On Downlink Space Division Multiplexing in Partial Cooperation Multiple Access Point Systems

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Abstract

It is well-known that multiple input multiple output (MIMO) systems increase the channel capacity so they are very attractive for future high data rate wireless access systems. To further increase the channel capacity possible with MIMO techniques, more antenna branches are required in both of the access point (AP) and the mobile station (MS). However, because of the non-uniform multipath distribution seen in actual environments, the channel capacity improvement may saturate against the number of antenna branches. To overcome these problems, the distributed wireless communication system which has multiple APs and an access controller (AC) has been proposed. In this paper, we consider the partial cooperation system that multiple APs are synchronized in terms of time but not in terms of phase. The AC is used to determine both the number of spatial channels at each AP and the transmission modes in the spatial channels. This system allows the transmission data rate to increase by installing more APs although frequency synchronization is not required among APs. Its effectiveness is clarified by computer simulations in Rayleigh and Ricean fading environments.

1. INTRODUCTION

The demand for higher data wireless communication systems is growing as wireless systems are becoming more popular. Multiple-input multiple-output (MIMO) techniques have been developed for such high speed wireless access systems because they make the channel capacity proportional to the number of antenna branches in rich multi-path environments [1][2]. With channel state information (CSI) at the transmitter, a higher channel capacity can be expected by utilizing both eigenvector transmission [1][3] and water pouring strategies [4]. We have reported the experimental results of eigenvector beamforming in the downlink in an indoor environment using eight transmit antenna branches [5]. However, it is unlikely that the number of antenna branches can be increased monotonically for future wireless systems because of the difficulty of hardware implementation.

In real wireless communication systems, the practical number of antenna branches at a mobile station (MS) is limited because of the requirement for MS compactness. The access point (AP), on the other hand, can support a larger number of antenna branches. Such an asymmetrical MIMO channel makes the channel capacity saturate against the number of antenna branches at the AP. Furthermore, in actual environments, the MIMO effect decreases since the number of effective spatial channels becomes less than that in the i.i.d. channel [6].

To overcome these problems, the downlink transmission using multiple APs has been proposed to generate a virtual array antenna [7][8][9][10]. In this system, the multiple APs artificially generate rich multipath environments and the MIMO effect is expected even in the LOS scenario. In this configuration, there are three approaches to implement the multiple AP technique; one is independent control, the next is full cooperation, and the last is partial cooperation.

In the independent control approach, no cooperation is established among the multiple APs so that the system can be regarded as the opposite systems of a multi-user MIMO system. In this system, transmission data are distributed among multiple APs equally and the transmission performance is strongly degraded when there is a big difference among the received signal powers of the APs. Although full cooperation, in which multiple APs are synchronized in terms of time and phase, has the potential to achieve the ideal channel capacity, it suffers from the carrier frequency offset among the multiple APs in the downlink. Thus, full cooperation is not realistic because the synchronization error degrades the transmission quality significantly. Therefore, this paper focuses on the partial cooperation approach to obtain the MIMO effect while achieving robustness against the frequency offset among the multiple APs.

This paper proposes a multiple AP system and a new beamforming method, which can exploit the spatial channels effectively while reducing the calculation complexity at an MS. The proposed multiple AP system requires the installation of an access controller (AC) which determines the number of spatial channels using CSI between each AP and an MS because transmission data must be distributed to each AP appropriately.

This paper is organized as follows. Section 2 introduces the proposed configuration of the multiple AP system and the beamforming method for linear decoding algorithms. Section 3 gives the mathematical formulation and describes the achievable bit rate as a measure of the transmission performance. In Section 4, the effectiveness of the proposed system is evaluated by a computer simulation. Finally, this paper is summarized in Section 5.

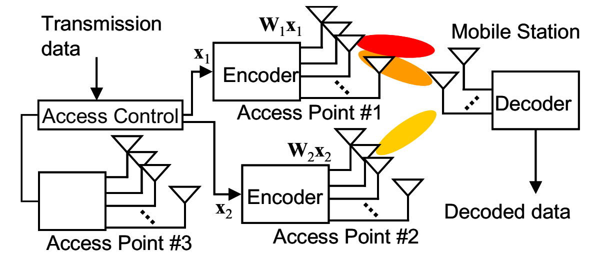

Fig. 1. Mutiple AP system configuration for downlink transmission

2. MULTIPLE ACCESS POINTS SYSTEM MODEL

A. Communication Flow of Multiple AP System

The system configuration of the multiple AP system is shown in Fig. 1 where two APs are transmitting to one MS; the AC enables the use of the same frequency channel among multiple APs. The i-th AP has $M_t(i)$ antenna branches, the MS has M_r antenna branches and the number of APs is M_a. The i-th AP has the CSI between the i-th AP and the MS by receiving the preambles which are known at both APs and an MS or receiving the feedback information that includes the CSI. Each AP estimates the quality of downlink transmission and lets AC know the estimated quality of data streams. AC then determines the number of data-streams and the coding scheme for each AP and distributes the transmission data to the APs. The APs transmit different data streams using their respective transmission weights. With this system configuration, we can increase the transmission data rate and/or the high data rate area by adding new APs without altering any existing AP or using any additional frequency band.

B. Perfect Cooperation among APs

When the APs cooperate perfectly, the received signal at the MS, $\mathbf{y} \in \mathbb{C}^{Mr\times 1}$, can be written as

$$\mathbf{y} = \left(\mathbf{H}_1 \quad \mathbf{H}_2 \quad \cdots \quad \mathbf{H}_{Ma}\right)\mathbf{WPx} + \mathbf{n} = \mathbf{HWPx} + \mathbf{n}\,, \quad (1)$$

where $\mathbf{W} \in \mathbb{C}^{Mt\times L}$ is the full transmission weight matrix, L is the number of spatial streams, $\mathbf{x} \in \mathbb{C}^{L\times 1}$ is the transmission signal, $\mathbf{P} \in \mathbb{C}^{L\times L}$ is the diagonal matrix (the diagonal components of $\mathbf{P}$ are power allocation factors which are expressed as $p_1, p_2, \ldots, p_L$), and $\mathbf{n} \in \mathbb{C}^{Mr\times 1}$ is additive white complex Gaussian noise, and the variance of the elements of $\mathbf{n}_i$ is σ_N^2. $\mathbf{H}_i \in \mathbb{C}^{Mr\times Mt(i)}$ expresses the channel matrix between the i-th AP and the MS and $\mathbf{H} \in \mathbb{C}^{Mr\times(\Sigma Mt(i))}$ is the total channel matrix. If the information of the total channel matrix, $\mathbf{H}$, is available at the AC, the maximum capacity is obtained by using the eigenvector transmission and water-pouring strategies. In the eigenvector transmission, the transmission weights are calculated as the eigenvectors of $\mathbf{H}^H\mathbf{H}$ and the power allocation factors are determined using the eigenvalues of $\mathbf{H}^H\mathbf{H}$ by water pouring strategies. However, the phase offset among the APs cannot be compensated since each AP has its own oscillator and they work independently. Thus, equation 1 can be rewritten as

$$\mathbf{y} = \mathbf{HQWPx} + \mathbf{n} \quad (2)$$

where

$$\mathbf{Q} = \begin{pmatrix} \mathbf{Q}_1 & 0 & \cdots & 0 \\ 0 & \mathbf{Q}_2 & & \vdots \\ \vdots & & \ddots & 0 \\ 0 & \cdots & 0 & \mathbf{Q}_{Ma} \end{pmatrix}, \quad \mathbf{Q}_i = \begin{pmatrix} e^{j\cdot\theta_i} & 0 & \cdots & 0 \\ 0 & e^{j\cdot\theta_i} & 0 & \vdots \\ \vdots & 0 & \ddots & 0 \\ 0 & 0 & \cdots & e^{j\cdot\theta_i} \end{pmatrix},$$

$\mathbf{Q} \in \mathbb{C}^{(\Sigma Mt(i))\times(\Sigma Mt(i))}$ is the total phase shift matrix, $\mathbf{Q}_i \in \mathbb{C}^{Mt(i)\times Mt(i)}$ is the phase shift matrix at AP #i and θ_i are the phase shift at the i-th AP. Because of the relationship $\theta_i \neq \theta_j$ ($i \neq j$), the total phase shift matrix frustrates the ideal transmission weight vector and the transmission quality is significantly degraded.

C. Partial Cooperation among APs in the proposed systems

Thus, we focus on the partial cooperation approach. In this approach, each AP has its own data streams for transmission. Thus, APs are synchronized in terms of transmission timing and the signal received at the MS is expressed as

$$\mathbf{y} = \mathbf{H}\begin{pmatrix} \mathbf{W}_1\mathbf{P}_1 & 0 & \cdots & 0 \\ 0 & \mathbf{W}_2\mathbf{P}_2 & & \vdots \\ \vdots & & \ddots & 0 \\ 0 & \cdots & 0 & \mathbf{W}_{Ma}\mathbf{P}_{Ma1} \end{pmatrix}\begin{pmatrix} \mathbf{x}_1 \\ \mathbf{x}_2 \\ \vdots \\ \mathbf{x}_{Ma} \end{pmatrix} + \mathbf{n}, \quad (3)$$

where $\mathbf{W}_i \in \mathbb{C}^{Mt\times L(i)}$, $L(i)$, and $\mathbf{x}_i \in \mathbb{C}^{L(i)\times 1}$ are the transmission weight matrix, the number of spatial streams, transmission signals, respectively. $\mathbf{P}_i \in \mathbb{C}^{L(i)\times L(i)}$ is the power allocation matrix and a diagonal matrix of which diagonal elements are expressed as $p_{i,1}, p_{i,2}, \ldots, p_{i,L(i)}$. is the power allocation matrix at the i-th AP, respectively. In this case, the full transmission weight matrix, $\mathbf{W}$, cannot be used because APs are not synchronized in terms of phase. Thus, i-th AP calculates its own transmission weight, $\mathbf{W}_i$ using $\mathbf{H}_i$.

Taking account of the phase offset error, Equation 2 can be rewritten as follows.

$$\mathbf{y} = \mathbf{H}\begin{pmatrix} \mathbf{Q}_1\mathbf{W}_1\mathbf{P}_1 & 0 & \cdots & 0 \\ 0 & \mathbf{Q}_2\mathbf{W}_2\mathbf{P}_2 & & \vdots \\ \vdots & & \ddots & 0 \\ 0 & \cdots & 0 & \mathbf{Q}_{Ma}\mathbf{W}_{Ma}\mathbf{P}_{Ma1} \end{pmatrix}\begin{pmatrix} \mathbf{x}_1 \\ \mathbf{x}_2 \\ \vdots \\ \mathbf{x}_{Ma} \end{pmatrix} + \mathbf{n}. \quad (4)$$

Here the phase shift matrix doesn't affect the transmission weight. Thus, the phase shift matrix is omitted. In the following, two transmission weight calculation methods are explained. One is a simple extension from that of the single AP MIMO systems and the other one is a new beamforming method that reduces the calculation complexity at the MS.

C-1. Independent Eigenvector (IE) beamforming method

First, we consider the eigenvector transmission at each AP. This independent eigenvector transmission method (IE method) maximizes the mutual information in terms of the connection between a single AP and a single MS. The transmission weight, $\mathbf{W}_i^{IE}$, is calculated as the eigenvectors of

$\mathbf{H}_i^H\mathbf{H}_i$ and the power allocation matrix, $\mathbf{P}_i$, is also determined by water pouring strategies using the eigenvalues of $\mathbf{H}_i^H\mathbf{H}_i$. Thus, Equation 3 is rewritten as follows.

$$\begin{aligned}\mathbf{y} &= \mathbf{H}\begin{pmatrix}\mathbf{W}_1^{IE}\mathbf{P}_1 & \mathbf{0}\\ \mathbf{0} & \mathbf{W}_2^{IE}\mathbf{P}_2\end{pmatrix}\begin{pmatrix}\mathbf{x}_1\\ \mathbf{x}_2\end{pmatrix}+\mathbf{n}\\ &= \begin{pmatrix}\mathbf{U}_1\mathbf{D}_1\mathbf{P}_1 & \mathbf{U}_2\mathbf{D}_2\mathbf{P}_2 & \cdots & \mathbf{U}_{Ma}\mathbf{D}_{Ma}\mathbf{P}_{Ma}\end{pmatrix}\mathbf{x}+\mathbf{n}\\ &= \mathbf{H}_w\mathbf{x}+\mathbf{n},\end{aligned} \tag{5}$$

where $\mathbf{H}_w \in \mathbb{C}^{Mr\times(\Sigma L(i))}$ is the total channel matrix, $\mathbf{U}_i \in \mathbb{C}^{Mr\times(L(i))}$ is the left singular matrix of $\mathbf{H}_i$, $\mathbf{D}_i \in \mathbb{C}^{(L(i))\times Mt}$ is the diagonal matrix, the diagonal components of $\mathbf{D}_i$ are the square root of the eigenvalues, and $\mathbf{x} \in \mathbb{C}^{(\Sigma L(i))\times 1}$ is $(\mathbf{x}_1^T, \mathbf{x}_2^T, \ldots, \mathbf{x}_{Ma}^T)^T$. Because the column vectors of $\mathbf{H}_w$ are not orthogonal to each other, the channels of data streams have a spatial vector correlation. Since the simple linear decoding algorithm such as zero forcing (ZF) or minimum mean square error (MMSE) [11] cannot remove the interference caused by this spatial vector correlation perfectly, the transmission quality is degraded. Note that the maximum likelihood detection (MLD) [11] approach is robust for the spatial vector correlation at the MS. However, the calculation complexity at the MS becomes high. The new transmission beamforming method, introduced below, enables simple linear decoding at the MS by suppressing the spatial vector correlation.

C-2. Beamforming method for linear decoding (B-LD method)

Here, to simplify the discussion, the number of APs is assumed to be two ($M_a = 2$). The new transmission beamforming method requires that the APs know the uplink transmission weight at the MS. In this paper, time domain duplex (TDD) systems are considered to exploit channel reciprocity for channel estimation. It is also assumed that the MS transmits signals using eigenvector transmission to the nearest AP (AP #1) in the uplink. During the uplink transmission, AP #2 estimates the uplink transmission weight, which is equal to the reception weight at the MS due to channel reciprocity. Alternatively, the AC can let AP #2 know the reception weight because AP #1 knows $\mathbf{H}_1$ and can give this information to the AC.

At first, we describe the case in which the number of data streams transmitted by AP #1 is $L(1)$ ($1 \le L(1) < M_r$). AP #2 estimates the provisional reception weight, $\mathbf{W}_{u,1} \in \mathbb{C}^{Mr\times L(1)}$, which is selected as $L(1)$ column vectors of the reception weight and then calculates the null-space reception weight, $\mathbf{W}'_{u,1} \in \mathbb{C}^{Mr\times L'(1)}$, which is orthogonal to $\mathbf{W}_{u,1}$ and $L'(1) = M_r - L(1)$. Thus, $\mathbf{W}_{u,1}^H \cdot \mathbf{W}'_{u,1} = \mathbf{0}$. After that, AP #2 estimates the orthogonal space channel matrix, $\mathbf{H}_2'$, as follows.

$$\mathbf{H}_2' = \mathbf{W}_{u,1}^T\mathbf{H}_2 \tag{6}$$

Then, the transmission weight, $\mathbf{W}_2^{\text{B-LD}}$, is calculated as the eigenvectors of $\mathbf{H}'^H_2\mathbf{H}'_2$. The power allocation matrix, $\mathbf{P}_2$, and the number of data streams, $L(2)$, at AP #2 are calculated by water pouring strategies using the corresponding eigenvalues of $\mathbf{H}'^H_2\mathbf{H}'_2$. Therefore, AP #1 transmits $L(1)$ data streams using eigenvector transmission weight $\mathbf{W}_1^{\text{B-LD}} = \mathbf{W}_1^{\text{IE}} \in \mathbb{C}^{Mt(1)\times L(1)}$ and AP #2 transmits signals using new transmission weight, $\mathbf{W}_2^{\text{B-LD}} \in \mathbb{C}^{Mt(2)\times L(2)}$. In this method, Equation 3 is rewritten as follows.

$$\begin{aligned}\mathbf{y} &= \mathbf{H}\begin{pmatrix}\mathbf{W}_1^{B-LD}\mathbf{P}_1 & 0\\ 0 & \mathbf{W}_2^{B-LD}\mathbf{P}_2\end{pmatrix}\begin{pmatrix}\mathbf{x}_1\\ \mathbf{x}_2\end{pmatrix}+\mathbf{n}\\ &= \begin{pmatrix}\mathbf{U}_1\mathbf{D}_1\mathbf{P}_1 & \mathbf{U}_2'\mathbf{D}_2'\mathbf{P}_2\end{pmatrix}\mathbf{x}+\mathbf{n}\\ &= \mathbf{H}_n\mathbf{x}+\mathbf{n},\end{aligned} \tag{7}$$

where $\mathbf{H}_n \in \mathbb{C}^{Mr\times(L(1)+L(2))}$ is the total channel matrix in the new transmission method, $\mathbf{U}'_2$ is the left singular matrix of $\mathbf{H}'_2$, and the squared values of diagonal elements of $\mathbf{D}'_2$ are the eigenvalues of $\mathbf{H}'^H_2\mathbf{H}'_2$. The column vectors of $\mathbf{H}_n$ are orthogonal to each other. Therefore, nearly maximum performance can be obtained with simple decoding algorithms, e.g. ZF or MMSE.

C-3. Access control

The AC determines how many data streams should be assigned to each AP from the CSI between the APs and the MS. In the IE method, the AC needs to consider the decoding algorithms at the MS because the transmission quality is determined assuming the use of ZF and MLD as the decoding algorithms. The AC estimates the transmission qualities considering all combinations of data streams for the APs. In this case, the computational load at the AC can be high because the AP needs to estimate the transmission qualities from the total channel matrix. In the B-LD method, the number of data streams can be judged by using eigenvalues of the channel matrices and the orthogonal space channel matrices. Thus, the B-LD method reduces the calculation load at the AC.

3. Mathematical Formulation

D. Channel Model

The channel matrix between i-th AP and the MS is expressed as

$$\mathbf{H}_i = \sqrt{\frac{K}{K+1}}\mathbf{H}_{i,LOS} + \sqrt{\frac{1}{K+1}}\mathbf{H}_{i,NLOS}, \tag{8}$$

where $\mathbf{H}_{i,\text{LOS}}$ is a rank one matrix corresponding to one line-of-sight (LOS) path, $\mathbf{H}_{i,\text{NLOS}}$ is a complex Gaussian variable with zero mean (random i.i.d.), and K is the Rice factor, which characterizes a Ricean distribution [11]. When K = - ∞ [dB], this model yields a Rayleigh distribution. Without loss of generality, $\|\mathbf{H}_{i,\text{NLOS}}\|_F^2 = \|\mathbf{H}_{i,\text{LOS}}\|_F^2 = \|\mathbf{H}_i\|_F^2$, where the expectation of $\|\mathbf{H}_i\|_F^2$ is expressed as $(M_t(1)+M_t(2))\times M_r\times\Gamma_i$. We assume that σ_N^2, $\|\mathbf{P}_1\|_F^2$, $\|\mathbf{P}_2\|_F^2$, $\|\mathbf{W}_1\|_F^2$, and $\|\mathbf{W}_2\|_F^2$ are one and $\|\mathbf{x}_1\|_F^2$ and $\|\mathbf{x}_2\|_F^2$ are $L(1)$ and $L(2)$, respectively. Thus, Γ_i expresses the expectation of the received SNR between i-th AP and the MS in SISO channel.

E. Achievable bit rate

We define here the achievable bit rate, which expresses the maximum number of information bits that can be carried by a channel. The achievable bit rate of the IE method in the proposed systems is calculated by using $\mathbf{H}_w$ in Eq. 5; MLD and ZF are used for decoding. When MLD can be mounted at the MS, the maximum performance can be attained, but the complexity of its operation is too high to implement. The achievable bit rate with MLD, $C_{\text{IE-MLD}}$, is expressed as

$$C_{IE-MLD} = \sum_{j}^{L(1)+L(2)} \log_2\left(1+\lambda_{w,j}\right). \tag{9}$$

where $\lambda_{w,j}$ is the eigenvalue of $\mathbf{H}_w^H\mathbf{H}_w$. Compared to MLD, ZF is a very simple decoding algorithm. The transmission signal at Eq. 5 can be estimated as

$$\begin{aligned}\mathbf{x}' &= \mathbf{H}_w^{-1}\mathbf{y} \\ &= \mathbf{x} + \mathbf{H}_w^{-1}\mathbf{n}.\end{aligned} \tag{10}$$

Thus, the transmission quality depends on the inverse matrix of $\mathbf{H}_w$. The achievable bit rate with ZF algorithm, $C_{\text{IE-ZF}}$, is expressed as follows.

$$\begin{aligned}C_{IE-ZF} &= \sum_{j}^{L(1)+L(2)} \log_2\left(1+\gamma_{w,j}\right), \\ \gamma_{w,j} &= \frac{1}{\left\|[\mathbf{H}_w^{-1}]_j\right\|_F^2}\end{aligned} \tag{11}$$

where $[\mathbf{A}]_j$ denotes the j-th row vector of matrix $\mathbf{A}$. $C_{\text{IE-ZF}}$ is less than $C_{\text{IE-MLD}}$ because of the noise enhancement of ZF algorithm. In this paper, we assume that the AC calculates the achievable channel capacities in all combinations of the data streams for AP #1 and #2 and selects the combination that maximizes the achievable bit rate.

In the B-LD method, the achievable bit rate is maximized by even simple decoding algorithm. When using ZF algorithm, the transmission signal can be expressed as

$$\begin{aligned}\mathbf{x}' &= \mathbf{H}_n^{-1}\mathbf{y} \\ &= \mathbf{x} + \begin{pmatrix}\mathbf{D}_1\mathbf{P}_1 & \mathbf{0} \\ \mathbf{0} & \mathbf{D}'_2\mathbf{P}'_2\end{pmatrix}^{-1}\mathbf{n}.\end{aligned} \tag{12}$$

The achievable bit rate, $C_{\text{B-LD}}$, can be written as

$$\begin{aligned}C_{B-LD} &= \sum_{i}^{L(1)} \log_2\left(1+p_{1,i}^2\lambda_{1,i}\right) + \sum_{i}^{L(2)} \log_2\left(1+p_{2,i}^2\lambda'_{2,i}\right) \\ &= \sum_{i}^{L(1)+L(2)} \log_2\left(1+\lambda_{n,i}\right).\end{aligned} \tag{13}$$

where $\lambda_{1,i}$, $\lambda'_{2,i}$, and $\lambda_{w,i}$ are the eigenvalues of $\mathbf{H}_1^H\mathbf{H}_1$, $\mathbf{H}'^H_2\mathbf{H}'_2$, and $\mathbf{H}_n^H\mathbf{H}_n$, respectively. Equation 13 means that the achievable bit rate with ZF algorithm is equal to that with MLD. Therefore, simple linear decoding algorithms, e.q. ZF algorithm, can be applied at the MS. In the B-LD method, i-th AP can calculate the transmission quality as well as the transmission weight using $\mathbf{H}_i$ or $\mathbf{H}'_i$. Thus, the calculation load can be distributed among the AC and APs while the AC in the IE method needs to calculate the transmission quality using all the channel matrices, $\mathbf{H}_1$ and $\mathbf{H}_2$.

For comparison, the achievable bit rate in the single AP system is calculated as follows.

$$C_S = \sum_{i}^{L(1)} \log_2\left(1+p_{1,i}\lambda_{1,i}\right). \tag{14}$$

where $\lambda_{1,j}$ is the eigenvalue of $\mathbf{H}_1^H\mathbf{H}_1$ and $p_{1,i}$ is the power allocation value of the i-th data stream. Note that the total transmission power in the single AP system is half that in the multiple AP system. Equation 14 indicates the maximum achievable bit rate when the maximum transmission power at each AP is constrained. Although such a power contraction at AP is appropriate, the total transmission power is not fair. Thus, the achievable bit rate in the single AP under the equal transmission power is defined as

$$C'_S = \sum_{i}^{L(1)} \log_2\left(1+2p_{1,i}\lambda_{1,i}\right). \tag{15}$$

Hereinafter, the both achievable bit rates in single AP system, C_s and C'_s, are calculated.

4. Evaluation of Performance of Proposed System

We assumed that the environment was quasi-static and the numbers of APs, transmit antenna branches, receive antenna branches were two (M_a = 2), eight ($M_t(1) = M_t(2) = 4$), and four (M_r= 2), respectively. Computer simulations were performed 20000 times and the cumulative probability of the achievable bit rate was obtained.

Figure 2 shows the cumulative probability of the achievable bit rate when $\Gamma_1 = \Gamma_2 = 5$ [dB] and $K = -\infty$, 6 dB. When K = -∞ dB, the median achievable bit rate of $C_{\text{B-LD}}$ is 2.5 bit/sec/Hz larger than that of C_s and 1.1 bit/sec/Hz larger than that of C'_s. The achievable bit rate in the single AP system under the equal power assumption approaches that of the multiple AP system using ZF algorithm. When K = 6 dB, the median achievable bit rate of $C_{\text{B-LD}}$ is 3.5 bit/sec/Hz larger than that of C_s and 2.2 bit/sec/Hz larger than that of C'_s. Furthermore, the median achievable bit rate in the single AP system under the equal power assumption is less than that of the multiple AP system using ZF algorithm. In Ricean fading, the improvement of the multiple AP system becomes large. In this case, the single AP system has difficulty to exploit the spatial multiplexing effect because the second and subsequence eigenvalues of a channel matrix of a single AP decrease. Therefore, multiple AP system can utilize the spatial channel more effectively than single AP. You can see the distribution of the achievable bit rate of the multiple AP system with ZF algorithm is distorted when K = 6 dB. This is because the IE method can select that $L(1) = 0$ or $L(2) = 0$. At this time, the achievable bit rate of multiple AP system with ZF algorithm is equal to that of the normal single AP system. Figure 3 shows the cumulative probability of the achievable bit rate when $\Gamma_1 = \Gamma_2 = 20$ dB. When K = - ∞ dB, the median achievable bit rate of $C_{\text{B-LD}}$ is 3.3 bit/sec/Hz larger than that of C_s and 1.3 bit/sec/Hz larger than that of C'_s. When K = 6 dB, the median achievable bit rate of $C_{\text{B-LD}}$ is 4.9 bit/sec/Hz larger than that of C_s and 2.9 bit/sec/Hz larger than that of C'_s. Compared to the results in $\Gamma_1 = \Gamma_2 = 5$ dB, the improvement slightly increases and the difference between the achievable bit rates, $C_{\text{B-LD}}$ and $C_{\text{IE-MLD}}$, becomes large. Figure 2 and 3 clarifies the B-LD method achieves the best performance.

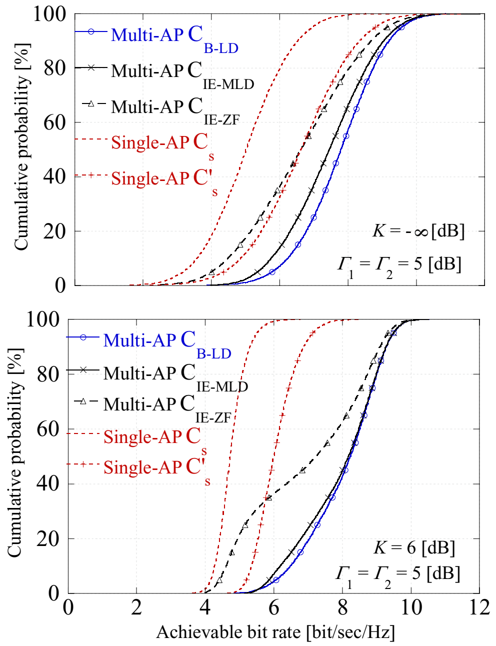

Fig. 2. Cumulative probability of achievable bit rate when $\Gamma_1 = \Gamma_2 = 5$ [dB].

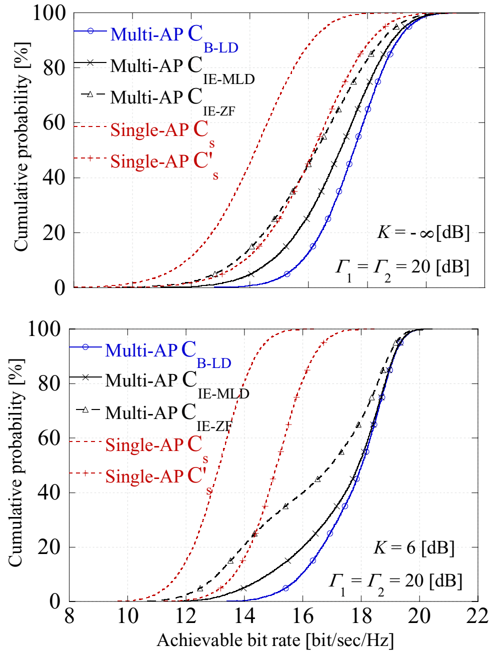

Fig. 3. Cumulative probability of achievable bit rate when $\Gamma_1 = \Gamma_2 = 20$ [dB].

5. Conclusion

This paper clarified the effectiveness of the multiple AP system where APs are synchronized in terms of time. In the multiple AP system, the AC controls the number of spatial channels at each AP appropriately. Simulation results showed that the multiple AP system improves the achievable bit rate in both the Rayleigh fading scenario and the Ricean fading scenario. Moreover, various beamforming methods for the partial cooperation multiple AP system were evaluated by a computer simulation. The results confirmed the B-LD method attained the highest achievable bit rate using a simple decoding algorithm at the MS.

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