패킷 기반 무선 시스템에서 다중 사용자 이득과 다중화 이득 획득을 위한 다중 직교빔 전송 기법

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Orthogonal Multi-beam Techniques for Multi-user Diversity and Multiplexing Gain in Packet-based Wireless Systems

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요 약

본 논문에서는 패킷 기반 무선 전송 시스템에서 다중 사용자 이득과 다중화 이득을 동시에 얻을 수 있는 직교 다중빔 전송 기법을 제안한다. 기존의 직교 다중빔 전송 기법에서는 채널 환경에 상관없이 항상 송신 안테나 개수만큼의 빔을 생성하였다. 하지만 이 경우 사용자 수가 적은 환경에서 다른 사용자로부터의 간섭 신호 영향으로 인해 시스템 성능이 저하되는 문제점이 발생한다. 본 논문에서는 이러한 문제점을 해결하기 위해 채널 상황에 따라 동적으로 빔의 개수를 조절하는 전송 기법에 대해 제안한다. 제안 기법은 채널의 상황에 따라 빔의 개수를 유동적으로 조절함으로써 사용자 수가 적은 환경에서도 높은 성능을 보장할 수 있다. 시뮬레이션 결과를 통해 기존 다중 직교 빔에 비해 성능 향상이 있음을 확인하였다.

Key Words : Beamforming, MIMO, Multi-user diversity, Multiplexing, Scheduling

ABSTRACT

In this paper, we consider the use of orthogonal multiple beams (OMBs) to simultaneously achieve multi-user diversity and multiplexing gain in a packet-based wireless system. Previous OMB scheme considers the use of a fixed number of multiple beams equal to the number of transmit antennas. However, unless the number of active users is sufficiently large, the use of a fixed number of multiple beams may not provide desired performance due to the interference signal transmitted through other beams, being even worse than the use of a single beam. To alleviate this problem, we consider the adjustment of the number of beams in use to maximize the spectral efficiency according to the operating condition. Simulation results show the validity of the proposed scheme.

Ⅰ. Introduction

Next generation communication systems should be able to provide high rate multimedia services to users in mobile, nomadic and fixed wireless environments in a seamless manner. In recent years, the capacity of wireless systems has significantly been increased with the use of multiple antennas for transmission and reception, so called multi-input multi-output (MIMO) and the use of

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opportunistic scheduling. When the channel gains between transmit and receive antennas are independent and identically distributed (i.i.d), the channel capacity increases in linear proportion to the minimum number of transmit and receive antennas[1][2]. The opportunistic scheduling can increase the spectral efficiency by exploiting multi-user diversity (MUD)[3][4]. The exploitation of MUD relies on the assumption that users in a wireless multi-user system experience independent channel condition. In such environments, the downlink throughput of a multi-user wireless system can be maximized by scheduling users in the most favorable channel condition at each slot time [3]. Allowing users in the best condition to utilize the radio resource, it can achieve a system capacity much larger than that in additive white Gaussian noise (AWGN) channel with the same average signal-to-noise power ratio (SNR).

Recently, there have been a number of researches on the MIMO techniques in multi-user environments, so called multi-user MIMO[5]-[9]. It has been reported that dirty paper coding (DPC) is a capacity achieving strategy in multi-user MIMO channels[5]-[7]. However, the DPC is too much computationally intensive and requires full channel state information (CSI) at the transmitter, making it difficult to be employed. Recently, the use of orthogonal multiple beams (OMB) has been proposed to improve the performance by generating orthogonal beams at the transmitter without significant increase of computational complexity[5]. However, it may suffer from interference through other beams. To alleviate this problem, a new scheme, called multi-user diversity and multiplexing (MUDAM), generates multiple beams in a sequential manner to minimize the interference among scheduled users[8]. However, although the MUDAM can outperform the OMB by reducing the interference at a certain level, it may be susceptible to the user mobility since it takes longer time to generate multiple beams than the OMB. As a consequence, it may work poorer than the OMB in high mobility environment.

In this paper, we consider the improvement of the OMB by adjusting the number of orthogonal multiple beams according to the operating condition. By adjusting the number of beams, the proposed scheme reduces the performance loss due to the interference, increasing the spectral efficiency. As a result, the proposed scheme can provide better performance than conventional OMB regardless of operation environment. In addition, the proposed scheme can noticeably improve the system throughput in mobile environment with the use of partial CSI (i.e., the SNR for each beam).

The remainder of this paper is organized as follows. Section II presents a signal model considered in this paper and Section III briefly discusses previous multi-beam schemes. Section IV describes a modified orthogonal multi-beam (MOMB) scheme that reduces the interference among selected users. Section V discusses computer simulation results for the verification of the performance of the MOMB. Finally, Section VI summarizes conclusions.

Ⅱ. System model

Consider the downlink of a cellular system, where base stations (BSs) are equipped with M transmit antennas and each of K users has a single receive antenna. We assume that all the users have the same average SNR $\overline{\gamma_0}$ and experience independent channel characteristics with fixed transmission power P at all times. We also assume that each user can estimate the CSI by making the use of a common pilot signal and the BS can get the CSI from users through a feedback signaling channel in the uplink. In what follows, we use boldfaces to denote vectors and matrices, $\boldsymbol{A}^T$ and $\boldsymbol{A}^*$ denote the transpose and conjugate transpose or Hermitian of $\boldsymbol{A}$, respectively. The notation $\|\boldsymbol{x}\|$ denotes the Frobenius norm of vector $\boldsymbol{x}$.

Let $\boldsymbol{x}$ be an $(M\times 1)$-dimensional transmit signal vector from the BS. Then the received signal y_k of user k can be represented as

$$y_k = h_k^* x + n_k \tag{1}$$

where h_k denotes the $(M \times 1)$ channel vector of user $k \in \{1,2,...,K\}$, whose elements are zero mean complex Gaussian random variables with unit variance, and n_k is zero mean complex circular-symmetric additive white Gaussian noise (AWGN).

When the signal is transmitted through L beams, the transmit signal x can be represented as

$$x = \sum_{l=1}^{L} w_l s_l \tag{2}$$

where s_l denotes the data symbol transmitted through the l-the beam w_l. We assume that the Frobenius norm $\|w_l\|$ of each beam is equal to one and the average power of each data symbol is set to P/L to preserve the total transmission power P.

Ⅲ. Previous Multi-beam Schemes

3.1 Orthogonal Multi-beam (OMB)

The amount of MUD gain depends on the rate and dynamic range of channel fluctuation. The MUD gain may not significantly contribute to the improvement of capacity unless the channel fluctuation is large. This problem can be alleviated by utilizing random beams, known as opportunistic beamforming[4]. The opportunistic beamforming technique can be extended to multi-user scheduling schemes by making the use of multiple beams.

The OMB scheme is one of multi-user scheduling techniques, that transmits signals using a set of orthonormal vectors $\{w_l, l=1,2,...,M\}$ $(M \le K)$ satisfying[5],

$$w_i^* w_j = \begin{cases} 0; i \ne j \\ 1; i = j \end{cases} \tag{3}$$

After a given period of time, another set of orthonormal weight vectors is chosen independently from previously chosen ones. Each user estimates the SINR for given beams, and reports the maximum SINR and the corresponding beam index to the BS. Then, the BS assigns each beam to a user with the highest SINR, transmitting M signals through M beams in parallel.

When the data of user k is transmitted over the l-th beam, the received signal can be represented as

$$y_k = h_k^* w_l s_l + \sum_{i=1 \ne l}^{M} h_k^* w_l s_l + n_k, \tag{4}$$

where the first term is the desired signal, the second term is the interference from other beams and the third term is AWGN. Letting $Q(l)$ be the index of the selected user for the l-th beam, the corresponding SINR can be represented as

$$\gamma_{OMB,Q(l)}^{(M)} = \max_{k=1,...,K} \frac{|h_k^* w_l|^2}{\sum_{i=1 \ne l}^{M} |h_k^* w_i|^2 + \frac{M}{\gamma_0}} \tag{5}$$

where the superscript number in the bracket is the number of beams used for the data transmission. Since $\{h_k^* w_l, l=1,...,M\}$ are independent complex Gaussian random variables, the desired signal power $|h_k^* w_l|^2$ and the interference power $\sum_{i=1 \ne l}^{M} |h_k^* w_i|^2$ from other beams can be represented by independent Chi-square random variables with 2 and $2(M-1)$ degrees of freedom, respectively.

Note that the OMB always uses M number of multiple beams for the data transmission. It can be seen from (5) that the selected users are interfered by each other. If the number of users is sufficiently large, beams can be assigned to users nearly in an orthogonal manner, significantly reducing the interference from other users. As the number of users increases to infinity, the sum-rate of the OMB exhibits the same growth rate as the DPC[5]. However, if the number of users is not large enough, the selected users may not be separated in an orthogonal manner, suffering from the interference signal transmitted through other beams. As a consequence, the performance of the OMB can be even worse than that of the opportunistic beamforming[6][8].

2. Multi-user Diversity and Multiplexing (MUDAM)

Fig. 1 illustrates the procedure of the MUDAM scheme. The MUDAM sequentially generates multiple beams to reduce the interference toward previous selected users. It is assumed that the channel is unchanged during the generation of multiple beams and it is independently changed after that.

The BS generates the first beam w_1 in a random manner[4]. Then, all the users estimate the SINR for the first beam and report it to the BS. The BS selects the best user for the first beam and notifies it to the selected user. Then, the selected user reports its CSI $h_{Q(1)}$ to the BS. Note that the scheduler needs only the CSI of the selected user. The BS generates the next random beam w_2 satisfying

$$h^*_{Q(1)} w_2 = \epsilon \tag{6}$$

where ϵ denotes the amount of interference to user $Q(1)$ by the second beam. Similarly, the BS selects a user corresponding to the second beam and gets the corresponding channel information $h_{Q(2)}$ from the selected user. In this manner, the weight of the l-th beam can be generated randomly, while satisfying

$$h^*_{Q(j)} w_l = \epsilon, \quad j = 1, 2, \ldots, l-1 \tag{7}$$

Letting $\epsilon = 0$, the instantaneous SINR of the selected user $Q(l)$ for the l-th beam can be represented as

$$\gamma^{(M)}_{MDAM, Q(l)} = \frac{\left|h^*_{Q(l)} w_l\right|^2}{\sum_{i=1}^{l-1} \left|h^*_{Q(l)} w_i\right|^2 + \frac{M}{\gamma_0}} \tag{8}$$

Since $\{h^*_{Q(l)} w_l, l = 1, 2, \ldots, M\}$ are independent complex Gaussian random variables, the desired signal power $\left|h^*_{Q(l)} w_l\right|^2$ and the interference power $\sum_{i=1}^{l-1} \left|h^*_{Q(l)} w_i\right|^2$ from other beams can be represented by independent Chi-square random variables with 2 and $2(l-1)$ degrees of freedom, respectively.

Note that as the number of users increases, the amount of interference can be lowered by selecting a user experiencing smaller interference. Moreover, unlike the OMB, the MUDAM can maintain the performance even when the number of users is not large. However, since the MUDAM takes a longer time for the generation of multiple beams than the OMB, it may suffer from the user mobility. In fact, the MUDAM can outperform the OMB in nomadic environments, but it can be worse in high mobility environments.

Ⅳ. Proposed Modified Orthogonal Multi-beam

Unless the number of users is sufficiently large, the OMB may not sufficiently separate the selected users in an orthogonal manner due to the mismatch between the orthogonal beams and the channel of selected users. In this case, the use of multiple beams can even be worse than the use of a single beam. To alleviate this problem, we

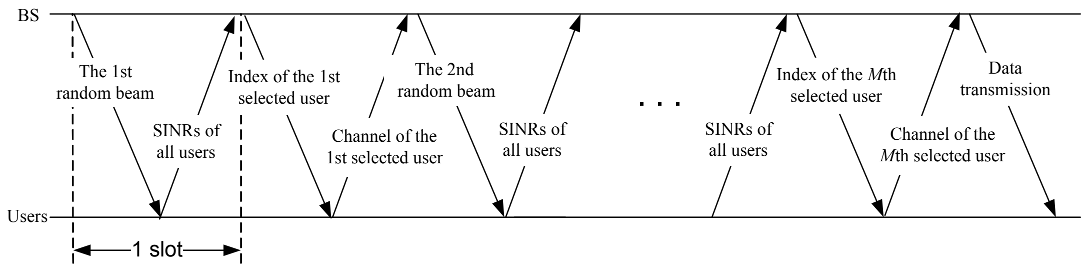

그림 1. MUDAM 기법의 빔 생성도
Fig. 1 Transmission procedure of the MUDAM

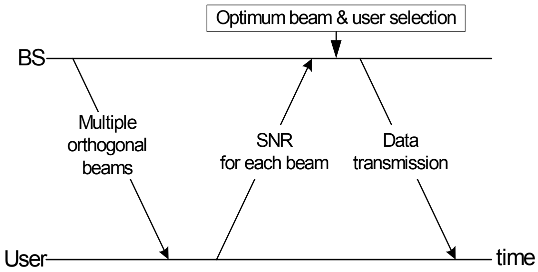

그림 2. MOMB 기법의 전송도
Fig. 2 Transmission procedure of the MOMB

consider adjusting the number of orthogonal beams for the data transmission in response to the operating condition to reduce the interference effect.

Fig. 2 illustrates the transmission procedure of the proposed modified orthogonal multi-beam (MOMB) scheme. It first generates M orthonormal random beams with weight $W=\{w_1,w_2,\ldots,w_M\}$ as in the OMB[5]. The instantaneous SINR of user k for the l-the beam can be represented as

$$\gamma_{\mathrm{Pro},k,l}^{(M)}=\frac{|h_k^* w_l|^2}{\sum_{i=1\neq l}^{M}|h_k^* w_i|^2+\frac{M}{\gamma_0}} \tag{9}$$

It can be seen that the SINR can also berepresented as a function of the instantaneous SNR assuming that each beam is used for the single beam transmission as follow.

$$\gamma_{\mathrm{Pro},k,l}^{(M)}=\frac{\gamma_{k,l}^{(1)}}{\sum_{i=1\neq l}^{M}\gamma_{k,i}^{(1)}+M} \tag{10}$$

Thus, if the BS has the instantaneous SNR for each beam, it can estimate the SINR independent of the number of beams. In the proposed scheme, all users report the SNR for each beam assuming that the signal is transmitted using a single beam. The BS estimates the SINR of all users for possible beam selections from the received SNR information. Note that unlike in the OMB scheme, the BS estimates the SINR in the proposed scheme. Since the SNR of all users for each beam is needed for the user selection, the amount of feedback overhead somewhat increases compared to the OMB which requires only the maximum SINR and the corresponding beam index. However, the amount of increased feedback signaling overhead is small compared to the amount of full CSI.

With the use of M transmit antennas, the BS can generate multiple beams of up to M beams in parallel for the signal transmission. The proposed MOMB scheme adjusts the number of beams in useto maximize the achievable capacity according to the operating condition. The achievable capacity can be calculated from the SNR information.

When L beams are used for the signal transmission, there can be ${}_MC_L$ number of possible multi-beam selections. Let $\pi(L,i)$ be the i-th choice among ${}_MC_L$ L-beam selections and $b(l)$ be an indication function representing the l-th beam index corresponding to choice $\pi(L,i)$. For example, when $M=3$ and $L=2$, there are $3(={}_3C_2)$ 2-beam choices (i.e., $\{(1,2),(1,3),(2,3)\}$denotes the use of beams $(1,3)$, $b(1)=1$ and $b(2)=3$. The BS can estimate the SINR of user k for the $b(l)$-th beam as

$$\gamma_{\mathrm{Pro},k,b(l)}^{(\pi(L,i))}=\frac{\gamma_{k,b(l)}^{(1)}}{\sum_{i=1\neq l}^{M}\gamma_{k,b(i)}^{(1)}+L} \tag{11}$$

With the use of opportunistic scheduling, the SINR of the selected user for the $b(1)$-th beam can be represented as

$$\gamma_{\mathrm{Pro},Q(b(l))}^{\pi(L,i)}=\max\left\{\gamma_{\mathrm{Pro},1,b(l)}^{\pi(L,i)},\gamma_{\mathrm{Pro},2,b(l)}^{\pi(L,i)},\ldots,\gamma_{\mathrm{Pro},K,b(l)}^{\pi(L,i)}\right\}. \tag{12}$$

The achievable capacity for $\pi(L,i)$ can be represented as

$$C_{\mathrm{Pro}}^{\pi(L,i)}=\sum_{l=1}^{L}\log_2\left(1+\gamma_{\mathrm{Pro},Q(b(l))}^{\pi(L,i)}\right) \tag{13}$$

Finally, the maximum achievable capacity with the use of L beams can be represented as

$$C_{\mathrm{Pro}}^{(L)} = \max\left\{C_{\mathrm{Pro}}^{(\pi(L,1))}, C_{\mathrm{Pro}}^{(\pi(L,2))}, \ldots, C_{\mathrm{Pro}}^{(\pi(L,{}_M C_L))}\right\} \quad (14)$$

Thus, the BS determines the optimum beam selection that yields the maximum capacity as

$$C_{\mathrm{Pro}} = \max\left\{C_{\mathrm{Pro}}^{(1)}, C_{\mathrm{Pro}}^{(2)}, \ldots, C_{\mathrm{Pro}}^{(M)}\right\} \quad (15)$$

Note that the capacity of the OMB is simply represented as $C_{OMB}^{(M)} = C_{\mathrm{Pro}}^{(M)}$. This proves that the MOMB always works better than or equal to the OMB. Moreover, it can also be seen that the MOMB works better than or equal to the opportunistic beamforming since the MOMB provide M times the beam selection diversity gain when a single beam is used for the data transmission.

For simplicity of performance analysis, we assume that the BS has two transmit antennas (i.e., $M=2$) and each user has a single antenna with perfect channel estimation. Then, the MOMB can have two possible combinations for the beam usage (i.e., $L=1$ or 2).

First consider the use of a single beam (i.e., $L=1$) for the signal transmission. The short term SNR of user k through the $b(l)$-th beam can be estimated as

$$\gamma_{\mathrm{Pro},k,b(l)}^{\pi(1,i)} = \overline{\gamma_0}\left|\boldsymbol{h}_k^* \boldsymbol{w}_{b(l)}\right|^2 \quad (16)$$

where $i=1,2$ and $l=1$. Assuming that the short term SNR through other beams have the same distribution, we can omit the subscript k in (16) without loss of generality. For simplicity of description, we also omit the subscript "Pro" in (16).

It can be shown that $\gamma_{b(l)}^{\pi(1,i)}$ can be modeled as a second order Chi-square random variable multiplied by a constant $\overline{\gamma_0}$ with probability density function (pdf) given by[11]

$$f_{\gamma_{b(l)}^{\pi(1,i)}}(\gamma) = \frac{1}{\overline{\gamma_0}} exp\left(-\frac{\gamma}{\overline{\gamma_0}}\right), \quad \gamma \geq 0 \quad (17)$$

Then, the SNR of the selected user for beam choice $\pi(1,i)$ can be represented as

$$\gamma_{Q(b(l))}^{\pi(1,i)} = \max\left\{\boldsymbol{c}_{b(l)}^{\pi(1,i)}\right\} \quad (18)$$

where $\boldsymbol{c}_{b(l)}^{\pi(1,i)} = \left\{\gamma_{1,b(l)}^{\pi(1,i)}, \gamma_{2,b(l)}^{\pi(1,i)}, \ldots, \gamma_{K,b(l)}^{\pi(1,i)}\right\}$.

Let Γ_z^K be the z-th element of $\boldsymbol{c}_{b(l)}^{\pi(1,i)}$ sorted in an ascending order, represented as

$$\Gamma_z^K = OS_z^K\left\{\gamma_{1,b(l)}^{\pi(1,i)}, \gamma_{2,b(l)}^{\pi(1,i)}, \ldots, \gamma_{K,b(l)}^{\pi(1,i)}\right\} \quad (19)$$

where $OS_z^K\{.\}$ denotes order statistic filtering with rank z. Then, the pdf and cumulative distribution function (cdf) of Γ_z^K can respectively be represented as[12]

$$f_{\Gamma_z^K}(\gamma) = z\binom{K}{z} F_{\gamma_{b(l)}^{\pi(1,i)}}^{z-1}(\gamma)\left[1 - F_{\gamma_{b(l)}^{\pi(1,i)}}(\gamma)\right]^{K-z} f_{\gamma_{b(l)}^{\pi(1,i)}}(\gamma) \quad (20)$$

$$F_{\Gamma_z^K}(\gamma) = \sum_{q=z}^{K}\binom{K}{z} F_{\gamma_{b(l)}^{\pi(1,i)}}^{q}(\gamma)\left[1 - F_{\gamma_{b(l)}^{\pi(1,i)}}(\gamma)\right]^{K-q} \quad (21)$$

where $F_{\Gamma_{b(l)}^{\pi(1,i)}}(\gamma)$ denotes the cdf of $\gamma_{b(l)}^{\pi(1,i)}$.

Since the largest SNR for $L=1$ is given by $\max\left\{\gamma_{Q(b(1))}^{\pi(1,1)}, \gamma_{Q(b(1))}^{\pi(1,2)}\right\}$, it is equal to Γ_{2K}^{2K} whose pdf is given by

$$\begin{aligned} f_{\Gamma_{2K}^{2K}}(\gamma) &= 2K\left[F_{\gamma_{b(l)}^{\pi(1,i)}}(\gamma)\right]^{2K-1} f_{\gamma_{b(l)}^{\pi(1,i)}}(\gamma) \\ &= \frac{2L}{\overline{\gamma_0}}\sum_{q=0}^{2K-1}\binom{2K-1}{q}(-1)^q \exp\left(-(i+1)\frac{\gamma}{\overline{\gamma_0}}\right) \end{aligned} \quad (22)$$

The corresponding system capacity can be represented as

$$\begin{aligned} E\left\{C_{\mathrm{Pro}}^{(1)}(\gamma)\right\} &= \int_0^\infty \log_2(1+\gamma) f_{\Gamma_{2K}^{2K}}(\gamma) d\gamma \\ &= \frac{2K}{\ln 2}\sum_{q=0}^{2K-1}\binom{2K-1}{q}\frac{(-1)^q}{q+1} exp\left(\frac{q+1}{\overline{\gamma_0}}\right) Ei\left(\frac{q+1}{\overline{\gamma_0}}\right) \end{aligned} \quad (23)$$

where $Ei(z) = \int_z^\infty e^{-t}/t \, dt$

Next, consider the use of two beams (i.e., $L=2$) in parallel for the signal transmission. Assuming that the transmit power is evenly split by each antenna, the received SINR of user k through the $b(l)$-th beam can be represented as

$$\gamma^{\pi(2,i)}_{\mathrm{Pro},k,b(l)} = \frac{\left|\boldsymbol{h}_k^* \boldsymbol{w}_{b(l)}\right|^2}{\sum\limits_{i=1 \neq l}^{2} \left|\boldsymbol{h}_k^* \boldsymbol{w}_{b(i)}\right|^2 + \frac{2}{\gamma_0}} \quad (24)$$

where $i=1$ and $l=1,2$. Let S_D and S_N be the denominator and numerator of $\gamma^{\pi(2,i)}_{b(l)}$ in (24), respectively. Then, S_N can be modeled as a second order Chi-square random variable and S_D as a second order Chi-square random variable plus a constant $2/\overline{\gamma_0}$. Letting f_{S_D} and f_{S_N} be the pdf of S_D and S_N, respectively, the pdf of $\gamma^{\pi(2,i)}_{b(l)}$ can be calculated as[13]

$$f_{\gamma^{\pi(2,i)}_{b(l)}}(\gamma) = \int_0^{\infty} \frac{1}{w^3} f_{S_D}\!\left(\frac{1}{w}\right) f_{S_N}\!\left(\frac{\gamma}{w}\right) dw \quad (25)$$

where $w = 1/S_D$ and $\gamma = S_N/S_D$.

Assume that the scheduler chooses a user having the maximum SINR for the $b(l)$-th beam as

$$\gamma^{\pi(2,i)}_{Q(b(l))} = \max\left\{\boldsymbol{c}^{\pi(2,i)}_{b(l)}\right\} \quad (26)$$

where $\boldsymbol{c}^{\pi(2,i)}_{b(l)} = \left\{\gamma^{\pi(2,i)}_{1,b(l)}, \gamma^{\pi(2,i)}_{2,b(l)}, \ldots, \gamma^{\pi(2,i)}_{K,b(l)}\right\}$. Letting $\Gamma^K_{z,b(l)}$ be the z-th element of $\boldsymbol{c}^{\pi(2,i)}_{b(l)}$ sorted in an ascending order, $\gamma^{\pi(2,i)}_{Q(b(l))}$ is equal to $\Gamma^K_{K,b(l)}$ having the pdf given by[13]

$$f_{\Gamma^K_{Kb(l)}}(\gamma) = K\left[F_{\gamma^{\pi(2,i)}_{b(l)}}(\gamma)\right]^{K-1} f_{\gamma^{\pi(2,i)}_{b(l)}}(\gamma) \quad (27)$$

where $F_{\gamma^{\pi(2,i)}_{b(l)}}(\gamma)$ denotes the cdf of $\gamma^{\pi(2,i)}_{b(l)}$. The corresponding system capacity through the $b(l)$-th beam is given by

$$E\left\{C^{\pi(2,i)}_{Q(b(l))}\right\} = \int_0^{\infty} \log_2(1+\gamma) K\left[F_{\gamma^{\pi(2,i)}_{b(l)}}(\gamma)\right]^{K-1} f_{\gamma^{\pi(2,i)}_{b(l)}}(\gamma) d\gamma \quad (28)$$

Since the highest SINR of the selected user for each beam has the same distribution, the total system capacity with the use of two beams can be represented as

$$E\left\{C^{(2)}_{\mathrm{Pro}}(\gamma)\right\} = E\left\{C^{\pi(2,1)}_{Q(b(1))}(\gamma) + C^{\pi(2,1)}_{Q(b(2))}(\gamma)\right\} \quad (29)$$

The total capacity of the proposed MOMB can be represented as

$$C_{\mathrm{Pro}} = E\left\{P_1 C^{(1)}_{\mathrm{Pro}}(\gamma) + (1-P_1) C^{(2)}_{\mathrm{Pro}}(\gamma)\right\} \quad (30)$$

where P_1 is the probability that the capacity of the MOMB using a single beam is larger than that using two beams. However, it may involve difficulty to analytically derive the probability P_1.

Ⅴ. Performance evaluation

The performance of the MOMB is verified by computer simulation. We consider the downlink of a frequency division duplexing (FDD) OFDM system where all users experience mutually independent Rayleigh flat fading channel with the same average SNR $\bar{\gamma}$. Since the use of spatial multiplexing is applicable when the SNR is high, we evaluate the performance at an SNR of 10 dB. We also assume that the MUDAM takes two packet slot interval for user selection for each beam and that the MOMB and OMB take a one slot interval for user selection for all beams, and that the duration of each slot is 5 ms in this simulation[10]. The common simulation condition is summarized in Table 1.

Fig. 3 depicts the performance of the MOMB according to the number of active users in a

표 1. 시뮬레이션 파라메터
Table 1. Common simulation parameters

Parameters	Setting
Antenna configuration	4 Tx, 1 Rx (MISO) 4 Tx, 2 Rx (MIMO)
Fading channel	Rayleigh fading
Link adaptation	Ideal (the Shannon's capacity formula)
Carrier frequency	2.3 GHz
Number of subcarriers	1024
Symbol duration	115.2 μsec
Guard interval	12.8 μsec
Bandwidth	10 MHz
Packet slot duration	5 ms
Doppler model	Jake's model

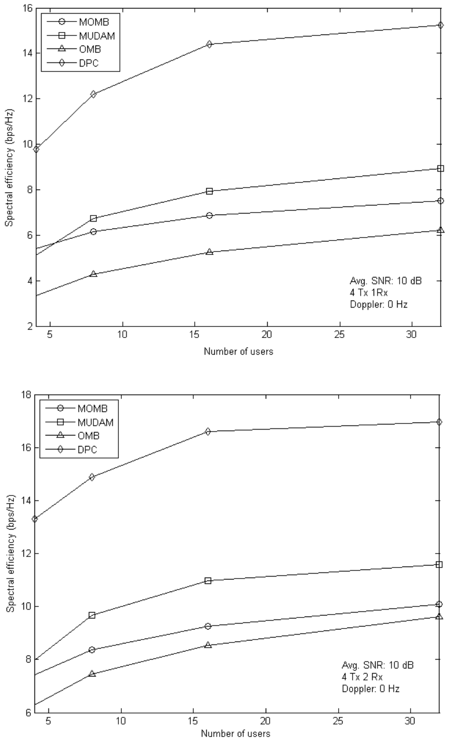

그림 3. 사용자 수에 따른 MOMB 성능
Fig. 3 The performance of the MOMB according to the number of users

(4x1) MISO and (4x2) MIMO fixed environments. The minimum mean square error (MMSE) received weight is applied at receiver to suppress the interference in MIMO environment[9]. It can be seen that the MOMB always provides the spectral efficiency better than or equal to the conventional OMB. As suggested by (15), it proves that the number of orthogonal beams should be optimized considering the operating environment. It can also be seen that the DPC provides the best performance among multi-user schemes because it is a capacity achieving strategy[5]. However, the DPC is too much computationally intensive and requires full channel state information (CSI) of all users at the transmitter. In systems with many users, obtaining full CSI from all users may not be feasible, making it difficult to be employed in practical systems. Among practical schemes, the MUDAM provides the better

표 2. 궤환 정보량 비교
Table 2. Feedback overhead of the MOMB, MUDAM, OMB

MOMB (12 bits)	MUDAM (60 bits)	OMB (5 bits)
SNRs for each beam (3x4=12 bits)	SNRs for each beam (3x4=12 bits) Selected user's full CSI (12x4=48 bits)	The highest SNR (3 bits) corresponding beam index (2 bits)

performance compared to the proposed MOMB and conventional OMB schemes in fixed wireless environments. This is mainly due to the fact that the MUDAM can suppress the interference toward previously selected users at a certain level. However, although the MUDAM scheme provides better performance in the fixed environment, it requires additional full CSI of the selected users to control the interference, causing signaling overhead. On the other hand, the proposed scheme can provide considerable system throughput with the use of partial CSI (i.e., the SNR for each beam). Table 2 compares the amount of feedback overhead of the MOMB, MUDAM, and OMB schemes. The CSI and SINR are quantized into a 12-bit using technique in[14] and 3-bit uniform quantization form, respectively.

Fig. 4 depicts the performance of the MOMB in the presence of user mobility when the number of users is 16 in a (4x1) MISO mobile

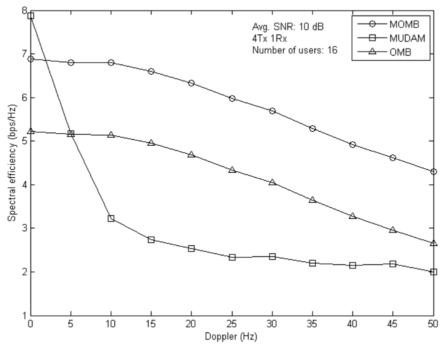

그림 4. 도플러에 따른 MOMB 성능
Fig. 4 The performance of the MOMB according to the mobility

environment. Since the DPC is an infeasible scheme in practical environment, we will not present the simulation result of this scheme in mobile environment. The mobility corresponding to Doppler frequency 0 ~ 50 Hz in simulation is 0 ~ 24 Km/h. As the user mobility increases, the channel measurement delay can make serious mismatch between the measured channel and the actual one due to the channel variation. The actual channel of the selected user for the -th beam can be expressed using Jake's model[11] as

$$\boldsymbol{h}_{actual,Q(l)} = \rho \boldsymbol{h}_{measured,Q(l)} + \sqrt{1-\rho^2}\,\boldsymbol{z} \tag{31}$$

where $\boldsymbol{z}$ is a random vector whose components are zero-mean complex Gaussian random variables with unit variance, and ρ denotes the correlation coefficient between $\boldsymbol{h}_{actual,Q(l)}$ and $\boldsymbol{h}_{measured,Q(l)}$, given by

$$\rho = J_0(2\pi f_d \tau) \tag{32}$$

Here, $J_0(.)$ is the zero-th order Bessel function of the first kind, f_d is the maximum Doppler frequency, and τ represents the amount of delay between the time instants of channel measurement and the actual transmission. The user mobility and feedback delay can significantly affect the performance of multi-beam schemes. Since the MUDAM takes the largest time for the beam generation among these three schemes, it most suffers from the mobility and thus it works even worse than the MOMB and OMB in the presence of moderate mobility. It can be seen that the proposed scheme is quite applicable to most of mobile environments.

Ⅵ. Conclusion

In this paper, we have proposed a multi-antenna transmission scheme that can simultaneously achieve the multi-user diversity and the multiplexing gain by adjusting the number of beams in use according to the channel condition and/or the number of users. By adjusting the number of beams, the proposed scheme reduces the performance loss due to the interference from other beams, increasing the spectral efficiency. The performance of the proposed scheme has been analyzed and verified by computer simulation. The simulation results show that the proposed scheme provides noticeable performance gain over the conventional schemes at a marginal increase of feedback signaling overhead.

References

〔1〕 I. E. Telatar, "Capacity of Multi-antenna Gaussian Channels," *Eur. Trans. Telecommun.*, Vol.10, No.6, pp.585–595, Nov. 1999.

〔2〕 G. J. Foschini and M. J. Gans, "On limits of wireless communications in a fading environment when using multiple antennas," *IEEE Pers. Commun.*, Vol.6, No.3, pp.311–335, June 1998.

〔3〕 R. Knopp and P. Humblet. "Information capacity and power control in single-cell multiuser communications," in *Proc. IEEE Int. Conf. Commun. (ICC'05)*, Vol.1, pp.331–335, June 1995.

〔4〕 P. Viswanath, D. N. C. Tse and R. Laroia, "Opportunistic beamforming using dumb antennas," *IEEE Trans. Inf. Theory*, Vol.48, No.6, pp.1277–1294, June 2002.

〔5〕 M. Sharif and B. Hassibi, "On the capacity of MIMO broadcast channels with partial channel state information," *IEEE Trans. Inf. Theory*, Vol.51, No.2, pp.506–522, Feb. 2005.

〔6〕 D. Aktas and H. E. Gamal, "Multiuser scheduling for MIMO wireless systems," in *Proc. IEEE Veh. Tech. Conf. (VTC'03)*, Vol.3, pp.1743–1747, Oct. 2003.

〔7〕 N. Jindal and A. Goldsmith, "Dirty paper coding vs. TDMA for MIMO broadcast channel," in *Proc. IEEE ICC'04*, Vol.2, pp. 682–686, June 2004.

〔8〕 S.-S. Hwang and Y.-H. Lee, "Multiuser diversity and multiplexing using multiple random beams in wireless systems," *IEEE*

Trans. Wireless Commun., Vol.6, pp.120–127, Jan. 2007.

[9] R. W. Heath, S. Sandhu, and A. J. Paulaj, “Antenna selection for spatial multiplexing systems with linear receivers,” *IEEE Commun. Lett.*, Vol.5, No.4, pp.142–144, Apr. 2002.

[10] IEEE Std 802.16e, *Part16: air interface for fixed and mobile broadband wireless access systems*, Dec. 2005.

[11] W. C. Y. Lee, *Mobile Communication Engineering*, NewYork: McGraw-Hill, 1998.

[12] H. A. David, *Order statistics*, NewYork: Willey, 1981.

[13] A. L. Garcia, *Probability and random process for electrical engineering 2nd Edition*, Addison Wesley,1994.

[14] B. Nevio, C. Ermanna, T. Stefano, and T. Matteo, “Predictive channel quantization and beamformer design for MIMO-BC with limited feedback,” in *Proc. IEEE Globecom’07*, pp.3607–3611, Nov. 2007.

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