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

Dong-Chan Oh and Yong-Hwan Lee

School of Electrical Engineering and INMC, Seoul National University

Kwanak P.O. Box 34, Seoul, 151-600 KOREA

E-mail: {mac81, ylee}@.snu.ac.kr

*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 schemes consider the use of a fixed number of OMBs according to the number of transmit antennas. However, unless the number of active users is sufficiently large, the use of multiple beams may not provide desired performance mainly due to the interference from other users' signals, 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 development of two key technologies. One is the use of multiple antennas for transmission and reception, so called multi-input multi-output (MIMO). When the channel gains between transmit and receive antennas are independent and identically distributed (i.i.d), the channel capacity increases in linear proportional to the minimum number of transmit and receive antennas, even though the transmitter has no information on the channel [1, 2]. The other is opportunistic scheduling that can provide multi-user diversity (MUD) gain in proportion to the number of users [3, 4]. The exploitation of MUD relies on the assumption that users in a wireless multi-user system experience independent channel condition. In such circumstances, the downlink throughput of a multi-user wireless system can be maximized by scheduling the user in the most favorable channel condition at each slot time [3]. Allowing a user 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). 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.

In the context of multi-user MIMO channels, dirty paper coding (DPC) is known as a capacity achieving strategy [5]. However, the DPC is computationally intensive and requires full channel state information (CSI) at the transmitter, making it difficult to be employed. Recently, multi-user diversity and multiplexing (MUDAM) scheme was proposed to improve the performance without significant increase of computational complexity [6]. Orthogonal multi-beam (OMB) scheme can significantly improve the system throughput by scheduling multiple users in an orthogonal manner with the use of partial CSI (i.e., the maximum SINR with the corresponding beam index) when the number of users is large [5]. However, unless the number of users is sufficiently large, it may suffer from performance degradation due to interference from other users, even being worse than a single beam transmission scheme [6]. To alleviate this interference problem of the OMB, we consider a new orthogonal multi-beam scheme. For further improvement, the proposed scheme adjusts the number of orthogonal multiple beams according to the operating condition.

The remainder of this paper is organized as follows. We present a signal model considered in this paper in Section II and briefly discuss previous multi-beam schemes in Section III. The proposed orthogonal multi-beam (POMB) scheme is described in Section IV. The performance of the POMB is verified by computer simulation in Section V. Finally, conclusions are summarized in Section VI.

## II. SYSTEM MODEL

Consider the downlink cellular system, where the base station (BS) has $M$ transmit antennas and each of $K$ users has a single receive antenna. We assume that all the users have the same average SNR $\gamma_0$ 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, $\mathbf{A}^T$ and $\mathbf{A}^*$ denote the transpose and conjugate transpose or Hermitian of $\mathbf{A}$, respectively. The notation $\|\mathbf{x}\|$ denotes the Frobenius norm of vector $\mathbf{x}$.

Let $\mathbf{x}$ 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

$$y_k = \mathbf{h}_k^* \mathbf{x} + n_k \tag{1}$$

where $\mathbf{h}_k$ denotes the $(M\times 1)$ channel vector of user $k\in\{1,2,\cdots,K\}$ whose elements are zero mean complex

Gaussian random variables with unit variance, $n_k$ is zero mean complex circular-symmetric additive white Gaussian noise (AWGN).

When the signal is transmitted using $L$ beams, the transmit signal $\mathbf{x}$ can be represented as

$$\mathbf{x} = \sum_{l=1}^{L} \mathbf{w}_l s_l \tag{2}$$

where $s_l$ denotes the data symbol transmitted through the $l$-the beam $\mathbf{w}_l$. We assume that the Frobenius norm $\|\mathbf{w}_l\|$ 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. Orthogonal Multi-beam Techniques

The amount of MUD gain depends on the rate and dynamic range of channel fluctuation. Therefore, 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 beam, known as opportunistic beamforming [4]. The opportunistic beamforming transmits the signal with a single beam weight $\mathbf{w}$ generated in a random manner, while preserving the transmission power (i.e., $\|\mathbf{w}\| = 1$). Each user estimates short term SNR $\gamma_k$ for this beam and reports it to the BS. Then, the BS selects a user based on the reported SNR.

Assume that the BS employs a scheduler that allocates the resource to a user in the best SNR condition. Letting $Q$ be the index of the selected user, the short term SNR of the selected user can be represented as

$$\gamma_{\text{Opp},Q}^{(1)} \triangleq \max_{k=1,\cdots K} \gamma_0 \left|\mathbf{h}_k^* \mathbf{w}\right|^2 = \max_{k=1,\cdots K} \gamma_k^{(1)} \tag{3}$$

where the superscript number in the bracket is the beam number used for data transmission. Note that equivalent channel gain $\mathbf{h}_k^* \mathbf{w}$ has the same distribution as the channel gain in a single-input single-output (SISO) Rayleigh fading channel. Since it is possible to find a user whose channel is matched to a generated random beam as the number of users goes to infinity, the opportunistic beamforming can provide performance as the coherent beamforming [4].

The opportunistic beamforming technique can be extended to multi-user scheduling 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 $\{\mathbf{w}_l,\ l = 1,\cdots,M\}$ $(M \le K)$ satisfying [5]

$$\mathbf{w}_i^* \mathbf{w}_j = \begin{cases} 0; & i \ne j \\ 1; & i = j\ . \end{cases} \tag{4}$$

Each user estimates the SINR for a given orthonormal beam and reports the maximum SINR with the corresponding beam index to the BS. Then, the BS assigns each beam to a user with the highest SINR and thus it transmits $M$ 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

$$y_k = \mathbf{h}_k^* \mathbf{w}_l s_l + \sum_{i=1 \ne l}^{M} \mathbf{h}_k^* \mathbf{w}_i s_i + n_k \tag{5}$$

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 short term SINR can be represented as

$$\gamma_{\text{OMB},Q(l)}^{(M)} \triangleq \max_{k=1,\cdots,K} \frac{\left|\mathbf{h}_k^* \mathbf{w}_l\right|^2 \gamma_0}{\sum_{i=1 \ne l}^{M} \left|\mathbf{h}_k^* \mathbf{w}_i\right|^2 \gamma_0 + M} \tag{6}$$

Since $\{\mathbf{h}_k^* \mathbf{w}_l,\ l = 1,\cdots,M\}$ are independent complex Gaussian random variables, the desired signal power $\left|\mathbf{h}_k^* \mathbf{w}_l\right|^2$ and the interference power $\sum_{i=1 \ne l}^{M} \left|\mathbf{h}_k^* \mathbf{w}_i\right|^2$ 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 fixed $M$ number of multiple beams for data transmission. It can be seen that 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, significantly reducing the interference from other users. As a consequence, 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 from other users. As a consequence, the performance of the OMB can be even worse than that of the opportunistic beamforming [6].

## IV. Proposed Orthogonal Multi-beam Technique

Unless the number of users is sufficiently large, the OMB may not sufficiently separate the selected users due to the channel mismatch between the orthogonal beam and the selected user. In this case, the use of a single beam can be better than the use of multiple beams. To alleviate this problem, we consider the generation of beams while controlling the interference to others. The number of beams for data transmission is adjusted in response to the operating condition to reduce the interference effect.

Fig. 1 illustrates the transmission procedure of the proposed orthogonal multi-beam scheme. It first generates $M$ orthonormal random beams with weight $\mathbf{W} = \{\mathbf{w}_1 \mathbf{w}_2 \cdots \mathbf{w}_M\}$ as in the OMB [5]. The SINR of user $k$ for the $l$-the beam can be represented as

$$\gamma_{\text{Pro},k,l}^{(M)} = \frac{\left|\mathbf{h}_k^* \mathbf{w}_l\right|^2 \gamma_0}{\sum_{i=1 \ne l}^{M} \left|\mathbf{h}_k^* \mathbf{w}_i\right|^2 \gamma_0 + M}\ . \tag{7}$$

It can be seen that the SINR in (7) can also be represented as a function of the short term SNR assuming that each

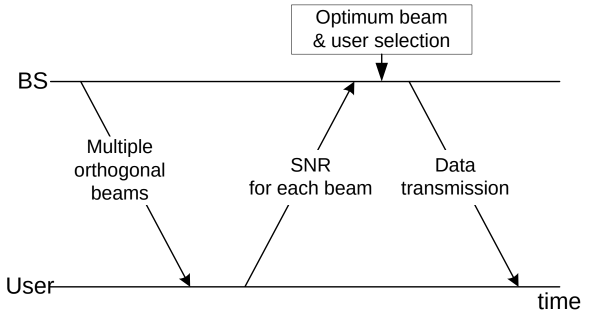



**Fig. 1. Transmission procedure of the POMB.**

beam is used for the single beam transmission as follow.

$$\gamma_{\text{Pro},k,l}^{(M)} = \frac{\gamma_{k,l}^{(1)}}{\sum_{i=1\neq l}^{M} \gamma_{k,i}^{(1)} + M}. \tag{8}$$

Thus, the user SINR can be estimated at the BS from the SNR information regardless of the number of beams. 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 from the received SNR information for possible beam pair cases. Note that unlike in the OMB scheme, the BS estimates the SINR in the proposed scheme. Since all the user's SNR for the 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 corresponding beam index. However, the amount of increased feedback overhead is small compared to the amount of full CSI feedback.

With the use of $M$ transmit antennas, the BS can generate multiple beams of up to $M$ beams in parallel for signal transmission. Note that the OMB always generates $M$ beams for signal transmission. The proposed OMB (POMB) adjusts the number of beams in use to 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 signal transmission, there can be ${}_M C_L$ number of possible choices for the multi-beam selection. Let $\pi(L,i)$ be the $i$-th choice among ${}_M C_L$ $L$-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 $3(={}_3 C_2)$ 2-beam selections (i.e., $\{(1,2),(1,3),(2,3)\}$). In this case, $\pi(3,2)$ denotes the use of beams $\{\mathbf{w}_1\ \mathbf{w}_3\}$, $b(1)=1$ and $b(2)=3$. The BS can estimate the SINR of user $k$ for the $b(l)$-th beam as

$$\gamma_{\text{Pro},k,b(l)}^{\pi(L,i)} = \frac{\gamma_{k,b(l)}^{(1)}}{\sum_{i=1\neq l}^{L} \gamma_{k,b(i)}^{(1)} + L}. \tag{9}$$

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

$$\gamma_{\text{Pro},Q(b(l))}^{\pi(L,i)} = \max\left\{\gamma_{\text{Pro},1,b(l)}^{\pi(L,i)}, \gamma_{\text{Pro},2,b(l)}^{\pi(L,i)}, \cdots, \gamma_{\text{Pro,K},b(l)}^{\pi(L,i)}\right\}. \tag{10}$$

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

$$C_{\text{Pro}}^{\pi(L,i)} = \sum_{l=1}^{L} \log_2\left(1+\gamma_{\text{Pro},Q(b(l))}^{\pi(L,i)}\right). \tag{11}$$

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

$$C_{\text{Pro}}^{(L)} = \max\left\{C_{\text{Pro}}^{\pi(L,1)}, C_{\text{Pro}}^{\pi(L,2)}, \cdots, C_{\text{Pro}}^{\pi(L,{}_M C_L)}\right\}. \tag{12}$$

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

$$C_{\text{Pro}} = \max\left\{C_{\text{Pro}}^{(1)}, C_{\text{Pro}}^{(2)}, \cdots, C_{\text{Pro}}^{(M)}\right\}. \tag{13}$$

Note that the capacity of the OMB is simply represented as $C_{\text{OMB}}^{(M)} = C_{\text{Pro}}^{(M)}$. This proves that the POMB always works better than or equal to the OMB. Moreover, it can also be seen that the POMB also works better than or equal to the opportunistic beamforming since the POMB provide $M$ times the beam selection diversity gain when a single beam is used for 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. We also assume that all the users experience the same average SNR. Then, the POMB can have two possible choices for the beam usage (i.e., $L=1$ or 2).

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

$$\gamma_{\text{Pro},k,b(l)}^{\pi(1,i)} = \gamma_0 \left|\mathbf{h}_k^* \mathbf{w}_{b(l)}\right|^2 \tag{14}$$

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 (14) without loss of generality. For simplicity of description, we also omit the subscript 'Pro' in (14).

It can be shown that $\gamma_{b(l)}^{\pi(1,i)}$ can be modeled as a second order Chi-square random variable multiplied by constant $\gamma_0$ with probability density function (pdf) given by [8]

$$f_{\gamma_{b(l)}^{\pi(1,i)}}(\gamma) = \frac{1}{\gamma_0}\exp\left(-\frac{\gamma}{\gamma_0}\right), \quad \gamma \geq 0. \tag{15}$$

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

$$\gamma_{Q(b(l))}^{\pi(1,i)} = \max\left\{\mathbf{c}_{b(l)}^{\pi(1,i)}\right\}, \tag{16}$$

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

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

$$\Gamma_z^K = OS_z^K\left\{\gamma_{1,b(l)}^{\pi(1,i)}, \gamma_{2,b(l)}^{\pi(1,i)}, \cdots, \gamma_{K,b(l)}^{\pi(1,i)}\right\} \tag{17}$$

where $OS_z^K\{\cdot\}$ denotes order statistic filtering with rank $z$. Then, the pdf and cumulative distribution function (cdf) of $\Gamma_z^K$ can respectively be represented as [9]

$$f_{\Gamma_z^K}(\gamma) = z\binom{K}{z} F_{\gamma_{b(l)}^{\pi(1,i)}}^{z-1}(\gamma)\left[1 - F_{\gamma_{b(l)}^{\pi(1,i)}}(\gamma)\right]^{K-z} f_{\gamma_{b(l)}^{\pi(1,i)}}(\gamma) \quad (18)$$

$$F_{\Gamma_z^K}(\gamma) = \sum_{q=z}^{K}\binom{K}{z} F_{\gamma_{b(l)}^{\pi(1,i)}}^{q}(\gamma)\left[1 - F_{\gamma_{b(l)}^{\pi(1,i)}}(\gamma)\right]^{K-q} \quad (19)$$

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

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

$$\begin{aligned} f_{\Gamma_{2K}^{2K}}(\gamma) &= 2K\left[F_{\gamma_{b(l)}^{\pi(1,i)}}(\gamma)\right]^{2K-1} f_{\gamma_{b(l)}^{\pi(1,i)}}(\gamma) \\ &= \frac{2K}{\gamma_0}\sum_{q=0}^{2K-1}\binom{2K-1}{q}(-1)^q \exp\left(-(i+1)\frac{\gamma}{\gamma_0}\right). \end{aligned} \quad (20)$$

The corresponding system capacity can be represented as

$$\begin{aligned} E\left\{C_{\text{Pro}}^{(1)}(\gamma)\right\} &= \int_0^\infty \log_2(1+\gamma) f_{\Gamma_{2K}^{2K}}(\gamma)\, d\gamma \\ &= \frac{2K}{\ln 2}\sum_{q=0}^{2K-1}\binom{2K-1}{q}\frac{(-1)^q}{q+1}\exp\left(\frac{q+1}{\gamma_0}\right) Ei\left(\frac{q+1}{\gamma_0}\right) \end{aligned} \quad (21)$$

where $\text{Ei(z)} = \int_z^\infty \frac{\exp(-t)}{t} dt.$

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

$$\gamma_{\text{Pro},k,b(l)}^{\pi(2,i)} = \frac{\left|\mathbf{h}_k^* \mathbf{w}_{b(l)}\right|^2}{\sum_{i=1\neq l}^{2}\left|\mathbf{h}_k^* \mathbf{w}_{b(i)}\right|^2 + 2/\gamma_0} \quad (22)$$

where $i=1$ and $l=1,2$. Let $S_D$ and $S_N$ be the denominator and numerator of $\gamma_{b(l)}^{\pi(2,i)}$ in (22), 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 $2/\gamma_0$. Letting $f_{S_D}$ and $f_{S_N}$ be the pdf of $S_D$ and $S_N$, respectively, the pdf of $\gamma_{b(l)}^{\pi(2,i)}$ can be calculated as [8]

$$f_{\gamma_{b(l)}^{\pi(2,i)}}(\gamma) = \int_0^\infty \frac{1}{w^3} f_{S_D}\left(\frac{1}{w}\right) f_{S_N}\left(\frac{\gamma}{w}\right) dw \quad (23)$$

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

$$\gamma_{Q(b(l))}^{\pi(2,i)} = \max\left\{\gamma_{1,b(l)}^{\pi(2,i)}, \gamma_{2,b(l)}^{\pi(2,i)}, \cdots, \gamma_{K,b(l)}^{\pi(2,i)}\right\} \quad (24)$$

Letting $\Gamma_{z,b(l)}^K$ be the $z$-th element of $\left\{\gamma_{1,b(l)}^{\pi(2,i)}, \gamma_{2,b(l)}^{\pi(2,i)}, \cdots, \gamma_{K,b(l)}^{\pi(2,i)}\right\}$ sorted in an ascending order, $\gamma_{Q(b(l))}^{\pi(2,i)}$ is equal to $\Gamma_{K,b(l)}^K$ having the pdf given by [8]

$$f_{\Gamma_{K,b(l)}^K}(\gamma) = K\left[F_{\gamma_{b(l)}^{\pi(2,i)}}(\gamma)\right]^{K-1} f_{\gamma_{b(l)}^{\pi(2,i)}}(\gamma) \quad (25)$$

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

$$E\left\{C_{Q(b(l))}^{\pi(2,i)}(\gamma)\right\} = \int_0^\infty \log_2(1+\gamma) K\left[F_{\gamma_{b(l)}^{\pi(2,i)}}(\gamma)\right]^{K-1} f_{\gamma_{b(l)}^{\pi(2,i)}}(\gamma)\, d\gamma \quad (26)$$

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

$$E\left\{C_{\text{Pro}}^{(2)}(\gamma)\right\} = E\left\{C_{Q(b(1))}^{\pi(2,1)}(\gamma) + C_{Q(b(2))}^{\pi(2,1)}(\gamma)\right\}. \quad (27)$$

The total capacity of the POMB can be represented as

$$C_{\text{Pro}} = E\left\{P_1 C_{\text{Pro}}^{(1)}(\gamma) + (1-P_1) C_{\text{Pro}}^{(2)}(\gamma)\right\} \quad (28)$$

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

TABLE I

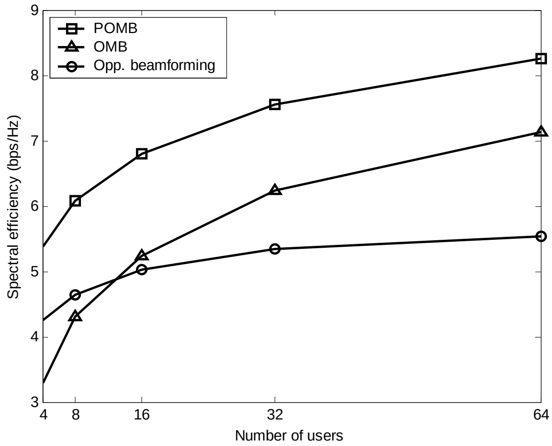
COMMON SIMULATION PARAMETERS

| Parameters | Figure 2 | Figure 3 |
|---|---|---|
| Antenna configuration | 4 Tx 1 Rx (4x1)<br>4 Tx 2 Rx (4x2) | 4 Tx 1 Rx (4x1) |
| Number of users | 4, 8, ···, 64 | 16 |
| Average SNR | 10 dB | -10 ~ 10 dB |
| Link Adaptation | Ideal<br>(i.e. using the Shannon's capacity formula) | |
| Fading channel | Rayleigh fading | |

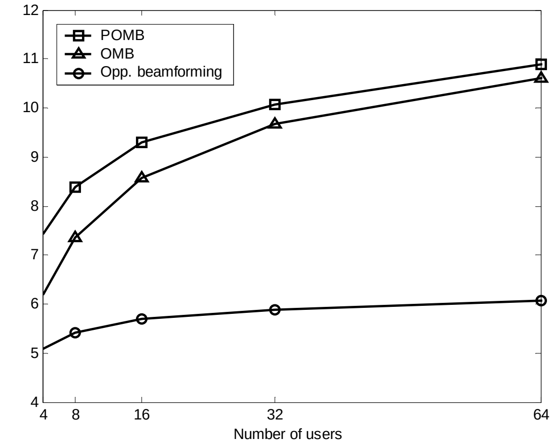
## V. PERFORMANCE EVALUATION

The performance of the POMB is verified by computer simulation. For the simulation, we assume that all the users experience mutually independent Rayleigh flat fading channel with the same average SNR. The simulation condition is summarized in Table I.

Fig. 2 depicts the performance of the POMB according to the number of active users in (4x1) MISO and (4x2) MIMO environments. The receiver employs an MMSE scheme for interference cancellation [10]. Since the use of spatial multiplexing is applicable when the SNR is high, we evaluate the performance at an SNR of 10dB. It can be seen that the OMB has poor performance in (4x1) environment when the number of uses is small because orthogonal beams can not sufficiently separate selected users, that is, selected user signals affect to other users as interference. As a consequence, interference from other users degrades the system performance. On the other hand, the OMB outperforms the opportunistic beamforming in (4x2) environment. This is mainly due to the fact that the MMSE receiver antenna technique can effectively suppress the interference from other beams. It can be seen that the POMB always provides higher spectral efficiency than conventional schemes by optimally determining the use of




(a) 4 Transmit, 1 Receive antennas




(b) 4 Transmit, 2 Receive antennas

**Fig. 2. Performance of the POMB according to the number of users.**

orthogonal beams according to the operating condition. When the POMB uses multiple beams for data transmission, the SNR for each beam is changed inversely proportional to the number of beams. However, multiple beams are utilized so that the multiplexing gain is larger than the decrease of the SNR, increasing the system performance.

Fig. 3 compares the performance of the proposed scheme with other conventional schemes according to the average SNR when the number of active users is 16. It can be seen that when the average SNR is low, the performance gain is small compared to the conventional schemes. This is mainly because the multiplexing gain is marginal in low SNR region, where the additive noise is dominant. However, when the average SNR is high, where the interference is dominant, the performance gain is noticeable. This is mainly due to the fact that the proposed scheme instantaneously optimizes the number of beams to reduce the interference effect according to the operation condition.

## IV. CONCLUSION

In this paper, we have proposed a multi-antenna transmission scheme that can simultaneously achieve the multi-user diversity and multiplexing gain by adjusting the

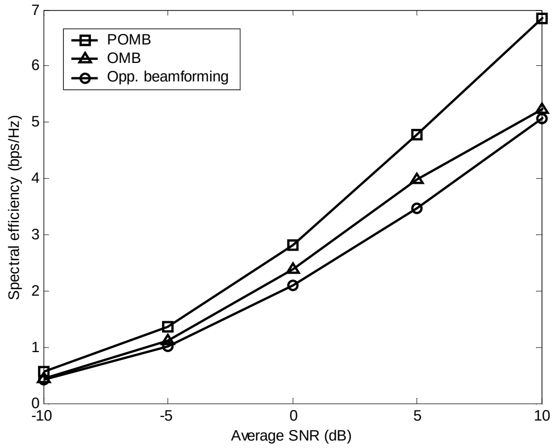



**Fig. 3. Performance of the POMB according to the average SNR.**

number of orthogonal multiple beams according to the channel condition and/or the number of users. 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. Numerical results show that the proposed scheme provides noticeable performance gain compared to the conventional schemes with a marginal increase of feedback overhead.

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