Adaptive Resource Allocation for ICIC in Downlink NOMA Systems

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***Abstract*—Inter-cell interference coordination (ICIC) has been widely studied for mitigating the effects of severe inter-cell interference (ICI) in cell-edge users. However, based on the scarcity of frequency resources in orthogonal multiple access systems, the ICIC methods proposed in the previous papers have difficulty in maintaining the overall performance and fairness of a system. Non-orthogonal multiple access (NOMA) is a promising radio access technology that can serve multiple users simultaneously with the same frequency resources. However, most previous work has not considered the ICI problem in NOMA systems. We propose a centralized adaptive ICIC framework for downlink NOMA systems, including a distributed clustering algorithm, a distributed power allocation algorithm, and a centralized frequency allocation algorithm. Simulation results demonstrate that the proposed framework outperforms all benchmark frameworks and can improve both the overall performance of a system and fairness among users.**

Keywords: inter-cell interference coordination, non-orthogonal multiple access, frequency allocation, power allocation

I. Introduction

In current network systems, all base stations (BSs) typically share the same frequency band to increase radio resource efficiency. Therefore, cell-edge user equipment (UE) may suffer from severe inter-cell interference (ICI) from adjacent cells. To handle the ICI problem, the concept of inter-cell interference coordination (ICIC) is introduced in release eight of the 3GPP specification [1]. It points out that radio resource management is the key to solving the ICI problem. Two main mechanisms are described as follows:

- Band division: The bandwidth is divided into several resource blocks (RBs). ICIC is realized by separating cell-edge UE in adjacent cells into different RBs.
- Power control: The power of a downlink data channel is adjusted for each piece of UE to suppress the effects of ICI. A BS typically transmits to cell-center UE with lower power and cell-edge UE with higher power.

Non-orthogonal multiple access (NOMA) is a promising candidate radio access technology for 5G networks. In NOMA, a BS is able to allocate one frequency sub-band to multiple users simultaneously. Therefore, each piece of UE can be allocated with more resources compared to orthogonal multiple access (OMA) systems. A BS in a NOMA system serves each piece of UE at different power level to ensure that each UE can decode its own signal successfully. Weaker UE (lower channel gains) is allocated with higher power, while stronger UE (higher channel gains) is allocated with lower power. Each piece of UE utilizes successive interference cancellation (SIC) to subtract higher-power signals for other users and decodes its own signal. Since cell-center UE is served at a low power level, most of signals for other users can be subtracted. Since cell-edge UE is served at a high power level, most of signals for other users can not be subtracted. Such signals are regarded as intra-cell interference (ITCI) in the UE.

Most previous work related to ICIC is based on OMA systems. Since frequency resources are scarce in OMA systems, a trade-off between the number of RBs allocated to cell-center UE and the number of RBs allocated to cell-edge UE cannot be avoided. If a system prefers to improve overall performance, it should increase the number of RBs allocated to cell-center UE. On the other hand, if a system prefers to improve fairness among UE, it should increase the number of RBs allocated to cell-edge UE. It is difficult for an ICIC framework in an OMA system to maintain the performance and fairness of a system simultaneously. Another problem is that when the number of UE devices waiting for service exceeds the maximum number of servable devices in one transmission time interval (TTI), the BS must perform scheduling to serve different pieces of UE in different TTIs. This reduces the throughput of each piece of UE proportionally to the total number of UE devices. When UE density is high in a cell, the throughput of each piece of UE in that cell is extremely low in OMA systems. To solve these two problems, we introduce NOMA for resource allocation in ICIC to increase the number of RBs allocated to each piece of UE.

Most previous work related to NOMA does not consider the ICI problem. Although it has been stated that being agnostic to ICI can severely degrade the performance of a system [2], [3], [4], no previous work is found to propose an ICIC framework for NOMA systems. As a result, our goal is to design an adaptive resource allocation framework for ICIC in NOMA systems. Additionally, we focus on the downlink portion of resource allocation in this work.

The remainder of the paper is organized as follows. Section II discusses some related work on ICIC and NOMA. Section III describes the main problem formulation. Section IV presents the proposed framework, which consists of a clustering algorithm (CA), a power allocation algorithm (PAA), and a frequency allocation algorithm (FAA). Section V analyses the performance of the proposed framework based on simulation results. Finally, conclusions are drawn in Section VI.

II. Related Work

The proposed framework is motivated by the recent work that applies graph theory to resource allocation. The paper [5] provides an introduction to channel assignment based on graph theory and the coloring principle. A scheduler and a resource optimizer based on graph theory are presented in [6] to realize ICIC with testbed implementation. Joint optimization of user-centric overlapped clustering and resource allocation is performed in [7] to maximize the spectral efficiency of an entire system. User-centric overlapped clustering allows each piece of UE to be served cooperatively by several BSs. A resource allocation algorithm based on an interference graph is proposed in [8] to mitigate the interference in a heterogeneous network. A scenario with dense users in a cellular network is considered in [9], where the authors utilize a group based graph-coloring algorithm to solve the resource allocation problem. The results evaluated in [10] also verify the performance of a graph based ICIC framework. This related work inspires us to design the proposed ICIC framework.

The proposed framework is also motivated by the recent work that optimizes resource allocation in NOMA systems. The survey [11] discusses potentials and challenges of power-domain NOMA in 5G systems and demonstrates that NOMA has better performance than OMA. Some work investigates resource allocation schemes to optimize energy efficiency for downlink NOMA systems [12], [13], [14]. Some other work investigates NOMA in heterogeneous networks [2], [3], [13], [15]. A cluster formation algorithm and a power-bandwidth allocation algorithm are designed for non-ideal SIC based imperfect NOMA [3], [15]. Besides, the negative impact of ICI on the performance of NOMA in 5G networks is investigated in [4]. This related work inspires us to design the proposed ICIC framework in NOMA systems.

III. Problem Formulation

We consider a network consisting of L BSs in a set $\mathbb{B} = \{b_i \mid i \in [1, L]\}$. UE is randomly distributed within the network. Each piece of UE connects to the BS with the best reference signals received power (RSRP). The UE devices connected to BS b_i are grouped into M clusters in a set $\mathbb{C}(i) = \{c_{i,j} \mid j \in [1, M]\}$. Each BS allocates resource block groups (RBGs), the minimum unit of resource allocation specified by 3GPP standard [16], to its M clusters evenly. UE in the same cluster uses all frequency resources allocated to that cluster. BS b_i serves $N_{i,j}$ pieces of UE in cluster $c_{i,j}$. Those pieces of UE are in a set $\mathbb{U}(i,j) = \{u_{i,j,k} \mid k \in [1, N_{i,j}]\}$.

In NOMA systems, a piece of UE receives not only its desired signal but also the undesired signals for other UE in the same cluster from the serving BS. Such undesired signals represent ITCI in UE. Each piece of UE utilizes SIC to subtract ITCI from broadcast signals and decodes the desired signal. However, only interference with higher signal strength than the desired signal is subtractable. Other interference with lower signal strength than the desired signal is unsubtractable. For a piece of UE $u_{i,j,k}$, the received signals from high signal strength to low signal strength are defined as

$$\underbrace{s^{u_{i,j,k}}_{u_{i,j,N_{i,j}}} > \ldots > s^{u_{i,j,k}}_{u_{i,j,k+1}}}_{\text{Subtractable Signals}} > \underbrace{s^{u_{i,j,k}}_{u_{i,j,k}}}_{\text{Desired Signal}} > \underbrace{s^{u_{i,j,k}}_{u_{i,j,k-1}} > \ldots > s^{u_{i,j,k}}_{u_{i,j,1}}}_{\text{Unsubtractable Signals}}, \tag{1}$$

where $s^{u_{i,j,k}}_{u_{i,j,k'}} = p^{u_{i,j,k'}}_{b_i} g^{u_{i,j,k}}_{b_i}$ is the strength of the signal for the UE $u_{i,j,k'}$ received by the UE $u_{i,j,k}$. $p^{u_{i,j,k}}_{b_i}$ represents the transmission power from the BS b_i to the UE $u_{i,j,k}$, and $g^{u_{i,j,k}}_{b_i}$ represents the channel gain from the BS b_i to the UE $u_{i,j,k}$. The received signal-to-interference-plus-noise ratio (SINR) at a piece of UE $u_{i,j,k}$ is given by

$$R_{u_{i,j,k}} = \frac{p^{u_{i,j,k}}_{b_i} g^{u_{i,j,k}}_{b_i}}{I_{\text{ici}} + I_{\text{itci}} + n_0}, \tag{2}$$

where I_{ici} and I_{itci} represent ICI and ITCI respectively, and n_0 is noise. I_{ici} is the sum of the interference from all the other BSs, and calculated as

$$I_{\text{ici}} = \sum_{b_l \in \mathbb{B}, l \neq i} \sum_{u_{l,m,n} \in U(l,m)} p^{u_{l,m,n}}_{b_l} g^{u_{i,j,k}}_{b_l}, \tag{3}$$

where the cluster $c_{l,m}$ is allocated with the same frequency sub-bands as the cluster $c_{i,j}$. I_{itci} is the sum of the interference from the serving BS. Since subtractable signals cannot be fully canceled based on the error propagation in SIC [17], some residual interference exists in subtractable signals after executing SIC. I_{itci} is given by

$$I_{\text{itci}} = \sum_{k'=1}^{k-1} p^{u_{i,j,k'}}_{b_i} g^{u_{i,j,k}}_{b_i} + \epsilon \sum_{k'=k+1}^{N_{i,j}} p^{u_{i,j,k'}}_{b_i} g^{u_{i,j,k}}_{b_i}, \tag{4}$$

where ϵ is the fractional error factor and $0 \leq \epsilon \leq 1$. After the SINR of each piece of UE under each BS is calculated, channel quality indicator (CQI) is derived from the SINR for each piece of UE. Then, we can derive the expected throughput $T_{u_{i,j,k}}$ of the UE $u_{i,j,k}$ directly from the CQI based on Table 7.2.3-1 in [16].

To evaluate the overall performance and fairness of a system simultaneously, we make use of the general proportional fairness (GPF) in [18] as an utility function as follows:

$$U(\mathbf{X}, \mathbf{Y}) = \sum_{b_i \in \mathbb{B}} \sum_{c_{i,j} \in \mathbb{C}(i)} \sum_{u_{i,j,k} \in \mathbb{U}(i,j)} \log T_{u_{i,j,k}}(\mathbf{X}, \mathbf{Y}). \tag{5}$$

$\mathbf{X} \in \mathbb{Z}_2^{L \times M \times R}$ is a matrix that denotes the frequency allocation of all L BSs for all served UE in M clusters on R RBGs. $\mathbb{Z}_2$ represents the binary set $\{0, 1\}$. $\mathbf{Y} \in \mathbb{P}^{L \times M}$ is a matrix that denotes the power allocation of all L BSs for all served UEs in M clusters. $\mathbb{P}$ represents the set of all available power levels. We consider eight power levels specified by the 3GPP standard [19] in this work. Therefore, $\mathbb{P} = \{0, 1, 2, 3, 4, 5, 6, 7\}$ and the transmission powers of the eight power levels are $\{-6$ dB, -4.77 dB, -3 dB, -1.77 dB, 0 dB, 1 dB, 2 dB, 3 dB$\}$ relative

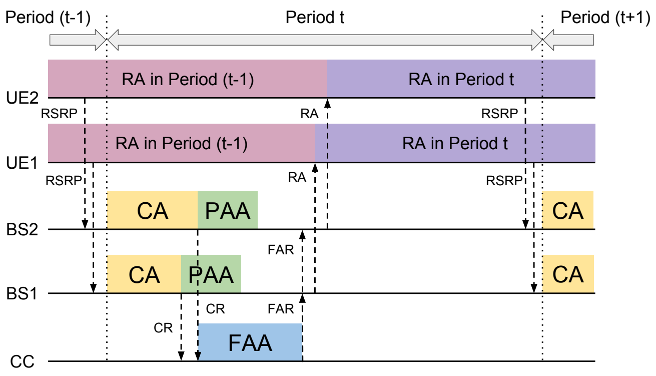

Fig. 1. Signal flow chart of the proposed centralized ICIC framework in downlink NOMA systems.

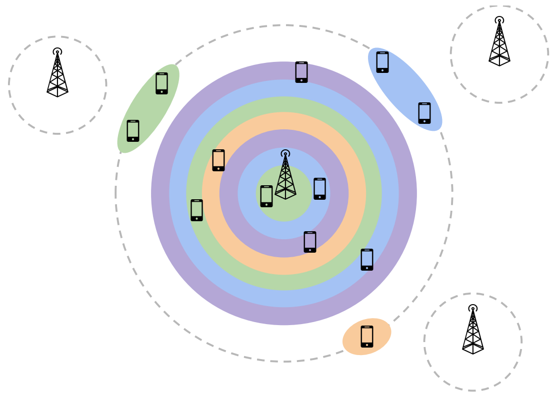

Fig. 2. Illustration of an example of the proposed CA.

to the RSRP respectively. The complete system is formulated as the following optimization problem:

$$\begin{aligned}
\max \quad & U(\mathbf{X},\mathbf{Y}) = \sum_{b_i \in \mathbb{B}} \sum_{c_{i,j} \in \mathbb{C}(i)} \sum_{u_{i,j,k} \in \mathbb{U}(i,j)} \log T_{u_{i,j,k}}(\mathbf{X},\mathbf{Y}) \\
\text{s.t.} \quad & \mathbf{X} \in \mathbb{Z}_2^{L\times M\times K} \\
& \sum_{c_{i,j} \in \mathbb{C}(i)} x^r_{c_{i,j}} \leq 1, \forall b_i \\
& \mathbf{Y} \in \mathbb{P}^{L\times M} \\
& y_{u_{i,j,k}} \neq y_{u_{i,j,k'}}, \forall k \neq k',
\end{aligned} \tag{6}$$

where $x^r_{c_{i,j}}$ indicates whether or not the RBG r is available for the cluster $c_{i,j}$, and $y_{u_{i,j,k}}$ represents the transmission power to the UE $u_{i,j,k}$. $\sum_{c_{i,j} \in \mathbb{C}(i)} x^r_{c_{i,j}} \leq 1$ indicates that an RBG can only be allocated to one cluster. $y_{u_{i,j,k}} \neq y_{u_{i,j,k'}}$ means that the power allocated to any two pieces of UE in the same cluster must not be equal.

IV. Proposed Framework

We propose a centralized two-layer ICIC framework, including a distributed CA, a distributed PAA, and a centralized FAA. The first layer is a CA and a PAA at each BS side. The second layer is a FAA at a central controller (CC) side. The proposed framework is a centralized framework because it requires a CC to determine the frequency resource allocation for each BS. Fig. 1 presents a signal flow chart for the proposed framework. Before every period, each piece of UE reports its RSRP to its serving BS and is classified as cell-edge UE or cell-center UE according to its RSRP values. When the RSRP of a UE device from its serving cell is lower than the one from an adjacent cell plus a threshold T_e, the UE device is labeled as cell-edge UE. Otherwise, the UE device is labeled as cell-center UE. At the beginning of every period, each BS executes the CA independently and sends a clustering result (CR) to a CC. Then, each BS continues to execute the PAA independently. At the same time, the CC executes the FAA and sends frequency allocation results (FARs) back to each BS. Finally, based on the FAR and the PAA result, each BS performs resource allocation (RA) for its served UE.

A. Clustering Algorithm

Each BS groups its served UE into several clusters. Cell-center UE is grouped into non-overlapping spatial ring zones according to the RSRP values from the serving cell. Cell-edge UE is grouped into neighboring zones according to the RSRP values from adjacent cells. For the sake of more effortless power allocation in the PAA, cell-center UE is grouped into clusters in the order from the highest serving RSRP value to the lowest serving RSRP value, whereas cell-edge UE is grouped into clusters in the order from the lowest serving RSRP value to the highest serving RSRP value. All clusters are classified into two types: edge clusters and center clusters. An edge cluster includes both cell-center UE and cell-edge UE. A center cluster includes only cell-center UE. The total number of clusters is fixed for every BS. To ensure separation of the resources allocated to cell-edge UE in adjacent cells, every BS must have at least one center cluster. The number of edge clusters varies from different distributions of cell-edge UE. Therefore, each BS may have one or more center clusters. Additionally, cell-edge UE is grouped into clusters according to certain vectors, which are defined below.

- BS vector: The size and number of BS vectors are both equal to the number of adjacent cells. Each adjacent BS forms a BS vector. For each BS vector, the index corresponding to the BS itself is one, and the index corresponding to an adjacent BS is a value between zero and one, which is predetermined by the distance between two consecutive adjacent BSs.
- Cluster vector: A cluster vector is the normalization of the linear combination of adjacent BS vectors in a cluster.
- UE vector: The size of a UE vector is also equal to the number of adjacent cells. The content of a UE vector is determined by the adjacent cells of the corresponding UE. If a BS b_i is one of the adjacent cells of the UE $u_{i,j,k}$, the ith index of the jth UE vector is set to one. Otherwise, it is set to zero.

Fig. 2 illustrates an example of the proposed CA. UE in the regions with the same color belongs to the same cluster. The purple cluster is a center cluster and the other three clusters are edge clusters. The entire procedure for the proposed CA is provided in Algorithm 1.

Algorithm 1 Clustering Algorithm

Require: RSRP of each piece of UE
Ensure: UE clusters
for each cell b_i **do**
  Initialize M clusters and queues Q_1, Q_2, Q_3
  Put cell-center UE into Q_1 from the highest serving RSRP value to the lowest serving RSRP value
  while Q_1 is not empty **do**
    for j = 1:M **do**
      Move the first element in Q_1 to cluster $c_{i,j}$
      Change the center cluster to cluster $c_{i,j}$
    end for
  end while
  Initialize $a \leftarrow 0$
  Put all clusters except the center cluster into Q_2
  Calculate the number of cell-edge UE devices under each adjacent BS b_j (N^j_{edge})
  Calculate $T_r = \frac{\sum_j N^j_{edge}}{M-1}$
  while Q_2 is not empty and any adjacent BS is unmarked **do**
    $a \leftarrow a+1$
    for each set of a consecutive adjacent BSs $\mathbb{S}$ **do**
      if any BS in $\mathbb{S}$ is marked **then**
        Continue to the next iteration
      else if $\Sigma N^j_{edge} > T_r$ **then**
        Pick the first element e_1 in Q_2
        Label e_1 with adjacent BSs in $\mathbb{S}$
        Mark all BSs in $\mathbb{S}$
      end if
    end for
  end while
  Construct a cluster vector for all clusters
  Put cell-edge UE into Q_3 from the lowest serving RSRP value to the highest serving RSRP value
  for each piece of cell-edge UE e_k in Q_3 **do**
    for each cluster $c_{i,j}$ **do**
      Calculate the inner product ($Z^{c_{i,j}}_{e_k}$) of the UE vector and the cluster vector
    end for
    Put e_k to the cluster with maximum $Z^{c_{i,j}}_{e_k}$
  end for
end for

B. Power Allocation Algorithm

For each cluster, each BS allocates cell-center UE with power from the lowest power level and cell-edge UE with power from the highest power level. Since UE is reordered before it is grouped into clusters in the proposed CA, UE with lower serving RSRP is allocated with higher power and UE with higher serving RSRP is allocated with lower power, which corresponds to the requirements of both ICIC and NOMA. Fig. 3 illustrates the power allocation process for UE in the blue cluster in Fig. 2. Cell-center UE like UE1 and UE2 is allocated with low power level, whereas cell-edge UE like UE3 and UE4 is allocated with high power level. The entire procedure of the proposed PAA is provided in Algorithm 2.

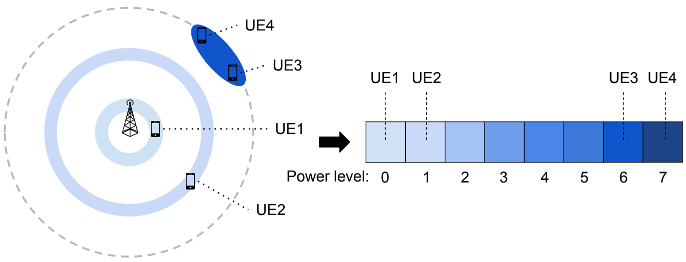

Fig. 3. Illustration of an example of the proposed PAA.

Algorithm 2 Power Allocation Algorithm

Require: RSRP of each piece of UE; UE clusters
Ensure: Power allocation
for each cell b_i **do**
  for each cluster $c_{i,j}$ **do**
    Initialize $a \leftarrow 0$
    Initialize $b \leftarrow 7$
    for each piece of UE $u_{i,j,k}$ **do**
      if $u_{i,j,k}$ is cell-center UE **then**
        Set the power level of $u_{i,j,k}$ to a
        $a \leftarrow a+1$
      else
        Set the power level of $u_{i,j,k}$ to b
        $b \leftarrow b-1$
      end if
    end for
  end for
end for

C. Frequency Allocation Algorithm

The proposed FAA is an improved version of the resource allocation algorithm which is proposed in [6]. The frequency allocation method in [6] focuses on individual pieces of UE, whereas the proposed FAA operates based on clusters. UE in the same cluster is allocated with the same frequency sub-bands. Since the UE in neighboring zones is grouped into the same cluster after executing the proposed CA for each BS, the proposed FAA is more efficient at allocating frequency resources to UE.

We make use of a weighted graph that follows the graph theory presented in [20] to determine the frequency sub-bands for each cluster. In a graph $G = (V, E)$, each node represents a cluster and the weights of the edges represent the interference levels when two clusters utilize the same sub-bands. Each node stores cells that are adjacent to the cluster. Two interference levels are considered in this work. Edge-to-edge interference indicates that two clusters store the serving cell of each other as one of their adjacent cells. If such clusters are allocated with the same sub-bands, all UE in both clusters suffer from edge-to-edge interference. Neighbor-to-edge interference indicates that one cluster does not store the serving cell of the other one while the other one does. If such clusters are allocated with the same sub-bands, the UE in the former cluster does not suffer from neighbor-to-edge interference, but the UE in the latter cluster does. Neighbor-to-edge interference and edge-to-edge interference are set as 1 and 2 respectively.

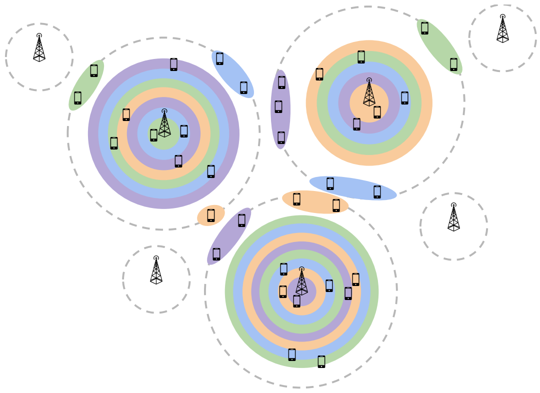

Fig. 4. Illustration of an example of the proposed FAA.

Algorithm 3 Frequency Allocation Algorithm

Require: RSRP of each piece of UE; UE clusters
Ensure: Frequency allocation

Construct a weighted graph $G = (V, E)$
Initialize a queue Q and a list L
while Any edge cluster is unmarked **do**
  Randomly choose an unmarked edge cluster x
  Put x into Q and mark x
  while Q is not empty **do**
    Move the first element y in Q to L
    Put other edge clusters in the same cell into Q
    Put edge clusters neighboring y into Q
    Mark those edge clusters in Q
  end while
end while
for each cell-edge cluster x in L **do**
  Allocate R/M RBGs with minimal increasing total interference to x
end for
for each cell b_i **do**
  Allocate remaining sub-bands to center clusters
end for

The order of frequency allocation for edge clusters is determined by breadth-first search (BFS). Initially, an edge cluster is randomly chosen as a search key. The other edge clusters in the same cell and the neighboring edge clusters in adjacent cells are the next-level nodes to be explored. These next-level nodes are considered as search keys to find subsequent next-level nodes. A node is skipped if it has already been explored. The search continues until all edge clusters have been explored once. The frequency resource allocation order of edge clusters is the search order returned by the BFS. Each edge cluster is greedily allocated with R/M RBGs with minimal increasing total interference. Finally, the remaining sub-bands for each BS are allocated to center clusters evenly. Fig. 4 illustrates an example of the proposed FAA. The UE clusters in each cell are determined in the proposed CA and illustrated by Fig. 2. The color on each cluster indicates sub-bands allocated to a cluster. The proposed FAA can allocates any two clusters in adjacent cells to different frequency resources. The entire procedure of the proposed FAA is provided in Algorithm 3.

TABLE I
SIMULATION PARAMETERS.

Model	Parameter	Assumption
System Model	Cell deployment	5×5 grid deployment
	Cell distance	50 m
	Carrier downlink frequency	2.66 GHz
	Bandwidth	10 MHz; 50 RBs
	Resource allocation type	Type 0
	Reference signal power	−7 dBm
	T_e	10 dB
	M	4
	R	17
Channel Model	Pass loss model	3GPP urban micro [21]
	Thermal noise density	−174 dBm/Hz
Traffic Model	User distribution	Uniform
	User density	4-24 users per cell
	Data generation	Full buffer
	Scheduler	Round Robin

V. SIMULATION RESULTS

We evaluated the performance of our proposed algorithms and several benchmark methods via simulation. The simulation scenario is a 5×5 grid deployment with a uniform UE distribution. In this scenario, the ratio of cell-edge UE is high (greater than 40%), which makes it possible to test ICIC frameworks in the case of dense cell-edge UE. The simulation parameters are listed in Table I. The results presented in this paper are the average results from 10 simulations. The proposed ICIC framework is composed of three parts: the (a) proposed CA, (b) proposed PAA, and (c) proposed FAA. To analyze the performance of the three proposed algorithms individually, we tested a (d) basic CA, (e) basic PAA, and (f) basic FAA for comparison with the three proposed algorithms. Algorithms (d), (e), and (f) randomly select UE clusters, power allocation, and frequency allocation respectively, regardless of how UE is distributed within each cell. By combining a CA, a PAA, and a FAA, we can derive several frameworks:

- proposed framework: (a)+(b)+(c)
- NOMA+CA/PAA: (a)+(b)+(f)
- NOMA+CA/FAA: (a)+(e)+(c)
- NOMA+CA: (a)+(e)+(f)
- baseline NOMA: (d)+(e)+(f)
- ICIC OMA [6]
- baseline OMA

NOMA+CA/PAA, NOMA+CA/FAA, NOMA+CA, and baseline NOMA frameworks can all be regarded as no ICIC frameworks in NOMA. Since both the proposed PAA and FAA require the outputs from the proposed CA as their inputs, combinations such as (d)+(b)+(c), (d)+(b)+(f), and (d)+(e)+(c) are invalid frameworks.

UE was randomly deployed in each cell based on several levels of user density. The throughput of each piece of UE was measured for the calculation of GPF for each framework. Fig. 5 presents the average throughput of cell-edge UE at different user densities. The proposed PAA increases the transmission power to cell-edge UE, and the proposed FAA separates cell-edge UE in adjacent cells into different RBGs. Therefore, the proposed framework can boost the average throughput of cell-

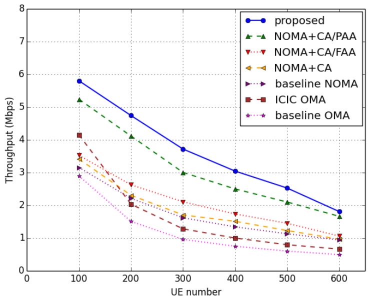

Fig. 5. Average throughput of cell-edge UE.

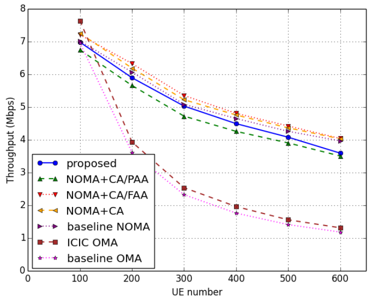

Fig. 6. Average throughput of all UE.

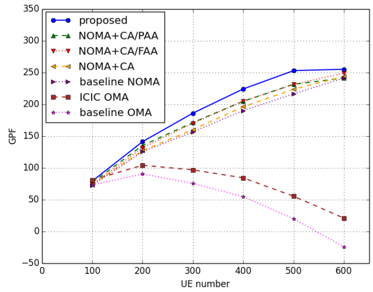

Fig. 7. GPF of all frameworks.

edge UE. Fig. 6 presents the average throughput of all UE at different user densities. Since the proposed PAA decreases the transmission power to cell-center UE, the proposed framework and NOMA+CA/PAA framework have lower average throughput compared to the other frameworks in NOMA. However, one can see that the proposed framework can maintain a consistent throughput level. Fig. 7 presents the GPF of all frameworks at different user densities. The proposed framework shows the best performance based on an increase in the throughput of cell-edge UE and negligible decrease in overall throughput. In addition, OMA systems have a limited number of servable UE devices for each TTI. When the number of UE devices is greater than the maximum number of servable UE devices, a BS must serve UE in a different TTI. Therefore, as the number of UE devices increase, the throughput of each piece of UE decreases significantly in OMA systems, leading to a decrease in the GPF of ICIC OMA and baseline OMA. One can conclude that the proposed framework outperforms all the benchmark methods in terms of maximizing GPF.

VI. Conclusion

Based on the problems surrounding ICIC in OMA systems and no ICIC in NOMA systems, we design an adaptive resource allocation framework for ICIC in downlink NOMA systems in this work. The proposed framework is a centralized two-layer ICIC framework consisting of a distributed CA, a distributed PAA, and a centralized FAA. We adopt three basic algorithms for comparison to the three proposed algorithms, and verify the effectiveness of the proposed algorithms through simulation. It is shown that the proposed framework has superior performance compared to ICIC in OMA systems and no ICIC in NOMA systems.

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