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New beamforming method robust against timing offsets in multiuser MIMO-OFDM systems

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1. Introduction

Increasing the spectrum efficiency is one of the most important issues facing the next generation WLAN systems [1]. Multiple–Input–Multiple–Output (MIMO) is one of the most attractive candidates with respect to this issue [2]. However, the channel capacity depends on the number of antenna branches at the mobile stations (MSs) so the possible improvement in the channel capacity for simple MSs is limited. This results in insufficient improvement in the overall spectrum efficiency when most of the MSs have only a few antenna branches.

To overcome this problem, multiuser MIMO systems were proposed [3]. In multiuser MIMO systems, multiple MSs are considered as a large virtual array antenna so that a large MIMO effect is expected even with simple MSs. In uplink multiuser MIMO systems, all of the available spatial channels are assigned to multiple MSs and the spatial resources are used effectively even when a few antenna branches are used for MSs. In uplink multiuser MIMO systems, since the perfect coordination among multiple MSs is impossible in actual wireless access ystems, the access point (AP) must cope with the frequency offsets as well as the timing offsets among multiple MSs. For the frequency offsets in multiuser MIMO-OFDM systems, we proposed the use of the pre-space-frequency equalization to suppress the interference from the other spatial channels while the frequency offset is compensated in the time domain [4]. In this paper, we focus on the timing offset problem in the uplink multiuser MIMO-OFDM systems.

For the timing offset problem, a pre-space-time equalization technique was proposed [5]. However, large number of the weights is required in a long delay spread environment and it results in a high calculation complexity. In this paper, we propose a new beamforming method to mitigate the influence of the timing offsets. It employs a multiuser detection method which we have developed for single carrier systems [6]. In the proposed method, first, the time domain signal block is converted to the frequency domain one and equalized by the beamforming. Then, the signals are converted to the time domain and the influence of the inter-block-interference (IBI) is suppressed by discarding the both ends of the signal block. To recover the discarded signals, Fast Fouried transformation (FFT) windows for the space-frequency equalization are overlapped each other. Since the configuration of the frequency-space equalization is similar to that in [4], the proposed method is also expected to be robust against the frequency offsets. The optimum weight vector for the beamforming in the proposed configuration is studied and it is found that the weight vector obtained by the minimum mean squared error (MMSE) criteria in the frequency domain is not optimum and the performance is degraded in a long delay spread environment. To attain the further improvement, a new decoding scheme using two beams for each spatial channel is proposed. Computer simulations show that the proposed scheme reduces the number of overlapped samples of the FFT block.

2. Proposed Method

2.1 Proposed Configuration

Figure 1 shows the receiver configuration for the proposed beamforming method. In the proposed method, space-frequency equalization and overlapped FFT are used to suppress interference from other spatial channels as well as the IBI. After the equalization, the signals are decoded by the conventional OFDM signal detection scheme. Figure 2 illustrates the window

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position and the equalization scheme of the proposed method. The details of the proposed method are as follows.

First, received signals at each antenna branch are input to the FFT block and the FFT is performed for all spatial signal streams. Note that guard interval (GI) is not removed here. Next, two beams are generated for each spatial signal stream in each sub-carrier and the signals from other spatial channels are suppressed. At this block, the first beam is designed to suppress the interference at the anterior part of each FFT block while the second one is designed to suppress the interference at the posterior part. The beamforming methods used in the proposed method are described in the next subsection. Then, the equalized frequency domain signal block is converted to the time domain one again by IFFT. After that, the samples are selected from the output of two beams for each sample and degraded samples at both ends of the signal block are discarded in each FFT window. By setting appropriate delays of the FFT window positions, *D*, the consecutive data samples can be obtained. Finally, the reproduced samples of each spatial channel are input to an OFDM demodulator and the normal OFDM decoding scheme is performed.

In this configuration, the number of FFT points at the space-frequency equalization part is not needed to be the same as that of the number of FFT points of OFDM, though, the different number of FFT points requires additional channel estimation. In the following, the number of FFT points for the space-frequency equalization is assumed to be equal to that of OFDM.

2.2 Beamforming Method

In the proposed configuration, two beams are generated to recover the central part of the signal block. The output signals of the *i*-th beam (i = 1 or 2) with the FFT window position delay of D_i is expressed as

$$\mathbf{y}_i^{(k)}\left(D_i\right) = \mathbf{W}_i^{(k)H}\mathbf{r}^{(k)}\left(D_i\right), \tag{1}$$

where the superscript $^{(k)}$ indicates the *k*-the frequency component, .$\mathbf{W}_i^{(k)}$ is the weight matrix for the *i*-th beam, $\mathbf{r}^{(k)}(\tau)$ is the reception signal vector of the k-th frequency component with the window position delay of τ. The first beam is designed to reproduce the anterior part of the FFT block using MMSE criteria in the frequency domain. The MMSE weight can be expressed as follows [6].

$$\mathbf{W}_1^{(k)} = \left(\mathbf{R}_d^{(k)} + \mathbf{B}_o^{(k)} + \mathbf{B}_i^{(k)} + \mathbf{R}_u^{(k)} + \sigma^2\mathbf{I}\right)^{-1}\mathbf{H}^{(k)}, \tag{2}$$

where the superscript $^{(k)}$ indicates the *k*-the frequency component, $\mathbf{W}_1^{(k)}$ is the MMSE weight matrix of the first beam, $\mathbf{R}_d^{(k)}$, $\mathbf{B}_o^{(k)}$, $\mathbf{B}_i^{(k)}$, $\mathbf{R}_u^{(k)}$ are the correlation matrices among multiple reception antennas for the desired signals, the IBI signals, the inter-symbol-interference (ISI) in the same FFT block and the signals from the undesired users respectively. σ^2 is the noise power at each receive antenna branch and $\mathbf{H}^{(k}$ is the channel response for the desired signals at the *k*-th frequency component. Since the first FFT is performed for asynchronous data, the channel responses of the posterior part of the FFT block becomes different from the anterior one. Thus, $\mathbf{W}_1^{(k)}$ suppresses the desired signals in the posterior part of the FFT block. To obtain the posterior part of the FFT block, the weight matrix for the second beam, $\mathbf{W}_2^{(k)}$, is obtained by the following equation.

$$\mathbf{W}_2^{(k)} = \left(\mathbf{R}_d^{(k)} + \mathbf{B}_o^{(k)} + \mathbf{R}_u^{(k)} + \sigma^2\mathbf{I}\right)^{-1}\mathbf{H}^{(k)}. \tag{3}$$

In this equation, since the correlation matrix for the ISI component is removed, $\mathbf{W}_2^{(k)}$ does not suppress the posterior part of the signal block, which causes ISI within the FFT block, while the resulting ISI affects the transmission quality of the anterior part of the FFT block. The same weight matrices obtained by Eq. (2) and Eq. (3) are used for the beamforming blocks for different window positions in each spatial channel.

3. Simulation Results

3.1 Simulation Condition

The following conditions are assumed to evaluate the effectiveness of the proposed beamforming method. The number of antenna branches at the MS was one, the number of antenna branches at the AP was eight, the number of MSs was two, and the number of FFT points was 64. The GI length was assumed to be 16 symbols. The exponential delay profile with maximum delay time of 2 T_{GI} was used. The delay spreads were 100 nsec and 200 nsec. Multipath waves were assumed to be uniformly distributed at AP. Perfect channel response estimation was assumed along with no frequency offsets among multiple MSs.

3.2 Effect of the proposed method

Figure 3 shows the interference power at each sample after the space-frequency equalization. The *x*-axis indicates the sample timing at each FFT block at the frequency space equalization. The interference power is normalized by the desired signal power and it is averaged over 1,000 trials where the angle of arrival and the phase of each multipath wave are changed randomly. The first beam is generated by the MMSE criteria in the frequency domain and the second beam is generated not to suppress the desired signals at the posterior part of the FFT block. Fig. 3 shows that the proposed method increases the low interference samples by using two beams regardless of the delay spread. It is also found that the proposed method is effective when the lower interference power is required. As Fig.3 (b) shows, for the interference power of -20dB with the delay spread of 200nsec, the number of discarded samples becomes 22 in the proposed method, i.e. the combination of the beam #1 and beam #2, while that becomes 40 in the MMSE beamforming, i.e. beam #1. Thus, the effective samples are increased by the proposed decoding scheme.

4. Conclusion

This paper proposed a new beamforming method for uplink multiuser MIMO-OFDM. The proposed configuration uses the space-frequency equalization to suppress the influence of the timing offsets. In addition, the residual interference is removed by discarding both ends of each FFT block and FFT windows are overlapped to reproduce the consecutive data samples. The proposed configuration compensates arbitral arrival timing differences among multiple spatial signal streams. It was found that the weight vector derived by the MMSE criteria in the frequency domain is not optimum and the number of discarding samples is increased in the long delay spread environment. To attain the further improvement, a new decoding scheme using two beams for each spatial channel was proposed. Simulation results confirm that the proposed method suppresses the influence of the arbitral timing offsets and the number of discarded samples is reduced by the proposed method. These results confirm the effectiveness of the proposed method.

Acknowledgments

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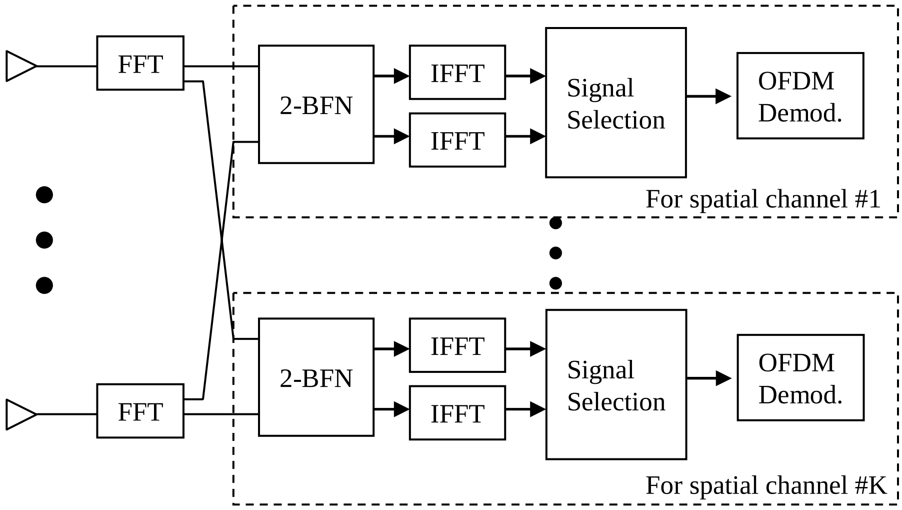


Figure 1: Proposed configuration

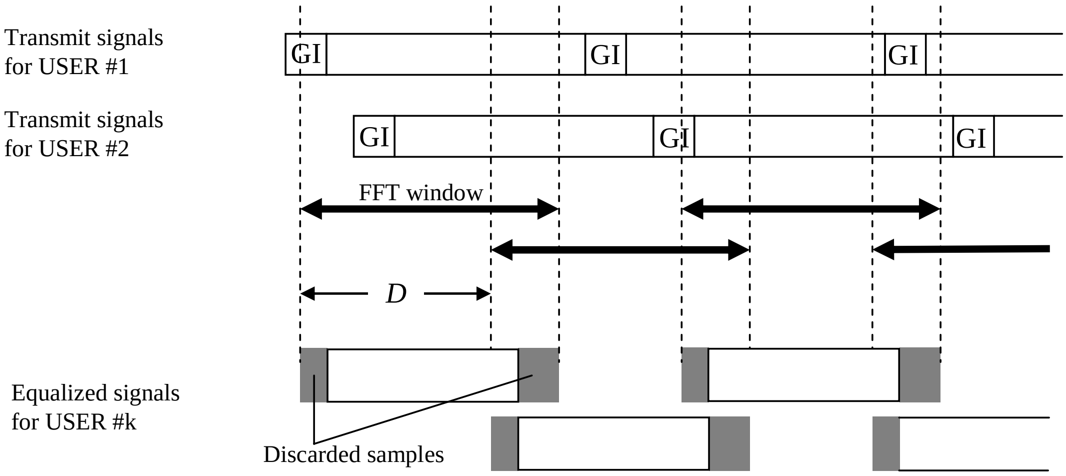
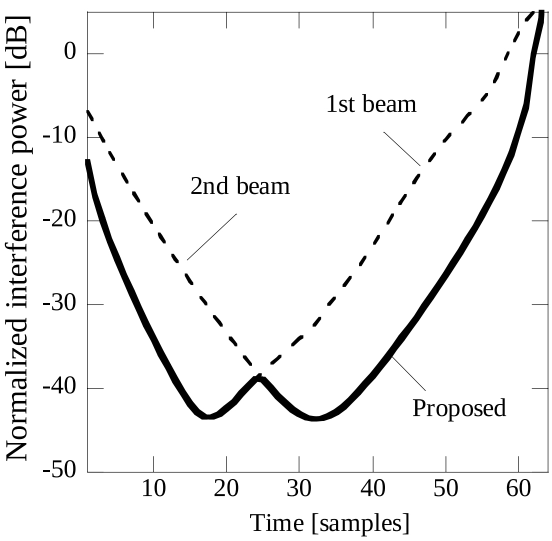
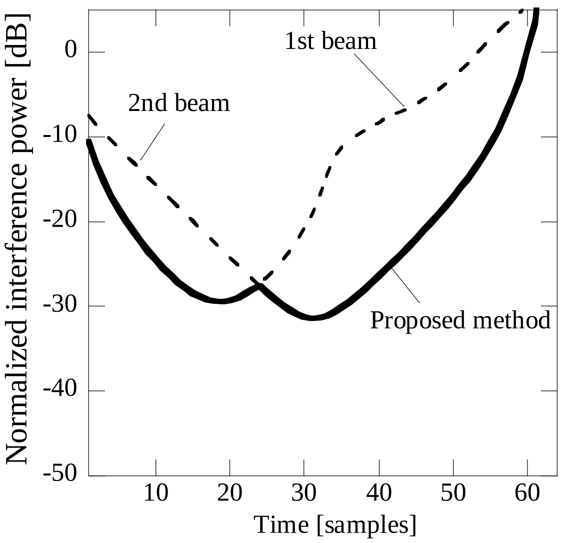


Figure 2: Proposed equalization scheme



(a) Delay spread = 100 [nsec]



(b) Delay spread =200 [nsec]

Figure 3 Normalized interference power at each symbol