Multi-BS Cooperative Interference Control for LTE Systems

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Abstract*- Inter-Cell Interference Coordination (ICIC) is attracting attention recently. In ICIC, cell-edge throughput can be improved by preventing BSs from transmitting signals (hereafter, muting BSs), and the information exchange among BSs is little because each UE is only served by a BS at any instant. However, when a BS is muted, no radio resource is allocated to UEs belonging to the muted BS while UEs belonging to other BSs enjoy high cell-edge throughput. Therefore, there is a possibility that overall cell performance may degrade. To prevent this, we propose a multi-BS cooperative interference control method. The basic concept of the proposed method is that the muting is triggered only when the total throughput of the cooperation area is increased by the muting compared to the total throughput possible without muting. The proposed method makes it possible to increase cell-edge throughput without degrading overall cell performance. We also propose a way to realize this interference control on practical systems. First, we propose a way to realized it on 3GPP Release 8 LTE systems. In the proposed interference control, it is important to estimate throughput (SINR) values with and without muting appropriately. We propose to utilize feedback signals defined in LTE such as Channel Quality Indicator (CQI) and Received Signal Received Power (RSRP) to achieve the accurate throughput estimation. Furthermore, we propose to realize the proposed interference control on a distributed sector configuration using optical fiber systems such as Radio over Fiber (RoF) or Remote Radio Head (RRH). With this configuration, it is possible to achieve ICIC with less burden of information exchange. Especially with three sector configuration, it is possible to achieve "inter-cell" cooperation with "inter-sector" cooperation, which can be easily implemented.

Keywords;LTE, ICIC, interference control, cell-edge throughput

I. INTRODUCTION

Next generation mobile communication systems are attracting much attention and many proposals have been made for them [1-6]. In mobile communications, it is an issue to be solved that the cell-edge users cannot enjoy high throughput while the throughput of the users close to the BSs can be excessively high. One approach to solve the issue is a multi-BS cooperative transmission control technique, which is referred to as coordinated multi-point (CoMP) transmission in 3rd Generation Partnership Project (3GPP) Long Term Evolution Advanced (LTE-Advanced) standardization activities, is especially attracting attention. Various technologies have been proposed for CoMP to improve cell-edge performance [7-14]. Most of these techniques are based on joint transmission (JT), in which multiple BSs coordinate their antennas to jointly transmit the desired signal to the user equipment (UE) [12-14]. We have proposed a simple JT implementation technique and conducted a field trial that confirmed its feasibility and performance [15, 16].

Although JT does improve throughput, its overheads of information exchange among the BSs and signal processing are heavy problems. These issues can be mitigated by introducing inter-cell interference coordination (ICIC) [14, 17]. ICIC needs only scheduling and control information exchange, so it is easier to implement than JT. This approach also eliminates the burden of JT signal processing because only one BS transmits a signal to the UE at any instant.

In ICIC, the cell-edge throughput is improved by adaptively preventing BSs from transmitting signals (hereafter, muting BSs) that would otherwise impose strong interference on the cell-edge UEs in the neighboring cells. One drawback of ICIC is that the UEs belonging to the muted BS are not allocated any radio resource, which may result in performance degradation of the muted BS. One possible approach for this drawback is to conduct muting when a resource is allocated to a UE close to the BS. The UE usually enjoys excessively high throughput, so that a little decrease in its resource allocation does not cause severe degradation of its satisfaction for communication quality. However, it is not favorable to decrease cell overall throughput performance drastically. Considering the above, we propose a multi-BS cooperative interference control method, in which user scheduling as well as muting decision are conducted by coordinating multiple BSs. The concept of the proposed cooperative interference control is that the muting is triggered only when the total throughput of the cooperative BSs is increased by the muting (i.e. relative to the total throughput possible without muting). The proposed method makes it possible to increase cell edge throughput without degrading overall cell performance.

We also propose a way to realize the above interference control on practical systems. First, we propose a way to realize it on 3GPP Release 8 (Rel. 8) LTE systems. The proposed interference control is based on estimated throughput values, which are determined from estimated SINR. We propose to use feedback signals defined in LTE such as Channel Quality Indicator (CQI) and Received Signal Received Power (RSRP) to estimate the SINRs with and without muting. Next, we propose to realize interference control by using optical fiber to establish a distributed sector configuration. Though the proposed method can be implemented using the X2 interface, an interface for signal exchange among BSs defined in LTE, a simpler implementation of the proposed method is preferable. In the distributed sector configuration, three sectors belonging to the same eNB are located at different antenna sites by using optical fiber solutions such as Radio over Fiber (RoF) or Remote Radio Head (RRH). With this configuration, multi-BS cooperative interference control can be realized as easily as "inter-sector" cooperation because the three sectors belong to the same eNB.

II. MULTI-BS COOPERATIVE INTERFERENCE CONTROL

1. BASIC CONCEPT

Fig. 1 shows the two-cell model used to explain the basic concept of multi-BS cooperative interference control; the two BSs each have one UE. The received desired signal power of UE1 belonging to BS1 is defined as S_{11}; the received interference signal power from BS2 is S_{12}. The received desired and interference signal power for UE2 is denoted as S_{22} and S_{21}, respectively. We denote the received noise power of both UEs as N_0. The signal-to-interference plus noise ratio (SINR) of both UEs, γ_1 and γ_2, can be written as

$$\gamma_1 = \frac{S_{11}}{S_{12} + N_0} \tag{1}$$

and

$$\gamma_2 = \frac{S_{22}}{S_{21} + N_0}. \tag{2}$$

When we assume that both UEs are located at the cell border of BS1 and BS2 and all the received desired and interference signal powers are the same, S, they can be expressed as

$$S_{11} = S_{12} = S_{22} = S_{21} = S. \tag{3}$$

When we assume S is sufficiently higher than the noise level, N_0, the SINRs, γ_1 and γ_2, are given as

$$\gamma_1 = \gamma_2 = \frac{S}{S + N_0} \approx 1. \tag{4}$$

In ICIC, when a BS is muted, the performance of the UE in the neighbor cell is improved because its major interference source is eliminated. The improved SINRs of UE1 and UE2, γ'_1 and γ'_2, can be written as

$$\gamma'_1 = \frac{S_{11}}{N_0} \tag{5}$$

and

$$\gamma'_2 = \frac{S_{22}}{N_0}. \tag{6}$$

Although the SINR of the UE in the neighbor cell is improved as shown in Eqn. (5) and (6), no radio resource is assigned to the UE in the muted BS, which may degrade overall cell throughput. To prevent this issue, we propose a scheduling criterion to trigger muting appropriately; BS muting is set only when it provides a gain in overall cell throughput. By using the Shannon capacity for throughput calculation, this criterion is expressed as

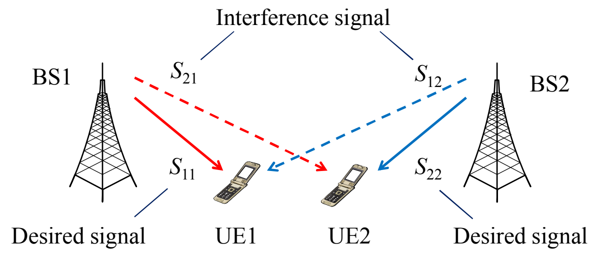


Fig. 1 Two-cell model

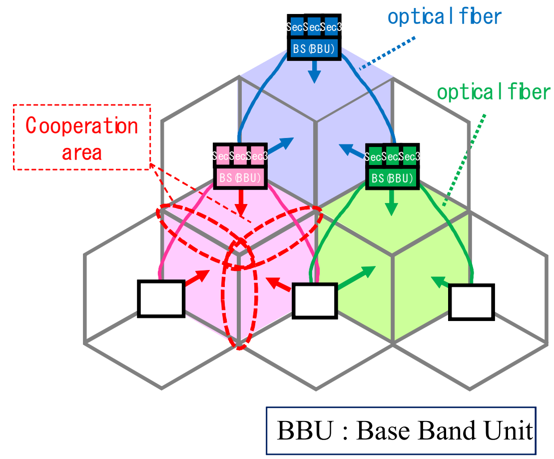


Fig. 2 Cell configuration

$$\log_2(\gamma'_1 + 1) > \log_2(\gamma_1 + 1) + \log_2(\gamma_2 + 1). \tag{7}$$

When this criterion is satisfied, BS2 is muted. If UE2's throughput with muting is higher than that of UE1, BS1 is muted. In this example, as in Eqn. (4), the SINRs for UE1 and UE2 without muting are assumed to be 1, each capacity (spectral efficiency) can be 1 from the Shannon limit as per inequality (7), so that muting is triggered if the capacity of UE1 or UE2 with muting becomes higher than 2. If we assume S/N_0 is 20 [dB], the capacity with muting is around 6.6 and so muting should be triggered.

Table 1 Interference stop pattern

	Stop pattern	Cell 1	Cell 2	Cell3
Without muting	1	ON	ON	ON
One-sector muting	2	ON	ON	OFF
	3	ON	OFF	ON
	4	OFF	ON	ON
Two-sector muting	5	ON	OFF	OFF
	6	OFF	ON	OFF
	7	OFF	OFF	ON

2. CONTROL ALGORITHM

The proposed multi-BS cooperative interference control can, theoretically, be realized with any number of BSs, although the number of BSs should be optimized by considering the burden of signal processing and/or the achievable gain. Hereafter, as an example, we assume the three-sector cooperation shown in Fig. 2, in which the three cooperating sectors are placed at different antenna sites. Details of the cell configuration are explained in the next section.

In three-sector cooperation, the interference suppression patterns can be summarized as shown in Table 1. Besides the pattern without muting (Stop pattern 1 in the table), there are three patterns for one-sector muting (Stop patterns 2 to 4) and for two-sector muting (Stop patterns 5 to 7). That is, there are seven stop patterns in total. The joint scheduler for cooperative interference control has to decide the stop pattern and the UE scheduled in each sector. Although the basic concept of the proposed method is to enable muting only when the throughput sum is increased by muting some BSs, we introduce scheduling metric as a criterion of the joint scheduler to take fairness among users into account. Moreover, muting is triggered only when the scheduling metric sum is increased by muting BSs.

We use a scheduling metric derived from a weighted proportional fair algorithm [18]. The scheduling metric is defined as r^{α}/R^{β}; r is instantaneous UE throughput and R is an average UE throughput. α and β are weights applied to instantaneous and average throughputs to adjust fairness arbitrarily. The weights are optimized to increase cell-edge throughput without degrading overall cell performance. In the joint scheduler, it is important to select the stop pattern, the metric sum of which is the highest among the seven stop patterns. To realize this, the joint scheduler first calculates the scheduling metric for each UE per stop pattern. Then, the UE with the highest scheduling metric is selected per cell per stop pattern. Then, the scheduling metric sum per stop pattern can be calculated. Finally, the scheduler compares the scheduling metric sums among the seven stop patterns and selects the best stop pattern. Once a stop pattern is selected, the UE scheduled in each cell is also determined.

III. REALIZATION OF MULTI-BS COOPERATIVE INTERFERENCE CONTROL ON PRACTICAL SYSTEMS

1. REALIZATION ON 3GPP REL. 8 LTE SYSTEMS

We propose a method to realize this multi-BS cooperative interference control on 3GPP Rel. 8 LTE systems. It is essential to accurately estimate SINRs with and without muting to select the proper interference stop pattern. We propose to use Channel Quality Indicator (CQI) and Reference Signal Received Power (RSRP) for SINR estimation. CQI and RSRP are the feedback signals defined in the LTE standard. Both signals are transmitted from UE to eNB; CQI reflects SINR at UE, and RSRP reflects received power at UE. When muting is not conducted, CQI reflects SINR without muting as in Eqn. (1), so the SINR with muting, Eqn. (5), should be calculated by using CQI and the received power obtained from RSRP as

$$\gamma_1' = \frac{S_{11}}{N_0} = \frac{S_{11}}{S_{11}/\gamma_1 - S_{12}}. \tag{8}$$

Here, γ_1 is obtained from CQI and S_{11} and S_{12} are obtained from RSRP. Similarly, when muting is not conducted, CQI reflects SINR with muting, so that the SINR without muting should be calculated from CQI and RSRP as

$$\gamma_1 = \frac{S_{11}}{S_{12} + N_0} = \frac{S_{11}}{S_{12} + S_{11}/\gamma_1'}. \tag{9}$$

Here, γ_1', SINR with muting, is obtained from CQI.

2. DISTRIBUTED SECTOR CONFIGURATION USING OPTICAL FIBER

Multi-BS cooperative interference control with any number of BSs can be realized by using an inter-BS interface such as the X2 interface defined in LTE. However, the usage of such an interface increases complexity. Therefore, we propose to realize multi-BS cooperative interference control with a distributed sector configuration using optical fiber. Fig. 2 shows the distributed sector configuration using optical fiber. In this configuration, a base band signal processing unit (BBU) handling three sectors is located at one place and its Radio Frequency Units (RFUs) are located at different antenna sites via optical fibers [16]. When we assume LTE systems, an eNB handling three sectors is placed at one place and its three sectors are placed at different antenna sites by using Remote Radio Head (RRH) or Radio over Fiber (RoF) systems. Each RFU is located at the vertex of a hexagonal cell per 120 degrees as in Fig. 2. With this sector configuration, UEs located at the cell-edge between sites (indicated by the dotted line in the figure) can enjoy the benefits of "inter-cell" cooperation, which is possible to show better performance compared to "inter-sector" cooperation, while there is no necessity to exchange information among cells because this cooperation is simply regarded as "inter-sector" cooperation from the view point of eNB [15, 16].

IV. EVALUATION

1. SIMULATION CONDITIONS

We evaluated the effect of the proposed multi-BS cooperative interference control by computer simulation. The simulation parameters are shown in Table 2. Cell configuration is a regular hexagonal cellular layout consisting of 19 sites with 3 sectors per site. Inter-site distance is 500m, transmit power is 46dBm, antenna configuration is SISO configuration, traffic model is a full buffer model. Three sector cooperation with the distributed sector configuration shown in Sector II-2

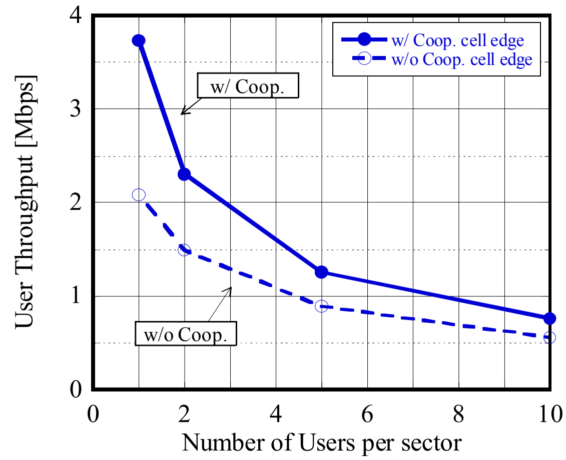
Table 2 Simulation parameters

Cell layout		Hexagonal grid, 19 cell sites, 3 sectors per site
Inter-site distance [m]		500
eNB transmit power [dBm]		46
Antenna configuration		Tx1, Rx1
Transmitter antenna gain [dBi]		14
Horizontal directivity [dB]		$A(\theta)=-\min[12(\theta/\theta_{3dB})^2, A_m]$ θ_{3dB}=70[deg] (Half value angle) A_m=20 (Front/back ratio)
Path loss [dB]		$L=128.1 + 37.6\log_{10}(R)$ R [Km] : (Distance)
Carrier frequency [GHz]		2
Shadowing deviation [dB]		8
Shadowing correlation	Inter-cell	0.5
	Inter-sector	1.0
Handover margin [dB]		3
Band width[MHz]		10
Traffic model		Full buffer traffic
Throughput calculation		Shannon capacity with LTE adjustment $0.75 \cdot \log_2(1+\gamma)$[bps/Hz] ($\gamma$: SINR)
PF weight	α	1
	β	1.0 (w/o cooperation), optimized for number of users(cooperation)

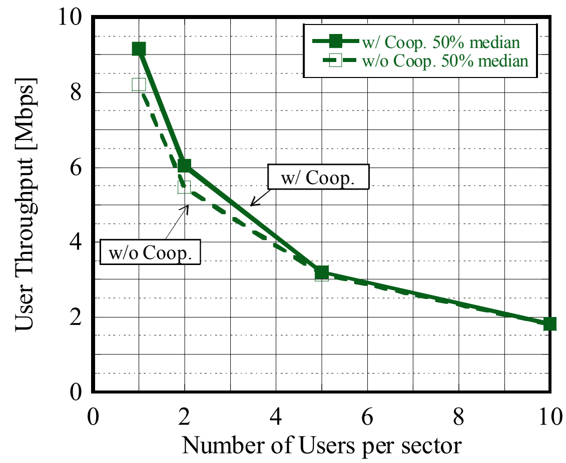
and III-2 was evaluated. For simplicity, we assumed a simple time-domain scheduling, in which only one UE is scheduled per time slot, and the throughput estimation was assumed to be conducted ideally; the throughput was calculated by using Shannon capacity based on SINR although the Shannon capacity was multiplied by 0.75 by taking realistic adaptive modulation and coding (AMC) loss into account [19]. Parameter α, the weight used in weighted proportional fair scheduler, is fixed at 1, and another parameter of the scheduler, β, is optimized for the number of users. As described in Sec. I, it is an issue to increase cell-edge throughput recently, while users close to BSs can enjoy excessively high data rate. To achieve this, it is acceptable to give priority to cell-edge users, while relatively low priority is given to the users close to BSs. Because the priority to high data-rate users is lowered, this results in lower cell average throughput. However, the satisfaction of the users can be increased because the throughput of low-rate cell-edge users is improved drastically and the throughput of the high data-rate users close to BSs degrade only a little. Considering the above, as an example, β is optimized to improve cell-edge throughput while permitting slight loss of average throughput by 10 %. We also assumed that there is no signal transmitted from a BS once it is muted, although signals other than data signal are usually transmitted in practical systems such as LTE. However, it is possible to eliminate the impact of other signal such as reference signal because the reference signal is a common signal, which can be detected and cancelled at UE with interference canceller even the signal comes from adjacent BSs. [20].

2. Evaluation Results

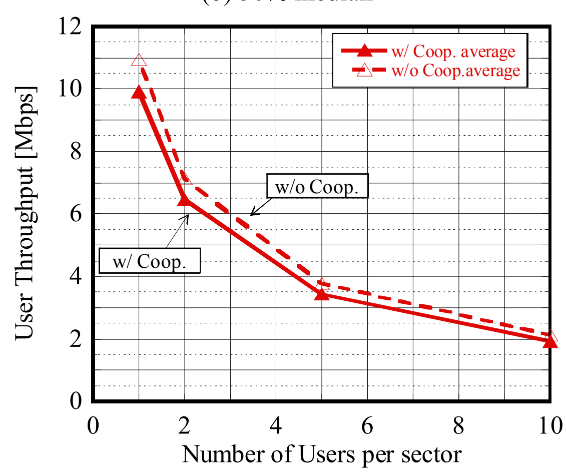
Fig.3 shows the user throughput characteristics with and without the proposed cooperative interference control. Fig.3



(a) Cell-edge



(b) 50% median



(c) Average

Fig. 3 User throughput characteristics

(a)-(c) show cell-edge throughput (5% value of cumulative distribution function (CDF)), 50% median of user throughput and average user throughput, respectively. The solid lines and broken lines in Fig. 3 show user throughput characteristics with and without the proposed cooperative interference control, respectively. The values of β were optimized as in previous subsection and set at 8, 2.5, 1.7, and 1.6 for the numbers of users per sector, 1, 2, 5, and 10, respectively. From the results, it is clearly shown that the cell-edge throughput has been improved greatly. Regarding cell overall performance, although average user throughput is permitted to degrade by 10 %, the 50% median throughput does not degrade at all; it rather improves especially when the number of users is less than 5. This means that the throughput of only UEs close to BSs is decreased and a majority of UEs can merit from the proposed cooperative interference control. Fig.4 shows the improvement ratio of cell-edge, 50% median, and average user throughput. It is shown that the cell-edge throughput improves by 80% when the number of users is 1. Even when the number of users is 10, it improves by around 40% without degrading 50% median user throughput.

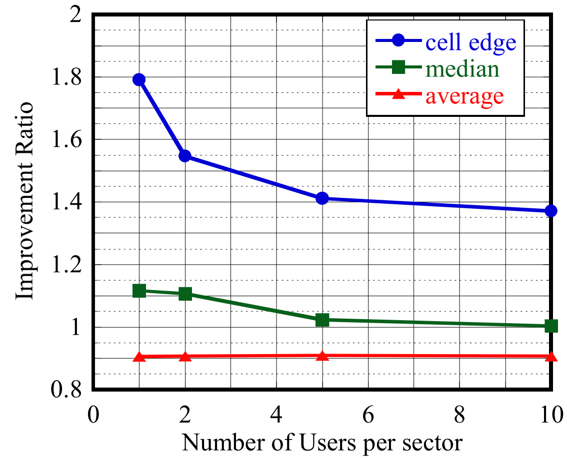


Fig. 4 Efficient of cooperative interference control

VI. CONCLUSION

In this paper, we proposed a multi-BS cooperative interference control for ICIC. In ICIC, it is possible to increase cell-edge throughput by muting some BSs. However, when a BS is muted, no radio resource is allocated to UEs belonging to the muted BS, which may result in overall cell performance degradation. The basic concept of the proposed method is that the muting is triggered only when the total throughput of the cooperation area is increased by the muting compared to the total throughput possible without muting. The proposed method makes it possible to increase cell-edge throughput without degrading overall cell performance. We also propose a way to realize this interference control on practical systems. First, we propose a way to realized it on 3GPP Release 8 LTE systems by utilizing feedback signals such as CQI and RSRP defined in LTE. Furthermore, we propose to realize the proposed interference control on a distributed sector configuration using optical fiber systems, which makes the implementation of the proposed interference control easier. We evaluated the proposed interference control method on the distributed sector configuration by computer simulation and clarified that it improves cell-edge throughput by around 40 % without degrading its 50% median throughput.

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