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2-step RCN-GCA for Interference Coordination for Multicell Distributed MU-MIMO in Ultra-dense RAN

Chang Ge †, ‡ ,a)　Sijie Xia †, ‡ ,b)　Qiang Chen ‡ ,b)　Fumiyuki Adachi †, b)

† Research Organization of Electrical Communication, Tohoku University

2-1-1 Katahira, Aoba-ku, Sendai, Miyagi, 980-8577, Japan

‡ Department of Communications Engineering, Graduate school of Engineering, Tohoku University

6-6-05 Aramaki Aza Aoba, Aoba-ku, Sendai, Miyagi, 980-8579, Japan

E-mail: a) ge.chang.q2@dc.tohoku.ac.jp, b) {xia-s, adachi, chenq}@eceic.tohoku.ac.jp

Abstract In our recently study, we proposed a restricted color number-based graph coloring algorithm (RCN-GCA) for interference coordination in cluster-wise distributed MU-MIMO. The RCN-GCA aims at mitigating the inter-cluster interference and its effectiveness for improving the link capacity was verified assuming single-cell system model. In this paper, we extend our study to multi-cell cluster-wise MU-MIMO and propose a 2-step RCN-GCA. The proposed 2-step RCN-GCA is designed to coordinate not only the inter-cluster interference but also the inter-cell interference simultaneously by dividing the users into 2 groups (cell-edge and cell-center), and applying GCA separately on these two groups. The computer simulation results confirm that our proposed 2-step RCN-GCA can achieve better performance than the previous RCN-GCA in a multi-cell system.

Keywords Graph Coloring, cluster, interference coordination, multi-cell system, MU-MIMO, ultra-dense RAN

1. Introduction

The ultra-dense radio access network (RAN) with distributed antennas has been regarded as a promising approach in 5G advanced [1]. In our previous study [2], it was shown that forming user/antenna clusters in each base station coverage area (or cell) is an efficient way to reduce the computational complexity required in the presence of the massive users and antennas. However, the inter-cluster interference will be produced. Therefore, we proposed a restricted color number-based graph coloring algorithm (RCN-GCA) [3] for interference coordination to mitigate the inter-cluster interference. Our RCN-GCA is based on graph coloring algorithm, and we improved it by setting an upper limit to the number of colors that can be used so as to avoid dividing the available band into too many narrow bands. The simulation results of our RCN-GCA in single-cell indicates that 1) For sum capacity, our proposed graph coloring algorithm can improve the link capacity when the number of users is more than half of the number of antennas; 2) For user capacity, our proposed RCN-GCA can increase the performances of 10% user capacity in all the cases and therefore is capable to further enhance the users' experience and satisfaction. Later in [4], we also verified that when our RCN-GCA algorithm is jointly used with user-based clustering method, the results are stable and less affected by antenna's location, therefore is capable to provide universal conclusions.

It should be noted that since no inter-cell interference is present in the single-cell model, the RCN-GCA, which performs well in single-cell model, cannot guarantee its effectiveness in multi-cell system. In a multi-cell network, not only the inter-cluster interference but also the inter-cell interference exists. If the previously proposed RCN-GCA is utilized in a multi-cell system, there are some problems as follows. On the one hand, if the RCN-GCA is extended to the entire multicell system, named as the coordinated RCN-GCA, a problem of huge computational complexity arises as well as a problem less flexibility when new cells need to be added into the network. On the other hand, if the RCN-GCA algorithm is applied to each cell independently, named as the non-coordinated RCN-GCA, the color collision will appear in the cell edge area due to the lack of cells coordination. Therefore, the inter-cell interference still exists, which degrades the performance of multi-cell system. To sum up, we need a more advanced algorithm that can avoid the color collision in cell-edge while at the same time, with comparable computational complexity as non-coordinated RCN-GCA.

In LTE/LTE-A cellular network, the fractional frequency reuse (FFR) [5] or soft frequency reuse (SFR)

[6] with a fixed reuse factor (e.g., Reuse-3 scheme) is one of the important techniques in inter-cell interference coordination (ICIC). The basic idea is to pre-assign different fractional frequency bands to the adjacent cell-edges so as to improve the cell-edge users' signal-to-interference plus noise ratio (SINR). On the basis of this, many novel algorithms have been proposed. In [7], the author divided the available frequency band into 3 fractional frequency bands, one for cell-edge, the other 2 bands for cell-center. In cell-edge, the Reuse-3 scheme is applied; while in cell-center, the directional antennas are used to divide the cell-center region into 6 sectors, and make sure the interference is not given to the cell-edge region. Through this way, the author proved that by intelligently design the frequency band allocation, the ICIC can be achieved with no need to reduce the transmit power, a commonly used method in SFR. Also, R. Chang in [8] introduced the graph coloring algorithm to achieve dynamic FFR. Recently, T. Saito [9] also applied the FFR into distributed MIMO and formed a de-centralized adaptive 2-step interference coordination algorithm.

In this paper, we propose a 2-step RCN-GCA for the multi-cell cluster-wise distributed MU-MIMO. The first step is to apply the GCA on the cell edge in order to mitigate the inter-cell interference. The optimization algorithm based on the information of antennas' locations will be applied in this step so as to have better interference mitigation with less number of colors. Since the antenna's location is fixed and known in advance, this step can only be applied once at the very beginning of system operation, and after that, the color of each cell become a known condition for the later second step. From the beginning of second step, no more coordination from other cells is needed. In each cell, conditional RCN-GCA is applied under the control of BS to mitigate the inter-cluster interference, which is similar to the situation in single-cell model. Our proposed 2-step RCN-GCA can successfully achieve the inter-cell coordination with the affordable computational complexity, and therefore make it possible to be applied in multi-cell system with massive cells.

The rest of paper is organized as follows. In Chapter 2, multi-cell model is presented and the previously proposed RCN-GCA is reviewed. In Chapter 3, our proposed 2-step RCN-GCA is described in detail. In Chapter 4, the link capacity is evaluated by computer simulation. Finally, Chapter 5 provides the conclusion and our future research plan.

2. The review of RCN-GCA in multi-cell network

2.1. Multi-cell model

In previous studies, we assumed the single cell model to be a normalized square-shaped BS area of 1 by 1 in which 128 distributed antennas are randomly located and remain unchanged in our simulation. On this basis, we keep our target cell (shown in Fig. 1) to be the same of single cell model in order to make easy comparison later. Since we are going to mimic an infinite area, we need to take full considerations of all possible inter-cell interference nearby. Therefore, we prepared 2 layers of cells to surround the target cell (the entire model contains 25 cells in total). For simplicity, each surrounded cell is set to have the same number of antennas (A), users (U) and clusters (C) as the target cell.

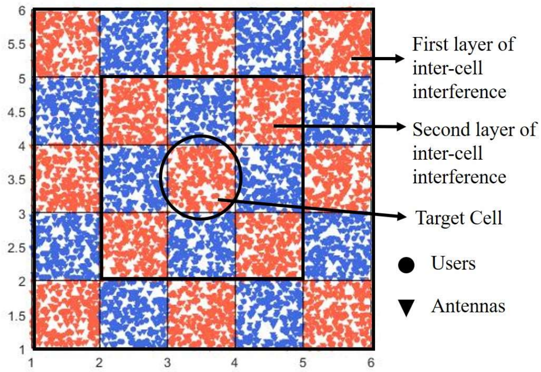


Fig.1 multicell model.

2.2. Previously proposed RCN-GCA

Our previously proposed RCN-GCA [3] assuming the single-cell model makes it possible to assign different colors (or frequency) to neighboring clusters in order to mitigate the inter-cluster interference. In this RCN-GCA, the neighboring relationship is decided by Delaunay Triangulation, which can successfully cope with the situation when clusters' location changed flexibly. Also, in RCN-GCA, we can restrict the maximum number of colors that has been used so as to improve the bandwidth efficiency. Based on our previous study on single cell model, our proposed RCN-GCA algorithm can realize a significant increase in both sum and user link capacity. However, the performance of its application in multicell network remains unknown.

There are two ways to apply the RCN-GCA algorithm in the multicell simulation model. One of which is named as non-coordinated RCN-GCA, where each BS apply RCN-GCA algorithm independently without any coordination with each other at all; The other way is named as coordinated RCN-GCA, in which we suggest an organizer is available to cooperate all the BSs so that we can regard the entire 25 cells to be one single cell. Through this way we can apply the RCN-GCA algorithm in this huge single cell. The coloring result of these two methods when applying the same users and antennas distribution (U=96, A=128, C=8) is shown in Fig.2 and Fig.3.

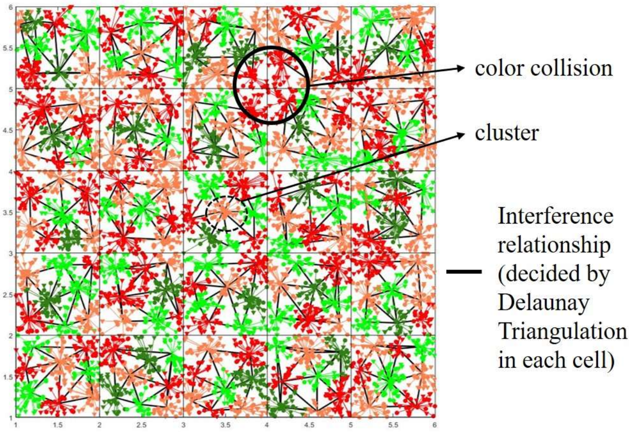


Fig.2 The graph coloring results of non-coordinated RCN-GCA.

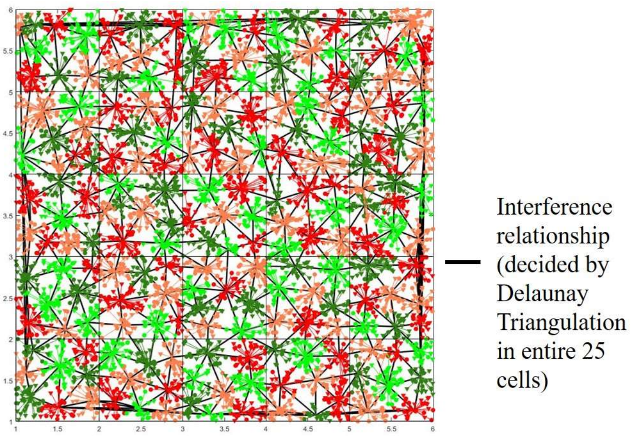


Fig.3 The graph coloring results of coordinated RCN-DCA.

In Fig.2, due to the lack of cells coordination, the color collision (shown in Fig.2) may happen frequently in the cell edge area and therefore, strong inter-cell interference still exits. In this case, the application of the RCN-GCA sacrifices the bandwidth but in return, do not successfully mitigate all the interference, therefore the advantage of graph coloring algorithm in multicell system will be less apparent than in single cell situation.

In Fig.3, since we consider all the cells as one single cell, the clusters at the cell edge area can be successfully distinguished and the color collision can be avoided. However, this method requires extremely high computational complexity when a large number of cells exist. Also, in the situation when new cells are needed to be added into this network, the flexibility of the system is quite low. Therefore, in some extent, the result of coordinated RCN-GCA is the goal for us to strive for but cannot be realized in practical applications.

3. Proposed 2-step RCN-GCA

As we mentioned above, the coordinated RCN-GCA is an ideal situation but difficult to realize, while the non-coordinated RCN-GCA is computationally feasible but needs to be improved. Therefore, we are looking for an algorithm with nearly the same computational complexity as non-coordinated RCN-GCA, but better performance that can approach the coordinated RCN-GCA. Under this background, our 2-step RCN-GCA has been proposed.

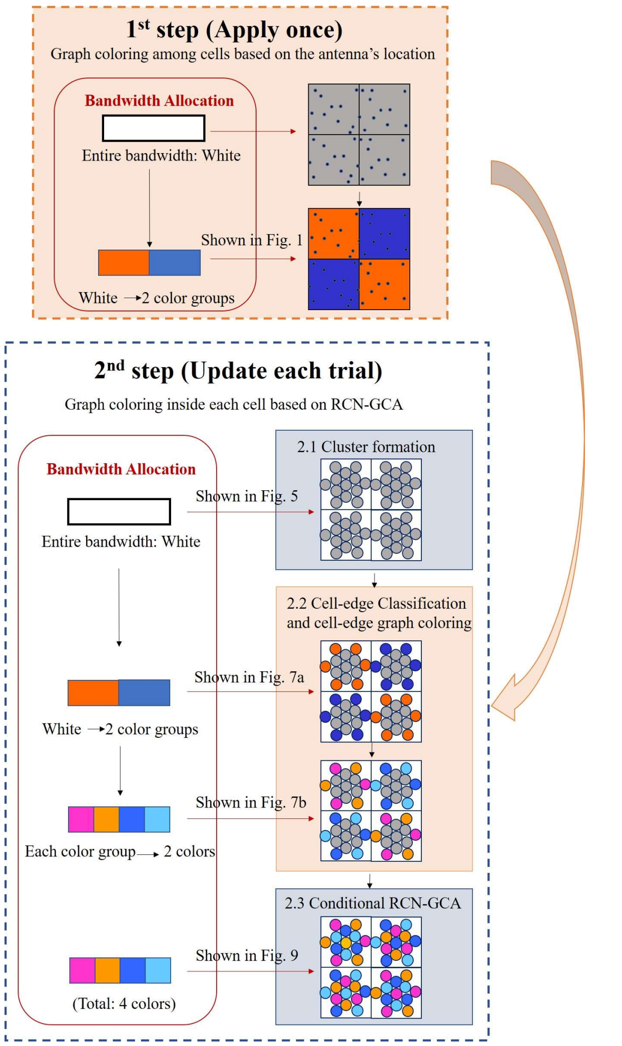


Fig.4 2-step RCN-GCA.

The 2 step RCN-GCA consists of 2 separate steps as shown in Fig. 4. The 1st step is to coordinate the inter-cell interference by temporarily neglecting the inter-cluster interference inside each cell. Here, the 1st step is designed to be an optimization process based on antennas' location. Since the antennas' location is known in advance when deployed, the 1st step can be applied at the very beginning and will not leave extra computational burden in the succeeding system operation. Later, if new cells are added to our network, this step can be updated again, so the flexibility can also be attained. Since this is a preliminary research, we adopt the idea of Reuse-3 scheme [7] in FFR and propose a Reuse-2 scheme based on our square-shaped multicell simulation model. The supposed Reuse-2 scheme-based 1st step coloring result is shown in Fig.1. The optimization algorithm that can be used for non-uniform multi-cell system is left for our future study.

In actual communication, only the 2nd step is performed. Since the users' location is changing all the time, therefore, clusters formation needs to be updated each trial. In step 2.1, K-means clustering algorithm(user-based) [3] will be applied and the clustering results for the target cell is shown in Fig.5 for the same distribution of U, A and C as shown in Fig.2 and Fig 3.

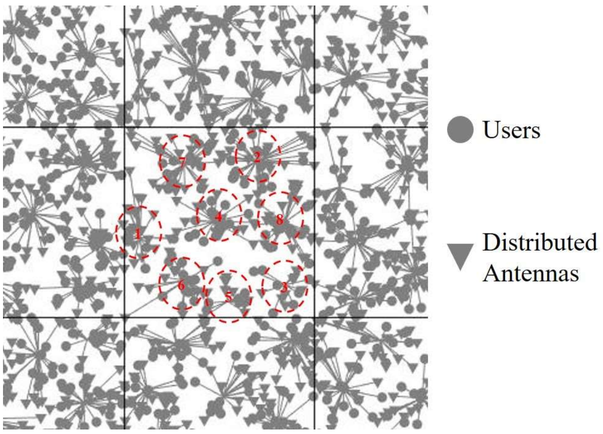


Fig.5 Cluster formation based on K-means algorithm.

Once the clusters have been formed, the cell-edge classification and cell-edge graph coloring (step 2.2) becomes the critical process in our proposed 2 step RCN-GCA. In each cell, all the clusters need to be divided into two groups (cell-edge and cell-center). For simplicity, we did this classification based on cluster centroid's location. For those clusters whose centroid is near the cell boundary, they will be regarded as cell-edge clusters, and the remaining clusters will be categorized into cell-center group. The results of cell-edge classification for the same U, A, C is shown in Fig.6.

After the cell-edge classification, the cell-edge clusters will be colored first. Before in the 1st step, all the cells are divided into 2 color groups as shown in Fig.1, therefore in cell-edge graph coloring process, we firstly divide the entire bandwidth into two parts. In other words, each cell's cell-edge clusters can only share half of the entire bandwidth. However, as we can see from the Fig.7(a), the cell-edge clusters themselves will have color collision problem, therefore we further divide each color group into two colors (in total, there are 4 colors) as shown in Fig.7(b) to coordinate the inter-cell interference and inter-cluster interference at the same time.

After the colors of cell-edge have been decided, in step 2.3, our previously proposed RCN-GCA can be applied to cell-center clusters in order to mitigate the inter-cluster interference inner cell. Since there are some limiting conditions (cell-edge clusters' colors) this time. We slightly modified the previously RCN-GCA algorithm into the conditional RCN-GCA algorithm, and the flow chart has been shown in Fig.8. The number of colors been used is fixed to 4 this time. The details of our RCN-GCA and the introduction of how to apply Delaunay Triangulation, and how to restrict the maximum color number is shown in Reference [3].

The final graph coloring results of the proposed 2-step RCN-GCA in multicell simulation model is shown in Fig. 9. In short, the cell-edge clusters can only use the 2 of 4 colors, while the cell-center clusters can use all the 4 colors.

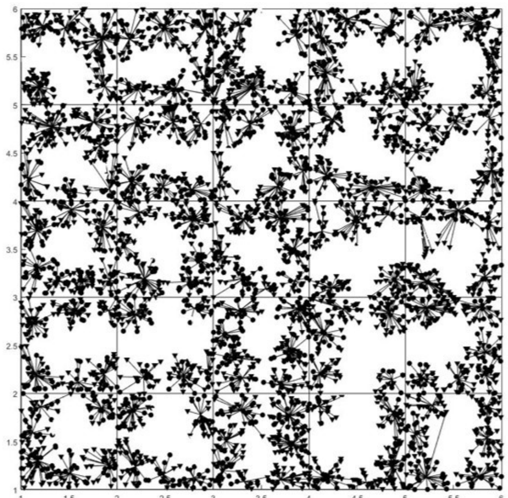
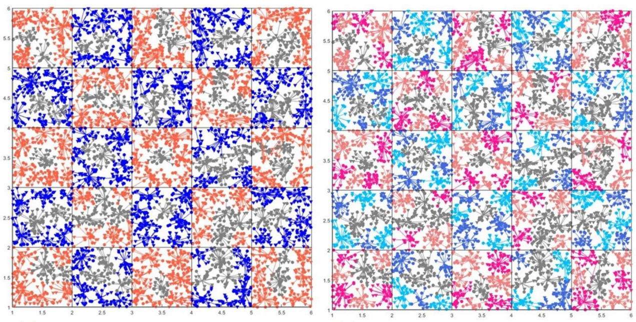


Fig. 6 Cell-edge classification results.



(a) Original cell-edge coloring results (b) Modified cell-edge coloring results

Fig.7 Cell-edge clusters coloring results.

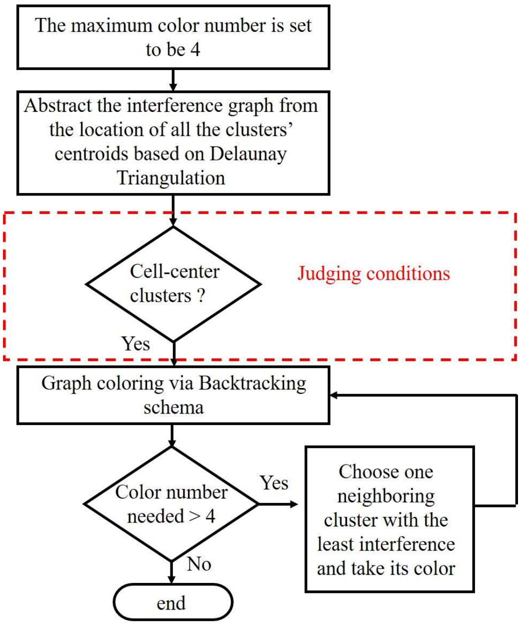


Fig.8 Conditional RCN-GCA algorithm.

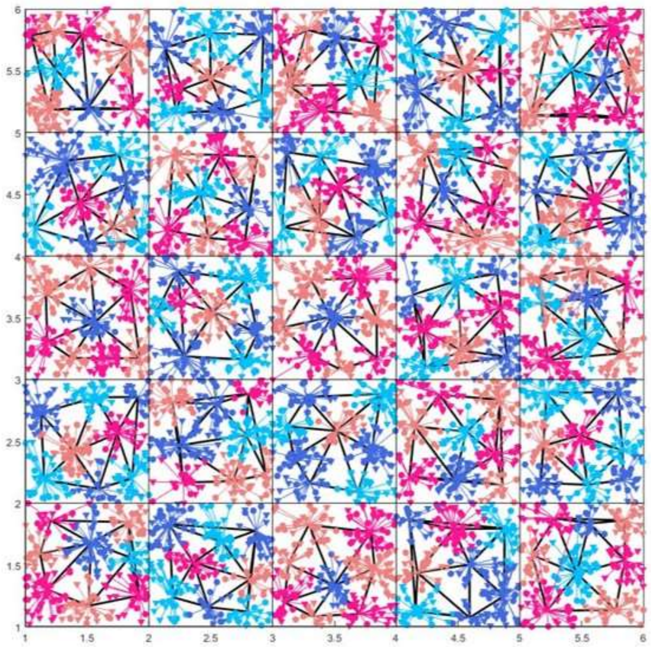
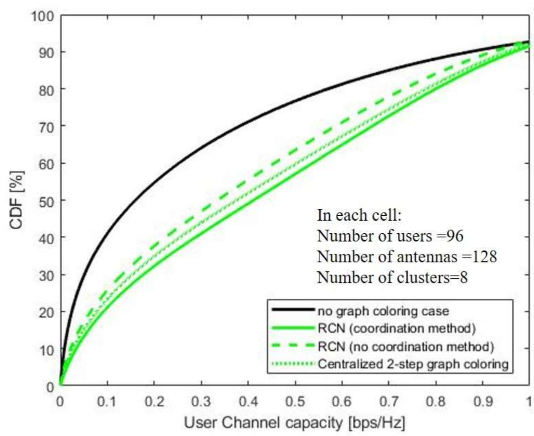


Fig.9 2-step RCN-GCA results.

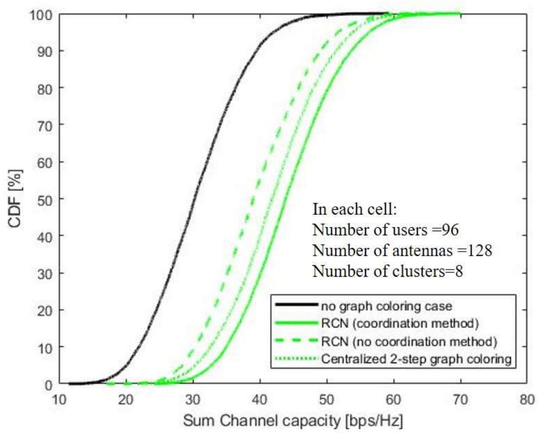
4. Monte Carlo simulation & discussion

In this chapter, we evaluate the downlink sum capacity and user capacity when Zero-Forcing (ZF)-based cluster-wise distributed MU-MIMO is performed. It is assumed that 96 users, 128 antennas, and 8 clusters are present in each cell. The transmit power for each user is set so that the received signal-to-noise ratio becomes 0dB when the distance between the transmitter and receiver is equal to the side length of square-shaped BS area. The channel is modelled by the pathloss, the log-normal shadowing, and multipath fading. The pathloss exponent is set to be 3.5 and the shadowing standard deviation is set to be 8dB. The fading type assumed in the simulation is frequency-nonselective Rayleigh fading. The cumulative distribution function (CDF) of the sum capacity is obtained by 10,000 trials (realized by 100 times changes in pathloss and then, for each change, 10 times changes in shadowing loss and 10 times changes in Raleigh fading per each shadowing loss change) assuming the quasi-stationary users (i.e., fading does not change during communication) for a certain set of antenna locations shown in previous Fig.2 or Fig.3.

Fig.10 plots the cumulative distribution functions (CDFs) of the sum capacity and the user capacity for the target cell in our multi-cell simulation model. In Fig.11, for comparison, we also presented the previously proposed RCN-GCA's CDF results of sum capacity when applied in single cell model. In singe cell, since our proposed RCN-GCA graph coloring algorithm can successfully assign different colors to neighboring clusters, it can realize a 49% increase in sum link capacity over no graph coloring case. In multicell network, if we regard all the cells as a huge single cell (as mentioned as coordinated RCN-GCA), the graph coloring algorithm can also achieve a 45% increase over no coloring case. However, this is unachievable in reality due to the computational complexity problem. The other method, mentioned as non-coordinated RCN-GCA, which suggest there are no-coordination among cells at all, can achieve only an increase of 29% due to the color collision on cell edge area. In the end, our proposed 2-step RCN-GCA can reach an increase of 38%, which is higher than the non-coordinated RCN-GCA, and is approaching the coordinated RCN-GCA. The user capacity result provides the same conclusion as the sum capacity results.



(a) User capacity



(b) Sum capacity

Fig.10 CDF of user capacity and sum capacity for the target cell in multicell system.

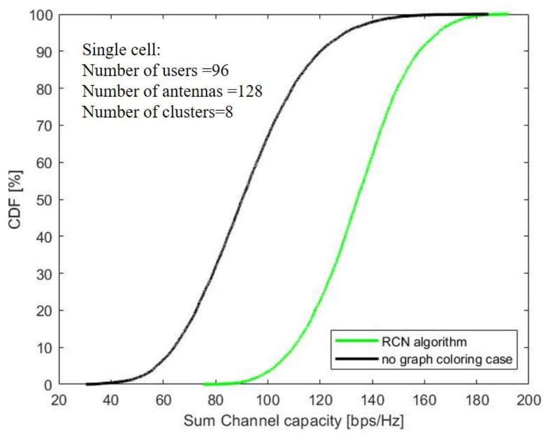


Fig.11 CDF of sum capacity for single-cell simulation model

5. Conclusion

In our recent study, we proposed a restricted color number-based graph coloring algorithm (RCN-GCA) for interference coordination in multi-cell system with cluster-wise distributed MU-MIMO. However, if the GCN-GCA is applied directly to multi-cell network, the inter-cell interference still remains due to the lack of cell's coordination. Also, the huge computational complexity prohibits us from applying the RCN-GCA to the entire multi-cell system. Therefore, we modified the previously proposed RCN-GCA and proposed a 2 step RCN-GCA, which can coordinate the inter-cell interference and the inter-cluster interference by 2 steps. As a result, higher link capacity can be obtained with almost the same computational complexity.

In our future study, we will further develop our 2-step RCN-GCA by introducing the optimization algorithm that can be utilized in the 1st step. Later, we also plan to improve our proposed algorithm into a decentralized 2-step RCN-GCA with the help of machine learning.

Acknowledgement

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