An efficient downlink beamforming scheme for FDD/SDMA systems

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ABSTRACT

Without channel information of the downlink, the base station can generate downlink beam pattern using the weight vector used for the uplink. In the frequency division duplex system, however, it may result in significant performance degradation due to the carrier frequency offset between the uplink and downlink. To resolve this problem, we propose an efficient downlink beamforming algorithm based on a least square method with constraints. We also consider the control of null depth to obtain a desired signal to interference power ratio. Simulation results show that the proposed scheme can sufficiently reduce the interference from other users, improving the BER performance in the downlink

I. INTRODUCTION

The use of space division multiple access (SDMA) systems has been considered as an efficient method for improvement of spectral efficiency in mobile communication systems [1]. The SDMA system can support multiple users by exploiting spatial separation between the users in the same cell.

The beamforming is a powerful method for improvement of the downlink capacity by reusing the channel 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 [2]. As a result, the downlink beamformer can use the same weight as the uplink one. In the frequency division duplex (FDD) system, however, the use of same beam weight may not be applied to both the uplink and downlink because of different carrier frequencies [3]. If the weight of the uplink beamformer is directly applied to the downlink, the positions of the main lobe and nulls can be shifted, resulting in additional interference to other users. In a high-level modulation scheme such as 64-QAM, it can cause significant performance degradation.

To mitigate this problem, a number of methods have been proposed. The use of a feedback channel was proposed to determine the downlink weight in the FDD system [4]. However, the latency problem, due to the roundtrip and processing time, may decrease the spectral efficiency. Without the use of a feedback channel, the downlink weight can be obtained by making an effective use of desired and interference signal subspaces extracted from the uplink signal [5]. However, this subspace-based algorithm involves singular value decomposition of complex matrix, requiring a large computational complexity. The weight can be obtained by transposing the second order statistics of the channel from the uplink to the downlink in a least square (LS) sense [6]. However, this method may not be able to make a zero gain in the direction of interference signals. By broadening the phase of nulls, it may be possible to make the nulls robust to the variation of carrier frequency [7]. This approach can be effective only when the system uses many antennas. The direction of the main lobe in the downlink beam can be adjusted by using a frequency calibration method [3]. However, it may not provide the nulls for other users. The downlink beam pattern can be modified so that the null positions of the downlink coincide with those of the uplink [8]. However, this approach requires a large computational complexity in search of all null positions of each user.

In this paper, we propose an efficient downlink beamforming scheme for FDD/SDMA systems. The downlink weight is generated using an LS method with some gain constraints at the interested phases. We also propose a method for control of the null depth to provide a desired signal to interference power ratio (SIR) by putting a scaling factor on the constraints.

This paper is organized as follows. The system model is described in Section II. In Section III, the proposed downlink beamforming scheme is derived. The performance of the proposed scheme is verified by computer simulation in Section IV. Finally, Section V summarizes the 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 an $(N \times 1)$ spatial channel from the base station to mobile i , where L is the number of mobiles [9]. We assume that the base station simultaneously communicates with L mobile stations using downlink beamforming, where $L \le N$.

The transmitted signal can be represented as

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

where $\mathbf{w}_{d,i} = [w_{d,i_1} \ w_{d,i_2} \ \ldots \ w_{d,i_N}]^T$ is an $N-$ dimensional downlink weight vector to the $i-$ th mobile and $s_i(t)$ denotes the data symbol to the $i-$ th mobile. Here, the superscript

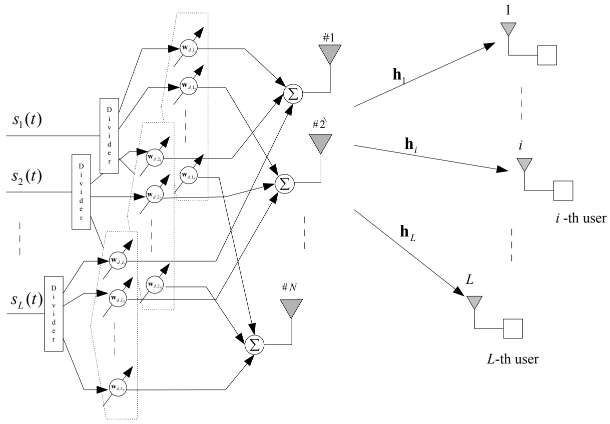

Fig. 1. Adaptive antenna scheme for downlink transmission

T denotes the transpose of a vector. The received signal of the $i-$th mobile can be represented as

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

where n_i denotes zero-mean complex-valued additive white Gaussian noise (AWGN) with variance σ^2, and the superscript H denotes conjugate transpose of a vector. The first term in the right side of (2) is the desired signal and the second term is the interference to the $i-$ th mobile. The SNIR of the $i-$th mobile can be defined as

$$SNIR_i = \frac{\left|\mathbf{h}_i^H \mathbf{w}_{d,i}\right|^2}{\sum_{j \neq i}^{L} \left|\mathbf{h}_i^H \mathbf{w}_{d,j}\right|^2 + \sigma^2},\ 1 \leq i \leq L \quad (3)$$

For a given steering vector of the downlink

$$\mathbf{a}_d(\theta) = \left[1\ e^{j2\pi\frac{d}{\lambda_d}\sin\theta}\ \ldots\ldots\ e^{j2\times(N-1)\pi\frac{d}{\lambda_d}\sin\theta}\right]^T \quad (4)$$

the gain of the downlink beam is defined as

$$G_d = \left|\mathbf{w}_d^H \mathbf{a}_d(\theta)\right| \quad (5)$$

where λ_d is the wavelength corresponding to the downlink carrier frequency and d is the space of the antenna elements. Similarly, for a uplink steering vector given by

$$\mathbf{a}_u(\theta) = \left[1\ e^{j2\pi\frac{d}{\lambda_u}\sin\theta}\ \ldots\ldots\ e^{j2\times(N-1)\pi\frac{d}{\lambda_u}\sin\theta}\right]^T \quad (6)$$

the gain of the uplink beam is also defined as

$$G_u = \left|\mathbf{w}_u^H \mathbf{a}_u(\theta)\right| \quad (7)$$

where λ_u is the carrier wavelength of the uplink.

III. The proposed beam forming scheme

For ease of implementation, we consider the gain of the uplink and downlink beam pattern at K number of phases with scaling factor

$$G_d(\theta_i) = \delta_i \cdot G_u(\theta_i),\ \ i=1,2,\ldots,K \quad (8)$$

or

$$\left|\mathbf{w}_d^H \mathbf{a}_d(\theta_i)\right| = \delta_i \cdot \left|\mathbf{w}_u^H \mathbf{a}_u(\theta_i)\right| \quad (9)$$

where δ_i is the scaling factor at phase θ_i. This condition can be represented in a matrix form

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

where $\mathbf{A}$ and $\mathbf{B}$ are a $(K \times N)$ matrix with the $(k,n)-$th element,

$$\mathbf{A}_{k,n} = e^{j2\pi(n-1)\frac{d}{\lambda_d}\sin\theta_k} \quad (11)$$

$$\mathbf{B}_{k,n} = e^{j2\pi(n-1)\frac{d}{\lambda_u}\sin\theta_k} \quad (12)$$

and $\mathbf{\Delta}$ is a $(K \times K)$ matrix with the $(k,n)-$th element.

$$\mathbf{\Delta}_{k,n} = \begin{cases} \delta_k, & k = n \\ 0\ , & k \neq n \end{cases} \quad (13)$$

Here, the superscript * denotes complex conjugate. Thus, the downlink beamforming weight can be determined by

$$\mathbf{w}_d = \mathbf{A}^T\left(\mathbf{A}^*\mathbf{A}^T\right)^{-1}\mathbf{\Delta}^*\mathbf{B}^*\mathbf{w}_u \quad (14)$$

To reduce the computational complexity, we assume that K is equal to N. Then, we have

$$\mathbf{w}_d = \mathbf{A}^{-1}\mathbf{\Delta}^*\mathbf{B}^*\mathbf{w}_u \quad (15)$$

Note that $\mathbf{A}$ is a nonsingular matrix since it satisfies the condition of Vandermonde matrix [10].

It is desirable to efficiently choose K constraint phases, while reducing the computational complexity. As illustrated in Fig. 2, we estimate the 3dB beam width (BW) of each user. Then, we estimate the null positions in the 3dB BW because the direction of the desired signal can be different from the direction of the main lobe. These null positions can be used as the constraint phases. The rest $(N-L)$ phases can be chosen arbitrarily. We determine the scaling factor δ_i to adjust the null depth. Note that the

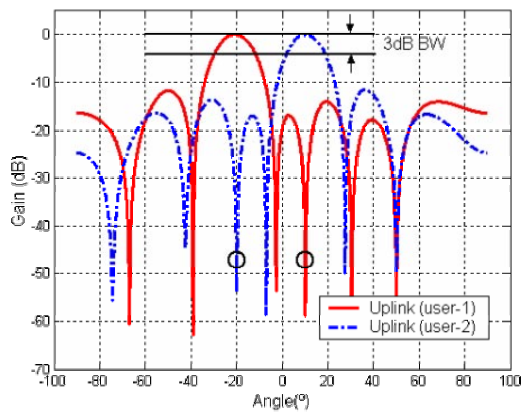

Fig. 2. Selection of constraint phases at -20° and 10° when N=7 and L=2

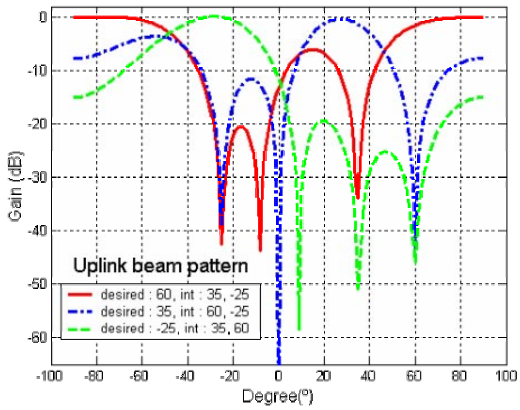

Fig. 3. Uplink beam pattern in case of close separation between the two users.

direction of the main lobe can be shifted due to noise enhancement. The noise enhancement can occur when minimizing the interference signal or separating the near-by users to maximize the SNIR. The direction of the main lobe represents the direction of the desired signal in the case of no interference or long separation between the users. An example is illustrated in Fig. 3, when the DOA of three users is -25°, 35° and 60°, respectively. It can be seen that the direction of the main lobe is different from that of the desired signal due to the near-by separation, even though the beam weight of the uplink is generated for each user using a maximum SNIR criterion.

IV. Numerical Results

The performance of the proposed scheme is verified by computer simulation. The simulation parameters are summarized in Table 1. We assume that base station transmits the signal with the same power to all the users with a single antenna. We also assume that K is equal to N.

For comparison, we consider a conventional scheme in [6] and the use of uplink weight for the downlink (Direct). Fig. 4 depicts the beam patterns with the use of four transmitter antennas, when the desired user is user-1 and the scaling factor is

Table 1. Simulation parameters

Access scheme	SDMA
DOA of user-1, power	-20°, 0dB
DOA of user-2, power	10°, 0dB
DOA of user-3, power	50°, 0dB
Modulation	64-QAM
N	4,5,6
d	$\lambda_u/2$
$f_u : f_d$	1990.5MHz:2175MHz
Channel	AWGN

$\delta=[1,1,1,1]$. It can be seen that the proposed scheme can properly generate the beam to user-1, while sufficiently reducing the amount of interference to other users. However, the use of other schemes cannot sufficiently reduce the gain at 10° and 50°, yielding a non-negligible amount of interference to user-2 and user-3. This is mainly due to the shift of null positions.

Fig. 5 depicts the BER performance of user-1 by the proposed beamforming. The proposed scheme generates the beam patterns of user-2 and user-3 so that they have very small gain at the direction of user-1. Thus, it can be seen that the BER performance of user-1 is almost the same as that without the interference. We can also see that the use of the uplink weight as the downlink weight is not working well because the co-channel interference is severely incresed by the shift of nulls.

Table 2 summarizes the SIR of each user obtained by different beamforming schemes. It can be seen that the proposed scheme consistently provides high SIR for all the users, unlike other schemes.

Fig. 6 depicts the BER performance of user-3 as the degree of freedom increases, i.e., the number of antennas increases from four to six. We can see that the proposed scheme outperforms the conventional scheme by suppressing the interference signals provided that $N \geq L$.

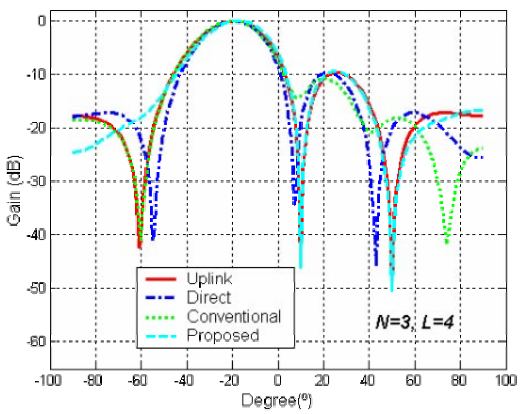

Fig. 4. Beam pattern of user-1

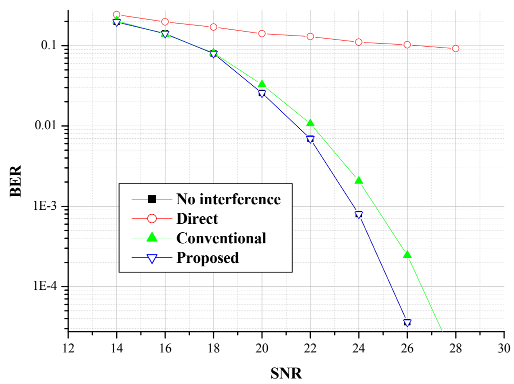

Fig. 5. BER performance of user-1

Table 2. Gain ratio to each users

	User-1	User-2	User-3
Direct	17.69 dB	15.47 dB	18.15 dB
Conventional	29.97 dB	14.04 dB	14.05 dB
Proposed	42.97 dB	41.05 dB	40.57 dB

However, conventional schemes may need more antennas than the proposed one to provide the performance similar to the proposed one.

Fig. 7 shows the effect of δ_i on the beam pattern when $N = K = 4$ and the constraint phases are $[-35^{\circ}, -20^{\circ}, 10^{\circ}, 50^{\circ}]$ with $\delta_i = [1, 0.2, 0.3, 1]$. It can be seen that the null depth on the constraint phases can be controlled by adjusting the magnitude of δ_i. The use of a smaller value of δ_i may result in the increase of sidelobe level to other directions, while reducing the null gain. The proposed null depth method can be effectively applied when strong interferences or high-data rate users exist in the downlink or different modulation schemes are employed in the uplink and downlink.

V. Conclusion

In this paper, we have proposed an efficient downlink beamforming algorithm for the FDD/SDMA system. By putting the gain constraint at a finite number of desired directions, the proposed scheme can provide desired beamforming performance by using the uplink weight information without requiring the feedback information on the channel. The gain at the desired direction can arbitrarily be controlled using a scaling factor on constraints. Simulation results show that BER performance of the proposed scheme almost identical to that without the interference.

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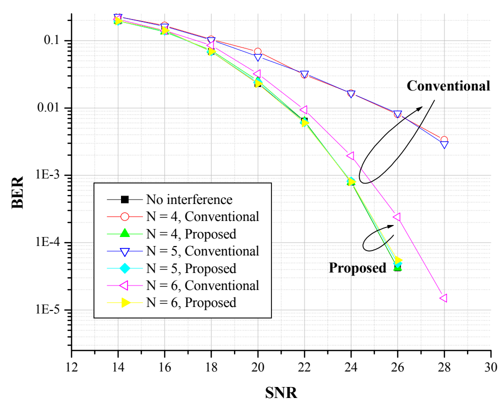

Fig. 6. BER performance of user-3

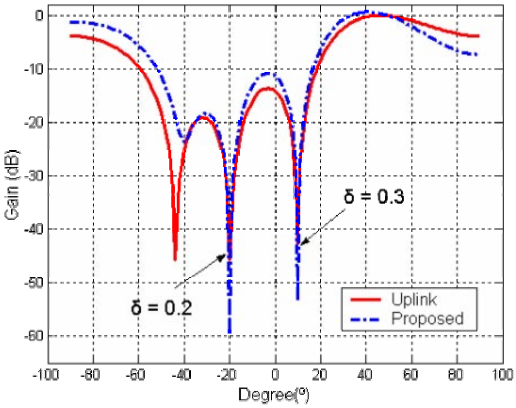

Fig. 7. Null depth control when $\delta_i = [1, 0.2, 0.3, 1]$