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The performance of MIMO cooperative communication systems using the relay with multi-antennas and DSTC

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Abstract

The cooperative communication systems using MIMO(multiple input multiple-output) relay are known as one of the most promising techniques to improve the performance and coverage of wireless communication systems. In this paper, we propose the cooperative communication systems using the relay with multi-antennas and DSTC(distributed space time coding) for decode-and-forward protocol. As using DSTC for DF(decode-and-forward), we can minimize the risk of error propagation at the wireless system using relay system. Also, the MIMO channel cab be formed by multi-antenna and DSTC at the MS(mobile station)-RS(relay station) and at the RS-BS(base station).Therefore, obtaining truly constructive the MIMO diversity and cooperative diversity gain from the proposed approach, the performance of system can be more improved than one of conventional system (relay with single antenna, no relay). The improvement in bit error rate is investigated through numerical analysis of the cooperative communication system with the proposed approach.

Keywords:. *Cooperative diversity, MIMO, Space-Time Coding, Relay*

1. Introduction

Cooperation communication is the technique that a mobile for transmitting the signal is cooperated with other mobile station or the relay in the cell. Combining the received signals at base station from all mobiles and the relays cooperating communication, we can get cooperative diversity gain. Therefore, the performance of system through the cooperative diversity is greatly improved in the poor wireless channel [1][2][3]. Recently, the concept of cooperative relay have been proposed to improve the performance of system and to extend coverage area [4][5]][6][7]. In case of conventional cooperation communication, the mobile station and the relay with single antenna for DSTC have been exploiting[8]. In this paper[8], EADST(error aware distributed space time) code scheme was proposed to overcome the loss of diversity of the distributed space coded system. EADST technique outperformed the existing regenerative systems by considering minimum error reception at the relays. Also, cooperation communication systems using relay with multi-antenna and DF or AF (Amplify-and-Forward) have been issued[1][2][4][5]. For the DF scheme,

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the process at the cooperative relay nodes was to decode the received signal, and then re-encode and transmit it to the destination. The DF could decrease the error propagation. Therefore, the DF scheme could be minimized the error propagation at the wireless system using relay system. The amplify-and-forward (AF) protocol is used to linearly process the received signals and to re-transmit them toward the destination. In such a system, more errors are generated at the relay and the generated errors are propagated into the base station. And then, the performance of total system is greatly degraded. In this paper, to overcome this problem and to improve the performance, we propose the cooperative communication system exploiting the relay with multi-antenna and DSTC for DF. Also, we analyze the performance of cooperative communication system applying the proposed technique

2. Performance of the cooperative communication systems using the relay with multi-antennas and DSTC

Fig.1 shows structure of cooperative communication system using the relay with multi-antenna and DSTC. In this figure, the protocol for cooperation communication is described as follows. For the first time slot, the alamouti encoding signals are transmitted to the relay and base station through MIMO channel. And then, the ML detected signals are encoded by DSTC to improve the frequency efficiency at each relay. For the second time slot, the DSTC encoded signals are transmitted to BS. And the detected signals at BS during two time slots are combining to improve the performance of total system.

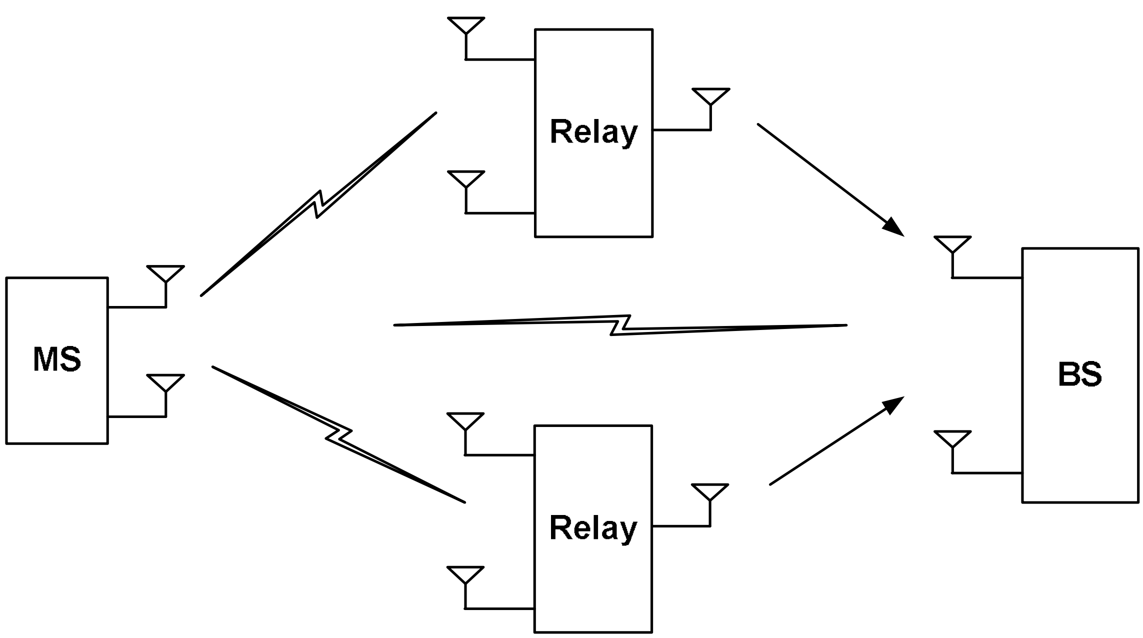

Figure 1. A structure of cooperative communication system using the relay with multi-antenna and DSTC

The transmitting signal matrix encoded Alamouti at the multi-antenna can be written by

$$\mathbf{T}_t\_\mathbf{Y} = \left[\mathbf{T}_t\_\mathbf{Y}_1 \quad \mathbf{T}_t\_\mathbf{Y}_2\right] \tag{1}$$

where $\mathbf{T}_t\_\mathbf{Y}_1 = \begin{bmatrix} y_0 \\ -y_1^* \end{bmatrix}$, $\mathbf{T}_t\_\mathbf{Y}_2 = \begin{bmatrix} y_1 \\ -y_0^* \end{bmatrix}$.

The received signal matrix of RS or BS can be written as follow

$$\tilde{\mathbf{Y}} = \begin{bmatrix} \alpha_1\beta_1 H_{00} y_0 + \alpha_2\beta_2 H_{10} y_1 + n_0 & \alpha_1\beta_1 H_{01} y_0 + \alpha_2\beta_2 H_{11} y_1 + n_1 \\ -\alpha_1\beta_1 H_{00} y_1^* + \alpha_2\beta_2 H_{10} y_0^* + n_2 & -\alpha_1\beta_1 H_{01} y_1^* + \alpha_2\beta_2 H_{11} y_0^* + n_3 \end{bmatrix} \tag{2}$$

α_i is the weight according to distance between MS and RS(BS). β_i is the power ratio allocated to RS. Those parameters is defined as at next section. H_{ij} is channel between the i-th transmitted antenna and the j-th received antenna. The rearranging signal matrix is represented to detect the received signals by space decoding as follows

$$\mathbf{R} = \sqrt{P}\,\tilde{\mathbf{H}}\mathbf{y} + \mathbf{N}_b \tag{3}$$

where

$$\tilde{\mathbf{H}} = \begin{bmatrix} \alpha_1\beta_1 H_{00} & \alpha_2\beta_2 H_{10} \\ \alpha_1\beta_1 H_{01} & \alpha_2\beta_2 H_{11} \\ \alpha_2\beta_2 H_{10}^* & -\alpha_1\beta_1 H_{00}^* \\ \alpha_2\beta_2 H_{11}^* & -\alpha_1\beta_1 H_{01}^* \end{bmatrix} \tag{4}$$

$$\mathbf{y} = \begin{bmatrix} y_0 \\ y_1 \end{bmatrix}, \quad \mathbf{N}_b = \begin{bmatrix} n_0 \\ n_0 \\ n_2^* \\ n_3^* \end{bmatrix}$$

$\mathbf{N}_b$ is the noise vector.

Fig.2 is given by shows a geometrical block diagram for cooperative diversity at the system using the relay with multi-antennas.

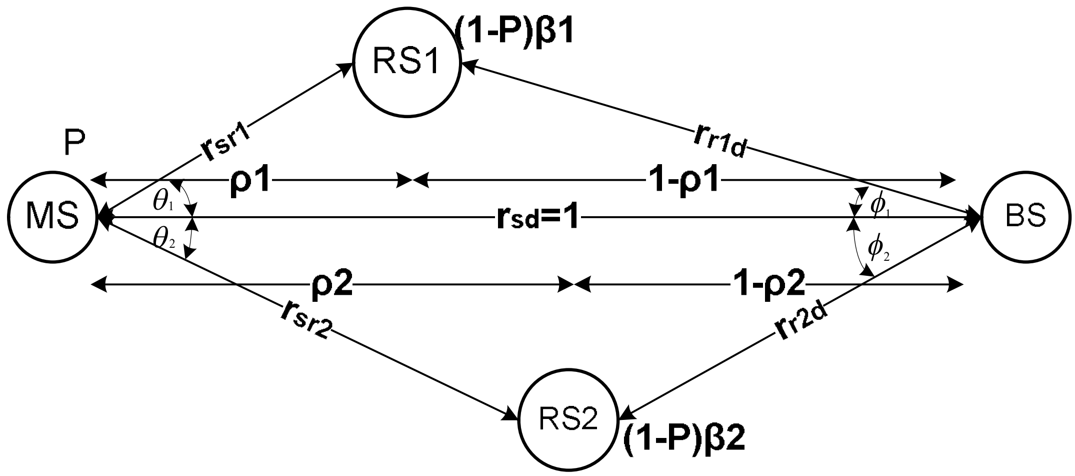

Figure 2. A geometrical block diagram of system for cooperative diversity

Here, when the sum of allocated power to MS and RS equal to one, P is defined as the power allocated to MS. β_1 and β_2 are the power ratio allocated to relay1 and relay2, respectively. ρ_1, ρ_2 are the distance between MS and relay1 or relay2, respectively.

We can analyze the performance of cooperative communication system with relay as follows

2.1 MS-to-RS1

From equation(4) and Figure 2, those parameters are defined as

$$\alpha_1 = \alpha_2 = \frac{\mathrm{P}}{\rho_1^{\kappa}} \cos^{\kappa} \theta_1 , \;\; \beta_1 = \beta_2 = 1 \tag{5}$$

The channel matrix for MIMO channel between MS and RS1 can be written by

$$\tilde{\mathbf{H}}_{sr\_1} = \frac{\mathrm{P}}{\rho_1^{\kappa}} \cos^{\kappa} \theta_1 \begin{bmatrix} H_{00}^{r1} & H_{10}^{r1} \\ H_{01}^{r1} & H_{11}^{r1} \\ H_{10}^{*\,r1} & -H_{00}^{*\,r1} \\ H_{11}^{*\,r1} & -H_{01}^{*\,r1} \end{bmatrix} = \frac{\mathrm{P}}{\rho_1^{\kappa}} \cos^{\kappa} \theta_1 \mathbf{H}_0^{r1} \tag{6}$$

Here, $\mathbf{H}_0^{r1}$ is channel matrix with independent ZMCSSG(zero mean circularly symmetric complex Gaussian) random variable between MS and RS1. The probability of error to be upper-bounded is given by [9]

$$P_{err\_1} \le \bar{M}_e \exp(-\sum_{i=1}^{4} \left\| \mathbf{H}_0^{r1} \right\|^2 \frac{d_{\min}^2}{4} \frac{\mathrm{P}\cos^{\kappa} \theta_1}{2} \rho_1^{-\kappa} SNR_{r1}) \tag{7}$$

Here, $\bar{M}_e$ and $d_{\min}$ are the number of nearest neighbors and the minimum distance between constellations and SNR_{r1} is signal-to-noise ratio at the RS1. κ is power of distance.

2.2 MS-to-RS2

From equation(4) and Figure 2, those parameters are defined as

$$\alpha_2 = \alpha_1 = \frac{\mathrm{P}}{\rho_2^{\kappa}} \cos^{\kappa} \theta_2 , \quad \beta_1 = \beta_2 = 1 \tag{8}$$

In the same manner, the channel matrix between MS and RS2 can be defined by

$$\tilde{\mathbf{H}}_{sr\_2} = \frac{\mathrm{P}}{\rho_2^{\kappa}} \cos^{\kappa} \theta_2 \begin{bmatrix} H_{00}^{r2} & H_{10}^{r2} \\ H_{01}^{r2} & H_{11}^{r2} \\ H_{10}^{*\,r2} & -H_{00}^{*\,r2} \\ H_{11}^{*\,r2} & -H_{01}^{*\,r2} \end{bmatrix} = \frac{\mathrm{P}}{\rho_2^{\kappa}} \cos^{\kappa} \theta_2 \mathbf{H}_0^{r2} \tag{9}$$

Here, $\mathbf{H}_0^{r2}$ is channel matrix with independent ZMCSSG random variable between MS and RS2.
Also, the probability of error to be upper-bounded is given by

$$P_{err\_2} \leq \bar{M}_e \exp(-\sum_{i=1}^{4} \left\| \mathbf{H}_0^{r2} \right\|^2 \frac{d_{\min}^2}{4} \frac{\mathrm{P} \cos^{\kappa} \theta_2}{2} \rho_2^{-\kappa} SNR_{r2}^{'}) \tag{10}$$

Here, SNR_{r2} is signal-to-noise ratio at the RS2

2.3 Relay(RS1,RS2)-to-BS

From equation(4) and Figure 2, those parameters are defined as

$$\alpha_1 = \frac{(1-\mathrm{P})}{r_{rd\_1}^{\kappa}} = \frac{(1-\mathrm{P})}{(1-\rho_1)^{\kappa}} \cos^{\kappa} \phi_1 , \quad \alpha_2 = \frac{(1-\mathrm{P})}{r_{rd\_2}^{\kappa}} = \frac{(1-\mathrm{P})}{(1-\rho_2)^{\kappa}} \cos^{\kappa} \phi_2 \tag{11}$$

where $\phi_1 = \tan^{-1}[\frac{\rho_1}{1-\rho_1} \tan \theta_1]$, $\phi_2 = \tan^{-1}[\frac{\rho_2}{1-\rho_2} \tan \theta_2]$.

When $\beta_1 = \frac{\alpha_2}{\alpha_1 + \alpha_2}$ and $\beta_2 = \frac{\alpha_1}{\alpha_1 + \alpha_2}$, MIMO channel matrix with DSTC between relays and BS is given by

$$\begin{aligned} \tilde{\mathbf{H}}_{r12d} &= \frac{\alpha_1 \alpha_2}{\alpha_1 + \alpha_2} \begin{bmatrix} H_{00}^{r12d} & H_{10}^{r12d} \\ H_{01}^{r12d} & H_{11}^{r12d} \\ H_{10}^{r12d*} & -H_{00}^{r12d*} \\ H_{11}^{r12d*} & -H_{01}^{r12d*} \end{bmatrix} \\ &= \frac{(1-\mathrm{P}) \cos^{\kappa} \phi_1 \cos^{\kappa} \phi_2}{(1-\rho_2)^{\kappa} \cos^{\kappa} \phi_1 + (1-\rho_1)^{\kappa} \cos^{\kappa} \phi_2} \mathbf{H}_0^{\mathrm{r12d}} \end{aligned} \tag{12}$$

$$\alpha_1 = \frac{(1-\mathrm{P})}{(1-\rho_1)^{\kappa}}\cos^{\kappa}\phi_1, \quad \alpha_2 = \frac{(1-\mathrm{P})}{(1-\rho_2)^{\kappa}}\cos^{\kappa}\phi_2$$

$$\phi_1 = \tan^{-1}[\frac{\rho_1}{1-\rho_1}\tan\theta_1], \quad \phi_2 = \tan^{-1}[\frac{\rho_2}{1-\rho_2}\tan\theta_2]$$

$\mathbf{H}_0^{r12d}$ is channel matrix with independent ZMCSSG random variable between relays and BS. By using (12), the probability of error to be upper-bounded is given by

$$P_e^{stc} \le \bar{M}_e \exp(-\sum_{i=1}^{M}\left\|\mathbf{H}_0^{r12d}\right\|^2 \frac{d_{\min}^2}{4}\frac{(1-\mathrm{P})\cos^{\kappa}\phi_1\cos^{\kappa}\phi_2}{(1-\rho_1)^{\kappa}\cos^{\kappa}\phi_2+(1-\rho_2)^{\kappa}\cos^{\kappa}\phi_1}SNR_b) \tag{13}$$

SNR_b is signal-to-noise ratio at the BS. Total performance of MIMO system using the relay with multi-antenna can be written as follow [10]

$$P_e^{all} = [1-P_{err}]P_e^{Coop} + P_{err}P_e^{Direct} \tag{14}$$

When the number of relay is *N_r*, P_{err} is the total error probability of relay and given by

$$P_{err} = 1-\prod_{n=1}^{N\_r}(1-P_{err\_n}) = \sum_{n=1}^{N\_r}\binom{N\_r}{n}(-1)^{n+1}(P_{err\_n})^n \tag{15}$$

P_{err_n} is the probability of error at the *n*-th relay. Also, P_e^{Direct} is the error probability of BS when no relay forward. When the cooperation is useful, P_e^{Coop} is the error probability of BS and given by

$$P_e^{Coop} = P_{err}P_e^{x} + (1-P_{err})P_e^{stc} \tag{16}$$

P_e^{x} is error probability due to error propagation. P_e^{stc} is the error probability of BS when relays(RS1,RS2) forward.

4. Numerical analysis and results

In this section, the performance of MIMO cooperative communication system employing the relay with multi-antenna and DSTC is investigated by using the analytic formula derived in Sec. II. The radio channel model for numerical analysis is ZMCSSG with mean=1. The modulation scheme is binary phase shift keying (BPSK). The number of nearest neighbors($\bar{M}_e$) is 2 and the minimum distance between constellations($d_{\min}$) is 16 and the power of distance is 4. The figure 3 shows the BER performance of relay using SISO(single input single output) and MIMO(MS-RS1). This figure 4 shows comparison on BER performance at the proposed system and the conventional system(relay with single antenna, no relay) when $SNR_{r1} = SNR_{r2} = SNR_b = SNR$. From this figure, we can see that the performance of system with the proposed approach is more improved significantly than that of the conventional system. The figure 5 shows total BER performance of system when $SNR_{r1}(SNR_{r2})$ is differently varied from SNR_b. In this figure, balancing SNR_b on SNR_{r1} is more effective to improve the performance of total system.

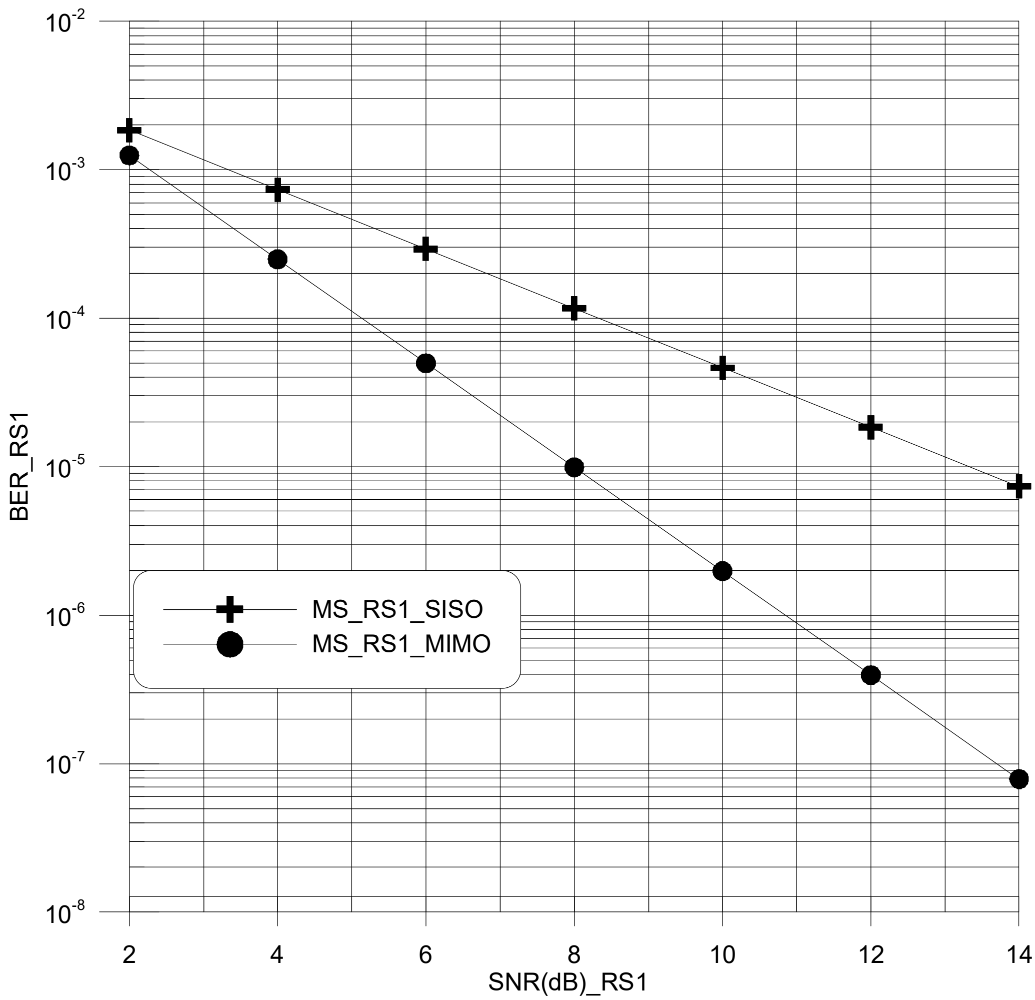

Figure 3. BER performance of RS1 using SISO and MIMO(MS-RS1)

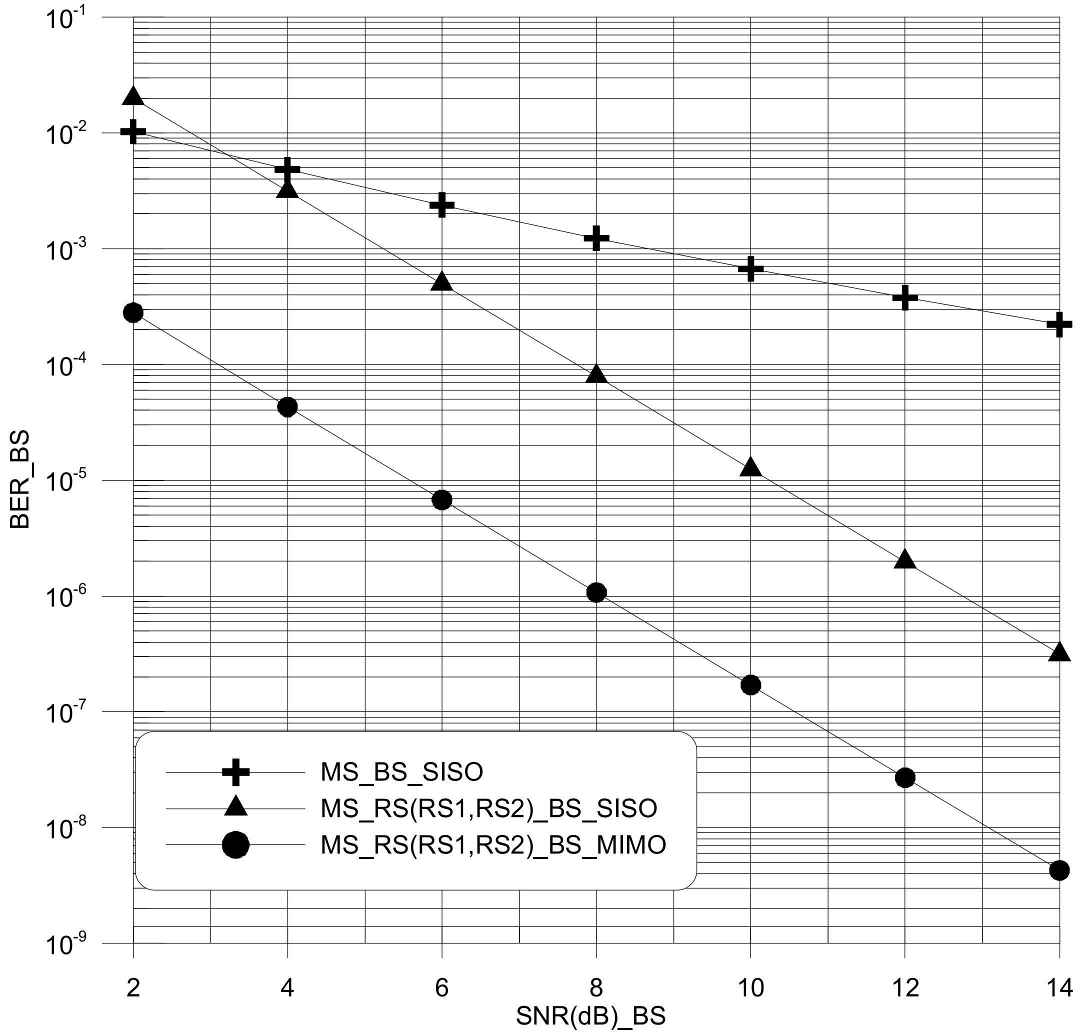

Figure 4. Comparison on BER performance at the proposed system(MS_RS_BS_MIMO) and the conventional system(MS_RS_BS_SISO, MS_BS_SISO)

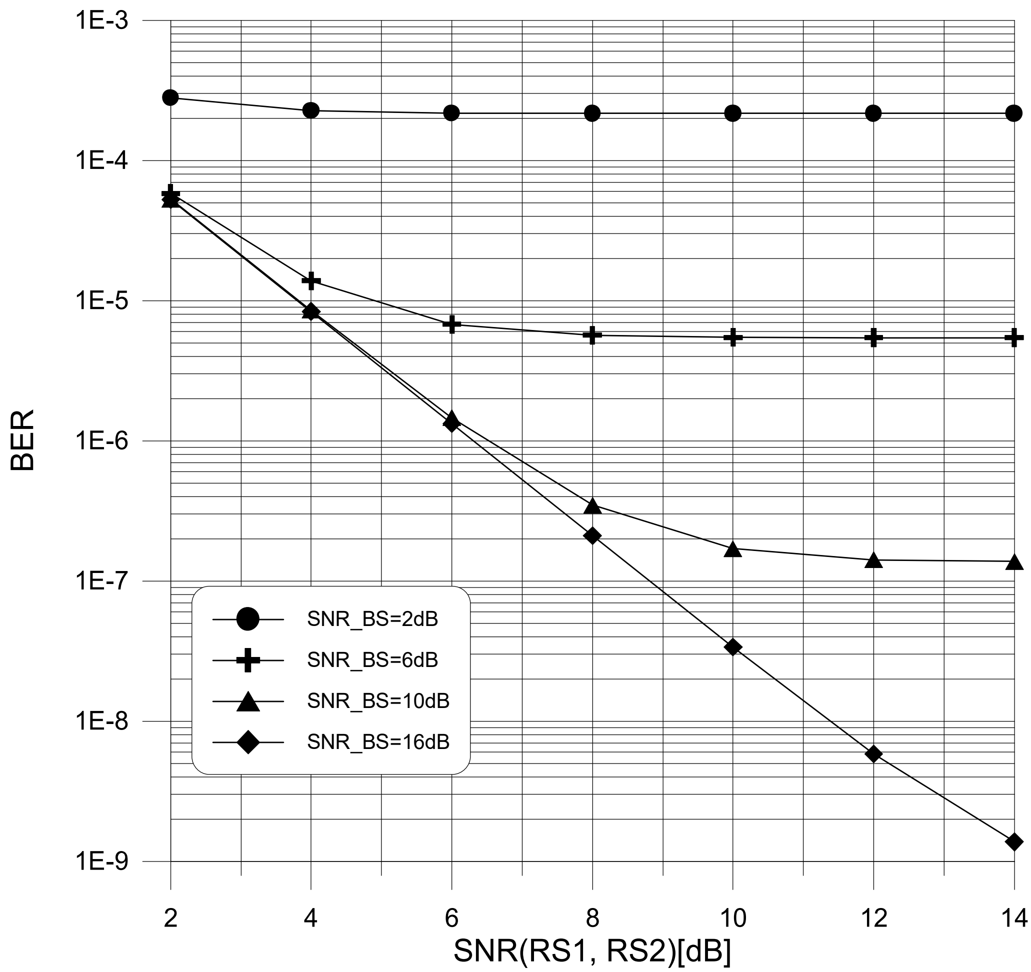

Figure 5. Total BER performance of system with cooperative diversity when SNR of Relay(SNR_{r1}) and BS are varied.

4. Conclusion

In this paper, we proposed new MIMO cooperative communication systems exploiting the relay with multi-antennas and DSTC for decode-and-forward protocol. The improvement of performance was investigated through numerical analysis of the cooperative communication system with the proposed approach. Here, we could get the MIMO diversity and cooperative diversity gain due to the MIMO channel formed by multi-antenna and DSTC at the MS-RS and at the RS-BS. We could see that the performance of the proposed system was more improved significantly than that of the conventional system. As minimizing error propagation, the proposed approach is effective technique to improve the performance in the poor wireless channel of cell edge. Therefore, we could conclude that the performance of MIMO cooperative system using the relay with multi-antennas and DSTC was greatly improved and also, balancing SNR_b on SNR_{r1} was more effective to improve the performance of total system. The performance of MIMO-OFDMA system using the relay with multi-antenna and DSTC is being further studied.

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