STBC) technique.

Section-II and III describe TB-MISO and TB-MIMO systems respectively in which CSI is available at both transmitter and receiver. Based on CSI at transmitter, maximum Eigen mode transmission is used to maximize the received SNR (Signal to Noise Ratio). It provides diversity gain along with antenna array gain also. Apart from it, it reduces delay spread by eliminating the echoes created by distant objects. By focusing power in one direction, it improves interference from other users.

Section-IV describes STBC techniques for MISO and MIMO systems in which CSI is required only at the receiver not at transmitter. It provides full diversity gain. However, it is not possible to exploit antenna array gain. There is a loss of code rate for multiple antennas. However, Alamouti has proposed a transmission scheme with two transmit antennas, using which diversity gain of order two can be achieved without losing data rate.

II. TB-MISO SYSTEMS

By considering a system with N transmit antennas and one receive antenna, the received symbol can be expressed as,

$$y = h^*(wx) + n \qquad (1)$$

Where x is a BPSK symbol and $x \in \{-\sqrt{E_s}, \sqrt{E_s}\}$. Both the binary symbols 0 and 1 are independent and equally probable, transmitted by $-\sqrt{E_s}$ and $\sqrt{E_s}$ respectively. n represents AWGN (Additive White Gaussian Noise) at the receiver. Flat-fading channel vector $h = \{h_1 .. h_N\}^T$ are also spatially and temporally independent and identically distributed. The unit beam forming vector is $w = \frac{\boldsymbol{h}}{\|\boldsymbol{h}\|}$. This vector is selected to maximize the received SNR.

To estimate the detection at the receiver, it is assumed to examine *y* by putting the value of w in (1).

So, $y = \|h\|x + n$

(2)

In this case, detection variable will be the received symbol y itself. It means,

If y ≥ 0, the detected symbol is 1.

If y ≤ 0, the detected symbol is 0.

From (2), instantaneous SNR (γ) can be expressed as,

$$\gamma = \| \boldsymbol{h} \|^2 + \gamma_c$$

(3)

Therefore, the expression of BER in this system,

$$P_e = \left(\frac{1-\mu}{2}\right)^N \sum_{p=0}^{N-1} \binom{N-1+p}{p} \left(\frac{1+\mu}{2}\right)^p$$

(4)

Where $\mu = \sqrt{\frac{E_s}{E_s+N_o}}$

(5)

It means that it provides diversity gain of *N* along with an antenna array gain.

III. TB-MIMO SYSTEMS

It is considered more than one antenna at both the transmitter and receiver. At the transmitter, transmit beam forming is used and at the receiver, MRC (Maximum Ratio Combining) is used. In this case, the unit beam forming vector is chosen using maximum Eigen mode transmission with a criterion to maximize received SNR. This system equipped with M transmit and N receive antennas is considered. The received symbol,

$$y = Hwx + n \qquad (6)$$

Where $y = |y_1 \dots y_N|^T$ represents the received symbol. *x* is a BPSK (Binary Phase Shift Keying) symbol and x Є $\{-\sqrt{E_s}, \sqrt{E_s}\}$. $n = \{n_1 .. n_N\}^T$ represents AWGN at the receiver antennas. Flat fading channel vector H is of the order *N* × *M*. All entries are spatially and temporally independent and identically distributed. To maximize the received SNR, maximum Eigen-mode transmission is assumed. Hence, the unit beam forming vector w of order *M* × *1* is the Eigen vector corresponding to the maximum Eigen value of matrix H*H. Using Eigen Value Decomposition (EVD), it is got H*H = UDU*, where each column in U represents eigen vector and the D is the diagonal matrix, which represents Eigen values. For detection, the effective channel vector *1* × *N* system with channel vector Hw. Hence, the detection variable *d*,

$$d = \frac{Hw^*}{\|Hw\|} y \qquad (7)$$

Hence, instantaneous SNR (γ),

$$\gamma = \|Hw\|^2 \gamma_c$$

(8)

Where $\gamma_c = E_b/N_0$.

BER P_e can be determined as,

$$P_e = \frac{1}{2} + \frac{\mu_2}{2} - \frac{\mu_1(11+16\gamma_c+8\gamma_c^2)}{8(1+\gamma_c)^2}$$

(9)

Where $\mu_1 = \sqrt{\frac{\gamma_c}{\gamma_c+1}}$ and $\mu_2 = \sqrt{\frac{\gamma_c}{\gamma_c+2}}$

(10)

Therefore, $P_e \propto \frac{1}{\gamma_c^4}$

(11)

It means the order of diversity gain provided by this system is four.

IV. SPACE TIME BLOCK CODING (STBC)

In this technique, coding between space (antenna) and time is used. Alamouti scheme, a special case of STBC is considered; in which two transmit antennas are used. At the first instant, transmit antenna 1 transmits symbol x_1 and transmit antenna 2 transmits symbol x_2. At the second instant, transit antenna 1 transmits symbol $-x_2^*$ and transmit antenna 2 transmits symbol x_1^*. It is assumed that channel will remain constant for these two consecutive instants. Using this scheme, the received symbols y_1 and y_2, for two consecutive two time constants, can be represented as,

$$[y_1\ y_2] = [h_1\ h_2]\begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix} + [n_1\ n_2]$$
(12)

Thus, each symbol is transmitted twice from the transmitter with two different antennas. Hence, to keep the same power E_s for each symbol, x_1 and x_2 from $\{-\sqrt{E_s/2}, \sqrt{E_s}/2\}$ are selected. Furthermore, two instants for each symbol are used; however, two symbols are transmitted at each instant. So, code rate of this scheme is one. By conjugating y2, (12) can be written as,

$$\begin{bmatrix} y_1 \\ y_2^* \end{bmatrix} = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix}$$
(13)

For two consecutive instants, n_1 and n_2 represent spatially independent and identically distributed AWGN. Flat-fading co-efficient h_1 and h_2 are quasi-static spatially independent and identically distributed.

To estimate the detection at the receiver, two columns (first is for *x1* and second is for *x2*) of the square matrix in (13) are orthogonal. Hence, the detection problem for x_1 and x_2 decomposes into two separate, orthogonal, scalar problems. It is assumed that $d_1 = Re\ (s_1)$ and $d_2 = Re\ (s_2)$ are decision variables for x_1 and x_2 respectively. Then,

$$s_1 = [h_1^*\ \ h_2]\begin{bmatrix} y_1 \\ y_2^* \end{bmatrix} = \|h\|^2 x_1 + w_1 \tag{14}$$

$$s_2 = [h_2^*\ \ -h_1]\begin{bmatrix} y_1 \\ y_2^* \end{bmatrix} = \|h\|^2 x_2 + w_2 \tag{15}$$

Where $h = [h_1\ h_2]^T$, $w_1 = h_1^* n_1 + h_2 n_2^*$,
$w_2 = h_2^*\, n_1 - h_1\, n_2^*$.

If $d1 \geq 0$, the detected symbol is 1 and if $d1 \leq 0$, the detected symbol is 0. The instantaneous SNR (γ) can be represented as,

$$\gamma = \|\ \boldsymbol{h}\ \|^2 +\ \gamma_c \tag{16}$$

Where $\gamma_c = E_s/2N_0$..

Therefore, BER, $P_e = \frac{1}{4}\ (2 - 3\mu + \mu^3)$ (17)

Where $\mu = \sqrt{\frac{E_s}{E_s+2N_0}}$. Thus, the diversity gain of order two can be achieved.

V. SL (SYMMETRIC LINEAR) DETECTOR WITH IMPERFECT CSIR (CHANNEL STATE INFORMATION AT RECEIVER)

For time-varying channel, SL detector is used. In this case, effective CSIR is taken as the average of CSIR available at two different instants. The received symbols (*r1* and *r2*) for two consecutive instants, using Alamouti scheme, can be represented as,

$$r_1 = h_1 x_1 + h_2 x_2 + n_1 \tag{18a}$$

$$r_2 = -\hat{h}_1 x_2^* + \hat{h}_2 x_1^* + n_2 \tag{18b}$$

Where x_1 and x_2 are BPSK symbols and both the symbols 0 and 1 are, independent and spatially independent, and identically distributed AWGN. Flat-fading channel coefficients for both the antennas, h_1 and h_2, are spatially independent and identically distributed.

To estimate the detection rule at the receiver, it is considered that imperfect CSIR is available at the receiver as $\hat{h}$,

Where $\hat{h} = \left[h_{r_1}\ h_{r_2}\right]^T$, $h_{r_1} = \sqrt{1 - \sigma_e^2 h_{r_{10}} +}\, \sigma_e \delta_1$ and

$$h_{r_2} = \sqrt{1 - \sigma_e^2 h_{r_{20}} +}\, \sigma_e \delta_2 \tag{19}$$

Where $\delta_1\ and\ \delta_2$ are mutually independent and also independent with $h_{r_{10}}$ and $h_{r_{20}}$. Where

$$h_{r_{10}} = 0.5\ (h_1 + \tilde{h}_1),\ \ h_{r_{20}} = 0.5\ (h_2 + \tilde{h}_2) \tag{20}$$

In eq.(19), σ_e^2 denotes the variance of channel estimation error at the receiver. For no estimation error, σ_e^2=0. It is assumed that $d_1 = Re\{s_1\}$ and $d_2 = Re\{s_2\}$ are decision variables for x_1 and x_2 respectively. Then,

$$s_1 = \begin{bmatrix} h_{r_1}^* & h_{r_2} \end{bmatrix} \begin{bmatrix} y_1 \\ y_2^* \end{bmatrix}, \quad s_2 = \begin{bmatrix} h_{r_2}^* & -h_{r_1} \end{bmatrix} \begin{bmatrix} y_1 \\ y_2^* \end{bmatrix} \tag{21}$$

As both the symbols are equally likely, d1 is used to calculate the BER.
If *d1* ≥ 0, the detected symbol is 1 and if *d1* ≤ 0, the detected symbol is 0.
The pdf of instantaneous SNR (γ) can be expressed as,

$$p_\gamma(\gamma) = \frac{\gamma}{\gamma_c^2} e^{\frac{-\gamma}{\gamma_c}}, \text{ where } \gamma_c = \frac{0.5E_s(1-\sigma_e^2)}{N_0+(\sigma_e^2+\sigma_f^2)E_s} \tag{22}$$

Where, $\sigma_f^2 = 0.5(1-\rho)$ (23)

The BER expression of this system,

$$P_e = \frac{1}{4}(2 - 3\mu + \mu^3) \tag{24}$$

$$\text{Where } \mu = \sqrt{\frac{\gamma_c}{\gamma_c+1}} \tag{25}$$

VI. RESULT AND CONCLUSION

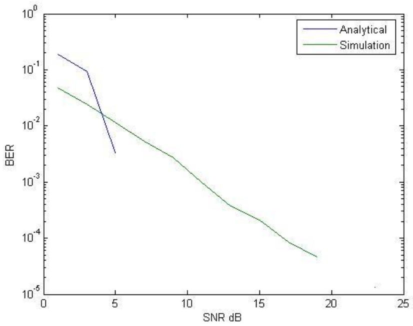

Fig. (1) shows the BER performance of a TB-MISO systems with two transmit antennas in spatially independent Rayleigh fading channels. It shows that simulation result is better than analytical one because it provides diversity gain better with an antenna array gain.

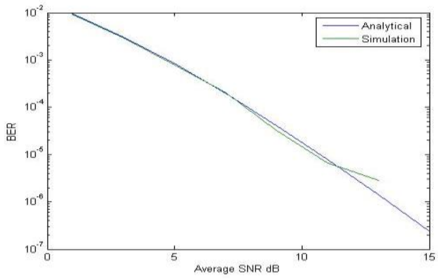

Fig. (2) shows the performance of a *M* × *N* (i.e. 2 × 2) TB-MIMO system in spatially independent Rayleigh fading channels. In general, the order of diversity gain is *MN*. Analytical result shows that order of diversity gain is four. By considering the different order of BER, average value of SNR also increases.

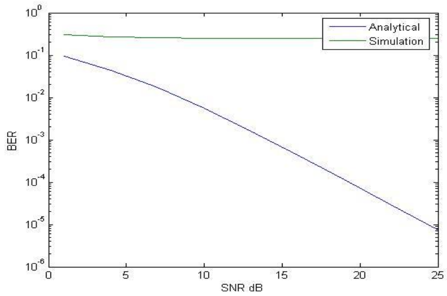

Fig. (3) shows the BER performance of a 2 × 1 STBC-MISO (Alamouti transmit diversity) systems in spatially independent quasi-static Rayleigh fading channels. In this case, Analytical result shows the order of diversity gain is two. Simulation result of Alamouti transmit diversity shows a degradation in BER performance by 3-dB because the received SNR is half in Alamouti system.

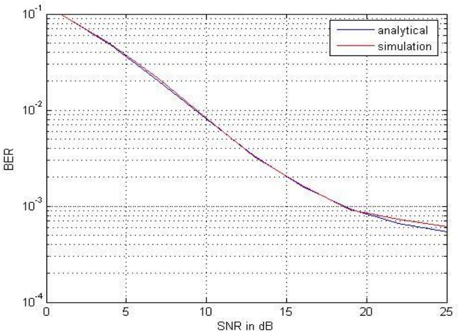

Fig. (4) shows the performance of Alamouti with linear slope detector and time varying channels. In this case, estimation error is assumed to be zero. For no estimation error, a result characteristic of LS detector is somehow better than other detector.

VII. ACKNOWLEDGMENTS

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