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Comparison of BER Performances with Receiving Antenna Selection Techniques in MIMO Systems

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Abstract – **This paper compares bit error rate (BER) performances when receiving antenna selection (RAS) techniques are applied to MIMO (Multi-Input Multi-Output) systems from the viewpoint of receiver structure. We assume two receiver structures. One is a structure for controlling gain in received signals centrally for all receiving antennas. The other is a structure for controlling gain in received signals individually in each receiving antenna. We show that a receiver which controls gain in received signals centrally can obtain good BER performances when utilizing RAS techniques using the channel matrix eigenvalue (RAS-E). Additionally, we consider RAS techniques using the phase of the channel components (RAS-PC) and received power (RAS-RP) for a receiver which controls received signal gain individually in each receiving antenna. We then compute and compare BER performances when employing RAS-PC and RAS-RP under Rayleigh fading channels, when the receiver uses inverse channel detection based on inverse matrix (ICD) or maximum likelihood detection (MLD).**

I. INTRODUCTION

The rapidly increasing number of users and services in mobile communications requires efficient usage of the available frequency band. MIMO systems are one possible candidate to meet these demands [1]-[10]. Consequently, much investigation has been carried out on techniques for obtaining good BER performances in such environments [1]-[4][6]-[10]. Space-time block code [3], space-time trellis code [4] and detection techniques [10] in MIMO systems have been investigated. Recently, techniques for antenna diversity techniques in MIMO systems have been investigated [6]-[9]. It has also been shown that the minimum eigenvalue power of the channel matrix eigenvalue influences BER performances in MIMO systems [5]-[7]. From this, antenna selection techniques based on the minimum power of the channel matrix eigenvalue in MIMO systems were investigated [6][7][9] and RAS techniques using the minimum power of the channel matrix eigenvalue have been proposed [9].

This paper compares BER performances employing RAS techniques in MIMO from the viewpoint of receiver structure. We assume two receiver structures. One is a structure for controlling gain in received signals centrally for all receiving antennas. The other is a structure for controlling gain in received signals individually for each receiving antenna. We show that a receiver which controls signal gain centrally can obtain good BER performances by employing RAS-E. Additionally, BER performances when employing RAS-PC are better than those when employing RAS-RP when the receiver controls received signal gain individually and uses ICD. On the other hand, BER performances when employing RAS-RP are better than those when employing RAS-PC when the receiver uses MLD. Thus, when the receiver has a structure for controlling received signal gain individually in each receiving antenna, the most effective RAS technique differs according to the detection method used by the receiver.

II. SYSTEM MODEL

The system model in this investigation is shown in Figure 1. The transmitter then has 2 antennas. The modulation signals of channels A and B are transmitted in transmitting antennas 1 and 2 respectively and the modulation is QPSK. The receiver has 3 antennas. The received signals Rx_k in the receiving antenna k are expressed as

$$\mathrm{Rx_k} = \begin{pmatrix} \mathrm{h_{k1}} & \mathrm{h_{k2}} \end{pmatrix} \begin{pmatrix} \mathrm{Tx_a} \\ \mathrm{Tx_b} \end{pmatrix} + \mathrm{n_k} \qquad (k=1,2,3) \tag{1}$$

where the transmitted signals of channel A and B are Tx_a and Tx_b. h_{k1} and h_{k2} are the channel component and n_k is white Gaussian noise. The channel model then is treated as Rayleigh fading channels, and the detection method is treated as ICD or MLD [10].

III. RECEIVING ANTENNA SELECTION TECHNIQUE

In this section, first the relationship between the minimum power of the channel matrix eigenvalue and received power is described. In consideration of received power, we examine the RAS-E, RAS-PC and RAS-RP techniques.

A. Relationship between Channel Matrix Eigenvalue and Received power

From (1), equation (2) is established in receiving antennas *i* and *j*.

$$\begin{pmatrix} \mathrm{Rx_i} \\ \mathrm{Rx_j} \end{pmatrix} = \begin{pmatrix} \mathrm{h_{i1}} & \mathrm{h_{i2}} \\ \mathrm{h_{j1}} & \mathrm{h_{j2}} \end{pmatrix} \begin{pmatrix} \mathrm{Tx_a} \\ \mathrm{Tx_b} \end{pmatrix} + \begin{pmatrix} \mathrm{n_i} \\ \mathrm{n_j} \end{pmatrix} \tag{2}$$

In (2), the phase difference φ_{ij} between the channel matrix components in receiving antennas *i* and *j* is defined by:

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$$\varphi_{ij}=\theta_j - \theta_i \qquad (-\pi\leq\varphi_{ij}\leq\pi \text{ radians}) \qquad (3)$$

where the phase difference of the channel matrix components h_{i1} and h_{i2} is θ_i ($-\pi\leq\theta_i\leq\pi$ radians) and the phase difference of the channel matrix components h_{j1} and h_{j2} is θ_j ($-\pi\leq\theta_j\leq\pi$ radians). Generality is established, even if the equation of (2) is substituted by equation (4).

$$\begin{pmatrix} Rx_i \\ Rx_j \end{pmatrix} = \begin{pmatrix} r_{i1}/\sqrt{2} & r_{i2}e^{j\theta_i}/\sqrt{2} \\ r_{j1}e^{-j(\theta_i+\varphi_{ij})}/\sqrt{2} & r_{j2}/\sqrt{2} \end{pmatrix} \begin{pmatrix} Tx_a \\ Tx_b \end{pmatrix} + \begin{pmatrix} n_i \\ n_j \end{pmatrix} \qquad (4)$$

The eigenvalue and eigenvector of the matrix in (4) are defined by $\lambda_{ij,1}(r_{i1},r_{i2},r_{j1},r_{j2},\varphi_{ij})$, $\lambda_{ij,2}(r_{i1},r_{i2},r_{j1},r_{j2},\varphi_{ij})$ and $\mathbf{v}_{ij,1}$, $\mathbf{v}_{ij,2}$, respectively. Then, the eigenvalue is expressed as:

$$\lambda_{ij,1} = \frac{1}{2\sqrt{2}}\left(r_{i1} + r_{j2} + \sqrt{(r_{i1}-r_{j2})^2 + 4 r_{i2} r_{j1} e^{-j\varphi_{ij}}} \right), \qquad (5)$$

$$\lambda_{ij,2} = \frac{1}{2\sqrt{2}}\left(r_{i1} + r_{j2} - \sqrt{(r_{i1}-r_{j2})^2 + 4 r_{i2} r_{j1} e^{-j\varphi_{ij}}} \right) \qquad (6)$$

where $|\lambda_{ij,1}|^2\geq|\lambda_{ij,2}|^2$. The vector $\mathbf{Tx}_{ij}=(Tx_a,Tx_b)^T$, $\mathbf{Rx}_{ij}=(Rx_i,Rx_j)^T$, $\mathbf{n}_{ij}=(n_i,n_j)^T$ is expressed as

$$\mathbf{Tx}_{ij}=\alpha\mathbf{v}_{ij,1}+\beta\mathbf{v}_{ij,2}, \qquad (7)$$

$$\mathbf{Rx}_{ij}=\alpha\lambda_{ij,1}\mathbf{v}_{ij,1}+\beta\lambda_{ij,2}\mathbf{v}_{ij,2}+\mathbf{n}_{ij} \qquad (8)$$

where α and β are coefficients given in the vector $\mathbf{Tx}_{ij}$. As shown in (8), the power of the vector $\alpha\lambda_{ij,1}\mathbf{v}_{ij,1}$, $\beta\lambda_{ij,2}\mathbf{v}_{ij,2}$ depends on the power of $|\lambda_{ij,1}|^2$, $|\lambda_{ij,2}|^2$, respectively. Next the receiving power is considered. In the receiver, the inverse matrix operation is carried out in (8), the estimation value α', β' of coefficient α, β is obtained and the estimation vector $\mathbf{Tx}_{ij}'$ of the vector $\mathbf{Tx}_{ij}$ is obtained. Then the receiving power of $\beta\mathbf{v}_{ij,2}$ in $\mathbf{Tx}_{ij}$ depends on $|\beta\lambda_{ij,2}|^2$ and the receiving power $\alpha\mathbf{v}_1$ in $\mathbf{Tx}_{ij}$ depends on $|\alpha\lambda_{ij,1}|^2$. Therefore the estimation accuracy of α' improves but the estimation accuracy of β' becomes deteriorates. However, the receiving power of $\alpha\mathbf{v}_{ij,1}$ depends on $|\alpha\lambda_{ij,2}|^2$ minimally because of $|\lambda_{ij,1}|^2\geq|\lambda_{ij,2}|^2$. Accordingly, the vector $\mathbf{Rx}_{ij}$ is approximated as:

$$\mathbf{Rx}_{ij}\approx(\alpha|\lambda_{ij,2}| \frac{\lambda_{ij,1}}{|\lambda_{ij,1}|}\mathbf{v}_{ij,1}+\beta|\lambda_{ij,2}|\frac{\lambda_{ij,2}}{|\lambda_{ij,2}|}\mathbf{v}_{ij,2})+\mathbf{n}_{ij}. \qquad (9)$$

Considering the received power from (9), the minimum effective power C'_{ij} in (8) is expressed as:

$$C'_{ij}(r_{i1},r_{i2},r_{j1},r_{j2},\varphi_{ij})=|\lambda_{ij,2}(r_{i1},r_{i2},r_{j1},r_{j2},\varphi_{ij})|^2 \qquad (10)$$

[5]. BER performances are therefore improved as the receiver obtains a high minimum effective power when using the receiving antenna selection techniques.

B. RAS-E

We propose a receiving antenna selection technique using the channel matrix eigenvalue in the following based on section III.*A*.

The receiver has *n* antennas ($n\geq3$). Therefore the receiver has ${}_nC_2$ combinations to select 2 receiving antennas from *n* receiving antennas. The minimum power of the eigenvalue of the channel matrix in selection pattern *p* ($p=1,2,\ldots,{}_nC_2$) is expressed as $|\lambda_{\min,p}|^2$. Then, the receiver selects the 2 receiving antennas which give the largest power $|\lambda_{\min,p}|^2$ at $p=1, 2, \ldots, {}_nC_2$.

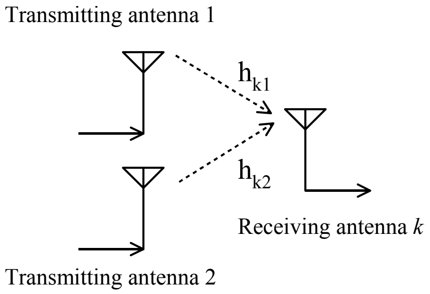

Fig.1. System model.

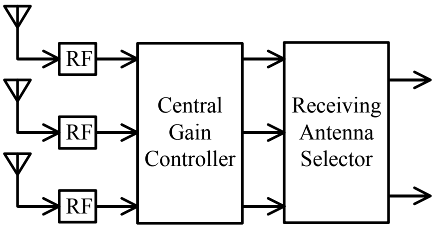

Fig.2(a). Receiver structure.

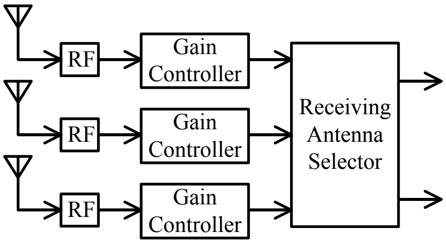

Fig.2(b). Receiver structure

The receiver structure is shown in Figure 2. We assume two receiver structures. One is a structure for controlling gain in the received signal centrally for all receiving antennas as in Figure 2(a). The other is a structure for controlling received signal gain individually in each receiving antenna as in Figure 2(b). Although the receiver requires a structure like Figure 2(a) for obtaining the minimum effective power $C'_{ij}(r_{i1},r_{i2},r_{j1},r_{j2},\varphi_{ij})$ from (10) in all selection patterns ($p=1, 2, \ldots, {}_nC_2$), a receiver which has a structure like Figure 2(b) cannot obtain the minimum power $C'_{ij}(r_{i1},r_{i2},r_{j1},r_{j2},\varphi_{ij})$.

Receiving antenna selection techniques for a receiver which has a structure like Figure 2(b) are described in sections III.*C* and III.*D* according to the two parameters which the receiver can easily obtain when the receiver has a structure like Figure 2(b): the phase of the channel matrix component, and the received power. Section III.*C* and III.*D* describes the RAS-PC and RAS-RP technique, respectively.

C. RAS-PC

The approximation from (10) is considered for a receiver which has a structure for controlling received signal gain individually in each receiving antenna as in Figure 2(b).

It can be considered that the minimum effective power C'_{ij} is a function of φ_{ij} alone, because the receiver controls received signal gain individually in each receiving antenna. So, if $|h_{i1}|=|h_{j2}|$ or $|h_{i2}|=|h_{j1}|$ is established and the phase differences φ_S and φ_L from (3) satisfies $0\le|\varphi_S|\le|\varphi_L|\le\pi$ radians, equation (11) is established.

$$|\lambda_{ij,2}(\varphi_S)|^2\le|\lambda_{ij,2}(\varphi_L)|^2 \qquad (11)$$

Based on this, we propose a receiving antenna selection technique using the phase of the channel components in the following.

The receiver has n antennas ($n\ge3$). The phase difference from (3) in selection pattern p (p=1, 2, …, ${}_nC_2$) is expressed as φ_p. The receiver selects the 2 receiving antennas which give the largest absolute value of the phase difference $|\varphi_p|$ at p=1, 2, …, ${}_nC_2$.

D. RAS-RP

The antenna selection pattern is expressed as p when the receiver selects receiving antennas i and j. The received power C_p is expressed as:

$$C_p=|h_{i1}|^2+|h_{i2}|^2+|h_{j1}|^2+|h_{j2}|^2 \qquad (12)$$

When noise is considered, the affect of the noise can be reduced by increasing the received power in (12). In the following, we consider a receiving antenna selection technique using the received power.

The receiver has n antennas ($n\ge3$). The received power from (12) in selection pattern p (p=1, 2, …, ${}_nC_2$) is expressed as C_p. The receiver selects the 2 receiving antennas which give the largest C_p at p=1, 2, …, ${}_nC_2$.

IV. COMPARISON OF BER PERFORMANCES

A. BER Performances Using Inverse Channel Detection

In this section, BER performances employing RAS techniques are shown using ICD.

The relationship between BER and C/N (carrier-to-noise power ratio) with 3 receiving antennas employing RAS-E, RAS-PC and RAS-RP techniques is shown in Figure 3. G_n is defined as the antenna gain at a diversity with n antennas and can be expressed as:

$$G_n=10\log(n/2)\ (\text{dB}) \qquad (13)$$

where the antenna gain with 2 antennas is set to be 0dB. Antenna gain increases according to the increase in the number of antenna and the carrier power also increases. The relationship between BER and E_b/No (energy per bit-to-noise spectral density ratio) with 3 receiving antenna employing RAS-E, RAS-PC and RAS-RP techniques is shown in Figure 4. As a comparison, BER performances with 2 receiving antennas are shown in Figures 3 and 4.

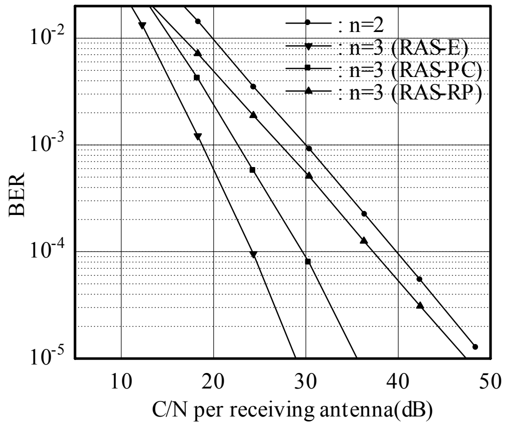

Fig.3. BER versus C/N per receiving antenna employing inverse channel detection.

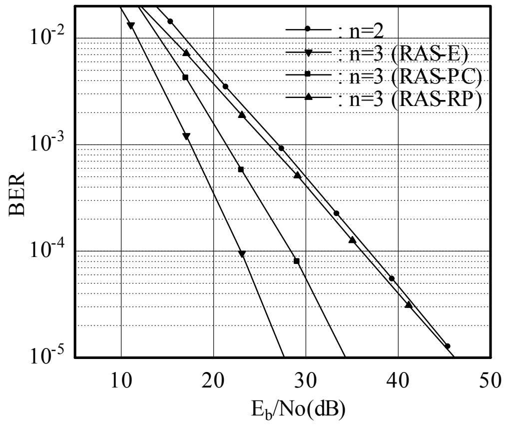

Fig.4. BER versus E_b/No employing inverse channel detection.

Here, we consider the performance of the receiver in Figure 3. The receiver with 3 antennas employing RAS-RP, RAS-PC and RAS-E techniques gives a margin of 4, 12 and 16dB at BER=1.0×10^{-4} compared to the receiver with 2 antennas. Thus, the effectiveness for improving BER performances is the greatest when the receiver use the RAS-E technique compared with the other techniques.

On the other hand, the RAS-PC technique is effective in improving BER performances when the receiver has a structure for controlling received signal gain individually in each receiving antenna although the RAS-RP technique is almost ineffective.

Furthermore, as can be seen in Figure 4, the bit energy efficiency is improved when applying the RAS techniques proposed here compared with that with 2 receiving antennas.

B. BER Performances Using MLD

In this section, BER performances employing RAS techniques are shown using MLD.

The relationship between BER and C/N with 3 receiving antennas employing RAS-E, RAS-PC and RAS-RP techniques is shown in Figure 5. In addition, the relationship between BER and E_b/No with 3 receiving antennas employing RAS-E, RAS-PC and RAS-RP techniques is shown in Figure 6. As a comparison, BER performances with 2 receiving antennas are shown in Figures 5 and 6.

Here, we consider the performance of the receiver from Figure 5. The receiver with 3 antennas employing RAS-RP and RAS-E techniques gives a margin of 2 and 5dB at BER=1.0x10^{-4} compared to the receiver with 2 antennas. However, the receiver with 3 antennas employing the RAS-PC technique cannot yield a margin. Therefore, the effectiveness for improving BER performances is the greatest when the receiver uses the RAS-E technique compared with the other techniques.

On the other hand, the RAS-RP technique is effective in improving BER performances when the receiver has a structure for controlling received signal gain individually in each receiving antenna, although the RAS-PC technique is not effective,.

Furthermore, as can be seen from Figure 6, although bit energy efficiency is improved by applying the RAS-E technique compared to that with 2 receiving antennas, it is not effective to apply the RAS-PC and RAS-RP techniques for the improvement of bit energy efficiency .

C. Results

As a result of the analysis of BER performances in section IV.*A*, IV.*B*, the following three results are particularly noteworthy:

- The effectiveness in improving BER performances is greatest when the receiver uses the RAS-E technique compared to the RAS-PC and RAS-RP techniques when employing either ICD or MLD.
- When the receiver has a structure for controlling received signal gain individually in each receiving antenna, the most effective RAS technique differs according to the detection method used by the receiver.
- The effectiveness for improvement of BER performances when applying RAS techniques with ICD is greater than that of MLD.

V. CONCLUSIONS

This paper has made a comparison of BER performances when employing RAS-E, RAS-PC and RAS-RP techniques. We have shown that the effectiveness for improving BER performances when employing either ICD or MLD is greatest when the receiver uses the RAS-E technique compared to the RAS-PC and RAS-RP techniques. Furthermore, we demonstrated that the most effective RAS technique when the receiver has a structure for controlling received signal gain individually in each receiving antenna differs according to the detection method used by the receiver.

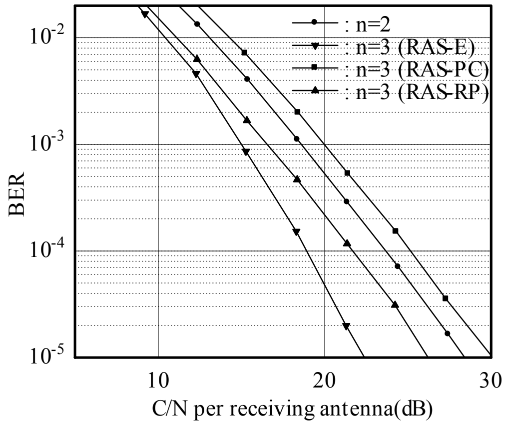

Fig.5. BER versus C/N per receiving antenna employing LD.

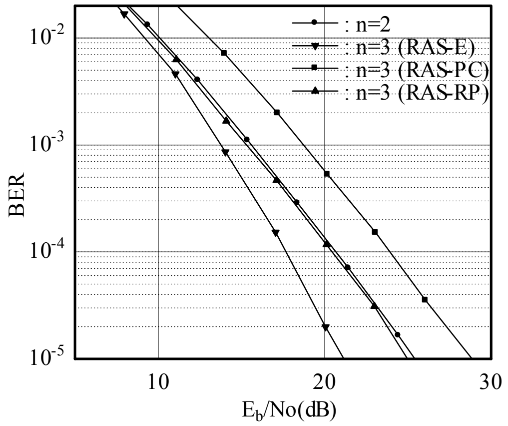

Fig.6. BER versus E_b/No employing LD.

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