Cell Edge Throughput Improvement by Base Station Cooperative Transmission Control with Reference Signal Interference Canceller in LTE System

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Abstract- **Inter-cell interference coordination (ICIC) is attracting attention recently. This is a technique mainly improving cell-edge throughput by coordinating scheduling and signal transmission of multiple BSs. Different from joint transmission (JT), in which the desired signals for a user equipment (UE) are simultaneously transmitted from multiple BSs, the burdens of information exchange among BSs and its attendant signal processing are mitigated in ICIC because it requires only the exchange of scheduling and control information. In ICIC, the cell-edge throughput is improved by adaptively preventing BSs from transmitting signals (in other words, muting BSs) that would otherwise impose strong interference on the cell-edge UEs in the neighbor cells. Although this improves cell-edge throughput, it may degrade cell overall performance because no radio resource is assigned to UEs belonging to the muted BS. To resolve this issue, we first propose a scheduling method, which enables muting only when the throughput improvement (cell-edge UE) obtained by muting is superior to the total throughput possible without muting. Also, when considering applying this ICIC technique to current commercial systems such as LTE, it should be noted that reference signal, also known as pilot signal, is always transmitted regardless of muting because reference signal is a common signal used for channel estimation. To solve this issue, we also propose a reference signal interference canceller, in which the UE cancels the reference signal being transmitted from the neighbor BS. We evaluate the performance improvement by computer simulations and confirm that cell-edge throughput is dramatically improved by introducing the proposed canceller. We also propose a control algorithm that activates the canceller only when throughput improvement is possible. A basic lab experiment was also conducted to confirm the effect of the proposed interference canceller with 3GPP Rel-8 LTE-compliant equipment.**

I. INTRODUCTION

Next generation mobile communication systems are attracting much attention and many proposals have been made for the systems [1-6]. The BS cooperative transmission control, which is referred to as coordinated multi-point (CoMP) transmission in LTE-Advanced standardization activities, is especially attracting attention recently. Various technologies have been proposed for CoMP, with the goal of improving mainly cell-edge performance [7-14]. Most of the techniques for CoMP are based on joint transmission (JT), in which multiple BSs jointly transmit the desired signal to a UE by coordinating the antennas of the jointly-transmitting BSs [12-14]. We have proposed a simple implementation technique of this JT and conducted a field trial to demonstrate the feasibility and performance [15, 16].

Although throughput is improved by JT, its heavy burdens of information exchange among the BSs and its attendant signal processing are problems. These issues can be mitigated by introducing inter-cell interference coordination (ICIC) [14, 17]. In ICIC, only scheduling and control information exchange is conducted, so that it is easier to implement compared to JT. This approach also eliminates the burden of signal processing for the simultaneous transmission from multiple BSs because the signal for a UE is transmitted from only one BS at any instant. In ICIC, the cell-edge throughput is improved by adaptively preventing BSs from transmitting signals that would otherwise impose strong interference on the cell-edge UEs in the neighboring cells. On the other hand, the cell overall throughput may degrade because no radio resource is allocated to UEs belonging to the muted BS. To resolve this issue, we propose a scheduling method, in which a neighbor BS is muted only when the improved throughput of a UE obtained by muting is superior to the total throughput possible without muting [18]. The proposed method makes it possible to increase cell edge throughput without degrading overall cell performance.

However, to apply this ICIC technique for current commercial systems such as LTE, one thing should be noted that reference signals (RSs) are always transmitted from each BS regardless of muting. RSs are generally known as pilot signals and used for channel estimation or received power estimation for handover. Therefore, even when muting is conducted, the muted BS still transmits RS and limits the performance improvement possible with the muting.

To solve this issue, we also propose an RS interference canceller for ICIC. In the proposed canceller, the RS received from the neighbor BS is cancelled by the UE; this is easily achieved because the RS is a common signal and can be detected by any UE. We also propose a control algorithm for the proposed canceller. When the received desired signal power is much larger than the received interference RS signal power, it becomes difficult to detect the neighbor RS accurately, which results in poor quality replica signal generation, which makes use of the canceller counterproductive. To prevent this, the proposed control algorithm activates the RS interference canceller according to the reception environment of UE. We also conduct a basic lab experiment with 3GPP Rel. 8 LTE-compliant equipment to confirm the effect of the proposed RS interference canceller.

II. INTER-CELL INTERFERENCE COORDINATION

Fig. 1 shows a two-cell model, in which two BSs exist, each with one UE. The following uses this two-cell model to explain the basic concept of ICIC. 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 $\gamma_1=S_{11}/(S_{12}+N_0)$ and $\gamma_2=S_{22}/(S_{21}+N_0)$, respectively.

When we assume that both UEs are located at the cell border of BS1 and BS2 and all the received desired and interference

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signal powers are the same as S, i.e. $S_{11}=S_{12}=S_{22}=S_{21}=S$, and the S is sufficiently higher than the noise level, N_0, the SINRs, γ_1 and γ_2, are given as $\gamma_1=\gamma_2=S/(S+N_0)\approx 1$. 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', γ_2', can be written as $\gamma_1'=S_{11}/N_0$ and $\gamma_2'=S_{22}/N_0$, respectively.

Although the SINR of the UE in the neighbor cell is improved, 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 criterion to trigger muting appropriately; BS muting is set only when it provides a gain in overall cell throughput [18]. This criterion is expressed as $\log_2(\gamma_1'+1)>\log_2(\gamma_1+1)+\log_2(\gamma_2+1)$.

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, the SINRs for UE1 and UE2 without muting are assumed to be 1, each capacity (spectral efficiency) can be 1 from the Shannon limit, 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.

III. RS INTERFERENCE CANCELLER

1. Interference cancellation

We assume the frame structure shown in Fig. 2. One subframe consists of 14 OFDM symbols, and the RSs are inserted every six subcarrier in the frequency domain and transmitted in the 1st, 5th, 8th, and 12th OFDM symbols in the time domain. We also assume that the received subframe and symbol timing for the UE are the same for BS1 and BS2, and that the RSs of each BS are offset by one-subcarrier in the frequency domain so as not to interfere with each other. Here, UE1 belongs to BS1 and receives its desired signal, and BS2 is muted by ICIC, which means that only RS is transmitted from BS2.

Because RS is transmitted every six subcarrier in the frequency domain and on four OFDM symbols out of the 14 OFDM symbols in a subframe, 4/84 of the total transmit power from the neighbor BS is still transmitted even when BS2 data signal transmission is muted. This remaining interference suppresses the performance gain possible with ICIC.

Therefore, we propose an RS interference canceller for ICIC, in which the RSs of neighbor cells are cancelled at UE. RS is a common signal used by all UEs to conduct channel estimation or measure received signal power from neighbor BSs for handover decision. Therefore, any UE can detect and cancel the RSs of neighbor cells with the following procedure. In the following, we assume that the first OFDM symbol in the subframe shown in Fig. 2 is transmitted, in which RSs are included for both BSs. The cancellation procedure is summarized by the following three steps.

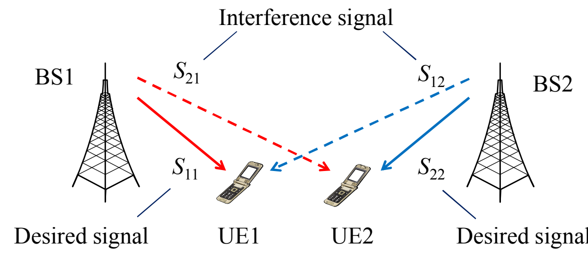

Fig. 1 Two-cell model

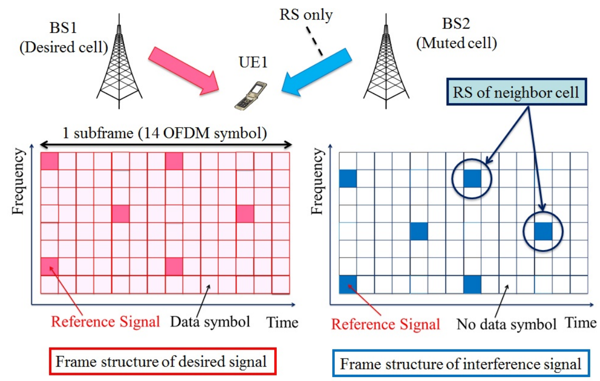

Fig. 2 Frame structure

(i) Conduct channel estimation for neighbor BS2
(ii) Generate replica signal from the channel estimate and cancel it from the original received signal
(iii) Conduct desired signal demodulation with the received signal after cancellation

Accordingly, first, channel estimation for BS2 is conducted. The received RS from BS2 experiences severe interference from the data signal from BS1, so an accurate channel estimation technique should be applied. There are many channel estimation techniques and any one of them can be used here as long as it offers sufficient channel estimation accuracy. As an example, we use the delay time-domain channel estimation approach, in which a primitive ZF channel estimate is transformed into the time domain channel impulse response. Then, only the cyclic prefix (called guard interval in some references) part of the channel impulse response is extracted and transformed again into the frequency domain [19]. This technique utilizes the fact that the channel elements in the channel impulse response are mainly present only in the cyclic prefix part, while the interference and noise elements are distributed evenly in the time domain.

In the second step, a replica signal is generated by using the channel estimate and canceled from the original received signal in the time domain. The replica signal cancellation can be conducted in the frequency domain if the received timings of signals from both BSs are close, within the cyclic prefix length; this can be realized by synchronizing the transmissions of BSs. To allow asynchronous BS operation, it is necessary to conduct replica signal cancellation in the time domain.

As the third, and final step, the refined signal is demodulated to yield the received data from BS1.

2. Control algorithm of RS interference canceller

If the channel estimation accuracy for BS2 is poor, applying the RS interference canceller can be counterproductive. Therefore, the RS interference canceller should be properly activated. Accordingly, we propose a control algorithm for the RS interference canceller. The proposed algorithm considers both the SINR of the RS received from BS2 and the received SINR for BS1. The latter is necessary because the RS interference canceller offers little gain if the received SINR is too low, which means that there is a lot of interference and the effect of cancelling only RS is limited. The proposed control algorithm has five steps. Its flow chart is shown in Fig. 3.

(i) Neighbor cell is detected when its RS is observed by UE.
(ii) The SINRs for the desired BS and the neighbor BS are measured periodically.
(iii) The SINR for the desired BS is checked and RS interference cancellation is not conducted when the SINR is lower than or equal to a certain threshold, x [dB].
(iv) The SINR for the neighbor BS is checked and RS interference cancellation is not conducted when the SINR is lower than or equal to a certain threshold, y [dB].
(v) If both conditions, (iii) and (iv), are satisfied, RS interference cancellation is started; the process from (ii) is repeated every time SINR measurement is updated, which is conducted periodically.

IV. Evaluation

1. Simulation conditions

We evaluated the proposed RS interference canceller by computer simulation. We assumed the two-cell model shown in Fig. 2. Simulation conditions are summarized in Table 1. We assumed a frame format, which is not exactly the same but as close as LTE system. The number of subcarriers is 1024 and the subcarrier spacing is 15 kHz; the OFDM symbol length is 66.7 µs. The cyclic prefix length is 4.69 µs. We used the path model shown in Fig. 4. This model represents a 5-path Rayleigh fading environment exhibiting exponential decay of averaged received power with equal interval of $\Delta\tau$ between adjacent paths. Its decay factor is 3dB per path, and each path is subjected to independent Rayleigh fading. We set the delay spread at 1.0 µs by adjusting $\Delta\tau$. We assumed quasi-static fading channel in this evaluation.

We used a frame structure shown in Fig. 2. The channel estimation technique explained in Sec. III-1 was used for both desired and neighbor BSs; the channel estimates are obtained

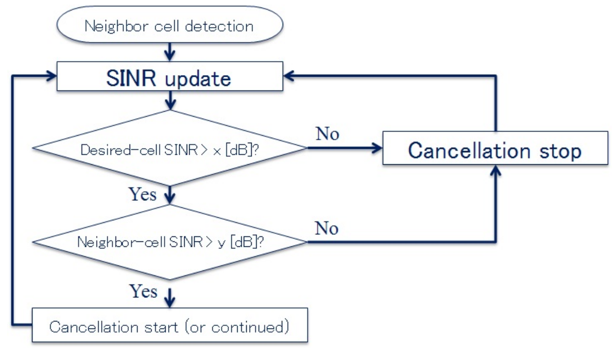

Fig. 3 Control algorithm of RS interference canceller

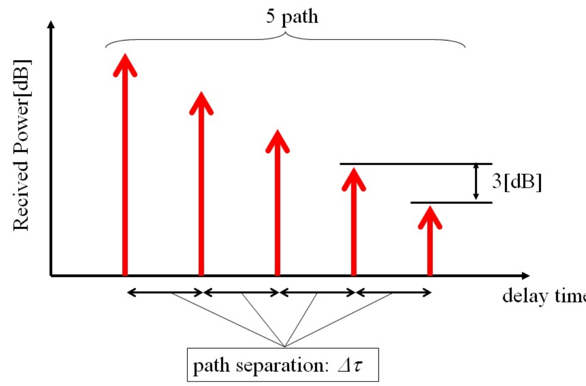

Fig. 4 Path model

on four OFDM symbols per subframe because RSs are transmitted on the OFDM symbols, and these channel estimates are averaged in the time domain within a subframe.

We evaluated the spectral efficiency as a function of signal-to-interference ratio (SIR). We assumed that the UE was always served by BS1 and handover was not considered. The SIR is defined as the ratio of the received desired signal power from BS1 to the received interference power from BS2; the SIR is defined by assuming BS2 is transmitting at its maximum power regardless of muting. SNR is set at 20 dB at the cell border and SIR is changed by changing the received desired power. Therefore, when SIR is 10dB, SNR is 30 dB because the received desired power is increased by 10 dB.

We assumed Single Input Single Output (SISO) as the antenna configuration and calculated spectral efficiency from the ratio of the received power of desired signal to the sum of the residual received power of interference signal and noise power after RS interference cancellation; this SINR calculation is conducted per subframe. The spectral efficiency is calculated

Table 1 Simulation conditions

Number of subcarriers	1024(15.36MHz)
OFDM symbol length	66.67µs (Subcarrier spacing: 15kHz)
Cyclic prefix length	4.69µs
Path model	Independent Rayleigh fading channel with exponential decay (Number of paths: 5, decay factor: 3dB)
Delay spread	1.0µs

as the Shannon capacity multiplied by 0.75 by taking a realistic AMC (Adaptive Modulation and Coding) into account [20].

2. EVALUATION RESULTS

Evaluation results are shown in Fig. 5. We evaluated following four methods.

(i) Without canceller (BS2 is not muted)
(ii) Without canceller (BS2 is muted)
(iii) With canceller (BS2 is muted)
(iv) With canceller (BS2 is muted, ideal channel estimation is assumed.)

As shown in Fig. 5, the spectral efficiency of (ii) is improved by muting BS2, but this performance gain is limited by the RS transmission from BS2. (iii) shows the spectral efficiency with the proposed RS interference canceller, and we can observe that the spectral efficiency is further improved. When SIR is 0 dB, the spectral efficiency is further improved, by 1.6 times, compared to (ii). While the RS interference canceller is effective near the cell border, the spectral efficiency with the RS interference canceller becomes inferior to that without it when SIR becomes larger than 10 dB. This is due to the channel estimation accuracy. When SIR is high, it is difficult to obtain accurate channel estimates for BS2 because the SIR of RS from BS2 is strongly suppressed by the interference from the BS1 data signal. Therefore, it is important to apply the control algorithm described in Section III-2 to prevent the drop in spectral efficiency by keeping the RS interference canceller active at all times. (iv) shows the performance assuming ideal channel estimation instead of the channel estimation described in Section III-1. This means that the spectral efficiency obtained by using the RS interference canceller can be further improved by applying more advanced channel estimation techniques; the SIR range, in which the RS interference canceller is effective, can also be extended to beyond 10 dB.

3. BASIC LAB EXPERIMENT

We also conducted a basic lab experiment to confirm the effect of the proposed RS interference canceller with 3GPP Rel. 8-compliant LTE equipment. The same configuration as in Fig. 2 was used and the detailed configuration of the lab experiment is shown in Fig. 6. The downlink and uplink signal of each eNB, which is an BS equipment in LTE, are separated by a duplexer, and the downlink signals from both eNBs are combined at a power divider and received by a UE. The received power was controlled by attenuators so as to make the same setting as the simulation evaluation. The received power of the uplink was controlled by attenuators so as to realize high quality received environment, which does not give any impact on the downlink performance.

The difference in parameters between the lab experiment and the simulation was the number of subcarriers and the path

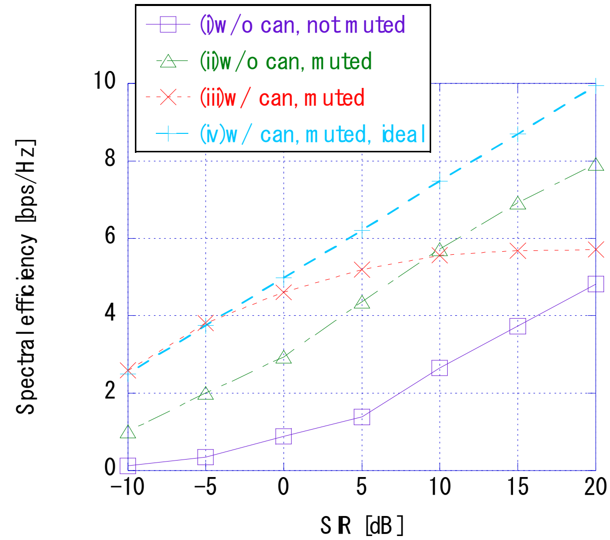

Fig. 5 Spectral efficiency

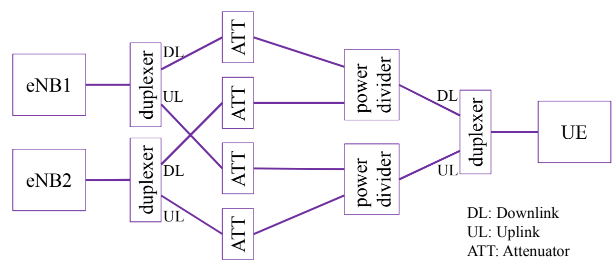

Fig. 6 Lab configuration

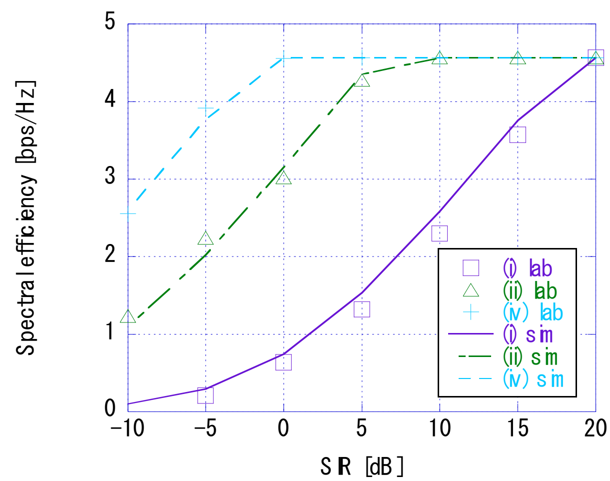

Fig. 7 Lab experiment results

models. The number of subcarriers was 600 following the setting of 5MHz in LTE, and the evaluation was conducted under an AWGN channel. The simulation conditions were the same as those in Table 1 except path model and that there exists an upper bound on spectral efficiency considering the realistic modulation and coding in LTE; the upper bound was set at 4.57 bps/Hz.

The UE used in this experiment was not equipped with the RS interference canceller, so that we evaluated the performance of the RS interference canceller virtually by stopping the transmission of RS signal from eNB2, which means that there was no signal transmission from eNB2. This corresponds to case (iv), “With canceller (BS2 is muted, ideal channel estimation is assumed.)”, because there is no interference by the ideal interference canceller in this case.

The lab experiment results are shown in Fig. 7. The experiment results are shown with marks and the simulation results are shown with lines. We evaluated the cases (i), (ii) and (iv), which correspond to the same cases in Sec. IV-2. From the results, it is clearly shown that the lab experiment results are almost the same as the simulation results. Therefore, we can say that the proposed RS interference canceller will achieve performance improvement as shown in the difference between the cases (ii) and (iv) even with 3GPP Rel-8 LTE-compliant equipment if the cancellation algorithm with accurate channel estimator is properly implemented.

V. CONCLUSION

We proposed an RS interference canceller for ICIC. In ICIC, the data signal transmission from a BS is stopped when it improves the throughput of cell-edge UE belonging to the neighbor BS without degrading overall system throughput. However, even when the data signal transmission is stopped, RS is still transmitted from the muted BS and the interference to the cell-edge UE in the neighbor BS limits the throughput improvement. In our proposed RS interference canceller, the RS received from the muted BS is cancelled at the active UE; this is easily done because RS is a broadcast common signal that can be detected by any UE. We also propose a control algorithm for the RS interference signal canceller. This algorithm deactivates the RS interference canceller when being active would be counterproductive. To reduce signal processing cost, the algorithm halts the canceller when there is no performance gain. We conducted a computer simulation and clarified that the proposed canceller improves spectral efficiency by 60 percent when SIR is 0 dB and SNR is 20 dB. We also clarified that the canceller is effective as long as SIR does not exceed 10 dB. We also conducted a basic lab experiment to confirm the effect of the proposed RS interference canceller, and it was clearly shown that the lab experiment results are almost the same as the simulation results.

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