Experimental Evaluation of Reference Signal Interference Canceller for Multi-BS Cooperative Transmission Control in LTE

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***Abstract-* Inter-cell interference coordination (ICIC) is attracting attention recently. In ICIC, mutual interference among cells are coordinated to mitigate strong interference to UEs, while the exchange of data signal is not necessary among eNBs, which results in lower signal processing and networking burdens compared to coordinated multi-point (CoMP) transmission. In ICIC, the interference from an eNB to UEs in surrounding cells can be mitigated by stopping signal transmission (muting) on some time or frequency radio resources. However, even when the data signal transmission is stopped, common signals such as reference signal (RS) continue to be transmitted in LTE systems. Therefore, UEs still receive the residual interference from the RS, which degrades the performance. To solve this issue, we proposed an RS interference canceller. Because the RS is a common signal, the signal can be detected and removed (cancelled) by any UE. We evaluated the effect of the canceller by computer simulation and clarified that it yields improved performance in the simple single-input single-output (SISO) antenna configuration. In this paper, we extended the canceller to the multiple-input multiple-output (MIMO) antenna configuration. We also propose a frequency-domain interference canceller, which drastically reduces signal processing cost without degrading performance. Furthermore, we implement the proposed canceller on 3GPP Release 8 LTE UE and conduct an experimental evaluation. The results demonstrate that the proposed canceller gives high performance improvement even with actual equipment.**

Key words: LTE, ICIC, Interference canceller, Experiment

I. INTRODUCTION

Multiple base station (Multi-BS) cooperation techniques have been attracting much attention recently to enable the throughput improvement of cell-edge users [1]. In the standardization of 3rd Generation Partnership Project (3GPP) Long Term Evolution-Advanced (LTE-Advanced), such techniques are referred to as coordinated multi-point (CoMP) transmission and reception and have been studied actively [1-3]. In LTE-Advanced, Joint Processing (JP) is considered to be a major candidate to enable further performance improvement [3-5]. JP is categorized into Joint Transmission (JT) and Dynamic Cell Selection (DCS). In JT, the data signal is transmitted from both the serving and non-serving evolved Node Bs (eNBs). The transmitted signal is coherently combined at the user equipment (UE), which results in the performance improvement especially for the cell-edge UEs. DCS is another way to improve the cell-edge performance. In DCS, the data signal is transmitted from one eNB at a time, however, either the serving or non-serving eNBs selected as the transmitter in order to increase UE throughput.

Although JP improves the cell-edge performance, the burden of information exchange among eNBs and its attendant signal processing is heavy. Though the signal processing cost of DCS is lower than JT by its transmission from single eNB, the data signal needs to be shared by both the serving and non-serving eNBs even in DCS, which results in the heavy overhead of information exchange on the network.

This issue can be mitigated by Inter-Cell Interference Coordination (ICIC) [3, 6]. In ICIC, multiple eNBs coordinate mutual interference to improve cell-edge performance; when an eNB gives strong interference to the cell-edge UEs of the surrounding cells, the transmission of the eNB can be stopped (muted), which improves the performance of the cell-edge UEs in the surrounding cells. Different from DCS, in ICIC, the data signal is transmitted by only the serving eNB. Therefore, eNBs do not need to exchange data information among themselves and only scheduling and control information needs to be exchanged, which leads to much lower network burden than JP. Although data signals cannot be transmitted from the non-serving cell in ICIC, when the received signal power from the non-serving eNB becomes higher than the serving eNB, the UE can receive data signal from the eNB by handover. Therefore, ICIC is expected to achieve similar effect as DCS.

We proposed an ICIC scheme that is applicable to 3GPP Release 8 LTE, and clarified its performance improvement by computer simulation [8]. We have also implemented this function on Release 8 LTE-compliant eNBs and demonstrated the performance improvement in a field trial [12]. Though we confirmed a certain degree of performance improvement in the field trial, the improvement was less than the simulation results, which assumed no signal transmission from the muted eNBs. This is because Reference Signal (RS), which is used for channel estimation or received power measurement for handover, continues to be transmitted from the muted eNBs. In LTE, around 10% of the total transmit power is allocated for RS and this residual interference, present even after muting eNBs, limits the performance improvement possible with ICIC.

To resolve this issue, we proposed an RS interference canceller for ICIC. In the proposed canceller, the RS received from the neighbor eNB is cancelled at the UE [7]. Because RS is a common signal for all UEs, it can be detected and cancelled by any UE, even if the RS is from a neighbor eNB. This RS interference canceller is effective not only for ICIC but also for the situation where eNBs have low traffic. In this case, some radio resources are not allocated to any UE, i.e. no data channel is transmitted from the eNBs. We clarified the performance improvement in the simple single input single output (SISO) antenna configuration by computer simulation.

In this paper, we first extend the proposed canceller to support its application to the multiple input multiple output (MIMO) antenna configuration, which is generally used in LTE systems. We also propose a simple implementation technique of the canceller, in which the RS interference cancellation is conducted in the frequency domain to decrease the signal processing cost. Furthermore, we implemented these functionalities on a 3GPP Release 8 LTE-compliant UE and conducted an experimental evaluation to demonstrate the effect of the proposed canceller in actual equipment.

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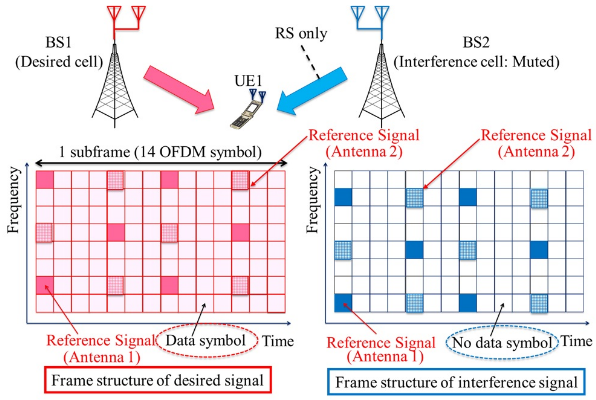


Fig. 1 Frame structure

II. RS INTERFERENCE CANCELLER

1. Interference cancellation for MIMO

We first extend the RS interference canceller to support the MIMO antenna configuration. In this configuration, all receiver antennas receive RSs from all transmit antennas. Therefore, the RS interference cancellation should be conducted for all transmit antennas per receiver antenna. We assume the 2x2 MIMO antenna configuration in the following for the simplicity of explanation, though the RS interference canceller can support 4x4 MIMO, which is the maximum antenna configuration in Release 8 LTE.

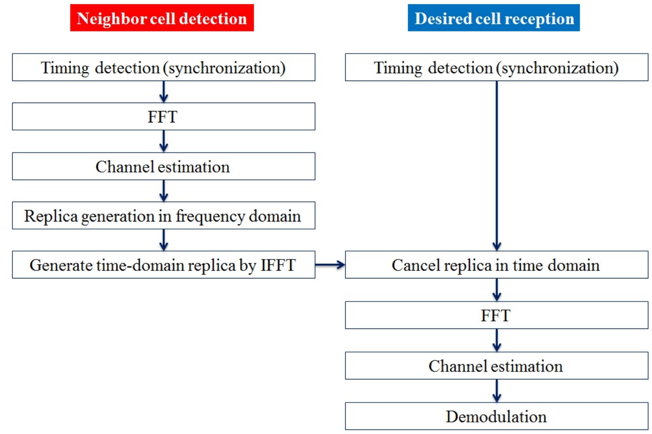
We assume the frame structure shown in Fig. 1. Here, UE1 is served by eNB1 and receives its data signal, and eNB2 is muted by ICIC, which means that only RS is transmitted from eNB2. One subframe consists of 14 OFDM symbols, and RS is inserted every six subcarriers in the frequency domain per antenna branch and transmitted in the 1st, 5th, 8th, and 12th OFDM symbols in the time domain. Therefore, 4 RSs are transmitted per 6 subcarriers by 14 OFDM symbols per antenna branch. Moreover, the transmission power of RS is usually set at twice that of the data symbols to improve channel estimation accuracy at UE. Therefore, around 10% of the total transmission power from eNB is used for RS transmission.

The procedure of the RS interference canceller is as follows.

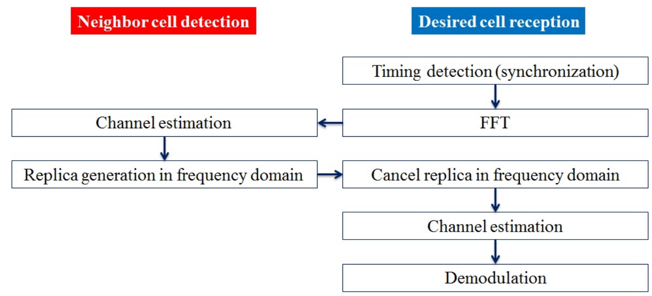
(i) Conduct channel estimation for neighbor eNB2
(ii) Generate replica signal by multiplying the channel estimate by the transmitted RS from eNB2
(iii) Cancel the replica signal from the original received signal
(iv) Conduct desired signal demodulation with the received signal after cancellation

2. Frequency-domain interference canceller

We have proposed a method to conduct this replica signal cancellation in the time domain [7]. The flow chart of the time-domain canceller is shown in Fig. 2 (a). First, timing detection



(a) Time-domain canceller



(b) Frequency-domain canceller

Fig. 2 Procedure of RS interference canceller

(synchronization) is conducted for the neighbor eNB. Then, the received signal is Fourier transformed into a frequency-domain signal. With the signal, channel estimation is conducted for the neighbor eNB and the replica signal is generated by multiplying the channel estimate and the RS transmitted from the neighbor eNB, which is a signal known by all UEs. This replica signal is transformed into a time-domain signal by IFFT (Inverse Fast Fourier Transform) and the cyclic prefix (CP) is generated from the signal. Finally, the replica signal is subtracted (cancelled) in the time domain, and normal demodulation is applied to receive the desired data signal. This method is applicable regardless of the signal reception timing difference between serving and neighbor eNBs. However, the signal processing cost is high because of its complexity.

To resolve this issue, we propose an RS interference canceller in the frequency domain. The procedure is shown in Fig. 2 (b). This frequency-domain canceller assumes inter-eNB synchronization. Because the signal transmission timing of the eNBs is synchronized, the received signal timing at UE from the eNBs is also almost the same. Though the received timings are not exactly the same, they depends on the UE location and the propagation difference, the UEs benefiting from the RS interference canceller are usually located at cell edge, so that the received timing is less than a few micro seconds and the effect of such a small difference can be absorbed by the CP of LTE, the length of which is 4.69 µs in normal CP and 16.67 µs in long CP. Therefore, RS interference cancellation can be simply conducted in the frequency domain. After Fourier transforming the received signal at the received timing of the serving cell, channel estimation is conducted for the neighbor eNB. The replica signal is generated in the frequency domain, and directly subtracted from the Fourier transformed frequency-domain signal. Finally, channel estimation and demodulation are conducted to receive the desired signal. Because FFT and IFFT processes are not necessary to generate the replica signal, the signal processing cost can be much reduced from the time-domain canceller. This also contributes to shorten the process delay required for the cancellation.

3. Control algorithm of RS interference canceller

The effect of the RS interference canceller depends on receiver environment such as received SINR for each eNB and the received timing difference between eNBs. If the RS interference cancellation is conducted on an environment where much performance improvement is not expected, it just results in an increase in signal processing cost.

Therefore, it is essential to introduce a control algorithm in order to conduct the cancellation only when it gives enough performance improvement. We have already proposed a way to control the activation of the canceller that considers both the SINR of the RS received from eNB2 and the received SINR for eNB1 [7]. 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. On the other hand, when the RS SINR of eNB2 falls, the activation of the canceller rather becomes counterproductive because the channel estimation is inaccurate. On top of this, in this paper, we propose to control the activation of the canceller depending on the timing difference. When the frequency-domain canceller is used, the performance improvement becomes lower as the timing difference becomes large. Therefore, fruitless interference cancellation is stopped by introducing a threshold for timing difference. The flow chart of the proposed control algorithm is shown in Fig. 3.

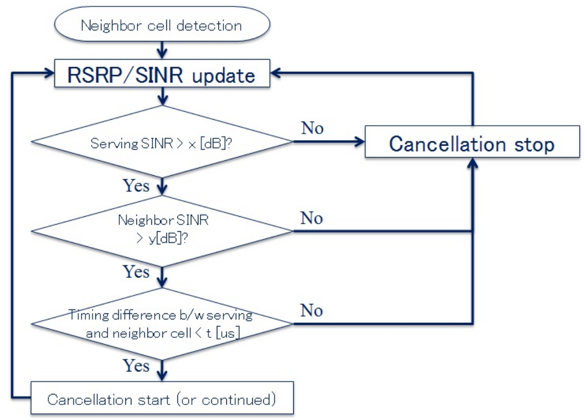


Fig. 3 Control algorithm

IV. Evaluation

1. Simulation conditions

We evaluated the proposed RS interference canceller by computer simulation. We assumed the two-cell model shown in Fig. 1. Simulation conditions are summarized in Table 1. The frame format is the same as that of the LTE system. The number of subcarriers is 600 and the subcarrier spacing is 15 kHz; the OFDM symbol length is 66.7 µs. The cyclic prefix length is 4.69 µs. RS power boosting was used and the RS power was set at 3dB higher than data symbols. We used a 5-path Rayleigh fading path model exhibiting exponential decay of averaged received power with equal interval of $\Delta\tau$ between adjacent paths [7]. 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.

Regarding the channel estimation method used to obtain the channel estimate for the neighbor eNB, which is then used to generate the replica signal, we used a simple channel estimation method, in which we first average in the time domain and then linearly interpolate in the frequency domain. The averaging in the time domain is conducted within a subframe, i.e. 1ms. The performance of the canceller is defined by the accuracy of this channel estimation for the neighbor eNB. Therefore, if more advanced channel estimation techniques as in [9] or [10] are used, the performance of the proposed canceller can be further improved. Regarding the channel estimation for the serving eNB, we assumed an ideal channel estimation. Timing synchronization was also assumed to be ideal.

We evaluated the spectral efficiency as a function of Signal-to-Noise Ratio (SNR). We assumed that the UE exists at the center of the serving and neighbor eNBs and the average received powers from both eNBs were the same, i.e. The Signal-to-Interference Ratio (SIR) was 0dB. The UE was always served by eNB1 and handover was not considered. A simple Multiple Input Multiple Output (MIMO) without cross-channel elements were used as the antenna configuration for simplicity. The spectral efficiency was calculated from the Signal-to-Interference plus Noise Ratio (SINR). When the canceller is not used, the RS interference and noise power is reflected in the denominator, while the residual RS interference and noise after cancellation is reflected when using the

Table 1 Simulation conditions

Item	Downlink specification
Access system	OFDMA
Subcarrier spacing	15kHz
Bandwidth	10MHz (600 subcarriers)
Symbol length	66.67µs+Cyclic Prefix(4.69µs)
Antenna configuration	2x2MIMO
RS power boosting	ON (3dB)

canceller. This SINR calculation is conducted per subframe, and then translated into spectral efficiency based on Shannon capacity, i.e. $\log_2(1+\text{SINR})$.

2. Evaluation Results

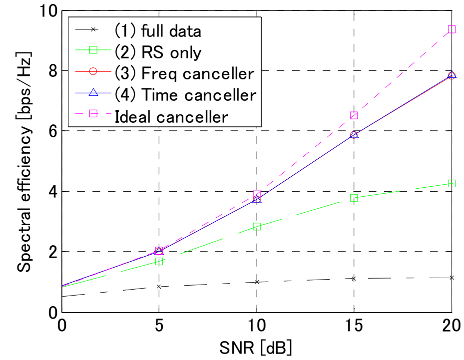
Evaluation results are shown in Fig. 4 (a). The x-axis shows SNR and the y-axis shows spectral efficiency. In the figure, the following five schemes are compared: (1) Full data and RS interference from neighbor eNB, (2) RS interference only (without canceller), (3) the proposed frequency-domain canceller, (4) the time-domain canceller, (5) canceller with an ideal channel estimation. In this evaluation, the reception timings from the both eNBs were assumed to be the same.

From the results, the spectral efficiency of (1) is around 1 even when SNR becomes larger because the strong data and RS interference comes from the neighbor eNB. When the data signal transmission from the neighbor eNB is stopped, the interference from the neighbor eNB consists of only RS and certain performance improvement is observed, twice and four times larger than (1) when SNR is 5 and 20dB, respectively. With the proposed canceller, the residual RS interference can be eliminated as in (3). When SNR is 15 and 20dB, the spectral efficiency becomes 1.5 and 2 times higher than (2), respectively. When compared with (4), the proposed frequency-domain canceller and the time-domain canceller have the same performance, while the signal processing cost can be decreased drastically by saving the process of FFT and IFFT. The degradation from the canceller with an ideal channel estimation is caused by the channel estimation accuracy. This degradation can be mitigated by introducing more advanced channel estimation techniques as in [9, 10].

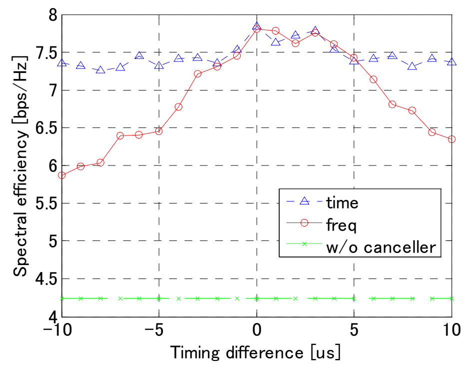
Fig. 4 (b) plots the spectral efficiency vs. timing difference. SNR was set at 20dB. The results show that no degradation is observed as long as the timing difference lies within cyclic prefix length. When the timing difference is out of this range, the performance of the frequency-domain canceller degrades gradually depending on the timing difference. However, even with the timing difference as large as 10 µs, the performance is still much higher than that without canceller.

3. Experimental Evaluation

We realized the function of the proposed frequency-domain RS interference canceller on a 3GPP Release 8 LTE-compliant UE. We also used 3GPP Release 8 LTE-compliant eNBs and conducted a laboratory experiment. The major parameters are the same as those in Table 1 regarding the downlink reception. Regarding the uplink transmission, it is compliant with Release 8 LTE. The transmit power of eNB was 43dBm per transmit antenna and that of UE was 23dBm. We conducted the experiment in a MIMO additive white Gaussian noise (AWGN) channel without cross channel elements for simplicity. The received timings from both eNBs were also set to be the same.



(a) Comparison among schemes



(b) Impact of timing difference (SNR=20)

Fig. 4 Simulation results

Fig. 5 (a) shows the results. The x-axis is SNR and the y-axis is throughput. The throughputs with and without the canceller were compared. Simulation results were also shown in the figure. In the computer simulation, the throughput was calculated by multiplying the Shannon capacity by the effective bandwidth of the data channel. The Shannon capacity was further multiplied by 0.75 by taking a realistic AMC (Adaptive Modulation and Coding) loss into account [11]. The effective bandwidth was calculated based on the LTE format by considering RS, other control channels, cyclic prefix and guard band, which results in 0.66 in this evaluation.

From the results, it is clearly demonstrated that the proposed canceller gives performance improvement even in the experimental evaluation with actual equipment. When SNR is 20dB, the throughput of the canceller is 46.4Mbps, while the throughput without the canceller is 26.8Mbps. Therefore, above 50% improvement was achieved. We also confirmed that the results basically matched those of computer simulation.

We also evaluated the effect of introducing control algorithm shown in Sec. III-3. The evaluation results are shown in Fig. 5 (b). In the figure, the x-axis is SIR, which is denoted as the ratio of the received RS powers of the serving and neighbor eNBs; the received RS powers from both eNBs are the same when SIR is 0dB. The noise power was set at 20dB lower than the total received power from eNB1 when SIR is 0. We changed SIR by changing the received power from eNB1. We compared the following four schemes: (1) full data signal transmission from the neighbor eNB, (2) only RS transmission (w/o canceller), (3) w/ the proposed canceller, and (4) the activation of the proposed canceller is controlled by the control algorithm. In this evaluation, we used only the threshold for neighbor SINR ("y" in Fig. 3) and set the parameter at -10dB.

In this evaluation, we changed the received power from eNB1 so as to change SIR from -10dB to 20dB in a continuous way. When comparing (2) and (3), when SIR is lower than 10dB, there is certain performance improvement by using the canceller, while the performance of the canceller degrades when SIR becomes larger than 10dB. This is because the accuracy of the channel estimation for eNB2 degrades. As shown in the bottom of Fig. 5 (b), neighbor SINR degrades as SIR becomes higher because of the strong interference from eNB1 data signal. However, by applying the control algorithm, the canceller is deactivated when SIR becomes larger than 10dB automatically and (4) always shows the best performance.

V. CONCLUSION

In ICIC, the residual RS interference degrades the performance of cell-edge UEs when a neighbor eNB is muted. To resolve this issue, we proposed an RS interference canceller. The contributions of this paper are summarized as follows.

(1) We extended the proposed canceller to support the MIMO antenna configuration.

(2) We proposed a frequency-domain RS interference canceller that drastically reduces signal processing cost without degrading performance.

(3) We implemented the proposed canceller on a 3GPP Release 8-compliant LTE UE and conducted an experimental evaluation. The results clarified that the performance improvement can be achieved as same as computer simulation even with actual equipment and the control algorithms worked well to always achieve the best performance regardless of receiver environments.

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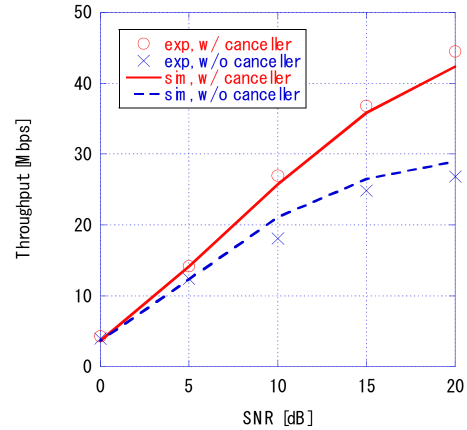
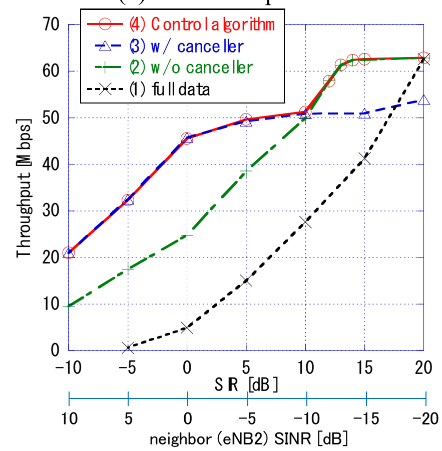


(a) Basic comparison



(b) Effect of control algorithm

Fig. 5 Experimental evaluation results

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