주파수 선택적 채널에서 OFDMA 시스템을 위한 적응 빔포밍 방법

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Channel-Adaptive Beamforming Method for OFDMA Systems in Frequency-Selective Channels

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ABSTRACT

In this paper, a channel-adaptive beamforming method is proposed for OFDMA (Orthogonal Frequency Division Multilexing Access) systems with smart antenna, in which the size of a cluster is determined adaptively depending on the frequency selectivity of the channel. The proposed method consists of 4 steps: initial channel estimation, refinement of channel estimates, region-splitting, and computation of weight vector for each region. In the proposed method, the size of a cluster for resource unit is determined adaptively according to a region-splitting criterion. It is shown by simulation that the proposed method shows good performances in both frequency-flat and frequency-selective channels.

Key Words : OFDMA, smart antenna, beamforming, channel-adaptive, frequency selectivity.

Ⅰ. Introduction

Recently, OFDMA(Orthogonal Frequency Division Multiplexing Access) has been investigated as a promising radio transmission technology for next-generation wireless communications[1]. Also, OFDMA systems employing smart antenna were introduced to enhance SNR (Signal-to-Noise Ratio), expand service coverage, reduce CCI (Co-Channel Interference), and increase system capacity through SDMA (Spatial Division Multiplexing Access) [2]. Adaptive beamforming for OFDMA systems can be performed in either the time-domain or frequency-domain where spatial signal processing is made after FFT (Fast Fourier Transform) for individual subcarriers. In order to operate the OFDMA system with smart antenna in frequency-selective channels, frequency-domain processing is known to have more advantages [3]. However, the number of OFDMA training symbols required for frequency-domain processing is at least twice the number of antennas (N_{ant}) per subcarrier, since the number of samples required for beamforming is more than $2N_{ant}$[4]. A large number of training symbols for beamforming per subcarrier can be a heavy burden (overhead) for data transmission systems with a short payload. In order to make the required number of training symbols smaller, beamforming is generally performed by grouping

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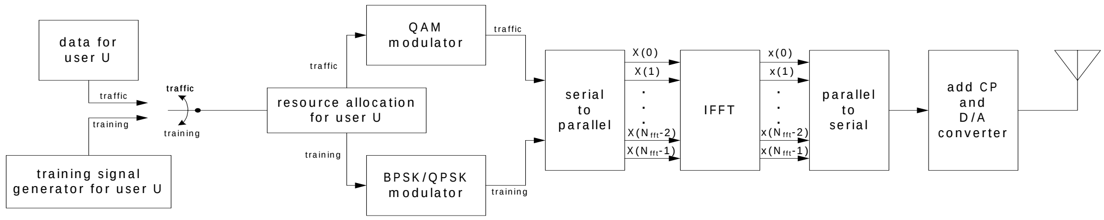
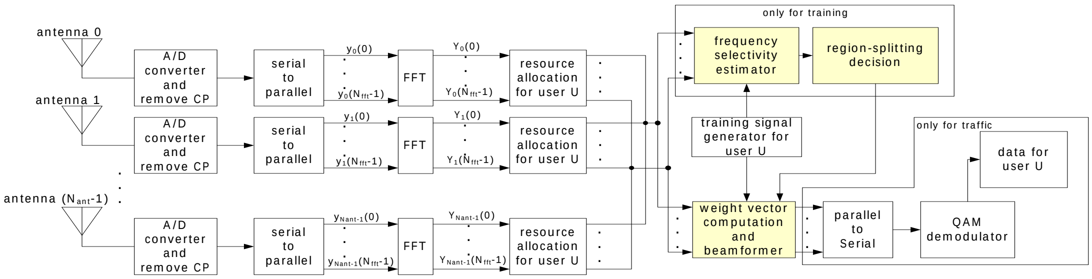


(a) Transmitter



(b) Receiver

Fig. 1. Bloack diagram of a transmitter and receiver for a channel- adaptive beamformer in OFDMA systems with smart antenna

adjacent subcarriers within the coherence bandwidth [5]. However, if the size of a cluster is too large compared to the coherence bandwidth of a channel, the beamformer will perform poorly due to incorrect estimation of the antenna weight vector. Alternatively, if the size of the cluster is too small, the performance of the beamformer will be degraded due to an insufficient number for averaging. In a real situation, frequency selectivity of a channel is time-varying, and the number of training symbols is limited in both frequency and time domain. In this paper, a channel-adaptive beamforming method is proposed for OFDMA systems with smart antenna, in which the size of a cluster is determined adaptively according to a region-splitting criterion.

Ⅱ. System Descriptions

A block diagram of a transmitter and receiver for the proposed channel-adaptive beamforming method for OFDMA systems is shown in Fig. 1. This diagram is the same as the one in the conventional uplink OFDMA system for the transmitter part (mobile). However, it is different from the one in the conventional uplink OFDMA system with smart antenna for the receiver part (base station), in that new blocks of a frequency selectivity estimator and a region-splitting detector are added, all in the frequency domain.

The frame structure for the proposed method is shown in Fig. 2. Notations used in this figure can be summarized as follows: the number of symbols for training signal: N_{train}, the number of symbols for traffic signal: $N_{traffic}$, the number of bins in a symbol: N_{bin}, and the number of subcarriers in a bin: N_{sub}. The frame structure in this figure is similar to the one in

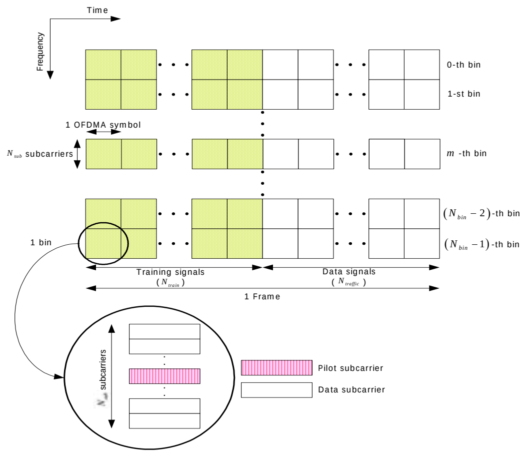


Fig. 2. Frame structure for a channel-adaptive beamformer in OFDMA systems with smart antenna

IEEE 802.16 OFDMA mode. One bin in Fig. 2 is composed of 9 adjacent subcarriers (N_{sub}=9): one for the pilot and eight for the training sequence (or data). As in IEEE 802.16 OFDMA mode, the training sequence consists of a maximum of 8 OFDMA symbols (N_{train}=8) to provide 64 QPSK (Quadrature Phase Shift Keying) symbols for training the weight vector up to 12 antennas[2]. Also, the number of symbols for training signal and the number of bins in a symbol are given as follows: $N_{traffic}$=40, N_{bin}=192.

Ⅲ. A Channel-Adaptive Beamforming Method for OFDMA Systems

In this section, the proposed channel-adaptive beamforming method consisting of four steps is described. In each step, two slightly different schemes (Scheme 1 and Scheme 2) are discussed. Scheme 1 can be considered as a general approach of channel-adaptive beamforming for OFDMA systems since it uses all the subcarriers within a region. Scheme 2 using specific subcarriers within a region can be regarded as a simplified version of the proposed method. When the required memory and computational complexity for channel-adaptive beamforming is limited, and the Scheme 2 can be applied. Here, it is assumed that N_{ant} antennas are employed at the receiver, and beamforming is performed at the receiver. The user index, U, is omitted for simplicity.

Step 1. Initial channel estimation

In Scheme 1, the channel estimate, $\hat{H}_s^m(k)$, of the k-th subcarrier in the m-th bin at the s-th antenna is given by

$$\begin{aligned}\hat{H}_s^m(k) &= \frac{1}{N_{train}}\sum_{n=0}^{N_{train}-1}\frac{Y_s^m(n,k)}{X^m(n,k)} \\ &= \frac{1}{N_{train}}\sum_{n=0}^{N_{train}-1}\left(H_s^m(n,k)+\frac{N_s^m(n,k)}{X^m(n,k)}\right) \\ &\textit{where } m=0,1,\cdots,N_{bin}-1 \textit{ and } k=0,1,\cdots,N_{sub}-1\end{aligned} \tag{1}$$

Here, N_{train}, N_{bin}, and N_{sub}, respectively, denote the number of OFDM symbols for training, bins in an OFDM symbol, and subcarriers in a bin. $X^m(n,k)$ represents the training signal of the k-th subcarrier in the m-th bin at the n-th symbol, which is already known at both the transmitter and receiver. Also, $Y_s^m(n,k)$, $N_s^m(n,k)$, and $H_s^m(n,k)$, respectively, represent the corresponding received signal, AWGN (Additive White Gaussian Noise), and the channel at the s-th antenna. In (1), the initial channel estimate of each subcarrier is obtained by LS (Least Square) method [6] and averaged over N_{train} OFDM symbols.

In Scheme 2, the channel estimate, $\hat{H}_s^m(k)$, is given by (2)

$$\begin{aligned}\hat{H}_s^m(k) &= \frac{1}{N_{train}}\sum_{n=0}^{N_{train}-1}\frac{Y_s^m(n,k)}{X^m(n,k)} \\ &= \frac{1}{N_{train}}\sum_{n=0}^{N_{train}-1}\left(H_s^m(n,k)+\frac{N_s^m(n,k)}{X^m(n,k)}\right) \\ &\textit{where } m=0,1,\cdots,N_{bin}-1 \textit{ and} \\ &\quad k=0,\ floor\left(\frac{N_{sub}-1}{2}\right), N_{sub}-1\end{aligned} \tag{2}$$

Step 2. Refinement of channel estimates

In Scheme 1, absolute values of the channels estimated by (1) are averaged over antennas as

$$\begin{aligned}\left|\tilde{H}^m(k)\right| &= \frac{1}{N_{ant}}\sum_{s=0}^{N_{ant}-1}\left|\hat{H}_s^m(k)\right| \\ &\textit{where } m=0,1,\cdots,N_{bin}-1 \textit{ and } k=0,1,\cdots,N_{sub}-1\end{aligned} \tag{3}$$

Note that in antenna systems spaced less than (wavelength/2), envelopes of channels for each subcarrier are highly correlated among antennas, while phase parts of the channels are quite different.

In Scheme 2, the absolute values of the channels estimated by (2) are averaged over antennas as

$$\begin{aligned}\left|\tilde{H}^m(k)\right| &= \frac{1}{N_{ant}}\sum_{s=0}^{N_{ant}-1}\left|\hat{H}_s^m(k)\right| \\ &\textit{where } m=0,1,\cdots,N_{bin}-1 \textit{ and} \\ &\quad k=0,\ floor\left(\frac{N_{sub}-1}{2}\right), N_{sub}-1\end{aligned} \tag{4}$$

Step 3. Region-Splitting

In Scheme 1, a decision parameter for region-splitting is defined as $\rho_{r1,\cdots,rl}^{m,l}$. At each stage, a region

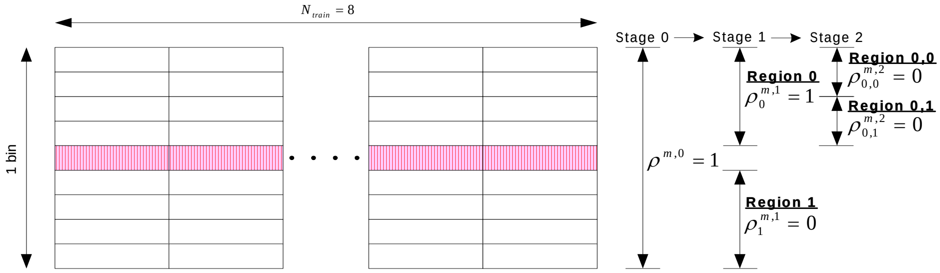


Fig. 3. An example of region-splitting in a training sequence

will be divided into two smaller regions when $\rho^{m,l}_{r1,\cdots,rl}$ =1, as shown in Fig. 3. The region will not be divided further when $\rho^{m,l}_{r1,\cdots,rl}$=0. Here, the first and second variables of the superscript in $\rho^{m,l}_{r1,\cdots,rl}$ denote the bin number and stage number, respectively. The subscript $r1,\cdots rl$ denotes the region at stage l. Region-splitting will continue until the channel in the region is regarded as frequency-flat. However, it will not go further if the number of training signals in the region is smaller than the minimum number of required training signals ($2N_{ant}$).

A criterion for region-splitting is given by

$$\frac{\min_k\left(\left|\tilde{H}^{m,l}_{r1,\cdots,rl}(k)\right|\right)}{\max_k\left(\left|\tilde{H}^{m,l}_{r1,\cdots,rl}(k)\right|\right)}\geq\lambda,\quad \begin{bmatrix}0\leq\lambda\leq 1\\ k=0,1,\cdots,N_{regsub}-1\end{bmatrix} \tag{5}$$

where N_{regsub} denotes the number of subcarriers in the region $r1,\cdots rl$ of the m-th bin. Also, $\max_k\left(\left|\tilde{H}^{m,l}_{r1,\cdots,rl}(k)\right|\right)$ and $\min_k\left(\left|\tilde{H}^{m,l}_{r1,\cdots,rl}(k)\right|\right)$ represent the maximum and minimum values of $\left|\tilde{H}^{m,l}_{r1,\cdots,rl}(k)\right|$ in the range of k in (5), respectively. Here, λ denotes a threshold value for region-splitting.

In Scheme 2, the decision parameter for region-splitting, $\rho^{m,l}_{r1,\cdots,rl}$, will be set to 0 when all three of the following criteria are satisfied:

$$\frac{\min\left(\left|\tilde{H}^m(i)\right|,\left|\tilde{H}^m(j)\right|\right)}{\max\left(\left|\tilde{H}^m(i)\right|,\left|\tilde{H}^m(j)\right|\right)}\geq\lambda,\quad 0\leq\lambda\leq 1$$

$$\begin{cases}Criterion\ \mathrm{I}:\ i=k_0\ and\ j=k_1\\ Criterion\ \mathrm{II}:\ i=k_1\ and\ j=k_2\\ Criterion\ \mathrm{III}:\ i=k_0\ and\ j=k_2\end{cases}$$

$$where\ k_0=0, k_1=floor\left(\frac{N_{sub}-1}{2}\right), k_2=N_{sub}-1 \tag{6}$$

Otherwise, it will be set to 1. Here, $max(|A|,|B|)$ and $min(|A|,|B|)$ denote a larger value and smaller value between $|A|$ and $|B|$, respectively. Note that region-splitting is performed only at stage 0 in this scheme. In this scheme, the subcarrier k_1 is inserted for the case where frequency selectivity is not detected with two outermost subcarriers.

Step 4. Computation of a weight vector for each region

In both Scheme 1 and Scheme 2, the weight vector of an adaptive beamformer, $\mathbf{w}^{m,l}_{r1,\cdots,rl}$, corresponding to the region $r1,\cdots rl$ in the final stage l, is computed by

$$\mathbf{w}^{m,l}_{r1,\cdots,rl}=\left(\mathbf{R}^{m,l}_{r1,\cdots,rl}\right)^{-1}\mathbf{p}^{m,l}_{r1,\cdots,rl} \tag{7}$$

$$\mathbf{R}^{m,l}_{r1,\cdots,rl}=E\left[\mathbf{Y}^{m,l}_{r1,\cdots,rl}(n,k)\left(\mathbf{Y}^{m,l}_{r1,\cdots,rl}(n,k)\right)^H\right] \tag{8}$$

$$\mathbf{p}^{m,l}_{r1,\cdots,rl}=E\left[\left(X^{m,l}_{r1,\cdots,rl}(n,k)\right)^*\mathbf{Y}^{m,l}_{r1,\cdots,rl}(n,k)\right] \tag{9}$$

where $(\cdot)^H$ and $(\cdot)^*$ denote the Hermitian transpose and complex conjugate, respectively. Here, (8) and (9) represent the covariance matrix, $\mathbf{R}^{m,l}_{r1,\cdots,rl}$, and cross-correlation vector, $\boldsymbol{p}^{m,l}_{r1,\cdots,rl}$, respectively. The expectation operator, $E[\cdot]$, in (8) and (9) can be approximated by averaging over the region $r1,\cdots,rl$ in the m-th bin. Also, $X^{m,l}_{r1,\cdots,rl}(n,k)$ and $\boldsymbol{Y}^{m,l}_{r1,\cdots,rl}(n,k)$ represent the training signal and the corresponding received signal vector of the k-th subcarrier in the region $r1,\cdots rl$ at the n-th symbol, respectively. $\boldsymbol{Y}^{m,l}_{r1,\cdots,rl}(n,k)$ is composed of N_{ant} signals received from N_{ant} antennas as follows:

$$\boldsymbol{Y}^{m,l}_{r1,\cdots,rl}(n,k)=\left[Y^{m,l}_{r1,\cdots,rl}(n,k,0)\ Y^{m,l}_{r1,\cdots,rl}(n,k,1)\cdots Y^{m,l}_{r1,\cdots,rl}(n,k,N_{ant}-1)\right]^T \tag{10}$$

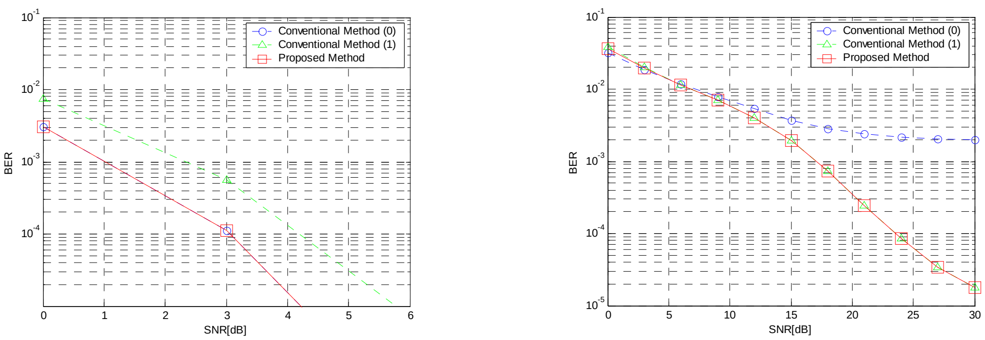
Various adaptive algorithms such as LMS (Least Mean Square) and RLS (Recursive Least Square) can be applied in this step for estimation of the weight vector for a beamformer[4].

Ⅳ. Simulation

In this section, performances of the proposed channel-adaptive beamforming method are evaluated with the following parameter set: carrier frequency=2GHz, bandwidth=20MHz, FFT size=2048, guard interval=6.4us, and the number of antennas N_{ant}=12. The number of unused subcarriers for guard band and DC is set to 320. The frame structure with corresponding parameters, used in simulation, is described in Section II. The pilot subcarrier, inserted for tracking in data transmission mode, is not used for computation of the weight vector for a beamformer. These parameter sets are similar to those specified in IEEE 802.16 OFDMA mode, especially when the AMC (Adaptive Modulation and Coding) mode configuration of 1 bin x 8 symbols is used. Power delay profiles in the ITU-R model are used for multipath fading channels at all antennas. QPSK modulation is used for both training and data transmission. The SMI (Sample Matrix Inversion) algorithm is used for estimation of the weight vector of a beamformer[4]. The threshold value for region-splitting is set to 0.9 because the coherence bandwidth, in this paper, is defined as the frequency interval over which envelopes of channel transfer functions have a correlation of 90%.

Since the RMS delay spreads of Pedestrian A and Pedestrian B channels are 45.994ns and 633.42ns, the numbers of subcarriers corresponding to 90% coherence bandwidth for the channels are approximately 44.5 and 3.2, respectively [7]. Note that the bin structure without region-splitting is appropriate for Pedestrian A channel, whereas it is too large for Pedestrian B channel. For Pedestrian B channel, it would be better to split the region into smaller ones so that channels in the smaller region can be assumed to be frequency-flat. Also notice that, since the minimum number of training signals for the system under consideration is 24, the procedure for region-splitting should not go further than stage 0. Since both schemes perform similarly within the above environment, we will consider only Scheme 2 in this simulation.

Fig. 4 compares BER (Bit Error Rate) performances of the proposed method with those of the



(a) Pedestrian A (b) Pedestrian B

Fig. 4. Comparison of BER performances (single user, DoA 20°)

conventional method for Pedestrian A and Pedestrian B channels. Here, the DoA of a user is set to 20°. In this figure, the lines with "Conventional Method" represent cases where a fixed number of subcarriers is used for training sequences in all channel environments. The value in parenthesis is the decision parameter for region-splitting of the m-th bin. In this figure, "Conventional Method (0)", which is the same case as $\rho^{m,0}=1$ in the proposed method, signifies that all 64 training signals are used to compute the weight vector. Also, "Conventional Method (1)", which is the same case as $\rho^{m,0}=1$ in the proposed method, signifies that a bin is divided into two frequency regions, and 32 training signals are used to compute two different weight vectors. From Fig. 4(a), one can see that the case of $\rho^{m,0}=0$ performs better, since the Pedestrian A channel can be reasonably assumed to be frequency-flat and the number of signals to be used for training is greater. On the other hand, the case of $\rho^{m,0}=1$ in Fig. 4(b) performs better, since Pedestrian B channel should be regarded as frequency-selective within a bin, and the channel becomes relatively flattened as the region is split. The BER performance of the proposed method is similar to the one of conventional method with $\rho^{m,0}=0$, when Pedestrian A channel is used, and $\rho^{m,0}=1$ when Pedestrian B channel is used. In the proposed approach, channel selectivity is automatically determined by the criterion for region-splitting in (6).

Fig. 5 shows the beam pattern when the proposed channel-adaptive beamforming method is applied to Pedestrian B channel with a SNR of 9dB. Here, it is assumed that a desired user, user 0, with a DoA (Direction-of-Arrival) of 0° coexists with two CCI (Cochannel Interference) sources, user 1 with a DoA of 30°, and user 2 with a DoA of -30°, each experiencing SIR (Signal-to-Interference Ratio) of 0dB. From this figure, one can see that the beamformer forms a beam in the direction of user 0 with 0°, and place nulls in the directions of user 1 with 30°, and user 2 with -30°. Note that the empty spaces in this figure correspond to subcarriers of the guard band, pilots, and DC. From this figure, one can see that system capacity can be increased by canceling CCIs through the spatial filtering, i.e. SDMA.

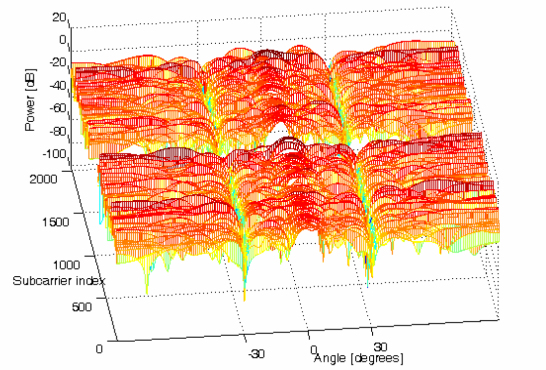


Fig. 5. Beam pattern for user 0 when 2 CCIs exist in Pedestrian B channel

Ⅴ. Conclusion

In this paper, a new beamforming method is proposed for OFDMA systems with smart antenna, in which the size of a cluster is determined adaptively depending on the frequency selectivity of the channel. The proposed method consists of four steps: initial channel estimation, refinement of channel estimates, region-splitting, and computation of a weight vector for each region. It is confirmed by computer simulation that the proposed method shows good performances for both frequency-flat and frequency-selective channels. From the corresponding beam patterns, one can confirm that system capacity can be increased by cancelling CCIs,even in frequency-selective channels. Although the proposed method, in this paper, is described for OFDMA systems, it can be applied to OFDM/TDMA systems in the same manner.

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