1. Introduction

Multi-Input Multi-Output (MIMO) transmission technique, in which both transmitter and receiver are equipped with multiple antennas, is attracting attention due to its many advantages such as its throughput improvement. For this reason, various cellular mobile radio systems based on MIMO have been developed such as 3GPP LTE (Long Term Evolution) [1] and Mobile WiMAX [2]. MIMO technique is also a promising technique in next generation cellular mobile radio systems such as 3GPP LTE-Advanced [3]. However, in cellular systems, cell-edge users generally suffer from large propagation loss and large inter-cell interference, and it is difficult for conventional single-cell based MIMO technique to improve throughput performance of cell-edge users. So, there is a strong need to improve cell-edge performance for the next generation systems [4].

Multi-cell MIMO transmission technique, in which multiple Base Stations (BSs) synchronize to each other and coordinate their wireless transmission [5]-[7], is a promising candidate due to the large cell-edge performance improvement for next generation cellular mobile systems [4]. On the other hand, adaptive MIMO, in which adaptively changes among multi-antenna transmission methods pre-defined between transmitter and receiver sides, is an effective technique. For example, 3GPP-LTE specifies two adaptive MIMO transmission modes of open-loop MIMO (OL-MIMO) and closed-loop MIMO (CL-MIMO) with simple feedback control, respectively [8]. Consequently, it is considered to be effective that Multi-cell MIMO applies the concept of simple feedback based adaptive MIMO such as the OL-MIMO and the CL-MIMO. The OL-MIMO feeds back only transmit rank information (TX rank) corresponding to the number of substreams in spatial multiplexing, and it adaptively switches two precoding types of Space Frequency Block Code based transmit diversity (SFBC) [9] and Space Division Multiplexing without TX-beamforming (SDM) [10]. On the other hand, The CL-MIMO feeds back TX rank as well as an index of selected TX-beamforming matrix (precoding matrix), and it adaptively switches the number of substreams and TX-beamforming matrix.

The authors propose two coordinated multi-cell MIMO transmission methods, based on the OL-MIMO and the CL-MIMO specified in 3GPP-LTE. In this paper, open-loop MIMO based multi-cell MIMO is called as “multi-cell OL-MIMO” and closed-loop MIMO based multi-cell MIMO is called as “multi-cell CL-MIMO”. This paper also investigates the precoding control schemes of the multi-cell MIMO transmission methods. Moreover, it evaluates the proposed multi-cell MIMO schemes and clarifies the effectiveness of multi-cell CL-MIMO.

2. System Model

As shown in Figure 1, we consider downlink multi-cell MIMO transmission to a mobile station (MS) at cell-edge in a cellular mobile radio system assuming the two (N_x = 2) adjacent and coordinated BSs (i.e., master and slave BSs, hereafter, BS#1 and BS#2). BS#1 and BS#2 simultaneously transmit signals to MS with the same frequency. The signal received at the MS receiver is the sum of the signals transmitted from BS#1 and BS#2. In this configuration, it is precisely required to consider the frequency offset of the local oscillators in these BSs, and the timing offset between the received signals transmitted from these BSs. In this paper, we assume that the frequency and the timing offsets are enough to be small [6],[7].

This paper proposes two multi-cell MIMO transmission methods (i.e, multi-cell OL-MIMO and multi-cell CL-MIMO) with simple
feedback precoding control based on an enhancement of 2-TX open-loop/closed-loop single-cell MIMO specified in 3GPP-LTE [8]. The transmitted data sequences are precoded at each BS. The precoding control schemes are described in detail in Subsection 3.2. Each element of MIMO channel matrix between each BS and MS, $H^{(i)} (i = 1, 2)$, is assumed to be independent and identically distributed and quasi-static Rayleigh fading, and the feedback control delay from MS to each BS is also assumed enough to be small. Moreover, in order to focus a subcarrier in OFDM signals, narrow-band flat fading is assumed. In this paper, we assume MMSE (Minimum Mean Square Error) algorithm [10] as a signal detection algorithm to estimate transmitted signals from each BS. When BS#i uses a precoding $V_k$ $(i = 1, 2)$ and MS uses MMSE receiver, the channel capacity $C(k_1, k_2)$ can be represented as

$$C(k_1, k_2) = \sum_j \log_2 \left(1 + \gamma_j(k_1, k_2)\right).$$

(1)

where $k_i$ denotes an index of selected precoding matrix at BS#i, and $\gamma_j(k_1, k_2)$ denotes average signal-to-interference-noise power ratio (SINR) of $j$-th substream, and $\gamma_j(k_1, k_2)$ can be expressed as [10]

$$\gamma_j(k_1, k_2) = \frac{w_j^H(k_1, k_2)h_j(k_1, k_2)}{1 - w_j^H(k_1, k_2)h_j(k_1, k_2)}.$$

(2)

where

$$H(k_1, k_2) = [\sqrt{P_1} H^{(1)} V_{k_1}, \sqrt{P_2} H^{(2)} V_{k_2}],$$

w_j = H(k_1, k_2)H^H(k_1, k_2) + \sigma^2 I^{-1} h_j(k_1, k_2).$$

(3)

(4)

In the above equations, $H(k_1, k_2), h_j(k_1, k_2), P_i, I$, and $\{\cdot\}^H$ denote the aggregate channel matrix in multi-cell MIMO, $j$-th column of its aggregate channel matrix, transmission power per antenna of BS#i, an identity matrix, and conjugated transpose, respectively. $w_j(k_1, k_2)$ and $\sigma^2$ denote MMSE spatial filtering vector for $j$-th substream and thermal noise power at the MS receiver, respectively. Therefore, the indexes of the optimum precoding combination, $\{k_{1, opt}, k_{2, opt}\}$, is determined by the following equation

$$\{k_{1, opt}, k_{2, opt}\} = \arg \max_{k_1, k_2} C(k_1, k_2).$$

(5)

Meanwhile, it is possible that multi-cell MIMO degrades transmission performance compared to single-cell MIMO when there is the received power difference between the signals from coordinated BS [5]. Consequently, when multi-cell MIMO has lower channel capacity than single-cell MIMO, user data sequences are transmitted from single BS, which can obtain single-cell MIMO channel capacity compared to the other BS.

3. MIMO Transmission Methods with Feedback Precoding Control

3.1 Single-Cell MIMO with Feedback Precoding Control

Before describing the proposed multi-cell MIMO, this subsection summarizes two MIMO transmission modes with feedback precoding control for 2-TX antennas specified in 3GPP-LTE i.e, open-loop MIMO (OL-MIMO) and closed-loop-MIMO (CL-MIMO) [8].

3.1.1 Open-loop MIMO for Single-Cell

In open-loop MIMO (OL-MIMO) for single cell, the transmitter can select a precoding scheme from two precoding schemes i.e., Space Frequency Block Code (SFBC) based transmit diversity and Space Division Multiplexing without TX-beamforming (SDM). The receiver adaptively selects an optimum precoding from two precoding of SFBC and SDM so as to maximize channel capacity (throughput), and it feeds back the information of “TX rank” corresponding to the number of substreams to the transmitter. As shown in Table I, SFBC and SDM modes are selected in case of TX rank = 1 and 2, respectively.

<table>
<thead>
<tr>
<th>Number of substreams (TX Rank)</th>
<th>Precoding scheme (Multi-antenna transmission mode)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SFBC</td>
</tr>
<tr>
<td>2</td>
<td>SDM w/o TX-beamforming</td>
</tr>
</tbody>
</table>

Table I: Precoding scheme for 2-TX single-cell open-loop MIMO [8]
3.1.2 Closed-loop MIMO for Single-Cell

In closed-loop MIMO (CL-MIMO) for single cell, an optimal precoding matrix is selected from the list of precoding matrices with TX-beamforming, which is known at the receiver and the transmitter can select. As shown in Table II, in the 3GPP-LTE specifications, six precoding matrices is pre-defined (four precoding matrices (vectors) is defined when TX rank = 1, and two precoding matrices is defined when TX rank = 2). MS adaptively selects an optimum precoding matrix so as to maximize channel capacity, and it feeds back the corresponding index of the value of TX rank and the corresponding precoding matrix indicator (PMI) to the transmitter.

<table>
<thead>
<tr>
<th>Number of substreams (TX Rank)</th>
<th>Precoding matrix/vector candidates</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\frac{1}{\sqrt{2}} \begin{bmatrix} 1 \ 1 \end{bmatrix}$</td>
</tr>
<tr>
<td>2</td>
<td>$\frac{1}{\sqrt{2}} \begin{bmatrix} 1 \ 1 \end{bmatrix}$</td>
</tr>
</tbody>
</table>

3.2 Proposed Multi-Cell MIMO with Feedback Precoding Control

This subsection describes the proposed two multi-cell MIMO transmission and their precoding control schemes. The coordinated precoding control at each BS can be realized by simple feedback information from MS.

3.2.1 Open-loop MIMO Based Multi-Cell MIMO (Multi-Cell OL-MIMO)

In the OL-MIMO based multi-cell MIMO (multi-cell OL-MIMO), each BS can select a precoding type from two precoding types i.e, SFBC and SDM. Hence, in two BS multi-cell MIMO case, the number of precoding combination candidates is $2^N = 2^2 = 4$. MS adaptively selects an optimum candidate so as to maximize channel capacity, and it feeds back the corresponding TX rank information to each BS. Each BS selects SFBC and SDM in case of TX rank = 1 and TX rank = 2, respectively. It is noted that TX rank information can be different each other between BS#1 and BS#2. Moreover, when multi-cell MIMO has lower channel capacity than single-cell MIMO, user data sequences are transmitted from single BS, which has higher channel capacity of single-cell MIMO than the other BS.

3.2.2 CL-MIMO Based Multi-Cell MIMO (Multi-Cell CL-MIMO)

In the CL-MIMO based multi-cell MIMO (multi-cell CL-MIMO), each BS can select a precoding matrix from six precoding matrices as shown in Table I as well as single-cell CL-MIMO. Hence, in two BS multi-cell MIMO case, the number of precoding combination candidates is $6^N = 6^2 = 36$. MS adaptively selects an optimum precoding matrix combination so as to maximize channel capacity, and it feeds back the corresponding index of the value of TX rank and the corresponding PMI to each BS. It is noted not only TX rank information but also precoding matrix can be different each other between BS#1 and BS#2. Moreover, when multi-cell MIMO has lower channel capacity than single-cell MIMO, user data sequences are transmitted from single BS, which has higher channel capacity of single-cell MIMO than the other BS.

4. Performance evaluations

We evaluated channel capacity characteristics of the multi-cell OL-MIMO and the multi-cell CL-MIMO. In this evaluation, we assume the same transmission power and the average received power transmitted from signals between the coordinated BSs.

Figure 2 shows the cumulative distribution function (CDF) of channel capacity in case of our proposed multi-cell OL-MIMO and multi-cell CL-MIMO, respectively at an average SNR = 5 dB. On the other hand, Figure 3 shows a mean channel capacity in case of the proposed multi-cell OL-MIMO and multi-cell CL-MIMO, respectively. In these figures, the channel capacity in case of single-cell 2x2 OL-MIMO and single-cell 2x2 CL-MIMO are plotted as a reference. From these figures, it is confirmed that the proposed multi-cell OL-MIMO/CL-MIMO can improve channel capacity compared to single-cell OL-MIMO/CL-MIMO. For example, when average SNR is 5 dB, the proposed multi-cell OL-MIMO and multi-cell CL-MIMO can approximately improve average channel capacity by 50% and 70% compared to single-cell OL-MIMO and single-cell CL-MIMO, respectively, with proposed simple feedback. The capacity of multi-cell MIMO transmission should improve the capacity by 100%, taking into account that the proposed multi-cell MIMO uses two BSs. However, there is a degradation due to the insufficient degree of freedom of MS receiver antennas, i.e., only two receive antennas for four transmit antennas (two antennas per one BS).
It is also found that multi-cell CL-MIMO can obtain higher channel capacity than multi-cell OL-MIMO because multi-cell CL-MIMO realizes coordinated TX-beamforming control based on feedback of PMI from MS. For example, when average SNR is 5 dB, the average channel capacity of multi-cell CL-MIMO can improve by about 22% compared to that of multi-cell OL-MIMO. From these results, we confirmed the effectiveness of multi-cell CL-MIMO with coordinated TX-beamforming control compared to multi-cell OL-MIMO without TX-beamforming.

5. Conclusions

This paper proposed open-loop MIMO based multi-cell MIMO (multi-cell OL-MIMO) and closed-loop MIMO based multi-cell MIMO (multi-cell CL-MIMO) with simple precoding feedback control based on an enhancement of open-loop/closed-loop single-cell MIMO specified in 3GPP-LTE. And then it also investigated their precoding control schemes. We evaluated channel capacity of multi-cell OL-MIMO and multi-cell CL-MIMO, and clarified that multi-cell CL-MIMO significantly improve channel capacity compared to multi-cell OL-MIMO.

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References