De-Centralized Adaptive 2-Step Inter-cell Interference Coordination in Distributed MIMO

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Abstract— **Distributed multi-input multi-output (MIMO) provides a good transmission quality over a macro-cell area. However, the cell-edge user equipments (UEs) still suffer from strong inter-cell interference (ICI) from surrounding macro-cells and hence, their transmission quality degrades compared to the cell-center UEs. In order to mitigate the ICI problem, in this paper, we propose a de-centralized adaptive 2-step ICI coordination (ICIC) based on fractional frequency reuse (FFR). Adaptive 2-step ICIC consists of the UE classification into cell-center UEs and cell-edge UEs and the adaptive selection of fractional bands.**

Keywords—distributed MIMO, cooperative transmission, space-time block coding, inter-cell interference coordination

I. INTRODUCTION

Recently, the development of advanced mobile communications technology for the 5th generation (5G) systems has been intensified. We have been studying distributed multi-input multi-output (distributed MIMO) cooperative transmission [1-5]. Because of spatial limitation, the number of antennas to be equipped at user equipment (UE) is limited. Space-time block coded transmit diversity (STBC-TD) can obtain a large spatial diversity gain by using an arbitrary number of distributed antennas (DAs) while limiting the number of antennas at user equipment (UE) side to less than or equal to 6 [5]. Therefore, a good transmission quality is achieved over a macro-cell area.

Similar to LTE/LTE-A cellular networks, the frequency reuse will be adopted in the 5th generation (5G) networks. However, the inter-cell interference (ICI) from surrounding macro-cells is produced and accordingly, the link capacity of cell-edge UEs is reduced. This ICI problem can be mitigated by applying the inter-cell interference coordination (ICIC). For LTE/LTE-A networks, a fixed type of ICIC was proposed, which uses the fractional frequency reuse (FFR) with frequency reuse factor of 3 [6-12]. The fixed ICIC pre-assigns a different fractional band to the cell-edge area of a different cell so that cell-edges of adjacent macro-cells are pre-assigned different fractional bands and accordingly, the received signal-to-interference plus noise power ratio (SINR) of cell-edge UEs can be improved [6-12]. However, the transmission bandwidth available for cell-edge UEs is reduced to 1/3 and therefore, the cell-edge UE's link capacity improvement is limited. To further improve the cell-edge UE's SINR, an adaptive ICIC was proposed in [10-12]. The information about FFR bands in use and transmit powers needs to be shared among neighbor macro-cell base stations (MBSs). An iterative algorithm to determine the transmit powers and FFR bands to be used taking into account the impact of ICI among MBSs was proposed in [12].

The concept of ICIC proposed for LTE/LTE-A networks can be applied to a distributed MIMO network. In a distributed MIMO network, the deployment of distributed antennas may not be regular. Furthermore, UEs' distribution may also not be uniform and can change in time. Therefore, defining the cell-edge area must be carefully considered. It is also highly desirable that cell-edge UEs of each macro-cell can select the fractional band independently in order to avoid the information sharing of fractional bands in use and transmit powers.

In this paper, we propose a de-centralized adaptive 2-step ICIC. In the first step, each MBS classifies its UEs into the cell-center UEs and cell-edge UEs according to the ICI distribution of whole UEs. In the second step, the MBS makes a decision to allow the cell-edge UEs to use an additional fractional band having high signal-to-interference power ratio (SIR) in addition to the one which is pre-assigned according to the fixed ICIC. The above proposed ICIC does not require the information sharing of fractional bands in use among neighbor MBSs.

This paper is organized as follows. Sect. II overviews the conventional ICIC. In Sect. III, the de-centralized adaptive 2-step ICIC is proposed. The link capacity improvement achievable with the proposed de-centralized adaptive 2-step ICIC is evaluated by computer simulation and is compared with the fixed ICIC in Sect. IV. Finally, Sect. V offers concluding remarks and a future study.

II. OVERVIEW OF CONVENTIONAL ICIC

Before describing our proposed de-centralized adaptive 2-step ICIC, we provide an overview of conventional ICIC techniques [6-12] proposed for LTE/LTE-A cellular networks.

A. Fixed ICIC [8,9]

Fig. 1 shows the frequency reuse of fixed ICIC [8, 9] using FFR with the frequency reuse factor of 3 (therefore, the system bandwidth is divided into three fractional bandwidths of W_1, W_2, and W_3). One of three fractional bands is pre-assigned to cell-edge area and the remaining fractional bands to cell-center area. The cell-edge bands of neighbor macro-cells are different to each other so as to avoid strong ICI and to improve the cell-edge UEs' received SINR. However, because the cell-edge UEs can use only one of three fractional bands, the improvement of the cell-edge UE link capacity is relatively small.

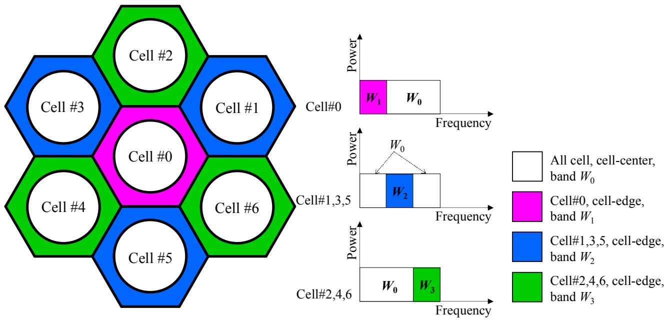


Fig. 1. Frequency reuse of fixed ICIC.

B. Conventional adaptive ICIC [11]

Fig. 2 shows an example of the frequency reuse of conventional adaptive ICIC [11]. Here, the bandwidths to be used in cell-edge area and in cell-center area are not fixed and can be adaptively changed (as a unit of resource block). Thus, the frequency band allocated to a particular cell-edge area may not be contiguous.

The MBS classifies the UEs into the cell-center area and the cell-edge area according to the SINR information informed from each UE and the ratio of the number of cell-edge UEs [11]. Then, neighbor MBSs share the information of resource blocks in use for the cell-edge UEs and assign the resource blocks so as to avoid the strong ICI and hence, the received SINR of cell-edge UEs can be improved. This is done from one MBS to the next in the predetermined order. Since the cell-edge UEs may be able to use more than 1/3 of total available bandwidth as long as those resource blocks are unoccupied, this adaptive ICIC achieves higher cell-edge UE link capacity than the fixed ICIC. However, this is achieved at the cost of frequent exchange of the bandwidth usage information among neighbor MBSs.

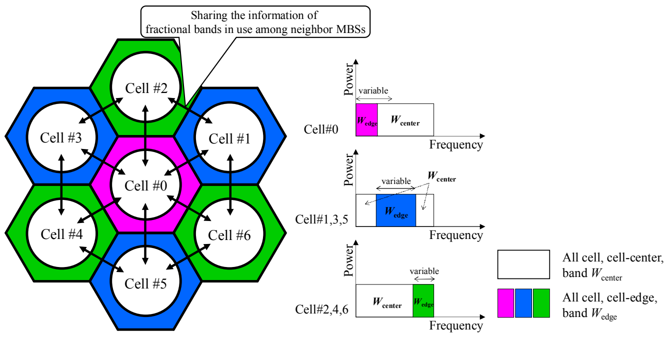


Fig. 2. Frequency reuse of conventional adaptive ICIC [11].

III. PROPOSED DE-CENTRALIZED ADAPTIVE 2-STEP ICIC

Distributed MIMO cellular network is considered. The proposed de-centralized adaptive 2-step ICIC adopts the downlink ICI measurement by UEs and the uplink SIR measurement by the MBSs. A TDD subframe structure [15] is used to implement the ICI and SIR measurements. Using this TDD subframe structure, uplink and downlink pilots are transmitted prior to data transmission. UEs listen to the downlink pilots transmitted from adjacent macro-cells and measure the ICI level and report back to their MBSs. Each MBS collects the ICI information and obtains the ICI distribution for classifying the UEs into the cell-center UE group and the cell-edge UE group (the first step). Then, each MBS measures the SIRs of scheduled cell-edge UEs by receiving their uplink pilots and assigns each of them an additional fractional band according to their SIR levels (the second step). Note that in this paper, we assume perfect measurements of ICI and SIR levels.

Fig. 3 and 4 show an example of frequency allocation in our proposed de-centralized adaptive 2-step ICIC and the transmission time allocation for cell-edge UEs and cell-center UEs. The cell-center UEs can use all frequency bands (W_1, W_2, W_3). In contrast with the fixed ICIC, the cell-edge UEs are allowed to use other frequency bands with low impact from ICI (in other words, the band having higher SIR than the predetermined SIR threshold) in addition to their pre-assigned fractional band. Since each MBS independently determines the available bands for cell-edge UEs, it is not necessary to share the information of fractional bands in use among neighbor macro-cells. For example, as shown in Fig. 3, the cell-edge UEs in cell#1, #3 and #5 may be able to use the same additional fractional band (W_3) together with their pre-assigned band (W_2) as long as the received SIR is above the SIR threshold.

Although each MBS selects a different fractional band independently without information sharing among neighbor MBSs, the cell-edge UE link capacity can be improved since only the band with strong SIR is allowed to use. It should be noted that whole network time synchronization is necessary.

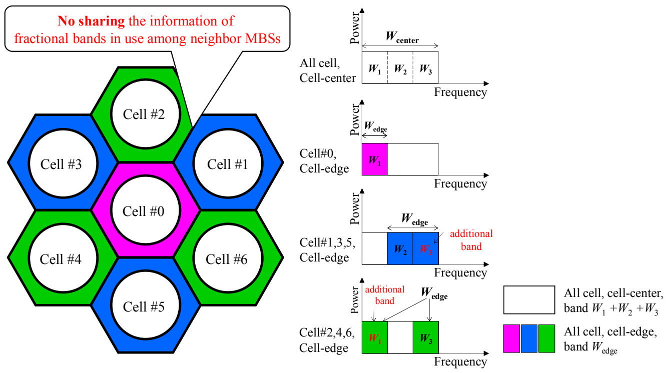


Fig. 3. Frequency reuse of proposed adaptive 2-step ICIC.

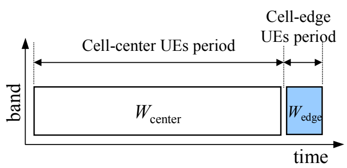


Fig. 4. Time allocation for cell-center UEs and cell-edge UEs.

Fig. 5 shows the flowchart of the proposed adaptive 2-step ICIC algorithm. Below, we describe the UE classification according to the ICI in the first step and the determination of available bands for cell-edge UEs according to the received SIR in the second step.

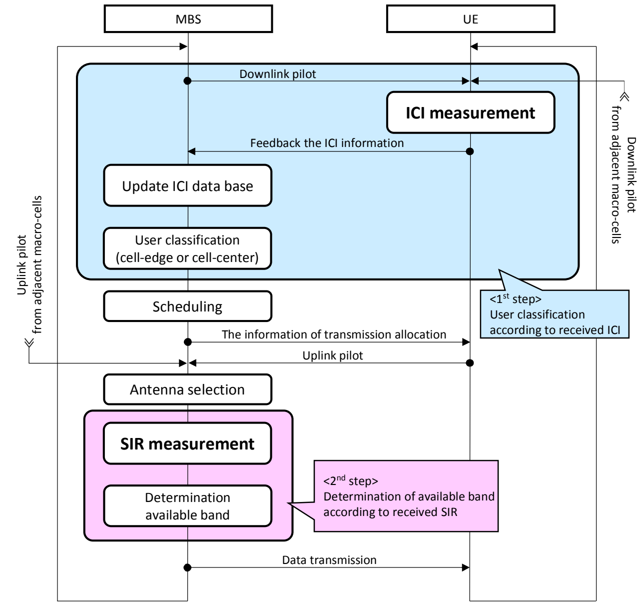


Fig. 5. Proposed de-centralized adaptive 2-step ICIC algorithm.

A. 1st step : UE classification

In contrast to Sect.II, the distribution of distributed antennas and UEs may be non-uniform in the distributed MIMO network. Therefore, we cannot simply classify the cell-edge UEs and cell-center UEs based on their location. We introduce the UE classification using the cumulative distribution function (CDF) of ICI level (hereinafter called the ICI database). UE measures the level of ICI from adjacent MBSs by using the downlink pilot in the TDD subframe [15] and then reports to the MBS. The MBS collects ICI information to construct an ICI database. The classification of UEs into cell-edge UEs and cell-center UEs is done by using the ICI threshold obtained from ICI database. The 95% ICI level (defined as an ICI level below which the probability of the received ICI falling is 95%) may be used as the ICI threshold (i.e., the UE with its ICI level higher than the threshold is considered as cell-edge UE). The ICI threshold is a design parameter.

B. 2nd step : Adaptive selection of fractional bands

The MBS allocates all of three fractional bands to cell-center UEs. The cell-edge UEs are allowed to use other fractional bands with SIR exceeding the SIR threshold together with their pre-assigned fractional band based on fixed ICIC. Each MBS measures the SIR level of each fractional band by using the uplink pilot [15]. Since the proposed adaptive 2-step ICIC allocates high received SIR bands to cell-edge UEs, an occasion of the same fractional band is used in the adjacent macro-cells may be avoided. Therefore, the improvement of the cell-edge UE link capacity can be expected.

IV. COMPUTER SIMULATION

A. Cellular model and propagation model

We assume a cellular model shown in Fig. 6. OFDM downlink transmission using STBC-TD is considered. The macro-cell of interest is surrounded by 18 co-channel macro-cells. N_{macro} distributed antennas are deployed uniformly over each macro-cell. R and R' denote macro-cell radius and small-cell radius, respectively. The propagation channel is characterized by distance-dependent path-loss, log-normally distributed shadowing loss and L-path frequency-selective fading [13]. The channel between a particular UE and DA is considered as either Nakagami-Rice fading or Rayleigh fading, depending on the distance between UE and DA [5].

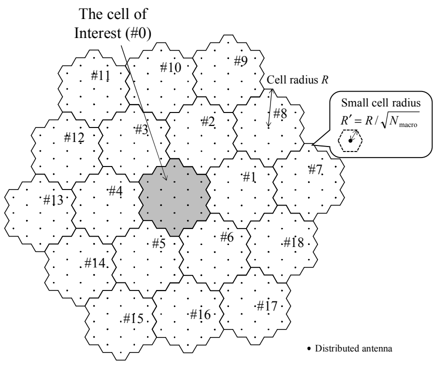


Fig. 6. Cellular model (N_{macro}=19, DA uniform deployment).

B. Link capacity

The UE downlink capacity using STBC-TD can be computed using

$$C = \frac{1}{N_c} \sum_{k=0}^{N_c - 1} \log_2 \left(1 + \gamma(k) \right), \tag{1}$$

where N_c and $\gamma(k)$ represent respectively the total number of subcarriers and the instantaneous SINR after STBC decoding [5, 14]. By computer simulation, we evaluate the CDF of instantaneous UE downlink capacity.

C. Simulation conditions

Table I. Computer simulation conditions.

Network	No. of distributed antennas	N_{macro}=19
	Small-cell radius	$R'=R/\sqrt{N_{\mathrm{macro}}}$
	Antenna deployment	uniform
Transmitter/ Receiver	Normalized transmit E_s/N_0	50dB
	No. of FFT/IFFT block size	N_c=128
	Guard interval length	N_{cp}=16
	No. of transmit antennas	N_{mbs}=4
	No. of receive antennas	N_{ue}=2
Propagation channel	Path loss exponent	α=3.5
	Shadowing loss standard deviation	σ=7.0dB
	Channel estimation	Ideal
	Frequency-Selective block	
	K factor of Nakagami-Rice	K=10dB
	Power delay profile (PDP) shape	16-path uniform
Schdeuling criteria	Round-robin scheduling	
	Active user	U_{act}=40
	Multiplexed user	U=1
Proposed adaptive ICIC	1st step ICI threshold	95%
	2nd step SIR threshold	10dB

Computer simulation conditions are summarized in Table 1. We assume perfect knowledge of the channel state information (CSI), the ICI level reported from the UEs, and the SIR level measured at the MBS. The 95% ICI level was set as the ICI threshold for the UE classification. The SIR threshold for allowing the cell-edge UE to use additional fractional bands was set as SIR_{th}=10dB. By computer simulation, we evaluate the CDF of cell-edge UE link capacity and the UE link capacity of the entire macro-cell. The 10% outage UE link capacity is discussed, which represents the link capacity of UEs suffering from poor communication quality (typically cell-edge UEs).

D. Comparison with proposed adaptive 2-step ICIC and fixed ICIC

Fig. 7 shows the CDF of cell-edge UE link capacity for OFDM downlink without ICIC, with fixed ICIC, and with proposed adaptive 2-step ICIC. When using proposed adaptive 2-step ICIC and the SIR threshold is set to 10dB, the average cell-edge UE link capacity improves about 1.6 times (5.0 bps/Hz→7.9 bps/Hz) compared to without ICIC. However, the 10 % outage UE link capacity degrades compared to that of fixed ICIC. This is because each MBS independently determines the usage of fractional bands for cell-edge UEs, leading to the SINR degradation due to the collision of frequency bands in use among neighbor macro-cell-edge UEs.

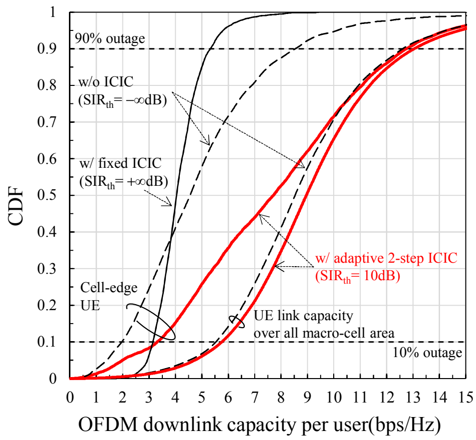


Fig. 7. UE link capacity for proposed adaptive 2-step ICIC (DA uniform deployment, maximum-3 fractional bands)

In order to mitigate the collision of the fractional bands among cell-edge UEs of neighbor macro-cells, we investigated the effect of limiting the maximum number of fractional bands to allocate to 2. Fig. 8 shows the CDF of cell-edge UE link capacity for our proposed adaptive 2-step ICIC. Limiting the maximum number of fractional bands improves the average cell-edge UE link capacity by about 1.3 times (5.0 bps/Hz→6.4 bps/Hz) compared to that of without ICIC. Furthermore, it can be seen from Fig. 8 that the cell-edge UE achieves similar 90% outage capacity to that of without ICIC. This is because the cell-edge UEs can be allowed to use 2 fractional bands while avoiding the strong ICI. This can be understood from Fig. 9 which plots the probability density distribution (PDF) of cell-edge UE link capacity.

It can be seen from Fig. 9 that when the fixed ICIC is used, the probability of falling into a low link capacity region (i.e., below 2 bps/Hz) decreases, but the probability of a high link capacity (i.e., over 6 bps/Hz) also decreases compared to that of without ICIC. On the other hands, in the case of proposed adaptive 2-step ICIC, both probabilities of falling into a low link capacity region and of achieving a high link capacity increase. It is interesting to notice that if cell-edge UEs are allowed to use up to 3 fractional bands, the probability of falling into a low link capacity region increases although the probability of achieving high link capacity increases, compared to that of fixed ICIC. If the maximum fractional bands to allocate is limited to 2, the probability of a high link capacity can be improved compared to that of fixed ICIC and without ICIC.

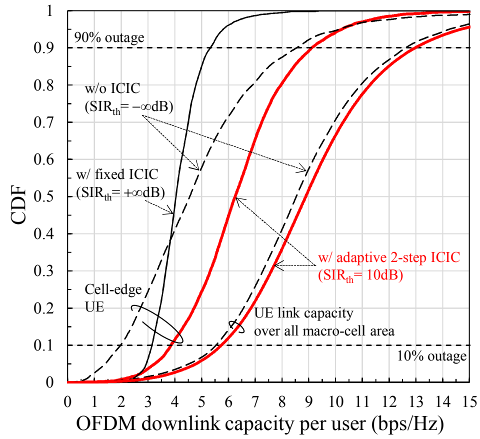


Fig. 8. UE link capacity for proposed adaptive 2-step ICIC (DA uniform deployment, maximum-2 fractional bands).

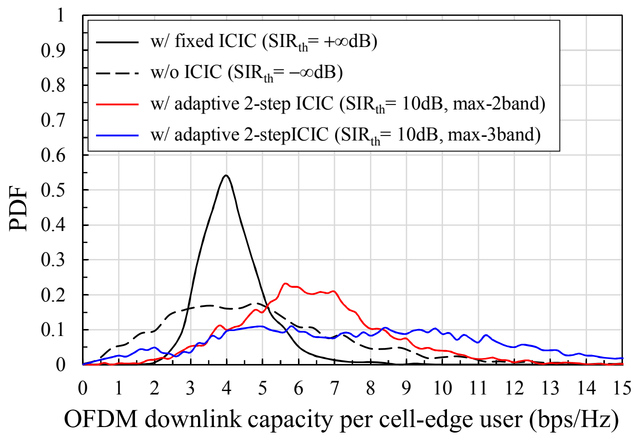
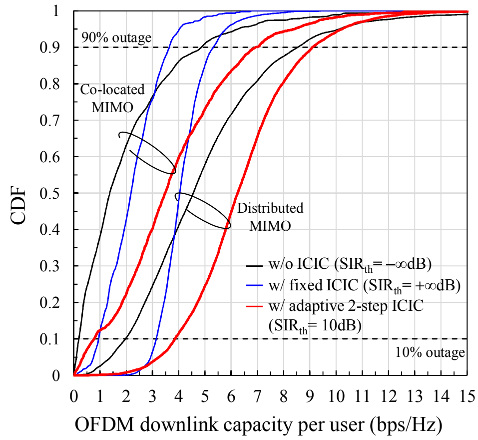


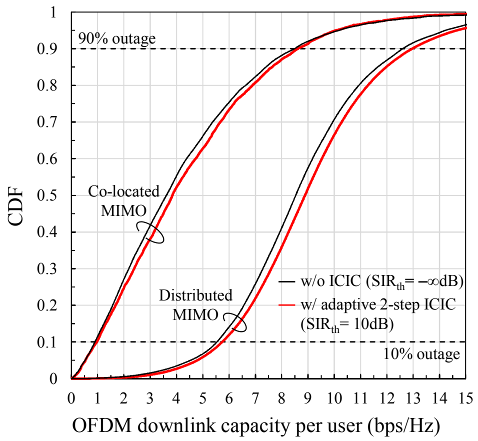
Fig. 9. The distribution of cell-edge UE link capacity (DA uniform deployment).

E. Comparison with distributed MIMO and co-located MIMO

The proposed adaptive 2-step ICIC techniques can also be applied to a co-locate MIMO network. Fig. 10 shows the CDFs of cell-edge UE link capacity and UE link capacity over all macro-cell area in distributed MIMO and co-located MIMO, respectively. It can be seen from Fig. 10 (a) that de-centralized adaptive 2-step ICIC improves the cell-edge UE link capacity for both distributed MIMO and co-located MIMO. However, distributed MIMO provides much higher cell-edge link capacity. The average cell-edge UE link capacity of distributed MIMO is about 6.4 bps/Hz while that of co-located MIMO is 3.8 bps/Hz. On the other hand, the 10 % outage cell-edge UE link capacity of distributed MIMO is 3.8 bps/Hz while that of co-located MIMO is 0.78 bps/Hz. Also compared is the average UE link capacity with de-centralized adaptive 2-step ICIC (averaged over entire macro-cell area). It is 9.2 bps/Hz for distributed MIMO while 4.4 bps/Hz for co-located MIMO, as seen from Fig. 10 (b).



(a) Cell-edge UE link capacity



(b) UE link capacity over all macro-cell area

Fig. 10. Distributed MIMO vs Co-locate MIMO.

V. CONCLUSIONS

In this paper, we proposed a de-centralized adaptive 2-step ICIC, which does not require the information sharing of fractional bands in use among neighbor macro-cells. In the proposed ICIC, the improvement of cell-edge UE link capacity can be obtained without sacrificing cell-edge UEs with poor communication quality when the maximum number of fractional bands to allocate is limited to 2. Furthermore, it was confirmed that the cell-edge UE link capacity is improved by about 1.3 times compared to that of without ICIC without degrading the UE link capacity over all macro-cell area. However, the whole network time synchronization is necessary. Problems related to optimization of the ICI threshold, the adaptive frequency reusing for the cell-edge areas, and radio access network time synchronization are left as our future study.

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