패킷 기반 무선 시스템에서 다중 직교 빔을 이용한 다중 안테나 송수신 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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Abstractor

In this paper, we consider the use of multiple beams to simultaneously achieve both diversity and multiplexing gain in multi-user domain in multiple access systems. Orthogonal multiple beams are generated to provide the users with multiple channels at the same time, achieving multi-user diversity through each channel. However, when the number of active users is not large, the performance can significantly be affected by the interference from other users. To alleviate this problem, we propose a multi-beam scheme to adjust the number of beams according to the channel condition or the number of users.

I. Introduction

[1]Next generation transmission systems should be able to provide high rate multimedia services to users in mobile, nomadic and fixed wireless environments. In recent years, the capacity of wireless systems has significantly been increased with the development of two key technologies. One is Multi Input Multi Output (MIMO) antenna technology that can offer high spectral efficiency without increasing the bandwidth. It was shown that the capacity of MIMO channel increases linearly by exploiting the antenna array characteristics at both the transmitter and receiver [1,2]. The other is opportunistic scheduling technology that can provide multi-user diversity (MUD) gain increasing as the number of users increases [3,4]. Allowing a user in the best channel condition to send the signal, we 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). However, when the channel gain has a small fluctuation and/or varies slowly, the MUD gain may not significantly contribute to the improvement of capacity. To overcome this problem, the base station (BS) generates random beams using multiple antennas, known as opportunistic beamforming [4].

When the number of users is large, the system throughput can significantly be improved by scheduling multiple users simultaneously [5,6]. Recently, a new scheme called an orthogonal multiple beams (OMB) was proposed to achieve the diversity and multiplexing gain simultaneously in multi-user MIMO domain by generating orthogonal beams at the transmitter [5]. However, this may cause the user signal to be interfered from other users' signals. Thus, it may be desirable to generate the multiple beams to interfere with other users at a minimum level.

To alleviate this problem, a new scheme called multi-user diversity and multiplexing (MUDAM) was proposed [7], where multiple beams are generated in a sequential manner to minimize the interference to other users. Although the MUDAM can outperform the OMB in nomadic/fixed wireless environments, it may suffer from performance degradation in the presence of user mobility since it takes longer time to generate the beam than the OMB. As a consequence, it may work poorer than the OMB in high mobility environments. In this paper, we

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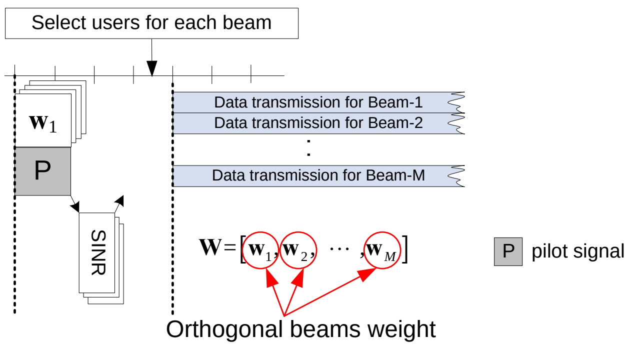


Fig. 1. Transmission procedure of the OMB

consider the improvement of the OMB by adjusting the number of multiple beams according to the number of users or the channel condition.

This paper is organized as follows. In Section II, previous multi-user MIMO schemes are briefly discussed. The proposed MOMB scheme is described in Section III. The performance of the proposed MOMB scheme is verified by computer simulation in Section IV. Finally, conclusions are summarized in Section V.

II. Previous multi-beam technique

1. Orthogonal multi-beam (OMB) technique [5]

The OMB is one of multi-beam techniques that can simultaneously achieve both the diversity and multiplexing gain by using orthogonal beams. We consider the transmission of multi-user data signal in a packet-based cellular downlink system. We assume that each mobile station (MS) can acquire perfect channel information from the received pilot signal. On the other hand, the BS can get the channel state information (CSI) through a feedback signaling channel in the uplink.

For ease of description, consider a multi-user MISO downlink scheme, where the BS has M transmit antennas and each of K users has a single receive antenna. This scheme can easily be extended to the use of multiple antennas in the receiver (i.e., MIMO). Fig.1 illustrates the transmission procedure of the OMB. In what follows, we use boldfaces to denote vectors and matrices, $\mathbf{A}^T$ denotes the transpose of $\mathbf{A}$, and $\mathbf{A}^H$ refers to the conjugate transpose or Hermitian of $\mathbf{A}$. The notation $\|\mathbf{x}\|$ denotes the Euclidean norm of a vector $\mathbf{x}$.

We assume that the BS transmits M signals $\mathbf{s}=[s_1, s_2, ..., s_M]^T$ to M out of K users through M beams in parallel. The received signal y_k of user k can be represented as

$$y_k = \mathbf{h}_k^H \mathbf{W}\mathbf{s} + n_k, \qquad k = 1, 2, \cdots, K, \qquad (1)$$

where $\mathbf{s}$ is the M-dimensional (dim) data symbol vector, n_k is zero mean complex circular-symmetric Gaussian noise with unit variance, $\mathbf{h}_k$ is the ($M \times 1$)-dim channel matrix of user k, and $\mathbf{W}=[\mathbf{w}_1, \mathbf{w}_2, \cdots, \mathbf{w}_M]$ is the orthogonal beamforming weight matrix whose l-th column represents the weight of the l-th beam. We assume that each user experiences independent channel characteristics with fixed transmission power P at all times. We also assume that the BS assigns the channel resource to a user in the best channel condition at each slot time, exploiting the MUD.

Representing the effective channel of user k as

$$\tilde{\mathbf{h}}_k^H = \mathbf{h}_k^H \mathbf{W}, \qquad (2)$$

the received signal y_k of user k for the each beam can be represented as

$$\begin{aligned} y_k &= \tilde{\mathbf{h}}_k^H \mathbf{s} + n_k \\ &= \mathbf{h}_k^H \mathbf{w}_l \mathbf{s}_l + \sum_{i=1,\neq l}^{M} \mathbf{h}_k^H \mathbf{w}_i \mathbf{s}_i + n_k \end{aligned} \qquad (3)$$

where $l = 1, 2, \cdots, M$, the first term is the desired signal for the l-th beam and the second term is the interference from other users and the third term is additive noise. Then, each user estimates its short term SINR of each beam and reports it to the BS. Based on this SINR information, the BS allocates each spatial channel to a user with the highest SINR.

Letting $Q(l)$ be the index of the selected user for the l-th beam, the SINR of the selected user for the l-th beam can be represented by

$$\gamma_{O,Q(l)}^{(M)} = \frac{\frac{P}{M}\left\|\mathbf{h}_{Q(l)}^H \mathbf{w}_l\right\|^2}{\frac{P}{M}\sum_{i=1,\neq l}^{M}\left\|\mathbf{h}_{Q(l)}^H \mathbf{w}_i\right\|^2 + \sigma_n^2} \qquad (4)$$

where M is the number of beams used for the transmission of data, P/M is the symbol power through each beam and σ_n^2 is the noise power. It can be seen that the selected users are interfered by each other. If the number of users is sufficiently large, orthogonal random beams can be assigned to users nearly in an orthogonal manner, reducing the interference from other beams. However, if the number of users is not large, the selected users may not be separated by orthogonal random beams, suffering from the interference from other users. As a result, the performance of the OMB can be worse than that of a single-beam scheme [7].

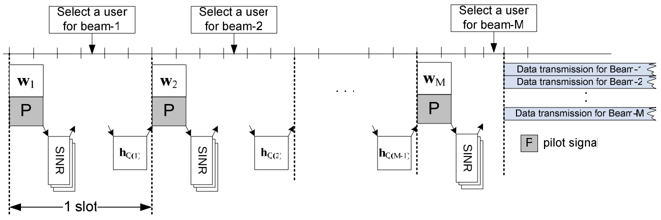


Fig. 2. Transmission procedure of the MUDAM

2. Multi-user diversity and Multiplexing (MUDAM) technique [7]

Fig. 2 illustrates the procedure of the MUDAM technique. The MUDAM sequentially generates multiple beams to reduce the interference from other users. It is assumed that the channel is unchanged during the generation of multiple beams and then it is independently changed after that.

The BS generates the first beam using a random weight $\mathbf{w}_1$. Then, all 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 $\mathbf{h}_{Q(1)}$ to the BS. Note that the scheduler needs only the CSI of the selected user. The BS generates the next random beam $\mathbf{w}_2$ satisfying

$$\mathbf{h}_{Q(1)}^H \mathbf{w}_2 = \varepsilon , \qquad (5)$$

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 $\mathbf{h}_{Q(2)}$ from the selected user. In this manner, the weight of the l-th beam can be generated randomly, while satisfying

$$\mathbf{h}_{Q(j)}^H \mathbf{w}_l = \varepsilon, \qquad j = 1, 2, \ \ldots \ , l-1. \qquad (6)$$

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

$$\gamma_{M,Q(l)}^{(M)} = \frac{\frac{P}{M}\left\|\mathbf{h}_{Q(l)}^H \mathbf{w}_l\right\|^2}{\frac{P}{M}\sum_{i=1}^{l-1}\left\|\mathbf{h}_{Q(l)}^H \mathbf{w}_i\right\|^2 + \sigma_n^2}. \qquad (7)$$

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.

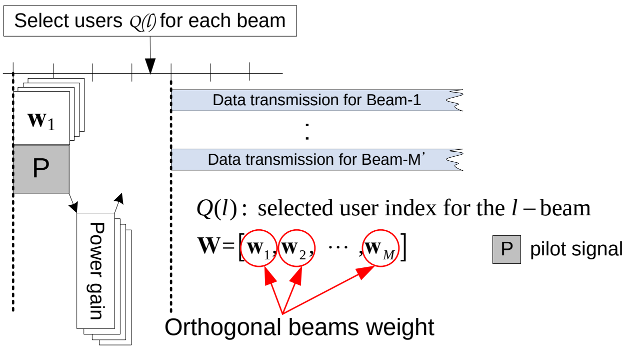


Fig. 3. Transmission procedure of the proposed MOMB

In fact, the MUDAM can outperform the OMB in nomadic environments, but it can be worse in high mobility environments.

III. A modified orthogonal multi–beam technique

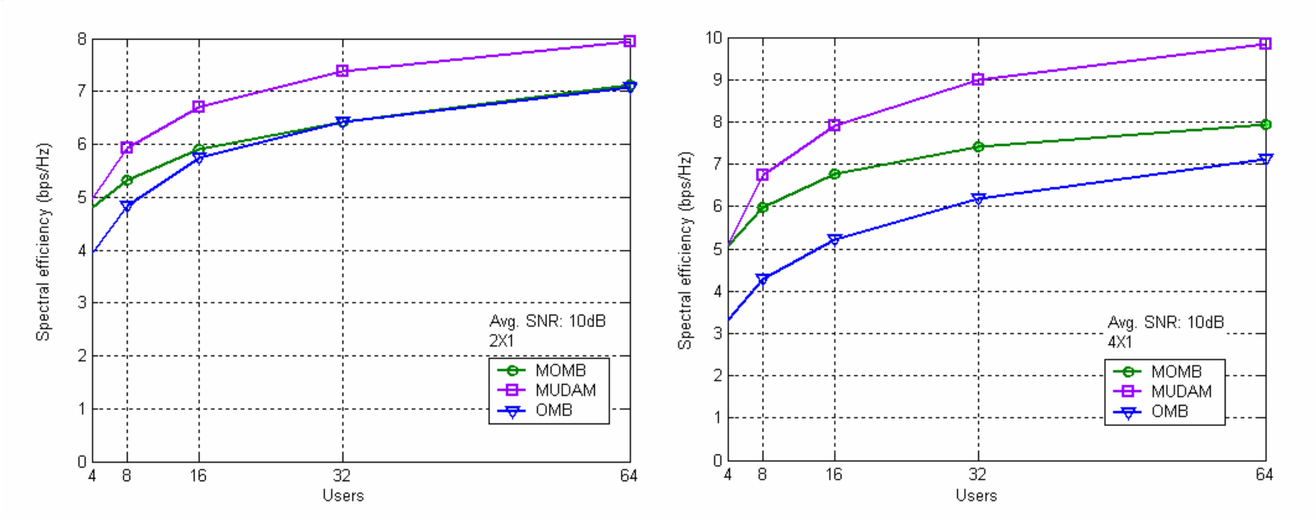
It can happen in the OMB scheme that unless the number of users is sufficiently large, the channels of selected users may not be orthogonal to each other. As a result, the capacity of the OMB can be reduced by the interference from other beams. To alleviate this problem, we consider the improvement of the OMB by adjusting the number of beams in response to the change of number of users or channel condition.

Fig. 3 illustrates the transmission procedure of the proposed modified OMB (MOMB). It first generates M orthogonal random beams with weight $\mathbf{W} = \left[\mathbf{w}_1, \mathbf{w}_2, \ldots, \mathbf{w}_M\right]$ as in the OMB [5]. Then the received signal of user k can also be represented by (3), where the squared value of each component of $\tilde{\mathbf{h}}_k^H$ represents the effective power gain through each beam. The effective power gain of the l-th beam from user k can be represented as

$$\eta_{l,k} = \left\|\mathbf{h}_k^H \mathbf{w}_l\right\|^2 . \qquad (8)$$

Note that the BS in the OMB scheme receives the estimated SINR of all users for each beam, but the BS in the proposed scheme estimates the SINR of all users by receiving the effective power gain (8) of all users for each beam.

When the number of transmit antennas is M, the proposed scheme can transmit signals using multiple beams of maximum M in parallel. Note that the OMB always uses M beams in parallel. In the proposed scheme, the BS determines the number of beams to maximize the achievable capacity in response to the



(a) 2 Transmit and 1 receive antennas

(b) 4 Transmit and 1 receive antennas

Fig. 4. Performance comparison of the MOMB and different schemes

change of operating environment. The capacity achievable with the use of multi-beam can easily be calculated from the power gain reported from each user.

In the case of transmission using m multiple beams, there can be ${}_M C_m$ number of possible beam choices for the data transmission. Let $\boldsymbol{\pi}(m,i)$ be the i-th choice among ${}_M C_m$ m-beam selections, and $b(l)$ be an indicate function representing l-th beam index corresponding to $\boldsymbol{\pi}(m,i)$. For example, when $M=4$ and $m=3$, there are $4\ (={}_4 C_3)$ 3-beam selections, i.e., $\{(1,2,3),(1,2,4),(1,3,4),(2,3,4)\}$. In this case, $\boldsymbol{\pi}(3,3)$ denotes the use of beams $(1,3,4)$, $b(1)=1$, $b(2)=3$, and $b(3)=4$. The BS can estimate the SINR of user k through the l-th beam as

$$\gamma^{(\boldsymbol{\pi}(m,i))}_{\mathrm{Pro},k,b(l)} = \frac{\frac{P}{m}\eta_{b(l),k}}{\frac{P}{m}\sum_{i=1\neq l}^{m}\eta_{b(i),k}+\sigma_n^2}, \qquad m=1,2,\ \cdots\ ,M \tag{9}$$

Note that BS requires the information on the noise power σ_n^2 and the power gain to estimate the user SINR.

For opportunistic scheduling, the SINR of the selected user for the $b(l)$-th beam can be given by

$$\gamma^{(\boldsymbol{\pi}(m,i))}_{\mathrm{Pro},Q(b(l))} = \max\left\{\gamma^{(\boldsymbol{\pi}(m,i))}_{\mathrm{Pro},1,b(l)}, \gamma^{(\boldsymbol{\pi}(m,i))}_{\mathrm{Pro},2,b(l)},\ \cdots\ ,\gamma^{(\boldsymbol{\pi}(m,i))}_{\mathrm{Pro},K,b(l)}\right\}. \tag{10}$$

The achievable system capacity for each $\boldsymbol{\pi}(m,i)$ can be represented as

$$C_{\mathrm{Pro},\boldsymbol{\pi}(m,i)} = \sum_{l=1}^{m}\log_2\left(1+\gamma^{(\boldsymbol{\pi}(m,i))}_{\mathrm{Pro},Q(b(l))}\right). \tag{11}$$

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

$$C_{\mathrm{Pro},m} = \max\left\{C_{\mathrm{Pro},\boldsymbol{\pi}(m,1)}, C_{\mathrm{Pro},\boldsymbol{\pi}(m,2)},\cdots,C_{\mathrm{Pro},\boldsymbol{\pi}(m,{}_M C_m)}\right\}. \tag{12}$$

Thus the BS determines the optimum number of beams that yields the optimum capacity represented as

$$C_{\mathrm{Pro}} = \max\left\{C_{\mathrm{Pro},1}, C_{\mathrm{Pro},2},\cdots,C_{\mathrm{Pro},M}\right\}. \tag{13}$$

Note that the capacity of the OMB is simply represented as $C_{\mathrm{O}} = C_{\mathrm{Pro},M}$. This proves that the proposed scheme always works better than or equal to the OMB. Moreover, it can also be shown that the proposed scheme at least work better than or equal to a single-beam scheme (i.e., $C_{\mathrm{Pro},1}$).

VI. Performance evaluation

The performance of the proposed MOMB is verified by computer simulation. We assume that all users experience mutually independent flat fading with the same average SNR. Since spatial multiplexing schemes are usually employed when the SNR is high, we evaluate the performance at an SNR of 10dB.

Fig. 4 depicts the performance of the proposed scheme with the use of 2 or 4 transmit antennas in fixed wireless environments. It can be seen that when the number of users is small, the proposed MOMB outperforms the OMB. As

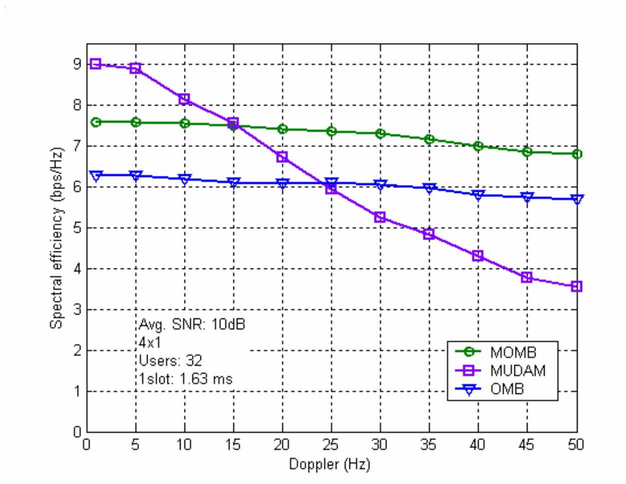


Fig. 5. Performance degradation due to imperfect CSI

suggested by (13), it proves that the use of multiple beams should be determined considering the operating environments. Note that the OMB always uses multiple beam as many as the number of transmit antennas regardless of the operating condition. It can be also seen that the MUDAM scheme always provides a capacity larger than the MOMB and OMB. This is mainly due to the fact that the MUDAM can control the interference to the previously selected users, at the expense of taking longer time for the generation of multi-beams.

Fig. 5 depicts the performance of the proposed scheme in the presence of user mobility when the number of users is 32 at an average SNR of 10 dB in a (4X1) MISO scheme. We assume that the MUDAM takes a slot interval to generate each beam, and the MOMB and OMB takes a one half slot interval because they can generate multiple beams and assign the users at one time. We also assume that the duration of each slot is 1.63ms in this simulation. When the user mobility increases, the channel measurement delay can make serious mismatch between the measured channel and actual one due to the channel variation. The actual channel of the selected user for the l-th beam can be expressed using Jake's model [8] as follows.

$$\mathbf{h}_{actual,Q(l)} = \rho \mathbf{h}_{measured,Q(l)} + \sqrt{1-\rho^{2}}\,\mathbf{z} \qquad (14)$$

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

$$\rho = J_0\left(2\pi f_d \tau\right) \qquad (15)$$

Here, $J_0(\cdot)$ 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 actual transmission [8].

As a consequence, 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 high mobility. It can be seen that the proposed scheme is quite applicable to most of mobile environments.

V. Conclusion

In this paper, we have proposed a multi-antenna transmission scheme that can simultaneously achieve the diversity and multiplexing gain by adjusting the number of orthogonal multiple beams in response to the operating condition. By controlling the number of beams to maximize the achievable capacity, the proposed scheme can improve the performance of the OMB particularly in the presence of a small number of users. The simulation results show that unless the mobility is too low, the proposed scheme works better than other multi-beam schemes, quite practical to the application of mobile environments.

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