A novel downlink beamforming scheme for FDD/SDMA systems

Ki−Yong Lee [*], Sung−Soo Hwang [**] and Yong−Hwan Lee [***]
School of Electrical Engineering and INMC, Seoul National University
Kwanak P. O. Box 34, Seoul 151−744, Korea

[*] hijack20@fruit.snu.ac.kr, [**] taoist@fruit.snu.ac.kr, [***] ylee@snu.ac.kr

Abstract: When beamforming is employed in the uplink without feedback channel, the beam pattern for the downlink can be generated using the weight used for uplink beamforming. However, this scheme may result in significantly performance degradation in the frequency division duplex (FDD) because of carrier frequency offset between the uplink and downlink. In this paper we propose a novel downlink beamforming algorithm based on least square method with some constraint points which have same gain in the up/downlink beam pattern. From the constraint points, we generate downlink weight and also propose how to choose the constraint points in order to satisfy the desired signal-to-interference power ratio. Simulation results show that the proposed method can sufficiently reduce the interference from other space division multiple access (SDMA) signals, providing interference-free spatial channel.

Keywords: FDD, SDMA, downlink beamforming

Ⅰ. Introduction

In recent, the use of SDMA systems has been proposed as an efficient way to improve the spectral efficiency to meet the capacity demand in mobile communication systems [1]. The SDMA system can support multiple users with the same radio channel in the same cell. In particular, it is often required for the downlink to provide higher transmission rates than the uplink.

Downlink beamforming is a powerful method for increasing the downlink capacity by providing the channel reuse in the same cell. In the time division duplex (TDD) system, it can be assumed that both the uplink and downlink have similar channel condition. As a result, it can be possible to use the same beam pattern for the uplink and downlink. In the frequency division duplex (FDD) system, since carrier frequency of the uplink and downlink is different, the beam pattern of the uplink and downlink should be differently determined [5-7]. If the beamforming weight used for the uplink is directly applied to the downlink, the location of the main lobe and nulls can be shifted, inducing interference to other users. When high-level modulation is employed, it can cause significant performance degradation

To solve this problem, several methods have been proposed. Although the use of a feedback channel can be considered [2], it requires a large overhead. Direction of arrival (DOA) can be computed using [3], but it may require large implementation. The null can be broaden to be robust to variation of the carrier frequency [4]. However, this approach may be effective only when the system uses many antennas. Carrier frequency calibration approach [5,6] maintains same main lobe position, and Null constraint (NC) [7] maintains the same null positions in up/downlink beam patterns. But the former don't maintain nulls for other users while desired user maintains same main lobe regardless of carrier frequency difference, the latter also increases the complexity that is searching for all null positions.

In this paper, we provide a practical method for downlink beamforming in the FDD/SDMA systems. The beamforming weights for the downlink is generated that for the uplink. The proposed scheme is based on least square method with some constraint points which have same gain in the up/downlink beam pattern. And we also propose constraint points selecting method that guarantees signal-to-interference ration (SIR) of desired user.

This paper is organized as follows. System model is presented in Section 2. In Section 3, the proposed downlink beamforming algorithm is derived. Section 4 verifies the performance using simulation. Finally, Section 5 summaries conclusions.

Ⅱ. System model

We consider a multi-input single-output (MISO) channel for each user, i.e., the base station has an N antenna array and each mobile has a single antenna. Let $\mathbf{h}_i$,$1 \le i \le L$, denote the an $(N \times 1)$ spatial channel from the base station to the mobile i, where L is the number of mobiles [9]. We assume that the base station simultaneously communicates with L mobiles with downlink beamforming.

The transmitted signal can be represented as

$$\mathbf{x} = \sum_{i=1}^{L} \mathbf{w}_{d,i} s_i(t) \quad (1)$$

where $\mathbf{w}_{d,i} = [w_{d,i_1} \; w_{d,i_2} \; \ldots \; w_{d,i_N}]^T$ is the downlink weight vector of the $i-$th mobile, $s_i(t)$ is the transmitted data symbol of the $i-$th mobile and the superscript T denotes the transpose of a vector. The received signal for $i-$th mobile can be represented as

$$r_i(t) = s_i^*(t)\mathbf{w}_{d,i}^H \mathbf{h}_i + \sum_{j \ne i}^{L} s_j^*(t)\mathbf{w}_{d,j}^H \mathbf{h}_i + n_i, \; 1 \le i \le L \quad (2)$$

where n_i denotes zero-mean additive white Gaussian noise with variance σ^2, and the superscripts * and H denote the conjugate and conjugate transpose of a vector, respectively. The first term on the right side of (2) is the desired signal and the second term is the interference to $i-\text{th}$ mobile. Thus, SIR of the $i-\text{th}$ mobile can be represented as

$$\gamma_i = \frac{\left|\mathbf{w}_{d,i}^H \mathbf{h}_i\right|^2}{\sum_{j\neq i}^{L}\left|\mathbf{w}_{d,j}^H \mathbf{h}_i\right|^2},\ 1 \le i \le L \qquad (3)$$

And the downlink beam pattern is represented by

$$G_{down} = \mathbf{w}_d^H \mathbf{a}_d(\theta) \qquad (4)$$

where $\mathbf{a}_d(\theta)$ is the downlink steering vector given by

$$\mathbf{a}_d(\theta) = [1\ e^{j2\pi\frac{d}{\lambda_d}\sin\theta} \ ....e^{j2\times(N-1)\pi\frac{d}{\lambda_d}\sin\theta}]^T \qquad (5)$$

and λ_d is the downlink carrier wavelength and d is the space between the elements. Similarly, the uplink beam pattern is represented by

$$G_{us} = \mathbf{w}_u^H \mathbf{a}_u(\theta) \qquad (6)$$

where $\mathbf{a}_u(\theta)$ is the uplink steering vector

$$\mathbf{a}_u(\theta) = [1\ e^{j2\pi\frac{d}{\lambda_u}\sin\theta} \ ....e^{j2\times(N-1)\pi\frac{d}{\lambda_u}\sin\theta}]^T \qquad (7)$$

and λ_u is uplink carrier wavelength.

III. Proposed scheme

We consider the minimization of beam pattern difference between the uplink and downlink for all θ, while duplex array approach [8] is minimizing the steering vector difference of up/downlink and steering vector-modifying approach [10] transforms uplink steering vector into downlink steering vector. For easy of realization, we consider only K constraint points

$$G_u(\theta_i) = G_d(\theta_i),\ \ i=1,2,...,K \qquad (8)$$

or

$$\mathbf{w}_u^H \mathbf{a}_u(\theta_i) = \mathbf{w}_d^H \mathbf{a}_d(\theta_i),\ i=1,2,...,K \qquad (9)$$

This condition can be represented in a matrix form,

$$\mathbf{A}\mathbf{w}_d^* = \mathbf{B}\mathbf{w}_u^* \qquad (10)$$

where

$$\mathbf{A} = \begin{bmatrix} 1\ e^{j2\pi\frac{d}{\lambda_d}\sin\theta_1} & ....\ e^{j2\times(N-1)\pi\frac{d}{\lambda_d}\sin\theta_1} \\ 1\ e^{j2\pi\frac{d}{\lambda_d}\sin\theta_2} & ....\ e^{j2\times(N-1)\pi\frac{d}{\lambda_d}\sin\theta_2} \\ .... & \\ 1\ e^{j2\pi\frac{d}{\lambda_d}\sin\theta_K} & ....\ e^{j2\times(N-1)\pi\frac{d}{\lambda_d}\sin\theta_K} \end{bmatrix},\ \ \mathbf{w}_d^* = \begin{bmatrix} w_{d_1}^* \\ w_{d_2}^* \\ .... \\ w_{d_N}^* \end{bmatrix}$$

$$\mathbf{B} = \begin{bmatrix} 1\ e^{j2\pi\frac{d}{\lambda_u}\sin\theta_1} & ....\ e^{j2\times(N-1)\pi\frac{d}{\lambda_u}\sin\theta_1} \\ 1\ e^{j2\pi\frac{d}{\lambda_u}\sin\theta_2} & ....\ e^{j2\times(N-1)\pi\frac{d}{\lambda_u}\sin\theta_2} \\ .... & \\ 1\ e^{j2\pi\frac{d}{\lambda_u}\sin\theta_K} & ....\ e^{j2\times(N-1)\pi\frac{d}{\lambda_u}\sin\theta_K} \end{bmatrix},\ \ \mathbf{w}_u^* = \begin{bmatrix} w_{u_1}^* \\ w_{u_2}^* \\ .... \\ w_{u_N}^* \end{bmatrix}$$

where $K \ge N$.

Thus, the optimum weight is determined by

$$\mathbf{w}_d^* = \mathbf{A}^H\left(\mathbf{A}\mathbf{A}^H\right)^{-1}\mathbf{B}\mathbf{w}_u^* \qquad (11)$$

To reduce the computational complexity, we can K equal to N. Then we have

$$\mathbf{w}_d^* = \mathbf{A}^{-1}\mathbf{B}\mathbf{w}_u^* \qquad (12)$$

As an example, Fig 1 depicts downlink beam pattern according to constraint points of the derived downlink weight equation (12) when $N=4$, $L=3$ located at $[50^\circ, 10^\circ, -20^\circ]$ and the carrier frequency of the uplink and downlink is 1990.5MHz and 2175MHz, respectively. We consider two sets of constraint points, $[52^\circ, 30^\circ, 12^\circ, -25^\circ]$ and $[60^\circ, 20^\circ, -20^\circ, -60^\circ]$.

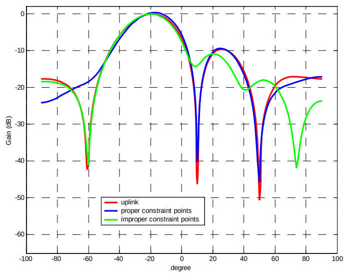

Fig 1. Beam pattern (according to constraint point)

As it can be seen in Fig 1, it is necessary to properly choose the constraint points to obtain the desired performance. Thus, we propose the proper constraint points selecting method following as: As Fig 2, (a) First of all, we estimate the 3dB beam width of each users. (b) And then we choose nulls that are included the estimated 3dB beam width. (c) The chosen nulls decide to constraint points, θ_i. (d) The other points, which subtract number of users from K, may be chosen uniformly. Here, the selected θ_i has a main role in guaranteeing same gain at θ_i location of up/downlink

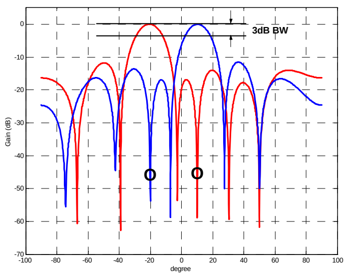

Fig 2. Constraint points selecting method

We summarize the proposed downlink algorithm following as:

1) Choose the nulls that is included the 3dB beam width of each user's main beam
2) Choose the other points uniformly
3) Insert the selected constraint points to equation (12), and generate $\mathbf{w}_d$

4) Compute gain ratio, A

If $A = \dfrac{G_{down}(\theta_i)}{\sum_{interfence} G_{down}(\theta_i)} \geq \delta$, go to step 5.

Otherwise go to step 2.

where A is signal to interference gain ratio in θ_i location and δ is a threshold of acceptability at base station.

5) Choose $\mathbf{w}_d$

Ⅳ. Numerical Results

Computer simulations are carried to verify the performance of proposed algorithm. The simulation parameters are shown in Table 1. The number of accommodated users is three. The DOA of each user is -20^o, 10^o and 50^o. The average power of each user is equal. We assume MISO channel that the base station has four, five, and six transmitting antenna elements, while the number of receiving antenna element at mobile is one. The antenna element spacing is $\lambda_u/2$ where λ_u is wavelength corresponding to an uplink carrier frequency. The modulation uses 64 QAM.

Table 1. Simulation parameters

Access scheme	SDMA
DOA of user 1, power	-20^o, 0 dB
DOA of user 2, power	10^o, 0 dB
DOA of user 3, power	50^o, 0 dB
Modulation level	64 QAM
Number of antenna elements(at BS)	4,5,6
Uplink : Downlink Carrier freq	1990.5MHz : 2175MHz
Noise	Gaussian

Fig 3. shows the downlink beam pattern of user 1 located at -20^o. We denote True(uplink), conventional, and proposed using conventional and proposed method. Here, the conventional method uses uplink weights for downlink directly while the proposed method uses the beamforming algorithm proposed in this paper. In the beam pattern using conventional method, the interference of user 3 is increased more than about 25 dB because the nulls are shifted from direction of original interference. Thus conventional beamforming can't provide the SDMA channel that is required high SIR. With proposed method, it is not generated any interference. And as the other null positions are not also generated any interference, the proposed beamforming can provide the SDMA channel.

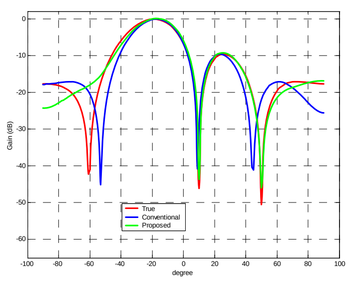

Fig 3. The proposed downlink beam pattern

Fig 4 show the BER performance of the conventional and proposed beamforming for each user, located in -20^o, 10^o, 50^o when antenna elements is four, modulation use 64 QAM. The proposed downlink beamforming outperforms conventional beamforming. Especially, in the case of user 3, we see the error floor at BER 1×10^{-1}, because user 3 is effected severe interference by distortion of beam pattern.

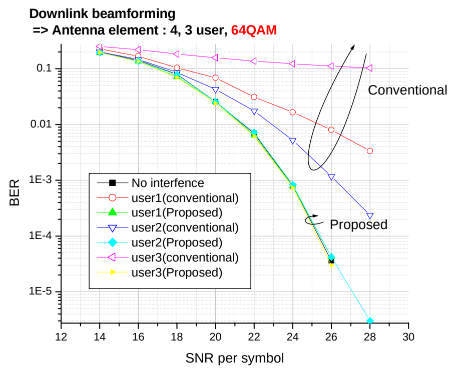

Fig 4. BER performance at the mobile (according to each user)

Fig 5 shows the BER performance of user 1 when the degree of freedom increases, that is, the number of antenna elements is four, five, and six $(N = 4,5,6)$, respectively. It also shows the same performance regardless of the number of antenna elements

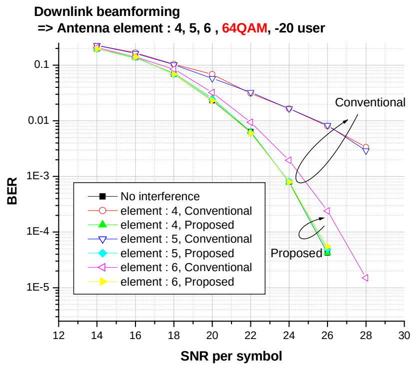

Fig 5. BER performance at the mobile (according to antenna elements)

Ⅴ. Conclusion

In this paper, we propose a novel downlink beamforming algorithm without performance degradation in FDD/SDMA system. The proposed method is based on putting the constraint points in up/downlink. From the constraint points, we generate the downlink weight equation also propose how to choose the constraint points satisfying quality of requirement to get a proper SDMA channel. The proposed method is simple and inexpensive method, which don't need feed back information. And the results of computer simulations show that the performance of the proposed algorithm outperforms the conventional case regardless of each users and the number of antenna elements.

References

[1] Chryssomallis, M, "Smart antennas," *IEEE antenna and propagation magazine*, vol. 42, pp. 129-136, June 2000

[2] D. Gerlach, A. Paulraj, "Adaptive transmitting antenna arrays with feedback," *IEEE signal processing letters*, vol. 1, pp. 150-152, Oct. 1994

[3] Guanghan Xu and Hui Lui, "An effective transmission beamforming scheme for frequency-division-duplex digital wireless communication systems," *ICASSP 1995*, vol. 3, pp. 1729-1732, May. 1995

[4] Er. M.H, " Technique for antenna array pattern synthesis with controlled broad nulls," *IEE Proceeding H*, vol. 135, pp. 375-380, Dec. 1988

[5] H. Taoka, S. Tanaka, T. Ihara, and M. Sawahashi, "Adatptive antenna array transmit diversity in FDD forward link for W-CDMA and broadband packet wireless access," *IEEE wireless communications*, vol. 9, pp. 34-41, Apr. 2002

[6]Ying-Chang Liang, and F. Chin, "FDD DS-CDMA downlink beamforming by modifying uplink Beamforming Weights," *VTC 2000*, vol. 1, pp. 170-174, Sept. 2000

[7]Ying-Chang Liang, and F. Chin, "Two suboptimal algorithms for downlink beamforming in FDD DS-CDMA mobile radio," *IEEE journal on selected area in communications*, vol. 19, pp. 1264-1275, July. 2001

[8] Gregory G. Raleigh, Suhas N. Diggavi, V.K Jones and A. Paulraj, "A Blind adaptive transmit antenna algorithm for wireless communication," *ICC1995*, vol.3, pp. 1494-149 9, June. 1995

[9] Martin Schubert and Holger Boche, " Solvability of Coupled Downlink Beamforming Problems," *GLOBECOM 2001*, vol. 1, pp. 614-618, Nov. 2001

[10] Angeliki Alexou, Ran Hong Yan, "Downlink capacity enhancement by employing SDMA in GSM," *Sensor array and multichannel signal processing workshop. 2000*, pp. 413-417, March. 2000

[11]Gene H., *Matrix Computations*, The Johns Hopkins University Press, 1989