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DIVERSITY TECHNIQUE OF RECEIVERS WITH W-EP SOFT-DECISION DECODER IN MIMO SYSTEMS

Kiyotaka KOBAYASHI, Yutaka MURAKAMI, Katsuaki ABE,
Masayuki ORIHASHI, Takashi MATSUOKA
Corporate Network Development Division, Matsushita Electric Industrial Co., Ltd.
Multimedia Center, 4-5-15 Higashishinagawa, Shinagawa-ku, Tokyo 140-8632, Japan
E-Mail kobayashi.kiyotaka@jp.panasonic.com

1. Introduction

This paper examines the diversity technique of receivers in convolutionally encoded MIMO (Multi-Input Multi-Output) systems. We have proposed W-EP (Weighting-by Eigenvalue Power) soft-decision decoder in 2x2 encoded MIMO systems, confirmed that the weighting factor based on the eigenvalue of channel matrix has a significant effect on BER (Bit Error Rate) performances [1]. On the other hand, large interleave size according to Doppler frequency is required in order to fully acquire coding gain. This leads to the increase in both hardware size and decoding process delay [2]. In this point, the technique achieving both interleave size reduction and BER performance improvement is demanded for real systems. In SISO (Single-Input Single-Output) systems, diversity technique is well-known as one of the effective solutions for the both demands mentioned above.

We focus on the antenna combining method for achieving both interleave size reduction and BER performance improvement in encoded MIMO systems. We propose a soft-decision decoder with the diversity technique based on the RAC-BME (Receiving Antenna Combining computing Branch Metric using Eigenvalue) technique [3] in 2x*n* (*n*=3, 4, 5) encoded MIMO systems. The results show that the RAC-BME decoder plays a greater role to improve BER performances than NWC (No-Weighting Combining) decoder. Moreover, it has been clear that the RAC-BME decoder can achieve the interleave size reduction with the improvement in BER performances.

2. System Model

The system model in this paper is shown in Figure 1. The transmitter has 2 antennas, the modulated signals of channels A and B are transmitted in transmitting antennas 1 and 2 respectively and the modulation is QPSK. The receiver has n ($n \geq 2$) antennas. The received signals Rx_k in the receiving antenna k are expressed as:

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

where the transmitted signals of channels A and B are Tx_a and Tx_b, h_{k1} and h_{k2} are channel components and n_k is white Gaussian noise. In this paper, the channel model is treated as Rayleigh fading channels, and the detection method is treated as inverse channel detection [1].

3. Diversity Technique of Receivers

In this section, first the W-EP decoding is described based on the minimum eigenvalue power of the channel matrix. We then explain the RAC-BME decoding.

A. W-EP Decoding[1]

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

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

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

$$\varphi_{ij}=\theta_{j,2} - \theta_{i,1} \qquad (-\pi \leq \varphi_{ij} \leq \pi \text{ radians}) \qquad (3)$$

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where the phase difference of the channel matrix components h_{i1} and h_{i2} is $\theta_{i,1}$ ($-\pi \leq \theta_{i,1} \leq \pi$ radians) and the phase difference of the channel matrix components h_{j1} and h_{j2} is $\theta_{j,2}$ ($-\pi \leq \theta_{j,2} \leq \pi$ radians). Generality is established, even if the equation of (2) is substituted by equation (4).

$$\begin{pmatrix} Rx_i \\ Rx_j \end{pmatrix} = \begin{pmatrix} r_{i1}/\sqrt{2} & r_{i2}e^{j\theta_{i,1}}/\sqrt{2} \\ r_{j1}e^{-j(\theta_{i,1}+\varphi_{ij})}/\sqrt{2} & r_{j2}/\sqrt{2} \end{pmatrix} \begin{pmatrix} Tx_a \\ Tx_b \end{pmatrix} + \begin{pmatrix} n_i \\ n_j \end{pmatrix} \qquad (4)$$

where r_{i1}, r_{i2}, r_{j1} and r_{j2} are the amplitudes of h_{i1}, h_{i2}, h_{j1} and h_{j2}.
Then, the eigenvalues of the channel matrix $\lambda_{ij,1}(r_{i1},r_{i2},r_{j1},r_{j2},\varphi_{ij})$, $\lambda_{ij,2}(r_{i1},r_{i2},r_{j1},r_{j2},\varphi_{ij})$ are 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 $|\lambda_{ij,1}|^2 \geq |\lambda_{ij,2}|^2$.

When using inverse channel detection, the minimum eigenvalue power $|\lambda_{ij,2}|^2$ becomes an effective carrier power and a leading parameter to determine BER performances. The W-EP method applies the $|\lambda_{ij,2}|^2$ ($\equiv |\lambda_{min}|^2$) as a weighting factor.

The W-EP method in MIMO systems is described as follows. The relationship between the ideal signal point, the received signal point and the Euclidean distance in the case of QPSK modulation is shown in Fig. 2. The weighting factor $|\lambda_{min}|^2$ is multiplied for each square Euclidean distance D[u,v] (u=0,1; v=0,1) in the decoder of Tx_a, Tx_b and each branch metric $metTx_{a[u,v]}$, $metTx_{b[u,v]}$ for soft-decision decoding can then be indicated as:

$$metTx_{a[u,v]} = |\lambda_{min}|^2 D_{[u,v]}^2 \quad (u=0,1;\ v=0,1), \qquad (7)$$

$$metTx_{b[u,v]} = |\lambda_{min}|^2 D_{[u,v]}^2 \quad (u=0,1;\ v=0,1) \qquad (8)$$

Soft-decision decoding using the W-EP method (W-EP decoding) is carried out based on (7) and (8). The decoder of channel A searches for the path metric which make the summation of $metTx_{a[u,v]}$ the minimum. The decoder of channel B does the same.

B. RAC-BME Decoding

The RAC-BME decoding is explained based on the W-EP decoding in section 3.A.

The receiver has n antennas ($n \geq 3$). Therefore the receiver has ${}_nC_2$ patterns to select 2 receiving antennas from n receiving antennas. The minimum eigenvalue power of the channel matrix in the selection pattern q (q=1,2, ... , ${}_nC_2$) is expressed as $|\lambda_{min,q}|^2$. This means that each antenna selection pattern has the different reliability of the branch metric because the states of the channel matrix are different. To obtain good BER performances, we propose the $|\lambda_{min,q}|^2$ as a weighting factor for the square Euclidean distances D_q[0,0], D_q[0,1], D_q[1,0] and D_q[1,1] in selection pattern q. Therefore, the branch metrics of channels A and B ($metTx_{a\_com[u,v]}$, $metTx_{b\_com[u,v]}$) are expressed as a summation of ${}_nC_2$ patterns.

$$metTx_{a\_com[u,v]} = \sum_{q=1}^{nC2}\left(|\lambda_{min,q}|^2 D_{a,q}^2[u,v] \right) \quad (u=0,1\ ;\ v=0,1), \qquad (9)$$

$$metTx_{b\_com[u,v]} = \sum_{q=1}^{nC2}\left(|\lambda_{min,q}|^2 D_{b,q}^2[u,v] \right) \quad (u=0,1\ ;\ v=0,1) \qquad (10)$$

where $D_{a,q}$[u,v] and $D_{b,q}$[u,v] are the square Euclidean distances of channel A and B in selection pattern q.
Soft-decision decoding using the RAC-BME method [3] (RAC-BME decoding) is carried out based on (9) and (10). The decoder of channel A searches for the path metric which make the summation of $metTx_{a\_com\,[u,v]}$ the minimum. The decoder of channel B does the same. In this paper, the RAC-BME decoding is evaluated by computer simulation compared to NWC (No-Weighting Combining) decoding.

4. BER performances

A. Comparison of RAC-BME and NWC

In this subsection, BER performances when employing the RAC-BME and NWC (No-Weighting Combining) decoding are evaluated. The system parameters are summarized in Table 1. The random interleaver sizes assume

<40> (40 times compared to the normalized doppler period 300T), <1> (equal to the 300T) and <not interleaved>. The size <40> corresponds to a sufficient size to randomize uncorrelated. On the other hand, the size <1> corresponds to an insufficient size to randomize uncorrelated.

E_b/N_0 versus BER performances with 2, 3, 4 and 5 receiving antennas using the RAC-BME and NWC decoding is shown in Figure 3.

As can be seen from Figure 3, the receiver with 3, 4, and 5 antennas employing the RAC-BME decoding needs 9, 8 and 7[dB] for achieving BER=$1.0\text{x}10^{-4}$. In comparison, the receiver with the NWC decoding needs 27, 26 and 24[dB]. This result leads that applying the RAC-BME decoding is effective in improving BER performances when the number of receiving antennas increases. This result also demonstrates that appropriate weighting factors such as $|\lambda_{min,q}|^2$ are essential for antenna combining techniques in encoded MIMO systems. In addition, it can be seen that the effectiveness in improving BER performances declines as the number of receiving antennas increases. This is because the diversity gain decreases according to the increase of the receiving antennas.

B. Interleave Size Reduction with RAC-BME Decoding

In this subsection, we comment that the effectiveness of interleave size reduction when RAC-BME decoding is applied.

E_b/N_0 versus BER performances employing the RAC-BME decoding with n=2<not interleaved> and <40>, n=3<not interleaved> and <40>, n=4<not interleaved> and <40>, are shown in Figure 4.

Fig.4. shows that the differences between <not interleaved> and <40> become smaller when receiving antennas *n* increases. The differences in case of *n*=2, 3, 4 can be seen 18, 12 and 7[dB]. This leads that in cases where it is difficult to set a sufficient interleave size, we can obtain good BER performances by increasing the number of receiving antennas.

Also, E_b/N_0 versus BER performances with n=2<40>, n=3<1>, n=3<40>, n=4<1>, with the RAC-BME technique is shown in Figure 5.

Fig.5. shows that the performance n=3<1> is similar to n=2<40> throughout a range of E_b/N_0. The same can be regarded between n=3<40> and n=4<1>.

Thus, when we are going to acquire a desired BER performance, it turns out that the RAC-BME decoding can achieve both the improvement in the BER performance and interleave size reduction.

5. Conclusions

This paper examined the technique of the receiving antenna combining in convolutionally encoded MIMO systems. We proposed the RAC-BME decoding to meet the both improvement in BER performance and interleave size reduction. In a computer simulation, we confirmed the RAC-BME decoding can fulfill the both demands. Thus, we can consider system designs flexibly based on the RAC-BME, and then the eigenvalue power of channel matrix is fundamental.

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Table 1. System parameters.

Fading model	Rayleigh fading (uncorrelated)
Doppler frequency	1/(300T) (T:symbol duration)
Interleave size	<40>,<1>, <not interleaved> (per 300T)
Encoding	Convolutional coding (R=1/2, K=7)
Decoding	W-EP, NW decoding (n=2)
	RAC-BME, NWC decoding (n=3, 4, 5)

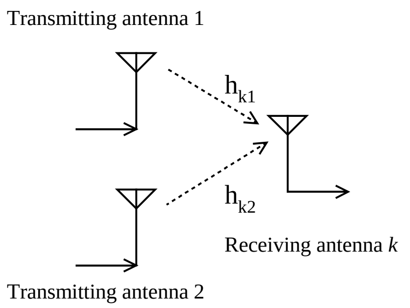

Fig.1. System model.

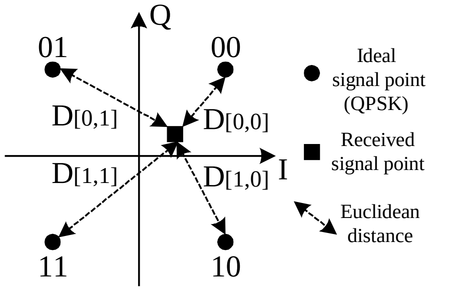

Fig.2. Relationship between ideal signal point, received signal point and Euclidean distance in the case of QPSK modulation.

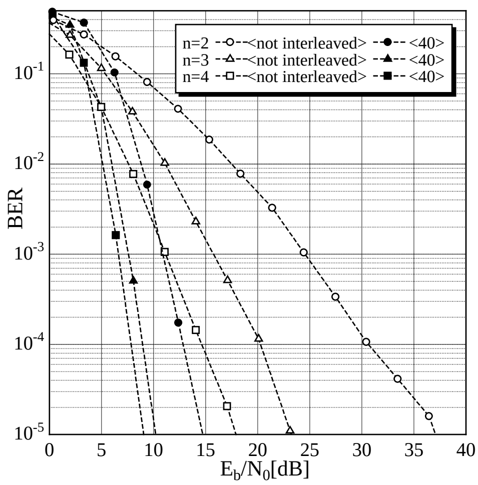

Fig.4. E_b/N_0 versus BER with RAC-BME in terms of the differences of interleave size.

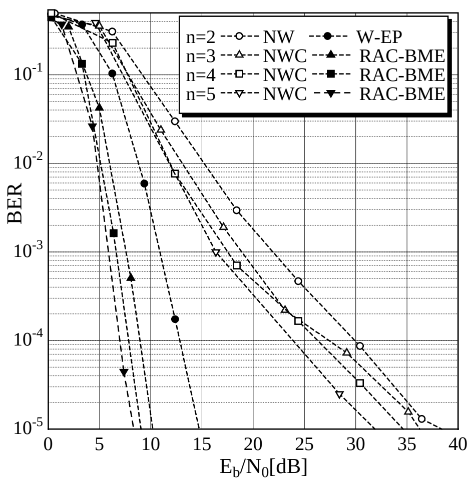

Fig.3. E_b/N_0 versus BER with RAC-BME and NWC in terms of the number of antennas.

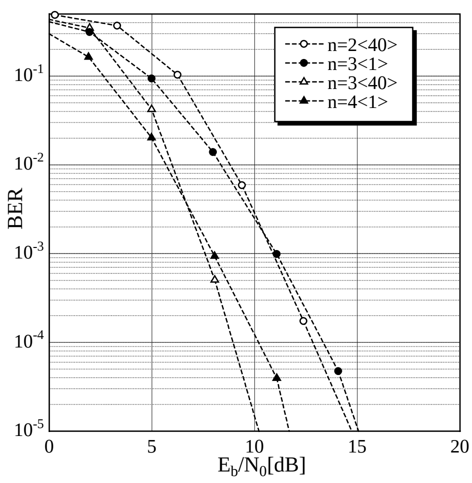

Fig.5. E_b/N_0 versus BER in terms of interleave size reduction.