Improvement of multiuser diversity and multiplexing gain using multiple coherent beams

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Abstract: In this paper, we propose a multi-beam multiplexing scheme that can simultaneously achieve the spatial multiplexing gain, multiuser diversity gain and beamforming gain by using coherent multiple beams in the multi-user domain. Multiple beams are generated sequentially so that each beam maximizes receive signal to interference and noise power ratio (SINR) while providing zero interference toward prevously selected users. The use of multiple beams reduces the SNR of each channel (beam) in proportion to the number of beams. However, multiple beams are utilized so that the multiplexing gain is much larger than the decrease of SNR, increasing the overall system capacity. The proposed scheme is also applicable to MIMO as well as MISO schemes.

1. Introduction

[1]In recent years, the capacity of wireless systems has been increased significantly with the development of two key technologies; the use of multiple antennas known as multi-input multi-output (MIMO) [1] and an opportunistic scheduling or multi-user diversity (MUD) [4].

The MIMO system can increase a spatial multiplexing gain, increasing the system capacity in proportion to the number of antennas in rich scattering channel environment. On the other hand, by using an opportunistic scheduling technique, one can exploit MUD gain as the number of users increases [4]. Furthermore when using multiple beams, the multiplexing gain can be achieved by scheduling multiple users simultaneously [5].

The use of multiple beams, however, causes inter-beam interference resulting in degreadation of the system performance. To alleviate this problem, multi-user diversity and multiplexing (MUDAM) was proposed [3]. By generating multiple beams in a sequential manner, it minimizes interfernce toward the previously selected users while achieving the MUD gain and multiplexing gain. However, since it generates multiple beams in a random manner, it does not exploit antenna array gain, i.e. it only controls the interference between multiple beams without considering antenna array gain. In this paper, we consider an improvment of MUDAM by using coherent beamforming [6], yielding the overall system capacity larger than that of MUDAM [3] as well as opportunistic beamforming [4] and orthogonal multiple beams [5].

This paper is organized as follows. In Section 2, we introduce basic concept of the proposed scheme. The performance of the proposed scheme is verified by computer simulation in Section 3. Finally, Section 4 concludes this paper.

2. The proposed coherent MUDAM scheme

Cosider a structure of multi-user MISO system that utilizes the beamforming technique in the transmitter, where the base station has M transmit antennas and each of K users has single receive antenna. We assume that base station transmits M signals $\mathbf{s} = [s_1, s_2, ..., s_M]^T$ to M out of K users through M parallel beams. The received signal y_k of user k can be represented as

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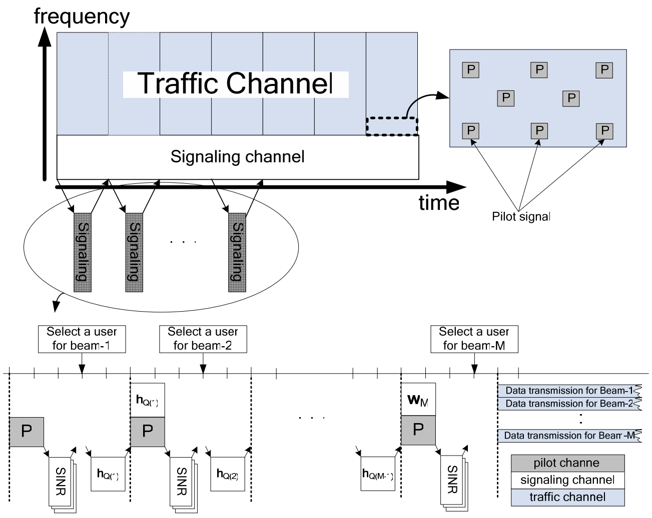

Figure 1. Beam generation procedure of the proposed scheme.

$$y_k = \mathbf{h}_k \mathbf{W}\mathbf{s} + n_k, \qquad k = 1,\ 2,\ \ldots,\ K \tag{1}$$

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

The effective channel of user k can be represented as

$$\tilde{\mathbf{h}}_k = \mathbf{h}_k \mathbf{W} \tag{2}$$

Then the received signal y_k of user k can be represented as

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

where 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.

In the proposed scheme, multiple beams are generated in a sequential manner to reduce the interference term in (3). Moreover, in the proposed shceme, each beam is generated so as to maximize the desired signal term in (3).

Figure **1** illustrates the beam generation procedure of the proposed scheme, where each user calculates the SINR assuming the use of optimum beam weight for a given channel. Let $\mathbf{w}_{1,k}$ be the optimum beam weight of user k for the first beam given channel $\mathbf{h}_k$, $\mathbf{w}_{1,k}$ can be determined as

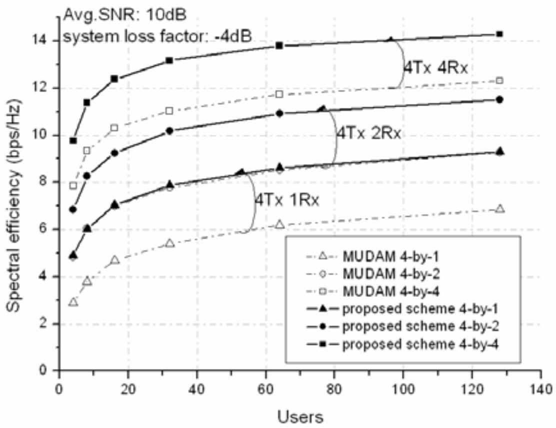

Figure 3. Comparison of system capacity between the proposed scheme and other schemes at 10dB

$$\mathbf{w}_{1,k} = \mathbf{h}_k^H / \left\| \mathbf{h}_k^H \right\| \tag{4}$$

Then, each user reports the estimated SINR to the base station through an uplink channel. The base station selects a user based on the reported SINR. Then, letting $Q(l)$ be the index of selected user for the l -th beam, the selected user reports its channel $\mathbf{h}_{Q(1)}$ to the base station. Note that only the selected user reports its channel information to the base station requiring marginal signaling burden. After receiving the channel information, the base station generates the optimun beam weight $\mathbf{w}_{1,Q(1)}$ for the first beam and broadcasts $\mathbf{h}_{Q(1)}$ to all users through the downlink signaling channel. Note that in the conventional scheme in [3], the beam weight is generated in a random manner, resulting no beamforming gain.

After receiving the channel vector $\mathbf{h}_{Q(1)}$, each user k calculates the SINR with the use of optimum beam weight $\mathbf{w}_{2,k}$ for second beam that satisfies zero interference toward pre-selected user (i.e. $\mathbf{h}_{Q(1)}\mathbf{w}_{2,k} = 0$). The optimum beam weight $\mathbf{w}_{2,k}$ of user k for second beam can be obtained as

$$\mathbf{w}_{2,k} = \left(\mathbf{h}_k^H\right)_{\perp \mathbf{h}_{Q(1)}} / \left\| \left(\mathbf{h}_k^H\right)_{\perp \mathbf{h}_{Q(1)}} \right\| \tag{5}$$

where $(\cdot)_{\perp \mathbf{h}_{Q(1)}}$ denotes the projection onto the subspace orthogonal to $\mathbf{h}_{Q(1)}$. In this manner, the optimum weight of k -th user for the l -th beam can be generated by

$$\mathbf{w}_{l,k} = \left(\mathbf{h}_k^H\right)_{\perp \mathbf{h}_{Q(1)},\ldots,\mathbf{h}_{Q(l-1)}} / \left\| \left(\mathbf{h}_k^H\right)_{\perp \mathbf{h}_{Q(1)},\ldots,\mathbf{h}_{Q(l-1)}} \right\|, \ l = 1,\ldots,l-1 \tag{6}$$

With the constraint on the interference to pre-selected users, the SINR of the selected user for the l -th beam can be represented as

$$\gamma_{l,Q(l)} = \frac{\left|\mathbf{h}_{Q(l)}\mathbf{w}_{l,Q(l)}\right|^2}{\sum_{i=0,<l}^{M} \left|\mathbf{h}_{Q(l)}\mathbf{w}_{i,Q(i)}\right|^2 + \sigma_n^2 / \sigma_s^2} \tag{7}$$

Note that the proposed scheme maximizes the desired signal term $\left|\mathbf{h}_{Q(l)}\mathbf{w}_{l,Q(l)}\right|^2$ in (7), while maintaining free interference toward the previously selected users. The proposed scheme can be applied to the MIMO system by using an eigenmode transmission

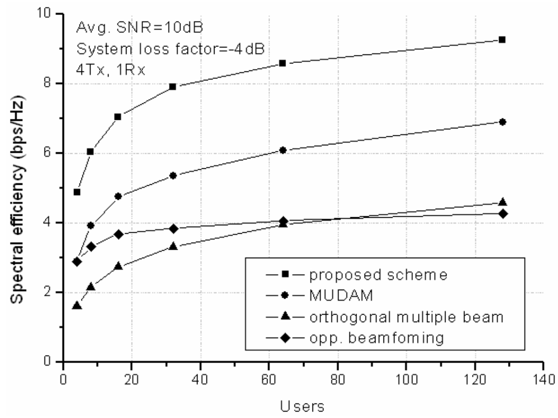

Figure 2. Comparison of system capacity between the proposed scheme and other schemes at 10dB

[6]. Thus, it enables the use of flexible antenna structures in the receiver.

3. Simulation result

Figure 2 and Figure 3 compare the performance of the proposed scheme with that of the MUDAM [3], the orthogonal multiple beams [5] and the opportunistic beamforming scheme [4]. We assumed a system loss factor is -4dB for simulation. It can be observed that the proposed scheme provides higher performance than any other schemes. This is mainly due to that in proposed scheme, each beam is generated so that it maximizes the beamforming gain for the selected user as well as maintaining zero interference to the previously selected users as in the conventional MUDAM.

4. Conclusion

In this paper, we have proposed multi-beam multiplexing scheme that provides higher performance over conventional MUDAM. The multiple beams are generated so that the desired signal power is maximized maintaining interference control ability of the conventional MUDAM. Simulation results show that the proposed scheme provides a larger system capacity than that of the conventional MUDAM, the orthogonal multiple beams, and the opportunistic beamforming regardless of the number of users. The proposed scheme can easily be applicable to MIMO systems by using eigenmode transmission, enabling the use of receivers with flexible antenna structure.

References

[1] G. J. Foschini and M. J. Gans, “On limits of wireless communications in a fading environment when using multiple antennas,” Wireless Personal Commun., Vol. 6, No. 3, pp. 311–335, June 1998

[2] S. M. Alamouti, “A simple transmit diversity technique for wireless communications,” IEEE J. Select. Areas Commun., Vol. 16, No. 8, pp. 1451 –1458, Oct. 1998.

[3] S. S. Hwang and Y. H. Lee, “Multi-beam multiplexing using multiuser diversity and random beams in wireless systems,” IEEE International Conf. on Communications (ICC), May 2005.

[4] P. Viswanath, D. N. C. Tse and R. Laroia, “Opportunistic beamforming using dumb antennas,” IEEE Trans. Inform. Theory, Vol. 48, No. 6, pp. 1277–1294, June 2002.

[5] D. C. Oh and Y. H. Lee, “An orthogonal multi-beam based MIMO scheme for multi-user wireless systems,” To appear: IEEE Vehicular Technology Conference (VTC), May 2005.

[6] T. K. Y. Lo, “Maximum ratio transmission,” *IEEE Trans. Comm.*, vol. 47, pp. 1458–1461, Oct. 1999.