DOWNLINK NULL STEERING USING CHANNEL ESTIMATION IN A TDD/SDMA SYSTEM

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I. Introduction

Recently, with the demand on capacity increase, space division multiple access (SDMA) which shares the same channel with multiple users has been investigated in order to improve the channel efficiency [1]-[6]. It requires a high-performance interference canceller. The most general way is employing an adaptive array at a base station [3]-[6].

Since the adaptive array is a signal processing in signal reception, another strategy for the transmitting beam pattern control is required for such SDMA systems. Using the same null pattern as in the signal reception is effective way in a TDD system [7]-[9]. In particular, reasonable performance is obtained when the transmission slot is positioned just after the reception slot.

In general, unfortunately, the time slots of uplink and downlink are located separately and the terminal moving changes the optimum array pattern. In this paper, a novel prediction method of array weight for the downlink null steering is proposed.

II. Uplink weight estimation

A. Channel model

Defining the array response vector of k-th user as $\boldsymbol{v}^{(k)}(t) = [\ h_1^{(k)}(t),\ h_2^{(k)}(t),\ \ldots,\ h_N^{(k)}(t)\ ]^T$ where $h_n^{(k)}(t)$ denotes the channel response of k-th user at n-th element, the array input vector $\boldsymbol{x}(t)$ can be expressed by

$$\boldsymbol{x}(t) = \sum_{k=1}^{K} \boldsymbol{v}^{(k)}(t) s^{(k)}(t) + \boldsymbol{n}(t) \tag{1}$$

where $s^{(k)}(t)$ is the transmitted signal of k-th user and $\boldsymbol{n}(t)$ denotes the noise vector at the receiver.

B. Multibeam adaptive array

Fig. 1 shows the block diagram of N-element adaptive array beam former. Let us assume a weight vector $\boldsymbol{w}^{(k)}$ for k-th user of the receiver. The optimal weight vector $\boldsymbol{w}_{opt}^{(k)}$ which minimizes the mean square error between the receiver output $y^{(k)}(t) = \boldsymbol{w}^{(k)T}\boldsymbol{x}(t)$ and the reference signal, i.e. the desired signal $d^{(k)}(t)$ is obtained by

$$\boldsymbol{w}_{opt}^{(k)} = \boldsymbol{R}_{xx}^{-1} \boldsymbol{r}_{xd}^{(k)} \tag{2}$$

where

$$\boldsymbol{R}_{xx} = E[\boldsymbol{x}^*(t)\boldsymbol{x}^T(t)], \quad \boldsymbol{r}_{xd}^{(k)} = E[\boldsymbol{x}^*(t) d^{(k)}(t)]. \tag{3}$$

Here, $E[\,]$ denotes the ensemble average operation. Consequently, with preparing the reference signals for all users in the same channel, the multibeam adaptive array in K-user SDMA can be realized.

III. Downlink weight estimation

A. Weight extrapolation

It is quite natural to estimate the future weight from its locus obtained during the uplink time slot. When the time delay until the downlink time slot cannot be ignored, the stablest prediction may be given by the first-order extrapolation. The previous work [9] had employed the weight extrapolation method as shown in Fig. 2. When we calculate the weight using the RLS algorithm, the successive weights are provided during the uplink time slot. Then, the weight vectors in the downlink are linearly extrapolated from the first and last values $\mathbf{w}_1$ and $\mathbf{w}_2$ in Fig. 2 of the weight in the uplink.

B. Channel extrapolation

As an entirely different aproach, we propose the indirect weight estimation based on the channel prediction. The channel vector in the downlink is estimated using the first-order extrapolation as in Fig. 3. Then, the weight for the transmission is indirectly estimated using the predicted channel response. This requires the channel state information in the uplink. Next, we discuss its estimation method.

C. Channel estimation in the uplink

Let us describe the algorithm assuming the K-user SDMA using the N-element adaptive array. The received signal vector $\boldsymbol{x}(i)$ at time $t = iT$, where T is symbol duration, is given by $\boldsymbol{x}(i) = [\ x_1(i),\ x_2(i),\ \ldots,\ x_N(i)\ ]^T$ where $x_n(i)$ is the received signal at n-th element. Considering both the channel response $h_n^{(k)}$ at the n-th element and the transmitted symbol replica $d^{(k)}(i)$ of k-th user, the received signal replica $\hat{x}_n(i)$ is written as $\hat{x}_n(i) = \boldsymbol{h}_n^T\boldsymbol{d}(i)$ where $\boldsymbol{h}_n$ and $\boldsymbol{d}(i)$ are defined as the channel vector at n-th element and the replica vector, respectively. These expanded forms are $\boldsymbol{h}_n = [\ h_n^{(1)},\ h_n^{(2)},\ \ldots,\ h_n^{(K)}\ ]^T$ and $\boldsymbol{d}(i) = [\ d^{(1)}(i),\ d^{(2)}(i),\ \ldots,\ d^{(K)}(i)\ ]^T$. Then, the channel vector $\boldsymbol{h}_n$ at n-th element can be estimated by minimizing the MSE between $x_n(i)$ and $\hat{x}_n(i)$ as

$$\boldsymbol{h}_n = \boldsymbol{R}_{dd}^{-1}\boldsymbol{r}_{dx} \tag{4}$$

where

$$\boldsymbol{R}_{dd} = E[\boldsymbol{d}^*(i)\boldsymbol{d}^T(i)], \quad \boldsymbol{r}_{dx} = E[\boldsymbol{d}^*(i)x_n(i)]. \tag{5}$$

It should be noted that the matrix $\boldsymbol{R}_{dd}$ is common to all elements and that the estimation procedure becomes less complex when K is small.

D. Weight calculation from predicted channel response

Using the extrapolated channel response $\hat{h}_n^{(k)}(i)$, downlink weight vector $\hat{\boldsymbol{w}}^{(k)}(i)$ of k-th user must be directly calculated. In this paper, we employ the idea to estimate the correlation matrix assuming the received signal at the downlink timing. The predicted array response vector of k-th user is expressed as $\hat{\boldsymbol{v}}^{(k)}(i) = [\ \hat{h}_1^{(k)}(i),\ \hat{h}_2^{(k)}(i),\ \ldots,\ \hat{h}_N^{(k)}(i)\ ]^T$. Then, assuming that each user's data are uncorrelated, the imaginary auto-correlation matrix at time $t = iT$ during the downlink time slot may be written as

$$\hat{\boldsymbol{R}}_{xx}(i) = \sum_{k=1}^{K} \hat{\boldsymbol{v}}^{(k)*}(i)\hat{\boldsymbol{v}}^{(k)T}(i) + \sigma^2\boldsymbol{I}, \tag{6}$$

where $\sigma^2\boldsymbol{I}$ is required to prevent $\boldsymbol{R}_{xx}(i)$ from becoming singular. Here, we put $\sigma^2 = 1.0 \times 10^{-5}$ in (6). Now, we obtain the predicted weight of k-th user in the downlink as

$$\hat{\boldsymbol{w}}^{(k)}(i) = \hat{\boldsymbol{R}}_{xx}^{-1}(i)\hat{\boldsymbol{v}}^{(k)*}(i). \tag{7}$$

IV. Performance evaluation

A. Simulation model and parameters

Computer simulations are carried out assuming the TDD/SDMA system which accommodates two users in a cell. When considering the angle-spread propagation model, Rayleigh fading channel assuming 13 reflection points around a user is employed and its angle spread $\Delta\theta$ is fixed at 5°. The average power of each user is equal and the carrier recovery at each mobile terminal is assumed to be perfect.

As shown in Fig. 4, the TDMA frame format consists of 8 time slots divided into the uplink and downlink, where each time slot has a 31-symbol training sequence followed by a 97-symbol data sequence. The bit rate is 400 kbps and the modulation is QPSK.

B. Point source model

First, we consider the point source model as shown in Fig. 5. Fig. 6 shows the transmitting array patterns for both weight estimation and proposed method. At the transmission timing, the null for the undesired signal has moved to 100°. The pattern for the proposed method shows the accurate null steering in comarison to that for the direct weight prediction.

C. BER performance

Fig. 8 shows BER performance versus the average E_b/N_0, where f_D is 20 Hz and the angle-spread model shown in Fig. 7. The parameter estimation is carried out using the RLS algorithm except the ideal case where the channel response is perfectly estimated in order to evaluate the lower bound.

In the lower E_b/N_0 situation, the fixed weight shows the best performance, since both the weght extrapolation and proposed method are affected by the estimation error. Such degradation can not be seen in the ideal case of the proposed type since there is no estimation error in the uplink.

In the higher E_b/N_0 situation, the proposed method shows considerable improvement compared to other estimation methods. It shows that the indirect weight estimation based on the channel response prediction is very effective for the downlink beamforming.

V. Conclusions

In order to improve the BER performance for the downlink transmission in the TDD/SDMA system, we have proposed the indirect weight estimation method based on the channel response extrapolation. By using the proposed method, the BER performance was much improved compared with that for the conventional methods.

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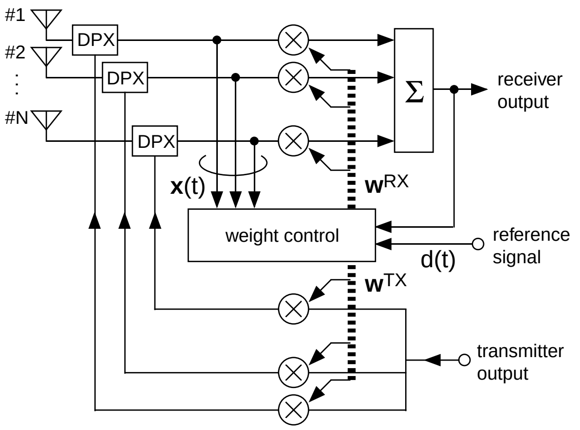

Fig. 1: Block diagram of the adaptive array for signal reception/transmission.

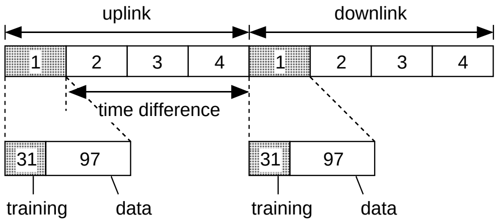

Fig. 4: TDMA frame format.

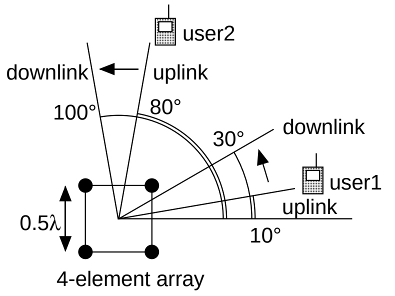

Fig. 5: Array positioning in a direction change model.

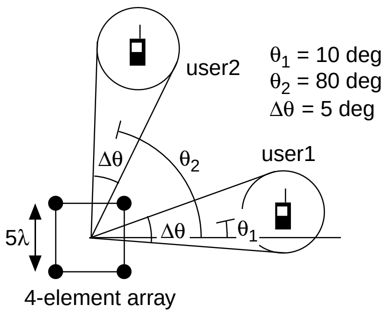

Fig. 7: Array positioning in a angle spread model.

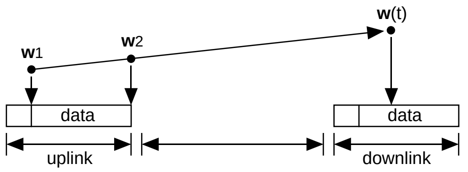

Fig. 2: Linear extrapolation of weight.

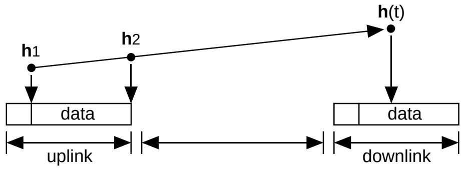

Fig. 3: Linear extrapolation of channel response.

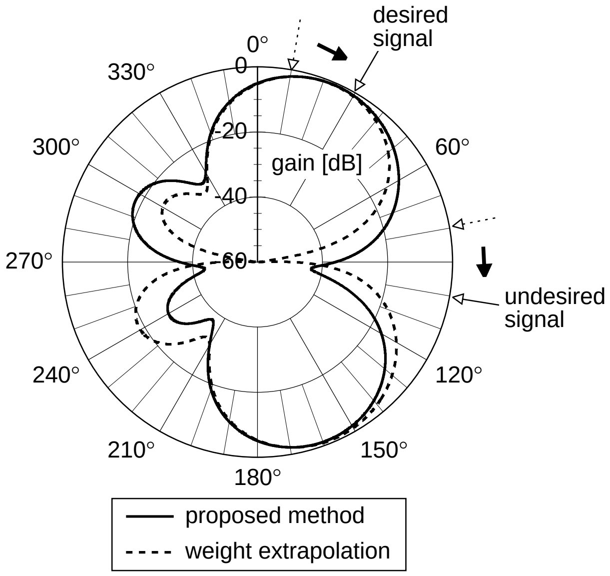

Fig. 6: Array patterns.

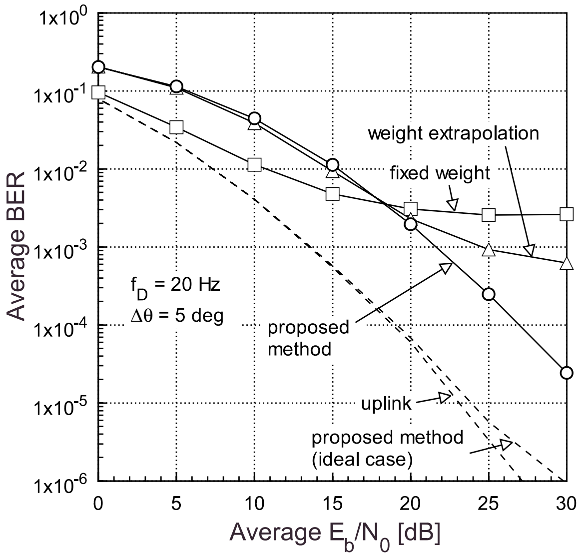

Fig. 8: BER performance versus average E_b/N_0 where f_D is 20 Hz.