Downlink Beam Forming Method for MIMO-SDMA
Using STBC for Multipath Fading Environments

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I. INTRODUCTION

With the increasing proliferation of multimedia communications, wireless access systems have gained popularity as free access systems. As the number of users increases, frequency reuse has become one of the most important issues facing mobile communications. Space-Division Multiple Access (SDMA) is an attractive candidate for better utilizing frequency resources [1-2]. In an SDMA system, adaptive array antennas are generally used at base stations and are used to generate multiple beams for terminal stations. In this system, signals from multiple terminals are spatially discriminated enabling the terminals to use the same frequency and the same timing [1]. Thus, more efficient frequency utilization is achieved by using SDMA in the downlink, which requires high channel capacity.

Since the adaptive array antennas for SDMA require the generation of deep nulls toward the interference, accurate channel response estimation is crucial to realizing an actual SDMA system. Moreover, in frequency-division-duplex (FDD) systems, since the downlink and uplink channel responses are different, downlink channel responses cannot be estimated from the uplink channel responses. To overcome this problem, open-loop and closed-loop techniques have been studied [3]. One well-known open-loop technique is the direction finding algorithm [3], which estimates the direction of arrival (DOA) from only the signals received at the base station. However, even if accurate DOAs are obtained, accurate complex amplitude estimation in the downlink is difficult, which results in degradation in the SDMA performance. Another technique is known as the "closed loop" technique, which measures raw channel responses at terminals [3] and highly accurate channel response estimation is possible. However, probing signals must be transmitted to all mobile stations from each branch of a base station antenna array. Since base stations do not form beams for the probing signal, the signal must be transmitted at high power to ensure adequate signal-to-noise ratios (SNRs). This increases the interference imposed on other cells.

We proposed a new downlink beam-forming method [4-5] that combines multiple beam-forming for each terminal and the space-time-block-coding (STBC) technique, which was developed to overcome fading environments [6]. The method not only provides a gain increase, but also robustness for fading environments. However, even using this technique, channel response estimation error occurs in fast fading environments and it causes degradation in the interference suppression performance. Thus, this method requires frequent feedback to adapt to fast fading environments.

In this paper, we propose the advanced SDMA downlink beam-forming techniques based on the above method using the Multiple-Input-Multiple-Output (MIMO) structure and this improves the interference suppression performance. In this method, the singular-value-decomposition (SVD)-minimum-mean-squared-error (MMSE) algorithm is employed for the base-station multi-beam-forming, and the MMSE combiner for each STBC signal is implemented to suppress the interference. This method improves the robustness for the Doppler frequency and reduces the amount of feedback information by dividing the feedback information into several frames. The degrees of robustness for the Doppler frequency are evaluated based on computer simulation results. This paper is organized as follows. Section II describes the proposed downlink beam-forming method. Section III presents simulation results for fading environments. Finally, the conclusions are given in Section IV.

II. PROPOSED DOWNLINK BEAM-FORMING

Figure 1 shows the system configuration of the MIMO-SDMA systems. In this system, the number of antenna elements at base stations and terminals are M and N, respectively. A base station transmits multiple data streams for K users at the same time, i.e., SDMA. At the proposed base station, B beams are generated for each user and STBC is applied to the respective multiple beams. Thus, the total

number of beams at the base station becomes *KB*. At the terminals, signals, received by each antenna element during the STBC time-block, are combined by the MMSE criteria. This enables interference suppression at the terminals. During the demodulation process, the channel responses can be estimated at the same time [4-5]. The estimates are fed-back to the base station in the up-link and those estimates are reflected in the next downlink beam-forming.

A. Base Station Configuration

Figure 2 shows the proposed base station antenna configuration for SDMA. As this figure shows, it forms *B* beams with *M* antenna elements for each user and STBC is applied to multiple beams. The signal flow is as follows. First, transmission signals $c_k(1)$, $c_k(2)$, …, $c_k(L)$ are input into the STBC encoder and *B* transmission signal streams for terminal *k* are generated. For instance, the *b*-th signal stream for user *k* can be expressed as $s_{k,b}(1)$, $s_{k,b}(2)$, …, $s_{k,b}(L/R)$ where *R* is the coding rate, *L* is the block length. After that, each signal is input into the beam-former and the signals are then transmitted from the *B* beams at the same time. In the above beam-forming stage, the beam-former employs different antenna tuples and generates different beam patterns. Thus, any kind of beam-forming algorithm can be applied to each beam-former while maintaining the transmission diversity effect. Then, the SVD-MMSE algorithm [7] is applied to optimize the directional pattern. In this algorithm, the initial weights are determined by the SVD algorithm and both the base station weight vector and the terminal weight vector are updated iteratively using the MMSE criteria. Alternatively, we employ the SVD algorithm for the base station beam-forming. With the SVD algorithm, while no iteration is required and the weight vector can be directly obtained from the estimated channel responses, it cannot suppress the interference at the transmitter. Thus, the interference must be suppressed only at the base station. The performance of both algorithms in the proposed SDMA systems is evaluated in the following section.

B. Terminal Station Configuration

Figure 3 shows the terminal antenna configuration. In the proposed SDMA system, since STBC is employed for each user, there are *KL-1* interference signals in a *K* user case. Thus, if *KL-1>N*, the interference signals cannot be suppressed by the factor of the terminal directional pattern control and additional techniques are required to suppress the residual interference. To overcome this problem, multiple MMSE-combiners for the respective desired signals are employed to demodulate the STBC signals. In the following, the control scheme is described. First, received signals are stored in memory during one STBC-block and are input into multiple demodulators for each signal, $c_k(l)$. Thus, there are *L* MMSE-combiners and the total number of input signals for each MMSE-combiner becomes *LN*. At the MMSE-combiner, all signals are combined and the interference can be eliminated. Therefore, if *KBR-1<LN*, the interference can be suppressed while gaining the transmission and the receiving diversity effect due to the surplus freedom at the receiver.

III. EFFECTS OF THE PROPOSED DOWNLINK BEAM-FORMING

In the following, the proposed downlink beam-forming method is evaluated in an angular spreading multi-path fading environment based on a computer simulation and the effectiveness of the proposed beam-forming method is confirmed.

A. Propagation environments

In the computer simulation, the number of base station antenna elements was 3, the element space was 2.0λ, the number of multi-beams for each user was 2, the STBC block number was 2, the coding rate was 1, the modulation format was QPSK, and the number of users was 2. The number of terminal antenna elements was 2 and the element space was 0.5λ. The number of incoming waves was 1,000 and flat-fading was assumed. Multi-path waves were assumed to be uniformly distributed at each terminal and the angular spread at the base station was assumed to be 60 degrees. For the proposed SDMA systems, each user did not use the *b*-th antenna element in the *b*-th beam-forming network. Thus, the *b*-th beam-forming network uses different antenna sets from those of other beam-forming networks. The SVD-MMSE algorithm and the SVD algorithm are used for each beam-forming network in the proposed method. In the conventional MIMO-SDMA beam-forming scheme, 3 antenna elements are assumed at the base station and the SVD-MMSE algorithm was used for all 3 elements comprising the array antenna. Thus, the conventional MIMO-SDMA base station forms only one beam for each terminal while the proposed SDMA base station forms multiple beams for each terminal. The estimated channel responses

are assumed to be reflected on the downlink beam-forming after T_{update} sec. Each beam is controlled to achieve the SNR of 20 dB at the terminals when $f_{d,max}T_{update}$ is 0. Then thousand trials were done and the transmission performance is evaluated by the 10% value of the output signal-to-interference-plus-noise-ratio (SINR).

B. Output SINR for Doppler Frequency

Figure 4 shows the output SINR of the conventional MIMO-SDMA and the proposed method. Additionally, the results of the conventional multiple-input-single-output (MISO)-SDMA are given. As this figure shows, since the conventional MISO-SDMA method does not have any interference suppression means at the terminals, the output SINR became lower than 0 dB when the normalized maximum Doppler frequency, $f_{d,max}T_{update}$, became greater than 0.1. On the other hand, since the conventional MIMO-SDMA system employs two antenna elements at the terminals and it employs a MMSE combiner at the terminals, the output SINR can be improved. However, in higher Doppler frequency environments, the conventional MIMO-SDMA systems also degrade the output SINR and it becomes almost 5 dB. On the contrary, the proposed method maintained the output SINR of 10 dB even in higher Doppler frequency environments. We found that a small peak appears at around $f_{d,max}T_{update} = 0.5$ in both cases. In this simulation, a uniformly distributed model is assumed at the terminal, and the direction of the terminal movement is assumed to be constant during the frame. Thus, the spatial correlation for $f_{d,max}T_{update} = 0.0$ has a peak at around $f_{d,max}T_{update} = 0.5$ and it causes a small peak. As these results show, the proposed method enables a larger T_{update} and this larger value indicates that the proposed method can reduce the feedback information in the uplink by dividing the feedback information into several frames. Therefore, the proposed method is suitable to actual FDD systems.

Figure 5 shows the cumulative probability of the output SINR for comparison of the base station beam-forming algorithms. Here, the maximum Doppler frequency $f_{d,max}DT_{update} = 0.5$ is assumed. Since the SVD algorithm has no ability to suppress the interference, the output SINR performance is significantly degraded regardless of the percentage of the cumulative probability. At the output SINR of 10 dB, the SVD algorithm achieves 60% while the SVD-MMSE algorithm achieves more than 90%. These results indicate that the null control at the base station using the SVD-MMSE algorithm is still effective even in fast fading environments in the proposed SDMA systems.

IV. CONCLUSION

A new downlink beam-forming method for MIMO-SDMA systems was proposed. It simultaneously achieves interference suppression and transmission diversity. Moreover, it can suppress the interference at terminals. Computer simulation results confirmed the robustness of the proposed beam-forming method compared to the conventional MIMO-SDMA system and that it achieved a 5-dB higher output SINR with large up-date time. It confirms that the proposed method can reduce the feedback information in the uplink by dividing the feedback information into several frames. Moreover, we compared the base station beam-forming algorithm and found that the SVD-MMSE algorithm achieves more than 90% for the output SINR of 10 dB while the SVD algorithm achieves only 60%.

Refferences

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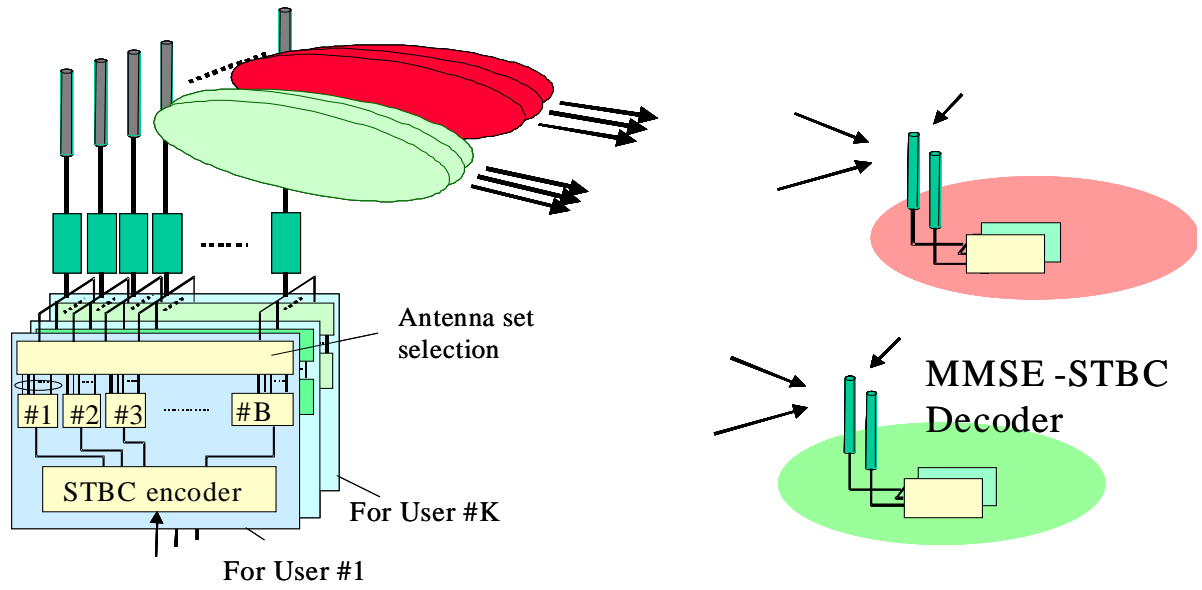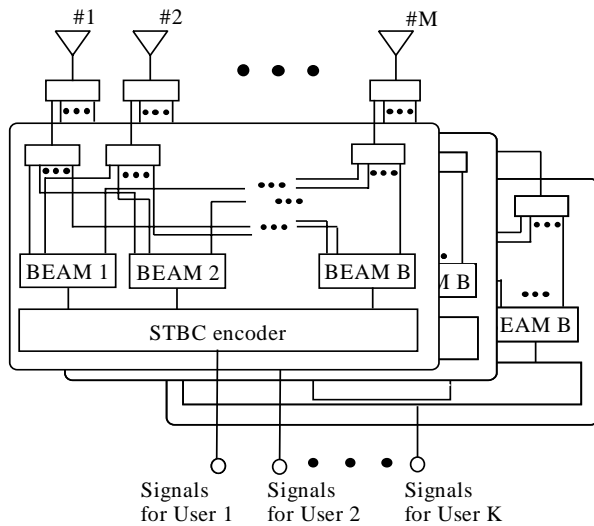
Figure 1. Proposed SDMA systems

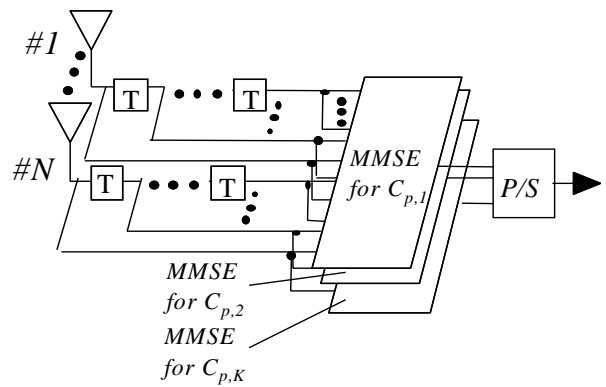**Figure 2. Base station configuration**

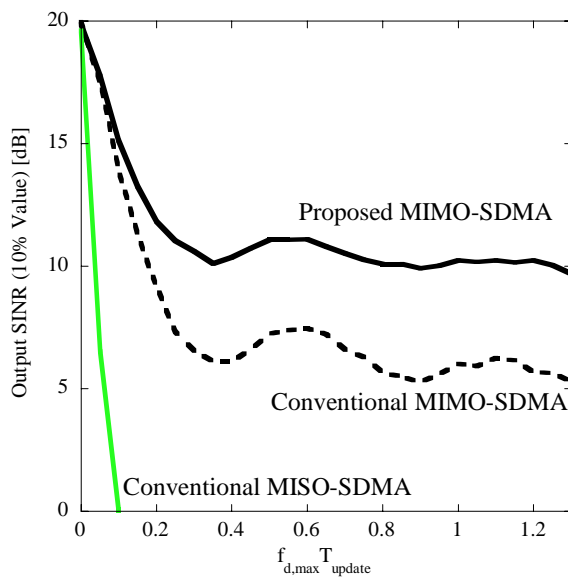**Figure 3. Terminal station configuration**
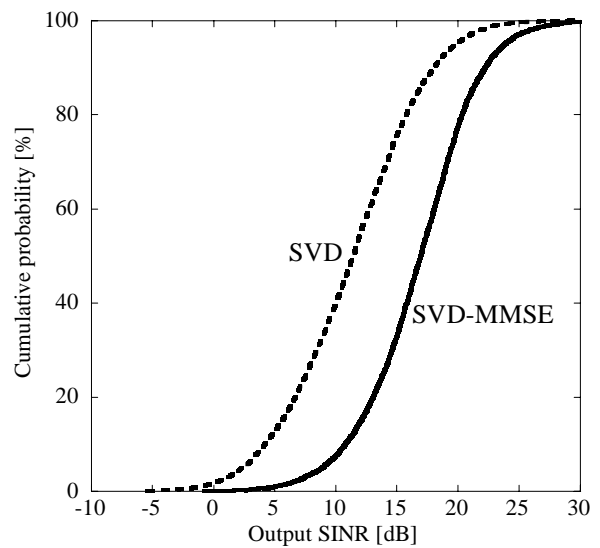

Figure 4. Influence of Doppler frequency

Figure 5. Comparison of base station beam-forming algorithms