An Improved Method in Graph Coloring Algorithm for Interference Coordination in Cluster-wise Ultra−dense RAN

Chang Ge[1*], Sijie Xia[1], Qiang Chen[1], and Fumiyuki Adachi[2]
[1]Department of communications Engineering, Tohoku University, Japan
[2]Research Organization of Electrical Communication, Tohoku University, Japan
[*]email: ge.chang.q2@dc.tohoku.ac.jp

***Abstract* - In our previous study, we proposed a Restricted Color Number (RCN) algorithm based on graph coloring for interference coordination in cluster-wise distributed MU-MIMO in ultra-dense RAN. In this algorithm, we applied Delaunay Triangulation to help decide the interference relationship, which is different from the common-used threshold setting method. In this paper, we will discuss about the advantages of the Delaunay Triangulation method over the threshold method in graph coloring algorithm for interference coordination.**

***Keywords* — Ultra-dense RAN, Cluster-wise MU-MIMO, Graph coloring algorithm, Interference coordination, Delaunay Triangulation.**

I. INTRODUCTION

The ultra-dense radio access network (RAN) with distributed antennas has been regarded as a promising approach in 5G advanced systems [1]. In order to reduce the computational complexity necessary to spatially multiplex a large number of users by using massive number of antennas, forming user/antenna clusters in each BS coverage area have been proved by our previous studies [2] to be an efficient way. However, the inter-cluster interference will be produced. Therefore, we have been trying to apply graph coloring algorithm to mitigate the inter-cluster interference, and proposed a Restricted Color Number (RCN) algorithm [3].

In the ultra-dense RAN with distributed antennas, the graph coloring problem can be abstracted into an undirected graph G= (V, E), in which the V denotes vertices (centroid of clusters) while E denotes edges (interference relationship). The decision of the interference relationship plays a critical role in the final graph coloring outcomes, and should be decided in advance. One common-used method is to set a threshold as a standard to judge whether the two clusters are interfered or not. The threshold can be determined based on Euclidean distance or interference (e.g. pathloss). However, in our proposed RCN algorithm, we used another solution by introducing the Delaunay Triangulation[4] from computational geometry, which makes it possible to simplified the threshold selecting problem in graph coloring algorithm for interference coordination.

In this paper, we will make comparison of the Delaunay Triangulation method with the distance and the pathloss threshold method in order to have an in-depth discussion on its advantages.

II. SIMULATION RESULTS

In this paper, we consider a case of 96 users, 128 antennas and 16 clusters as an example. The clustering method is explained in [3]. An example of clustering is shown in Fig. 1, where the Delaunay Triangulation result is also presented.

A Delaunay Triangulation is a way to generate triangles for a given set of discrete vertices in a plane, which follows the restriction that no vertex is inside the circumcircle of any triangles. If there is a triangle's edge connecting the two clusters, then these two clusters will be regarded as neighbors and therefore, should not share the same color.

Since the most severe interference happens among the neighboring clusters, so the triangulation result can be regarded as interference graph directly. Once the interference graph is decided, the coloring result is also determined and shown in Fig. 1 too.

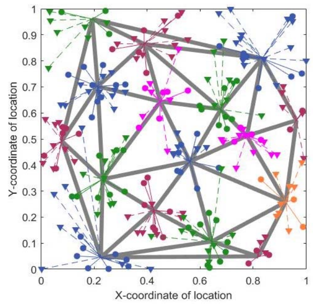
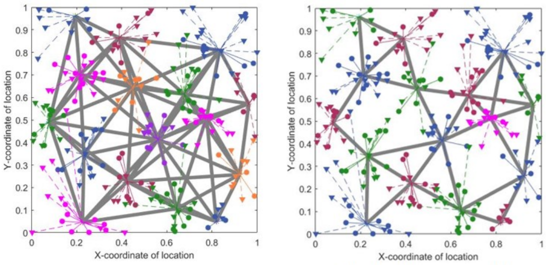


Fig. 1. Interference graph based on Delaunay Triangulation

Fig. 2 shows the interference graphs for one particular threshold setting method (both choose the mean value of the total distance or total pathloss). For distance threshold, if the distance between the two clusters' centroid is no more than the threshold, then these two clusters will be regarded as having interference. Similarly, if the pathloss between the two clusters is no less than the pathloss threshold, they will be considered as interfered too.

The coloring results in Fig.2 indicates that the value of threshold has strong influence on the final coloring results. The more stringent the threshold is, the more complicated the interference relationship will be, therefore more colors will be needed, and narrower bandwidth each color will get for the given total bandwidth. Therefore, the value of threshold should be decided seriously.



Threshold= mean distance   Threshold= mean pathloss

Fig. 2. Interference graph based on the threshold setting

For computer simulation, we prepare 8 different conditions for distance threshold and pathloss threshold separately, which are shown in Table I. The 50% sum capacity comparing the Delaunay Triangulation method with the threshold setting method is shown in Fig.3. It can be seen that the performance of Delaunay Triangulation is always at a relatively high level when compared with the maximum value of the threshold method.

TABLE I SIMULATION SETTING

Threshold Selection			
	Index	Mean Distance	Mean pathloss
Loose threshold ▲	1	0.25 times	1.0 times
	2	0.5 times	0.75 times
	3	0.75 times	0.5 times
	4	1.0 times	0.25 times
	5	1.25 times	0.1 times
	6	1.5 times	0.05 times
▼ Stringent threshold	7	1.75 times	0.04 times
	8	2.0 times	0.025 times

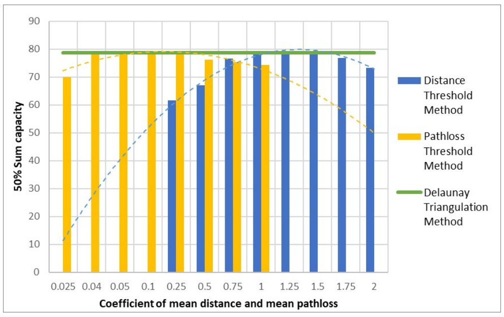


Fig. 3. The comparison of Delaunay Triangulation method with the threshold setting method

In Fig.4 we also counted the distribution of the number of colors based on 10,000 trials for each condition. In order to get a similar level of link capacity, Delaunay Triangulation method needs 4 or 5 colors, but threshold method needs more than 10. Therefore, applying Delaunay Triangulation can mitigate the most severe interference with the least cost of bandwidth sacrifice.

It should be noted that the threshold value which performs well in this case (96 users, 128 antennas, 16 clusters) may not fits the other situations. Therefore, it is hard to find the optimum threshold for every case, but the application of Delaunay Triangulation can simplify the threshold setting problem when any number of users, antennas or clusters are deployed.

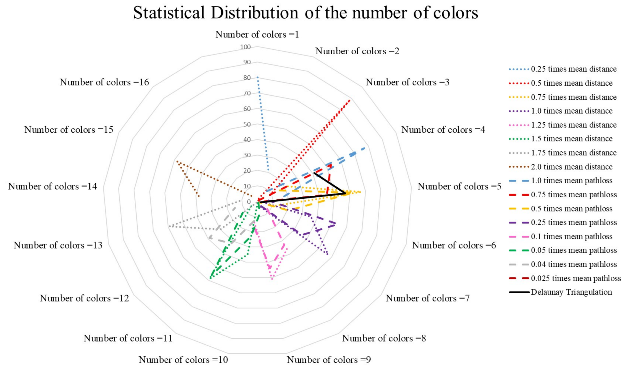


Fig. 4. The statistical distribution of the number of colors

III. CONCLUSION

In this paper, we have compared the performances of the Delaunay Triangulation method and the threshold setting method in graph coloring algorithm for interference coordination and draw the following conclusions:

1) For link capacity, the Delaunay Triangulation method can always requires a smaller number of colors compared with the threshold method;
2) The Delaunay Triangulation method can simplify the threshold setting problem in graph coloring algorithm.

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