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Cooperative Diversity in Downlink of Cellular CDMA Systems Using Maximum Ratio Precoding

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***Abstract*—Cooperative communication is an efficient technique for improving the performance and coverage of cellular mobile networks. In this paper, we consider signal transmission in downlink of cooperative cellular direct sequence code division multiple access (DS-CDMA) systems. In this case, signal is transmitted to the destination mobile terminals via direct links, i.e. links from the base station to users, and also from a cooperative link via the partner mobile terminal to the destination. Our purpose is to shift the spatial processing from the user terminal to the transmitter of the base station. We proposed two different precoding schemes. In the first scheme, we assume that the inter-user channel state information is available at the relay mobile terminals and the base station only has information about the direct links. In the second scheme, we assume that all direct and inter-user channel state information are available at the base station. We derive different linear precoding techniques for two schemes and evaluate their performance by computer simulations. We show that both proposed cooperation schemes improve the performance of the system with respect to the case when no cooperation is used in the system. In addition it will be shown that the proposed schemes can achieve maximum diversity with low complexity requirements at the mobile receivers.**

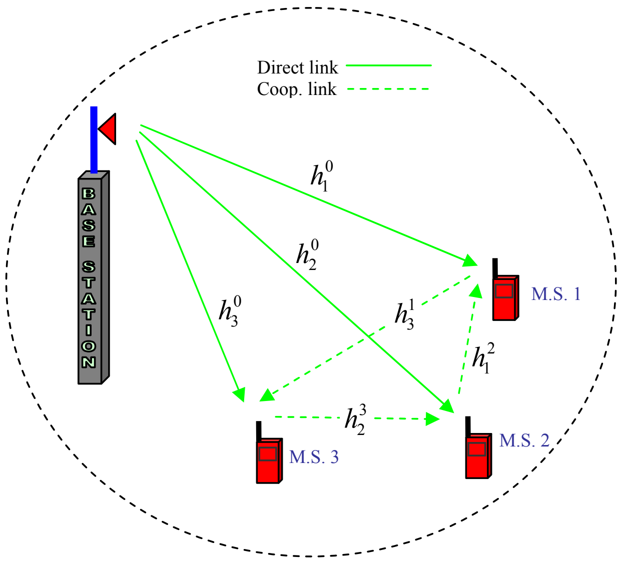

Fig. 1. Cooperation in Downlink of a DS-CDMA System

I. Introduction

Two main objectives of the future mobile communication systems are increasing the transmission rate and coverage. To reach these objectives, it is necessary to use some methods to increase the spectral efficiency and reliability of wireless communication systems. Several multiple-input multiple-output (MIMO) techniques have been proposed in recent years to realize high speed data transmission in mobile communication systems and to improve the performance of these systems by introducing space diversity. However, using MIMO in mobile cellular systems has some challenges. In mobile cellular systems, employing multiple antenna in mobile terminals is difficult due to hardware complexity and size of terminals. Therefore, these antennas usually are used in the base station. When these antennas are used in the base station's receiver, they can improve the performance of the uplink by introducing receive space diversity. In these cases some combining methods like maximum ratio combing (MRC) [1] are used at the receiver.

In downlink of mobile wireless systems, it is possible to use transmit diversity methods to exploit spatial diversity [2], [3]. However, most of these methods need perfect channel state information (CSI) and some spatial processing at the receiver side. In contrast, if CSI is available at the transmitter, it is possible to shift the spatial processing from receiver side to the transmitter which results in lower complexity at the mobile terminals' receiver. There are various transmit processing methods which have been proposed to improve the performance of MIMO systems including maximum ratio transmission [4] and transmit precoding method [5].

Another diversity method that has been recently proposed for exploiting spatial diversity in mobile wireless systems is cooperation diversity [6]. In this technique, multiple antennas are distributed between single antenna terminals where they cooperate with each other to send data from transmitter to the destination. This method can achieve a diversity order which is proportional to the number of cooperating terminals. There are many different relaying strategies for cooperative systems including decode and forward, amplify and forward and coded cooperation [6], [7]

In this paper, cooperative communication in downlink of cellular DS-CDMA systems is considered. Cooperation in DS-CDMA systems has been studied in previous papers

[8]- [13]. However, almost all of these papers consider uplink transmission. Using cooperative communication in uplink of cellular systems can eliminate the need for multiple transmit antennas at the mobile terminals when transmit diversity schemes are used. However, it will be also advantageous in downlink transmission since it remove the need for multiple antennas at the mobile users when receive diversity schemes are used. On the other hand, in next generation mobile cellular systems more data rates is required in downlink for multimedia services, such as web browsing and video conferencing. Hence, the reliability of this link is more important.

In this paper, two cooperation schemes for downlink transmission in cellular DS-CDMA systems are developed. and evaluate and compare their performances via computer simulations. These schemes are related to different cases of known and unknown inter-users channel state information at the relay terminals. We show that even by using single antenna in both base station and users' terminals, the full spatial diversity in the system can be exploited. To design the signals that are transmitted in the cooperative scenario, we use transmit precoding methods and try to shift all required spatial processing to the base station transmitter.

The paper is organized as follow. In section II, the users cooperation and system model are presented. In section III, the proposed cooperation and linear precoding methods are introduced and analyzed. Simulation results are presented in section IV and finally, section V concludes this paper.

II. SYSTEM MODEL

The cooperation model that is considered in this paper, is shown in Fig.1. In this scenario, there are K single antenna users in the system which cooperate and share their resources in groups. We assume that a partner denotes by q_k is assigned to each user kth in the system. The base station transmits data to the kth user via its partner user q_k in one time slot. It also sends data directly the kth user in another time slot. In our scenario, the cooperation is not bidirectional. That is, if the user q_k acts as the relay for user k, user k is the relay for another different user denoted by p_k and in general $p_k \neq q_k$. For example, in the scenario shown in Fig.1, $p_1 = 3,\ p_2 = 1,\ p_3 = 2$ and $q_1 = 2,\ q_2 = 3,\ q_3 = 1$. The channel coefficient from the ith terminal to the jth terminal is denoted by h_j^i where the base station is denoted by index 0. It is assumed that fading is constant across two consecutive time slots. We also assume that the total number of spreading codes remains the same as in non-cooperative case.

We assume that the cooperated transmission is performed in two phases. During the odd time slots, the base station transmits precoded data related to each user to its partner. During these time slots, each terminals receives the signal, estimates its partner data and constructs a signal which is send to the destination user during the next time slot. During the even time slots, in addition to the signal that transmitted by the mobile users, the base station also transmits the precoded data of each user directly to them. In these time slots the final decision on each user's data is made based on the received signals. To simplify the derivations, hereafter, we assume only two first time slots.

The signal that the base station transmits during the first time slot is denoted by $\mathbf{x}_0^{(1)}$ and it is defined as follow

$$\mathbf{x}_0^{(1)} = \gamma_0^{(1)} \sum_{k=1}^{K} d_{p_k}^c \mathbf{C}_k \tag{1}$$

where $\mathbf{C}_k = [C_{k1}, C_{k2}, \cdots, C_{kN}]^T$ is normalized spreading sequence of the kth user with length N and $C_{ki} = \pm 1$. $d_{p_k}^c$ is the precoded data related to the user p_k which is spread by spreading sequence $\mathbf{C}_k$. This signal is received by the kth user as well as by all the other users in the system. $\gamma_0^{(1)}$ is the power scaling factor which controls the transmit power of the base station and is used to ensure that the precoding (transmit processing) does not increase transmitted power [14]. This factor can be expressed by

$$\gamma_0^{(1)} = \sqrt{\beta_1^0 \ \mathrm{P}/\mathbf{E}\left[\left(\sum_{k=1}^{K} d_{p_k}^c \mathbf{C}_k\right)^{\mathrm{H}} \left(\sum_{k=1}^{K} d_{p_k}^c \mathbf{C}_k\right)\right]} \tag{2}$$

where P is total transmit power without precoding in each time slot and in this case, it is equal to K [14]. The parameter $0 \leq \beta_1^0 \leq 1$ controls the amount of power that is allocated to the signal transmitted by the base station in the first time slot versus the power of the signal transmitted by the partner during the second time slot.

During the first time slot, the received signal in the lth user can be expressed as

$$\mathbf{r}_l^{(1)} = h_l^0 \mathbf{x}_0^{(1)} + \mathbf{n}_l^{(1)} = \gamma_0^{(1)} h_l^0 \sum_{k=1}^{K} d_{p_k}^c \mathbf{C}_k + \mathbf{n}_l^{(1)} \tag{3}$$

where $\mathbf{n}_l^{(1)}$ is the additive white gaussian noise at the lth receiver during the first time slot with zero mean and variance σ_n^2. The signal in (3) is then passed through a matched filter to the lth user's spreading sequence $\mathbf{C}_l$. The output of the lth user's matched filter is represented by

$$\mathbf{y}_l^{(1)} = \mathbf{C}_l^T \mathbf{r}_l = \gamma_0^{(1)} h_l^0 d_{p_l}^c + \mathbf{v}_l^{(1)} \tag{4}$$

where $\mathbf{v}_l^{(1)} = \mathbf{C}_l^T \mathbf{n}_l^{(1)}$. In (4), we assumed that the spreading sequences are orthogonal to each other,i.e. $\mathbf{C}_i^T \mathbf{C}_j = 0$ if $i \neq j$. The data that is used to construct transmit signal from the lth user is computed as follow

$$\hat{d}_{p_l}^c = f(\mathbf{y}_l^{(1)}) \tag{5}$$

$f(.)$ is the function which is determined in the next section for the proposed schemes. The precoded data in (5) is used to construct the signal which is forwarded to the p_lth user during the second time slot as follow

$$\mathbf{x}_l^{(2)} = \gamma_l^{(2)} \hat{d}_{p_l}^c \mathbf{C}_{p_l} \tag{6}$$

where

$$\gamma_l^{(2)} = \sqrt{\beta_2^l \ 1/\mathbf{E}\left[\mathbf{C}_{p_l}^H \hat{d}_{p_l}^{cH} \hat{d}_{p_l}^c \mathbf{C}_{p_l}\right]} \tag{7}$$

The parameter $0 \leq \beta_2^l \leq 1$ controls the amount of power is allocated to the signal which is transmitted by the lth user in this time slot.

During the second time slot, the base station also transmits the precoded data d_k^d directly to the users using their spreading sequences as follow

$$\mathbf{x}_0^{(2)} = \gamma_0^{(2)} \sum_{k=1}^{K} d_k^d \mathbf{C}_k \quad (8)$$

where $\gamma_0^{(2)}$ is power scaling factor and is defined as

$$\gamma_0^{(2)} = \sqrt{\beta_2^0 \ \mathrm{P}/\mathbf{E}\left[\left(\sum_{k=1}^{K} d_k^d \mathbf{C}_k\right)^{\mathrm{H}} \left(\sum_{k=1}^{K} d_k^d \mathbf{C}_k\right)\right]} \quad (9)$$

The parameter $0 \leq \beta_2^0 \leq 1$ controls the amount of power that is allocated to the base station signal in the second time slot. As mentioned before the total power P without precoding is equal to K.

Here we assume that $\beta_1^0 = \beta_2^0 = \beta$ and the following relationship is between these parameters

$$\beta_2^l = 1 + (1-\beta)2P = 1 + (1-\beta)2K \quad (10)$$

By decreasing the factor β from one (i.e. decreasing the of power that is transmitted by the base station), the amount power that is transmitter by the cooperating users increases. During the second time slot, the received signal by the jth user is

$$\begin{aligned}\mathbf{r}_j^{(2)} &= h_j^0 \mathbf{x}_0^{(2)} + h_j^{q_j} \mathbf{x}_{q_j}^{(2)} + \sum_{k=1, k\neq j, k\neq q_j}^{K} h_j^k \mathbf{x}_k^{(2)} + \mathbf{n}_j^{(2)} \\ &= \gamma_0^{(2)} h_j^0 \sum_{k=1}^{K} d_k^d \mathbf{C}_k + \gamma_{q_j}^{(2)} h_j^{q_j} \gamma_{q_j}^{(2)} \hat{d}_j^c \mathbf{C}_j \\ &\quad + \sum_{k=1, k\neq j, k\neq q_j}^{K} \gamma_k^{(2)} h_j^k \hat{d}_{p_k}^c \mathbf{C}_{p_k} + \mathbf{n}_j^{(2)} \end{aligned} \quad (11)$$

where $\mathbf{n}_j^{(2)}$ is the additive white gaussian noise at the jth receiver during the second time slot with zero mean and variance σ_n^2. Note that in the following equation, we use the fact that $p_{q_j} = j$ (or $q_{p_j} = j$). In order to detect the jth user information data, the received signal in (11) is then passed through a matched filter which is matched to the spreading sequence $\mathbf{C}_j$. The output of the receiver can be expressed as

$$\mathbf{y}_j^{(2)} = \mathbf{C}_j^T \mathbf{r}_j^{(2)} = \gamma_0^{(2)} h_j^0 d_j^d + \gamma_{q_j}^{(2)} h_j^{q_j} \hat{d}_j^c + \mathbf{v}_j^{(2)} \quad (12)$$

where $\mathbf{v}_j^{(2)} = \mathbf{C}_j^T \mathbf{n}_j^{(2)}$. In the next section, we derive appropriate precoding data d_j^c and d_j^d to exploit maximum diversity.

III. Proposed Maximal Ratio Precoding Schemes

In this section, we show the design of the precoded data that are transmitted from the base station and users in two time slots. The method that is used is based on maximum ratio transmission method [4]. We try to achieve maximum diversity which is of order two in this case. In general, this diversity is proportional to the number of partners in each group, i.e., the number of users that cooperate with each other.

We assume that exact channel state information about direct links, i.e., links from base station to terminals are available at the base station. Channel state information can be extracted from uplink channel estimation in systems based on Time Division Duplex (TDD) [15], or by performing the actual channel measurements at the mobile unit and using feedback. About the inter-user channel state information, i.e., the channels between the mobile terminals, we consider two different assumptions. In the first case, we assume that this information are known at the base station and in the second case, they are known at the mobile terminals. We derive the equations for two above cases and compare the resulting cooperation schemes.

A. Scheme A: Unknown inter-user channel state information at the base station

In this case, the mobile terminals know the exact channel state information of the inter-user links. Our approach in designing the precoded data and the is achieving the maximum diversity gain. In this case, since the inter-user channel state information is available at the mobile terminals, some parts of spatial processing is performed in these terminals. In this paper, we consider decode and forward relaying strategy. The signal that is transmitted by the partner, is a spatially precoded of the estimated data.

In this scheme, the precoded data in (5) is computed as follow

$$\hat{d}_j^c = f(\mathbf{y}_{q_j}^{(1)}) = \frac{1}{h_j^{q_j}} \mathbf{y}_{q_j}^{(1)} = \gamma_0^{(1)} \frac{h_{q_j}^0}{h_j^{q_j}} d_j^c + \frac{1}{h_j^{q_j}} \mathbf{v}_{q_j}^{(1)} \quad (13)$$

Hence, the output of matched filter of the jth user in (12) can be expressed as

$$\begin{aligned}\mathbf{y}_j^{(2)} &= \gamma_0^{(2)} h_j^0 d_j^d + \gamma_{q_j}^{(2)} h_j^{q_j} \left(\gamma_0^{(1)} \frac{h_{q_j}^0}{h_j^{q_j}} d_j^c + \frac{1}{h_j^{q_j}} \mathbf{v}_{q_j}^{(1)} \right) + \mathbf{v}_j^{(2)} \\ &= \gamma_0^{(2)} h_j^0 d_j^d + \gamma_{q_j}^{(2)} \gamma_0^{(1)} h_{q_j}^0 d_j^c + \mathbf{z}_j^{(2)} \end{aligned} \quad (14)$$

where

$$\mathbf{z}_j^{(2)} = \gamma_{q_j}^{(2)} \mathbf{v}_{q_j}^{(1)} + \mathbf{v}_j^{(2)} \quad (15)$$

Based on maximum ratio transmission method, the choice of the precoded data is

$$\begin{cases} d_j^d = b_j \ h_j^{0*} / \sqrt{|h_j^0|^2 + |h_{q_j}^0|^2} \\ d_j^c = b_j \ h_{q_j}^{0*} / \sqrt{|h_j^0|^2 + |h_{q_j}^0|^2} \end{cases} \quad (16)$$

where b_j is the data of the jth user. We assume that the modulation type is binary phase shift keying (BPSK) and $b_j = \pm 1$. With the above choices the received signal is

$$\mathbf{y}_j^{(2)} = \frac{\gamma_0^{(2)} |h_j^0|^2 + \gamma_{q_j}^{(2)} \gamma_0^{(1)} |h_{q_j}^0|^2}{\sqrt{|h_j^0|^2 + |h_{q_j}^0|^2}} \ b_j + \ \mathbf{z}_j^{(2)} \quad (17)$$

where $\mathbf{z}_j^{(2)}$ was defined in (15). Ignoring the scaling factors γ, the output in (17) can be expressed as

$$\mathbf{y}_j^{(2)} = \left(\sqrt{|h_j^0|^2 + |h_{q_j}^0|^2} \right) b_j + \mathbf{z}_j^{(2)} \quad (18)$$

In the next section, we show the performance of this scheme by computer simulation. It will be observed that this scheme can achieve maximum diversity of order two.

B. Scheme B: Known inter-user channel state information at the base station

In this case, we assume that the exact inter-user channel state information is available only at the base station and hence all spatial processing can be performed at the base station. In this case, mobile users do not need to have any information about the channel sate information and in addition they do not need to perform any spatial processing. This makes the mobile terminals very simple which is important in practice. Similar to the previous case, the base station knows direct links channel state information.

In this scheme, the precoded data which is forwarded to the destination mobile terminals from the partner in (5) is

$$\hat{d}_j^c = f(\mathbf{y}_{q_j}^{(1)}) = \mathbf{y}_{q_j}^{(1)} = \gamma_0^{(1)} h_{q_j}^0 d_j^c + \mathbf{v}_{q_j}^{(1)} \quad (19)$$

Using (19), the output of matched filter in the second time slot in (12) can be expressed as

$$\begin{aligned}\mathbf{y}_j^{(2)} &= \gamma_0^{(2)} h_j^0 d_j^d + \gamma_{q_j}^{(2)} h_j^{q_j} \left(\gamma_0^{(1)} h_{q_j}^0 d_j^c + \mathbf{v}_{q_j}^{(1)}\right) + \mathbf{v}_j^{(2)} \\ &= \gamma_0^{(2)} h_j^0 d_j^d + \gamma_{q_j}^{(2)} \gamma_0^{(1)} h_j^{q_j} h_{q_j}^0 d_j^c + \mathbf{w}_j^{(2)} \end{aligned} \quad (20)$$

where

$$\mathbf{w}_j^{(2)} = \gamma_{q_j}^{(2)} h_j^{q_j} \mathbf{v}_{q_j}^{(1)} + \mathbf{v}_j^{(2)} \quad (21)$$

In this scheme, the precoded data is chosen form the data vector as follow

$$\begin{cases} d_j^d = b_j \ h_j^{0*} / \sqrt{|h_j^0|^2 + |h_{q_j}^0|^2} \\ \\ d_j^c = b_j \ h_{q_j}^{0*} / \left(h_j^{q_j} \sqrt{|h_j^0|^2 + |h_{q_j}^0|^2} \right) \end{cases} \quad (22)$$

where b_j is the data of the jth user. With this choices, the received signal in (20) is

$$\mathbf{y}_j^{(2)} = \frac{\gamma_0^{(2)} |h_j^0|^2 + \gamma_{q_j}^{(2)} \gamma_0^{(1)} |h_{q_j}^0|^2}{\sqrt{|h_j^0|^2 + |h_{q_j}^0|^2}} \ b_j + \ \mathbf{w}_j^{(2)} \quad (23)$$

and ignoring the scaling factors γ

$$\mathbf{y}_j^{(2)} = \left(\sqrt{|h_j^0|^2 + |h_{q_j}^0|^2} \right) b_j + \mathbf{w}_j^{(2)} \quad (24)$$

In the next section, the performance of this schemes is shown and compared with the performance of the scheme A.

IV. Simulation Results

In this section, simulation results for bit error rate (BER) performance evaluation of the proposed schemes are shown. In our simulations, we consider a DS-CDMA system with three synchronous users that cooperate with each other according to the scenario that was shown in Fig.1. The spreading sequences are normalized Walsh-Hadamard orthogonal codes with length $N = 12$. The fading channels are all flat and the channel gains are modelled by complex Gaussian random variables with variance 0.5 per dimension.

Figure 2 shows the BER of two proposed schemes A and B. In our simulations, we assumed that the signal to noise ratio (SNR) in all direct and inter-user links are the same. It is observed that both proposed schemes A and B can achieve maximum diversity order of two and they also outperform the case in which no cooperation is used in the system. The dashed line shows the slope of curve for diversity order of two. It is also observed in this figure that the proposed scheme A outperforms the proposed scheme B. That is, having inter-user channel state information at the mobile users and therefore performing some of precoding process at these terminals can enhance the performance. Although, this increases the complexity of the mobile terminals.

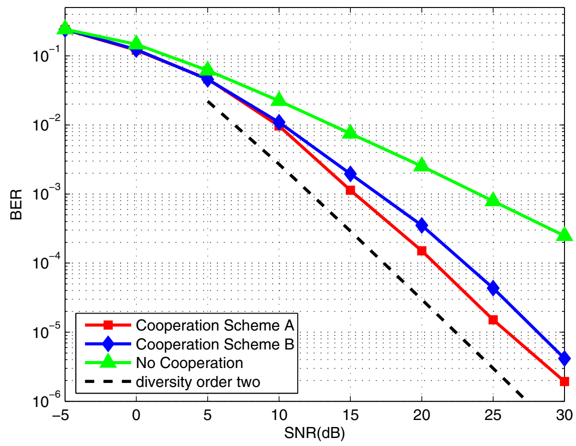

Fig. 2. Performance of the proposed cooperation schemes.

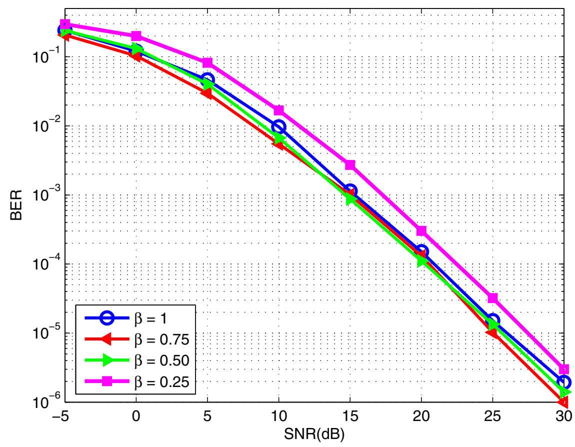

Fig. 3. Performance of the proposed cooperation scheme A in different values of the parameter β.

Figure 3 shows the performance of the scheme A, when the cooperation coefficient β is changing. As this parameter decreases from the value of one, more power is assigned to the relay terminals and the transmit power on direct links (the transmit power of the base station) decreases. That is, in this case, more power is assigned to cooperation. We can observe that this can change the performance of the proposed scheme and in small value of β the performance will degrade. This means, although cooperation can improve the performance of the system, however if the a large amount of the signal transmission is allocated to the relay user, the reliability of the direct links decreases and cooperation can be harmful for the

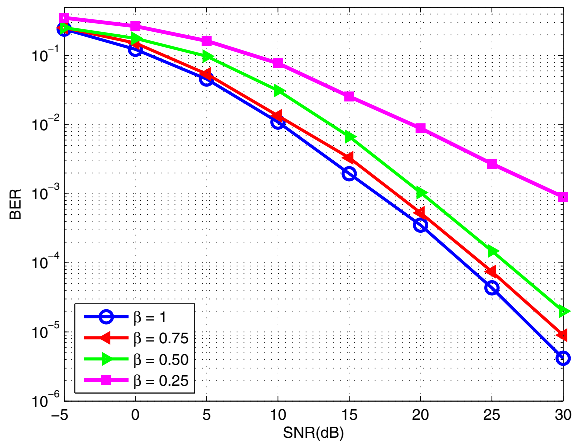

Fig. 4. Performance of the proposed cooperation scheme B in different values of the parameter β.

performance of the system. In Fig. 4 the same simulation results for scheme B is shown. It is seen that the scheme B is more sensitive to the change in the parameter β. That is, the performance degrades very faster when the amount of power that is allocated to cooperation is increased.

V. Conclusions

In this paper, cooperation in downlink of cellular DS-CDMA systems is considered. We proposed two linear precoding schemes for two cases of known and unknown inter-user channel state information at the mobile terminals. We derived the appropriate precoding methods and showed that the proposed precoding schemes can achieve maximum diversity gain of two. We also showed that cooperation can improve the performance compared to the case that no cooperation is used in the system. We also evaluated the effect of changing in cooperation ratio (i.e. the dividing power between the base station and cooperated mobile terminals) on the performance of the proposed schemes.

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