MIMO Precoding Scheduling

Technology Reports

Special Articles on Multi-dimensional MIMO Transmission Technology ― The Challenge to Create the Future ―

Precoding and Scheduling Techniques for Increasing Capacity of MIMO Channels

With IMT-Advanced imposing further demands for increasing capacity, advanced MIMO control techniques are becoming extremely important. At DOCOMO Beijing Labs, we are studying precoding and scheduling techniques to achieve higher spatial diversity gain, multiplexing gain, and multi-user diversity gain in MIMO systems.

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1. Introduction

IMT-Advanced offers a wide bandwidth of up to 100 MHz and requires higher performance while maintaining compatibility with the Long Term Evolution (LTE)[*1]. With regard to spectral efficiency, **Table 1** shows the values specified for LTE [1]-[3] and the requirements of IMT-Advanced indicated by the International Telecommunication Union - Radiocommunication sector (ITU-R) [4]. Compared with LTE (downlink 2×2, uplink 1×2), IMT-Advanced requires that the average throughput and cell edge throughput are increased by approximately 1.5 to 2 times.

The key to making further improvements in spectral efficiency is to use more antennas together with enhanced Multiple Input Multiple Output (MIMO)[*2] control techniques. In a Multi-User MIMO (MU-MIMO) environment, this entails somehow improving the spatial diversity[*3] gain, the spatial multiplexing gain[*4] and the multi-user diversity gain[*5]. Precoding techniques are generally capable of improving the first two types of gain, while scheduling techniques are generally capable of improving the latter. In particular, precoding using closed-loop control is expected to result in greater performance improvements than open-loop control due to its ability to optimize transmissions by exploiting

Table 1 Minimum requirements of IMT-Advanced (extract)

Standard		LTE (TR25.913, TR25.912, TR25.814)	IMT-Advanced minimum requirements (Base coverage urban environment)
Bandwidth (MHz)		1.4-20 (variable)	-40 (variable) (Expansion up to approx. 100 recommended)
Peak spectral efficiency (bit/s/Hz)	Downlink	15 (4×4)	15 (4×4)
	Uplink	3.75 (1×4)	6.75 (2×4)
Cell spectral efficiency (bit/s/Hz/cell)	Downlink	1.69 (2×2)	2.20 (4×2)
	Uplink	0.74 (1×2)	1.40 (2×4)
Cell edge user spectral efficiency (bit/s/Hz)	Downlink	0.05 (2×2)	0.06 (4×2)
	Uplink	0.024 (1×2)	0.030 (2×4)

*1 **LTE**: An evolutional standard of the Third-Generation mobile communication system specified at 3GPP; LTE is synonymous with Super 3G proposed by NTT DOCOMO.

*2 **MIMO**: A signal transmission technology that uses multiple antennas at both the transmitter and receiver to perform spatial multiplexing and improve communication quality and spectral efficiency.

the channel state information at the transmitter side [5].

Figure 1 shows an overview of precoding and scheduling techniques, and **Table 2** shows an overview of the aims and technical issues of precoding and scheduling, and the techniques proposed by DOCOMO Beijing Labs. These techniques are classified as follows in increasing order of the number of degrees of freedom: Single-User MIMO (SU-MIMO), MU-MIMO and multi-cell Cooperative MIMO (Co-MIMO).

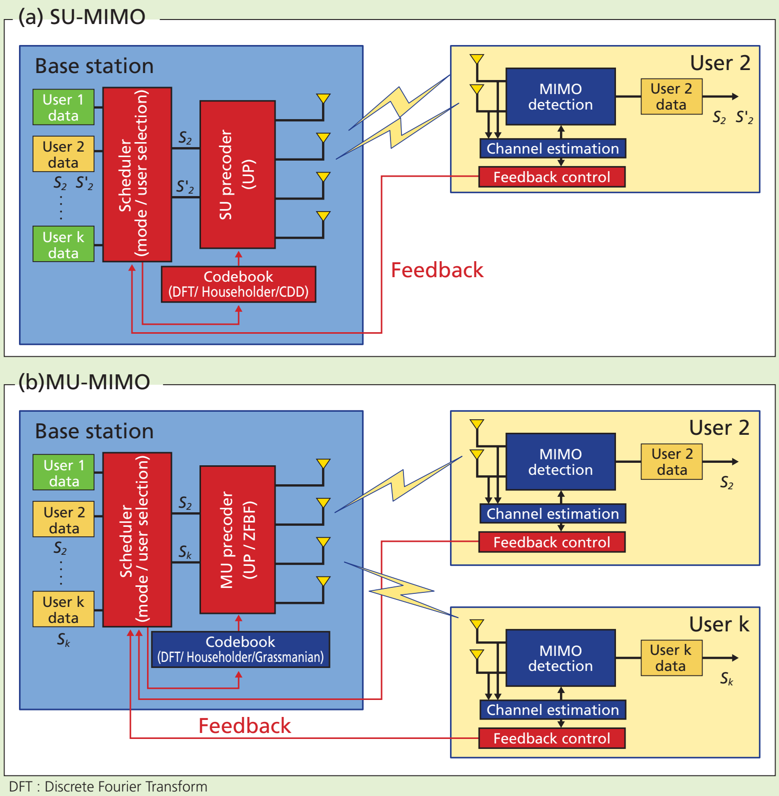

Figure 1 Precoding and scheduling

SU-MIMO is aimed at making improvements to the cell peak spectral efficiency and cell edge user performance, and is adopted in LTE R8 downlink. The technical issue of SU-MIMO is precoding to further increase the multi-user diversity gain and peak spectral efficiency.

MU-MIMO offers a greater degree of freedom than SU-MIMO in the spatial dimension because multiple users are multiplexed in the spatial channel [6]. MU-MIMO is aimed at making improvements to the cell average spectral efficiency, and is also adopted in LTE R8, and it is expected that further enhancements will be studied for R9. The technical issues in MU-MIMO are improving the cell average spectral efficiency in a limited feedback environment, developing an effective precoding technique that supports Space Division Multiple

Table 2 Issues of precoding and scheduling techniques, and overview of proposal

MIMO mode classification	Implementation period (forecast)	Target of improvements	Technical issues (precoding, scheduling)	Summary of proposals by DOCOMO Beijing Labs
SU-MIMO	LTE R8	Peak, Cell average, Cell edge	· Precoding for improved multi-user diversity gain · Precoding for improved peak rate	· CDD-based precoding · MB precoding
MU-MIMO	LTE R9	Cell average	· Precoding / scheduling for improved cell average spectral efficiency in limited feedback environments · Precoding to support SDMA	· Dynamic CQI update / feedback method for improved scheduling precision · Two-stage feedback for improved precoding precision
Co-MIMO	IMT-Advanced	Cell edge, Cell average	· Reduction of feedback overhead · Precoding and scheduling aimed at reducing computational complexity	· Multi-cell cooperative precoding and scheduling using selective feedback and partial channel state information

*3 **Spatial diversity**: A technique for improving communication quality by transmitting or receiving with multiple antennas. Each pair of transmit and receive antennas provides a signal path, and by sending signals that carry the same information through different paths, multiple independently faded replicas of the data symbol can be obtained and more reliable reception is achieved.

*4 **Spatial multiplexing gain**: The performance improvement derived from using multiple antennas to transmit multiple signal flows through space in parallel.

*5 **Multi-user diversity gain**: The improvement in system throughput derived from using a packet scheduler to exploit disparities in fading and interference characteristics between users.

Access (SDMA)[*6], and implementing scheduling with lower computational complexity.

In systems based on Orthogonal Frequency Division Multiple Access (OFDMA)[*7], inter-cell interference has a large effect on the system capacity, particularly when the frequency reuse factor is equal to 1. As cell sizes decrease in the future, inter-cell interference will become more of a problem. In conventional inter-cell resource coordination [7][8], it is possible to improve the performance for cell edge users, but an improvement in the cell average capacity cannot be expected. On the other hand, Co-MIMO [9][10] allows a signal from another cell to be used as the desired signal, and has thus become a prime candidate for improving not only the throughput at cell edge but also the average cell throughput. But so far, almost all of the studies of this technique have been performed on paper and under ideal assumptions, and it has not yet been shown to be practical enough for real environments. Co-MIMO is aimed at making improvements to the performance of cell edge users and the cell average spectral efficiency, and is being studied as a technology for IMT-Advanced. The technical issues in Co-MIMO are reduction of feedback overhead and computational complexity associated with precoding and scheduling.

In this article, to resolve the issues of SU-MIMO, MU-MIMO and Co-MIMO, we describe the scheme proposed by DOCOMO Beijing Labs with a focus on closed-loop precoding and scheduling techniques in low mobility environments.

2. The Issues of SU-MIMO and Their Solution

In a Rice channel[*8] or a slow fading environment, insufficient channel fluctuations can make it impossible to achieve adequate multi-user diversity gain. At DOCOMO Beijing Labs, we have proposed a precoding scheme based on Cyclic Delay Diversity (CDD)[*9] which combines open-loop CDD with a closed-loop precoding technique. In this scheme, multi-user diversity gain can be further exploited by increasing channel fluctuations in the frequency domain. Details of this scheme and the results of evaluation have been published in Ref. [11]. Furthermore, in order to increase the channel fluctuations in both the frequency and time domains, we have proposed a Multi-codeBook (MB) precoding scheme [12]. In the proposed scheme, a different codebook is used in each Resource Block (RB) and each time interval. The MB is generated by multiplying the left side of a conventional codebook W by a unitary matrix $Q^{(l)}$, where l is a number from 1 to the number of codebooks L. After generating MB, the signaling can be reduced by presetting the pattern in which the codebooks are switched at the transmitter and receiver sides.

Figure 2 compares the average spectral efficiency of the conventional Single codeBook (SB) scheme with that of the proposed MB scheme. We evaluated a 2×1 MIMO system with various number of users in a Typical Urban (TU) environment. The detailed simulation parameters can be found in Ref. [12]. Since user fairness is considered in Proportional Fair (PF) scheduling, the conventional scheme has performance loss in channels with insufficient fluctuations, whereas the spectral efficiency of the proposed scheme is improved by about 7%. In particular, the channel fluctuation range is small in a Line Of Sight (LOS)[*10] environment, so the effectiveness of the proposed scheme is significantly better than that in a Non-Line Of Sight (NLOS)[*11] environment.

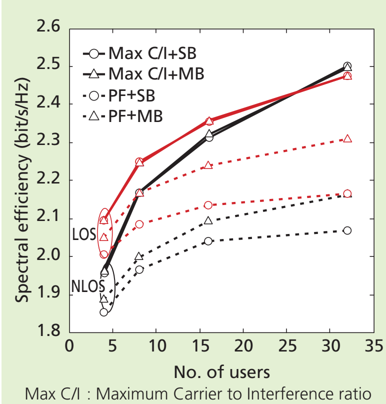

Figure 2 Average spectral efficiency of SB and MB

*6 **SDMA**: A technique for spatially separating each user's signals to achieve higher spectral efficiency by using mutually different directional beams with a narrow beam width to transmit to and receive from multiple users in the same cell.

*7 **OFDMA**: A wireless access scheme that uses Orthogonal Frequency Division Multiplexing (OFDM). OFDM uses multiple low data rate multi-carrier signals for the parallel transmission of wideband data with a high data rate, thereby implementing high-quality transmission that is highly robust to multipath interference (interference from delayed waves).

*8 **Rice channel**: A channel where a strong wave with little fluctuation (e.g., a direct wave) is accompanied by many reflected waves with large fluctuations.

3. The Issues of MU-MIMO and Their Solution

Unitary Precoding (UP) [13] and Zero-Forcing BeamForming (ZFBF) [14] are being studied as useful precoding schemes for limited feedback environments. In UP, the performance degrades when there is insufficient feedback information, and in ZFBF, the feedback precision affects the capacity. We investigated two schemes that have been proposed to resolve these issues: dynamic Channel Quality Indicator (CQI) feedback/updating, and two-stage feedback.

3.1 Dynamic CQI Feedback/Updating

In UP, each individual mobile terminal reports back to the base station to provide the preferred Precoding Matrix Index (PMI), Precoding Vector Index (PVI) and CQI. At the base station, groups of users are scheduled from users that selected different vectors from the same matrix and have the maximum total capacity or the total weighted capacity. In Evolved UTRA (E-UTRA)[*12], only the rank 1 CQI is fed back so as to reduce the amount of feedback. However, to perform rank adaptation[*13], the CQIs corresponding to other rank values are required at the base station. Hitherto, the rank 2 CQI value has been calculated by using a fixed offset, but precise scheduling is not possible because the values to be compensated differ depending on the channel status. In the proposed scheme, by concentrating on the fact that the rank values fluctuate gradually on the time axis, the user feeds back CQI value corresponding to the rank value used in the previous scheduling interval [15]. At the base station, the CQI is updated by using a lookup table prepared in advance based on the previous rank value and the received CQI.

- Step 1

  In an offline simulation, determine the CQI distribution of rank 2 corresponding to each CQI value of rank 1. Based on this distribution, generate a lookup table and store it in the base station.
- Step 2

  The base station determines the rank values at fixed time intervals and reports them to the users.
- Step 3

  Each individual mobile terminal feeds back the CQI value corresponding to the reported rank.
- Step 4

  The base station uses the lookup table to determine the CQI of the other ranks from the CQI of the reported rank. It determines the rank and performs scheduling so as to maximize the total capacity or weighted values.

The simulation parameters can be found in Ref. [15]. We evaluated the conventional scheme with rank 1 CQI feedback and fixed backoff, the proposed scheme, and also the case where CQI of rank 1 and 2 are both fed back for confirming the upper limit of performance. Compared with the conventional schemes, the proposed scheme achieved an increase of 20-40%, and it was confirmed that a capacity close to the upper limit value could be achieved (**Figure 3**).

3.2 Two-stage Feedback

In ZFBF, each individual mobile terminal feeds back a Channel Vector Quantization (CVQ) value, and at the base station, scheduling is performed by calculating a precoding matrix based on the CVQ values. In the conventional scheme, loss of capacity occurs because the limited amount of feedback leads to inadequate precoding precision. In the proposed scheme, by focusing on the fact that the CVQ values need to be more precise for precoding than for scheduling, we proposed a two-stage

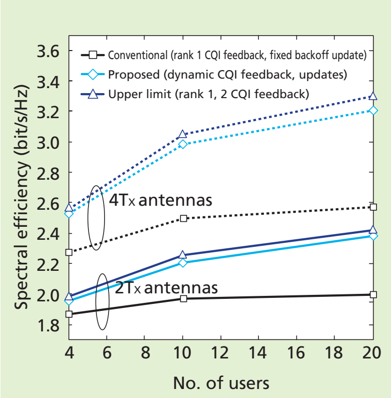

Figure 3 Dynamic feedback and updating method

*9 **CDD**: A diversity technique that is also used in OFDM-based systems. Transforms spatial diversity into frequency diversity while avoiding inter-symbol interference.

*10 **LOS**: Describes an environment where there are no obstacles between the transmitter and receiver, allowing them to communicate via direct waves.

*11 **NLOS**: Describes an environment where there are obstacles between the transmitted and receiver. In this case, communication can only take place over waves that have been reflected, refracted, etc.

*12 **E-UTRA**: An air interface used for advanced wireless access schemes in 3GPP mobile communication networks.

feedback method that makes effective use of limited feedback resources.

- Stage 1

  The base station and mobile terminals have two (large and small) codebooks *B1* and *B2*. The users use *B1* for the feedback of CVQ values. The base station performs scheduling and reports the results to the mobile terminals.

- Stage 2

  Only scheduled mobile terminals perform feedback using *B2*.

Figure 4 compares the capacity with that of a conventional scheme. To ensure fairness, the overall amount of feedback is kept the same. In other words, in the conventional scheme, a 3-bit codebook *B* is used, and in the proposed scheme, 2-bit and 8-bit codebooks (*B1*, *B2*) are used for stages 1 and 2 respectively ($3 \times 16 = 2 \times 16 + 8 \times 2$). Similarly, for a conventional scheme using a 4-bit codebook *B*, we used 3-bit and 8-bit codebooks in the proposed scheme. Compared with the conventional scheme, the proposed scheme improves the spectral efficiency by approximately 22% without incurring any increased overhead. Furthermore, there is also a big improvement when the Signal to Noise Ratio (SNR) is large because at that time the precision of the CVQ has a larger effect on performance improvement. **Figure 5** shows how the spectral efficiency varies with speed of mobility when the average SNR is 10 dB. At speeds of up to 25 km/h, the proposed scheme shows significant improvement, which indicates that it is effective in low-speed mobility environments.

4. The Issues of Co-MIMO and Their Solution

To improve the cell edge user throughput and average spectral efficiency, the cooperative precoding and scheduling on the same wireless resources from multiple transmitters is thought to be effective. This technique calls for high-speed sharing of channel information between transmitters, so it is more feasible under optical fiber connection based deployment (**Figure 6**). Here, we describe a selective feedback and cooperative precoding and scheduling technique proposed by DOCOMO Beijing Labs for use in real multi-cell and multi-user environments.

A cooperative area refers to an area

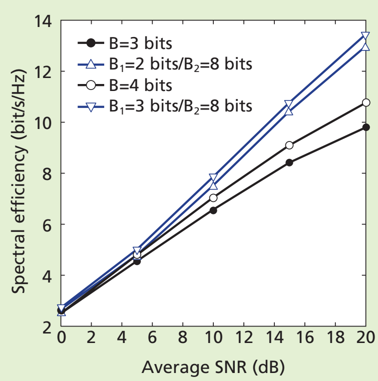

Figure 4 Variation of capacity with average SNR

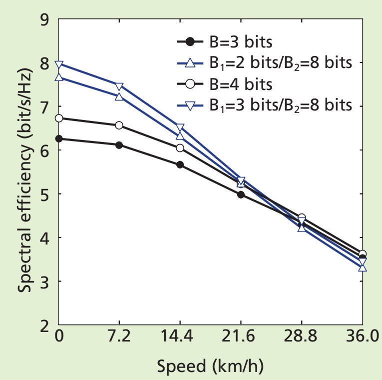

Figure 5 Variation of capacity with mobilty speed

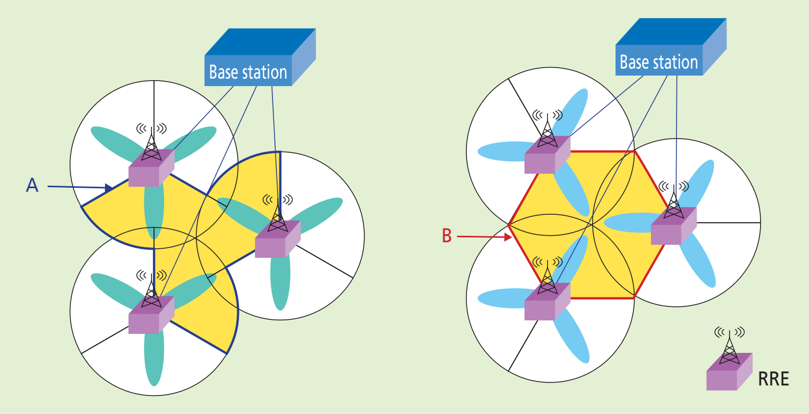

Figure 6 Cooperative area selection method

*13 **Rank adaptation**: A technique for adaptively switching the rank of signals transmitted in parallel in the same time slot and at the same frequency by switching the MIMO transmission method according to the channel state (the correlation between received SINR and fluctuations in fading between antennas).

where cooperative precoding and scheduling are performed by multiple Remote Radio Equipments (RREs). Considering the performance, signaling overhead and computational complexity, the cooperative area is decided under two considerations: (i) The cooperative area consists of multiple cells/sectors, and there are no overlapping between cooperative areas, and (ii) the users in a cooperative area are made capable of receiving reference signals from as many related transmitters as possible. With this in mind, we consider the scenario shown in Fig. 6 where cooperative area *B* is suitable for Co-MIMO.

The principle of the proposed scheme is as follows. A mobile terminal measures the received Signal to Interference plus Noise Ratio (SINR) over a long interval from multiple RREs. The RRE with the best received SINR is designated as the primary station, and a RRE for which the difference between the received SINR and that of the primary station is within a given range is selected as the secondary station. The mobile terminal reports to the primary station with the channel information on the secondary station. After each individual RRE has received feedback from each mobile terminal, it reports back to the base station. At the base station, a combined channel matrix H is constructed, and cooperative precoding and scheduling are performed between the RREs in this area.

We evaluated the performance for the case where a threshold value of 10 dB was used to identify the cooperative area. The detailed simulation parameters can be found in Ref. [16]. **Figure 7** and **8** show the cell average and cell edge user spectral efficiencies[*14] for 24 users. Compared with the conventional scheme where precoding and scheduling are performed independently in each cell, we have confirmed that Co-MIMO is able to simultaneously improve the cell average and cell edge user spectral efficiencies.

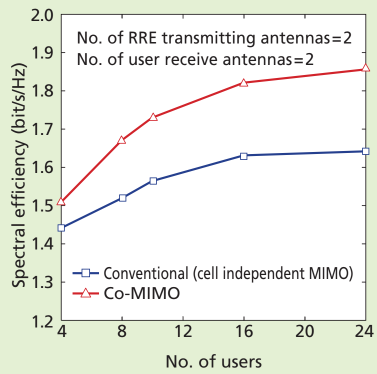

Figure 7 Cell average spectral efficiency characteristics

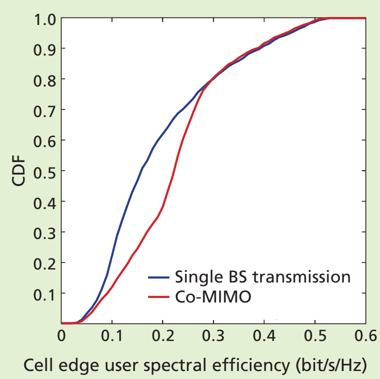

Figure 8 Cell edge user spectral efficiency

5. Conclusion

In this article, the technical issues of precoding and scheduling which increase the gain of multidimensional MIMO are clarified, and the schemes proposed by DOCOMO Beijing Labs are described. At DOCOMO Beijing Labs, we have drafted and submitted contributions to 3GPP LTE cooperating with the NTT DOCOMO Radio Access Network Development Department. In the future, towards the realization of mobile communication systems for IMT-Advanced and beyond, we plan to continue with studies aimed at further improving spectral efficiency, guaranteeing Quality of Service (QoS)[*15], reducing delay and enhancing battery-saving[*16] technology.

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*14 **Cell edge user spectral efficiency**: Defined as the 5% value of the Cumulative Density Function (CDF) of the user spectral efficiency.

*15 **QoS**: A level of quality on the network that is set for each service. Delay, packet loss and other quality factors are the main parameters.

*16 **Battery-saving**: Refers to technology that strives to reduce power consumption by such means as discontinuous reception and power-saving control techniques.

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