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Competitive IRS Assignment for IRS-Based NOMA System

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***Abstract*—This paper considers the downlink transmission of an intelligent reflecting surface (IRS)-aided multi-carrier (MC) non-orthogonal multiple access (NOMA) system, referred to as the IRS-aided MC-NOMA system. Due to the limitations on the availability of the IRS, a limited number of channels can be served with the support of the available IRS units. Therefore, a competitive approach is proposed to assign the available IRS units for the intended channels, and to group the users in each channel (i.e., clustering). To validate the effectiveness of the proposed competitive approaches, a power minimization problem is considered that aims to minimize the total transmit power while ensuring a set of quality-of-service requirements. Because of the non-convex nature of the joint power optimization problem, we develop a simple sequential convex approximation algorithm to solve it. Simulation results demonstrate that the IRS-aided MC-NOMA system with proposed IRS-assignment and grouping approaches outperforms the random IRS-assignment and grouping approaches regarding the transmit power consumption.**

***Index Terms*—Intelligent Reflecting Surface (IRS), IRS-assignment, Non-orthogonal Multiple Access (NOMA), Multi-carrier (MC), Grouping strategy.**

I. Introduction

The intelligent reflecting surface (IRS) has been recently identified as a potential candidate to meet the unprecedented requirements of beyond fifth-generation (B5G) [1]. An IRS unit contains a set of passive reflecting elements (i.e., mirrors) that can be dynamically tuned to configure the signal propagation in a communication system. Due to its lightweight and low cost [2], IRS is expected to be massively deployed in wireless communication systems.

Inspired by the potential capabilities of IRS, several emerging multiple access (MA) approaches have been recently integrated with IRS [3], such as orthogonal MA (OMA), multiple antennas [4] [5], non-orthogonal MA (NOMA) [6] [7], and hybrid OMA-NOMA. To be specific, the IRS-aided hybrid OMA-NOMA systems are expected to have a crucial role in B5G due to its several benefits. Firstly, the conventional hybrid OMA-NOMA (i.e., without IRS) is considered an advantageous solution to improve spectral efficiency (SE) while supporting the massive connectivity requirements of emerging wireless systems. On the other hand, the IRS-aided hybrid OMA-NOMA system can improve channel conditions, while mitigating the practical limitations of multi-antenna NOMA-based systems [2]. Accordingly, a set of IRS-aided hybrid OMA-NOMA systems was proposed in the literature, including the IRS-aided hybrid orthogonal frequency division MA (OFDMA)-NOMA, referred to as IRS-aided multi-carrier (MC)-NOMA systems. In this system, users are grouped into clusters, where NOMA is exploited to serve a cluster of users in each channel with the help of IRS units.

Several single-input single-output (SISO) IRS-aided MC-NOMA system configurations have been dealt with in the literature. For instance, a SISO IRS-aided single-carrier NOMA system was investigated in [8], where only one IRS unit was deployed to serve a group of two users. The power allocation strategy was assumed to be fixed, while the phase-shift matrix was optimized to maximize the received signal power at that user. Similarly, a simple multi-user SISO IRS-aided NOMA system was studied in [9], where an orthogonal resource block is reserved for serving each group of users (i.e., two users). In specific, the IRS is split into a set of sub-surfaces, each of which being reserved for serving a group of two users. A power minimization framework is developed, and the alternating optimization (AO) is used to solve the problem. It is obvious that several IRS-aided cluster-based NOMA configurations have been studied in the literature. However, most of these works have not considered different practical key considerations for the IRS-aided NOMA systems. We summarize these considerations as follows:

- Availability of IRS units: It has been assumed in the most of the existing works that an individual IRS unit can be deployed for each resource block (RB). This assumption is not practically realizable in dense networks, where the number of available RBs is much larger than that of the available IRS units. Therefore, determining the RB (i.e., clusters) that can be served with the aid of IRS units is a key issue that should be taken into account in the system design. The clusters that can be served with the aid of IRS units are referred to as IRS-assisted clusters, whereas clusters that cannot utilize IRS units are referred to as IRS-free clusters.
- Grouping Strategy: In the literature, most of the works have not considered the clustering strategy for IRS-assisted clusters. However, as the users inside each IRS-assisted cluster receive the same reflected signal from the IRS, determining the users in each cluster (i.e., clustering strategy) is vital. On the other hand, due to different

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circumstances, the clustering strategy for the IRS-free clusters should be different from that of the IRS-assisted clusters.

Motivated by the above-mentioned practical considerations of employing the IRS in MC-NOMA system, we consider the downlink IRS-aided MC-NOMA system with the number of IRS units less than that of the available channels. In particular, we propose a competitive algorithm to assign the available IRS units to the IRS-assisted clusters. In addition, an efficient clustering algorithm is proposed to form appropriate clusters. We validate the effectiveness of the proposed IRS-assignment and grouping approaches by comparing their performance against that of two benchmark schemes.

II. System Model and Problem Formulation

A. System Model

In this paper, a downlink transmission of an IRS-aided MC-NOMA system is investigated. Specifically, we consider a single-antenna BS, located at (x_{BS}, y_{BS}), which communicates with K single-antenna users through M IRS units, each has L reflecting elements as see in Fig. 1. Specifically, the m^{th} IRS is denoted as IRS_m and is located at (x_m, y_m) $\forall m \in \mathcal{M} = \{1, 2, \cdots, M\}$, while the k^{th} user is represented by U_k and it is located at (x_{U_k}, y_{U_k}) $\forall k \in \mathcal{K} = \{1, 2, \cdots, K\}$. Furthermore, the available bandwidth, B, is split into N channels (i.e., sub-band), where each channel is devoted to serving a group of two users (i.e., cluster) using the power-domain NOMA. However, it is assumed that the number of IRS units is less than that of the available channels, i.e., $M < N$. Accordingly, M clusters can only be served with the help of the available IRS, and such clusters are referred to as IRS-assisted clusters throughout this paper. On the other hand, $F = N - M$ clusters will not be able to use IRS for their transmission, and thus, these clusters are called IRS-free clusters. This imposes a constraint on forming appropriate clusters that the available IRS units can support.

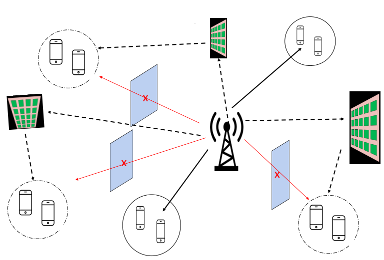

Fig. 1: An IRS-aided multi-carrier NOMA network.

In this system model, the transmitted signal over the i^{th} channel $(c_i), \forall i \in \mathcal{N} = \{1, 2, \cdots, N\}$ can be written as $x_i = \sqrt{p_{1,i}} s_{1,i} + \sqrt{p_{2,i}} s_{2,i}, \forall i \in \mathcal{N}$, where $s_{j,i}$ and $p_{j,i}$ denote the symbol designated to the j^{th} user in the i^{th} cluster $(u_{j,i})$, and the related power allocation, $j \in \{1, 2\}$, respectively. Note that the received signal at each user depends on whether an IRS unit supports the intended cluster or not.

1) IRS-free Clusters: For the F clusters that are served without the support of an IRS, i.e., IRS-free clusters, the received signal at the j^{th} user in the i^{th} cluster $(u'_{j,i})$ can be written as $r'_{j,f} = h'_{j,f} x_f + n_{j,f}, \forall j \in \{1, 2\}, \forall f \in \mathcal{F} = \{1, 2, \cdots, F\}$, where $h'_{j,f}$ denotes the channel coefficient between the BS and $u'_{j,f}$. Specifically, $h'_{j,f} = \frac{1}{(d_{BS \to u'_{j,f}})^{\alpha}}$, where $d_{BS \to u'_{j,f}} = \sqrt{(x_{BS} - x_{u'_{j,f}})^2 + (y_{BS} - y_{u'_{j,f}})^2}$ is the distance between the BS and $u'_{j,f}$, and α is the path loss exponent. Additionally, the term $n_{j,f}$ describes the additive white Gaussian noise (AWGN) with zero mean and $\sigma^2_{j,f} = \sigma^2$ variance. It is assumed that the BS has the perfect channel state information (CSI) of all communication terminals through channel estimation methods. For such an IRS-free transmission, the achieved signal-to-noise-and interference ratio (SINR) for the IRS-free users (SINR$'$) is similar to that of the users in conventional multi-carrier NOMA systems [10]. To be specific, the stronger user performs successive interference cancellation (SIC) in order to decode and subtract the signal of the weaker user with the SINR of: $\text{SINR}'^{1}_{2,f} = \frac{p_{2,i}|h'_{1,f}|^2}{p_{1,f}|h'_{1,i}|^2 + \sigma^2}, \forall f \in \mathcal{F} = \{1, 2, \cdots, F\}$. Next, the stronger user decodes the signal of the weaker user with the subsequent SINR: $\text{SINR}'_{1,f} = \frac{p_{1,f}|h'_{1,f}|^2}{\sigma^2}, \forall f \in \mathcal{F} = \{1, 2, \cdots, F\}$. The weaker user decodes its message with the following SINR $\text{SINR}'^{2}_{2,f} = \frac{p_{2,f}|h'_{2,f}|^2}{p_{1,f}|h'_{2,f}|^2 + \sigma^2}, \forall f \in \mathcal{F}$, and thus, $\text{SINR}'_{2,f} = \min\{\text{SINR}'^{1}_{2,f}, \text{SINR}'^{2}_{2,f}\}, \quad \forall f \in \mathcal{F}$.

2) IRS-assisted Clusters: Due to the severe blockage and channel conditions of cell-edge users, it is supposed that there is no direct communication link between the IRS-assisted clusters and the BS. In addition, it is also supposed that each IRS-assisted cluster can hear from one IRS unit. This is because each IRS-assisted transmission is performed over an orthogonal channel. With this, the received signal at the IRS-assisted clusters can be given as $r_{j,i} = \mathbf{h}^H_{m,j,i} \mathbf{\Theta}_m \mathbf{g}_m x_i + n_{j,i}, \forall j \in \{1, 2\}, \forall i \in \mathcal{M}$, where $\mathbf{h}^H_{m,j,i} \in \mathbb{C}^{1 \times L}$ is the channel vector between the IRS_m and $u_{j,i}$, and $\mathbf{g}_m \in \mathbb{C}^{L \times 1}$ represents the channel vector between the BS and the IRS_m. In addition, $\mathbf{\Theta}_m \in \mathbb{C}^{L \times L}$ is the diagonal phase shift (i.e., reflection) matrix of IRS_m, i.e., $\mathbf{\Theta}_m = \text{diag}(\beta_{1,m} e^{j\theta_{1,m}}, \beta_{2,m} e^{j\theta_{2,m}}, \cdots, \beta_{L,m} e^{j\theta_{L,m}})$, where $\beta_{l,m}$ and $\theta_{l,m}$ are respectively the amplitude and phase shift coefficients for the l reflecting element. In particular, $\mathbf{h}_{m,j,i} = (d_{m \to u_{j,f}})^{-\alpha} \mathbf{v}_{m,j,i}$, where $\mathbf{v}_{m,j,i}$ is the small-scale fading and is considered to be complex Gaussian distributed with zero mean and unit variance, and $d_{m \to u_{j,i}}$ is the distance between IRS_m and $u_{j,i}$. It is assumed that the amplitude of the reflection coefficient is one, i.e., $\beta_{L,m} = 1$. In addition, $u_{1,i}$ is the stronger user, and thus has better equivalent channel gain compared to $u_{2,i}$. This can be assured by satisfying the subsequent constraint:

$$|\mathbf{h}_{m,1,i}{}^H \mathbf{\Theta}_m \mathbf{g}_m|^2 \geq |\mathbf{h}_{m,2,i}{}^H \mathbf{\Theta}_m \mathbf{g}_m|^2. \qquad (1)$$

Note that the stronger user must be capable of decoding and subtracting the message designated for the weaker user before decoding its signal, and thus, the received signal after applying SIC is $\hat{r}_{1,m} = \mathbf{h}_{m,1,i}{}^H \mathbf{\Theta}_m \mathbf{g}_m \sqrt{p_{1,m}} s_{1,m} + n_{1,m}, \forall m \in \mathcal{M}$.

Consequently, the strongest user decodes its message with the subsequent SINR: $\text{SINR}_{1,m} = \frac{p_{1,m}|\mathbf{h}_{m,1,i}{}^H \mathbf{\Theta}_i \mathbf{g}_m|^2}{\sigma^2}, \forall m \in \mathcal{M}$. The strongest user decodes the message of the weaker user with the SINR of $\text{SINR}^1_{2,m} = \frac{p_{2,m}|\mathbf{h}_{m,1,i}{}^H \mathbf{\Theta}_i \mathbf{g}_m|^2}{p_{1,m}|\mathbf{h}_{m,1,i}{}^H \mathbf{\Theta}_i \mathbf{g}_m|^2 + \sigma^2}, \forall m \in$

$\mathcal{M}$. The weakest user in the cluster decodes its own message without SIC, and thus, its SINR can be computed as $\text{SINR}_{2,m}^2 = \frac{p_{2,m}|\mathbf{h}_{m,2,i}{}^H\mathbf{\Theta}_i\mathbf{g}_m|^2}{p_{1,m}|\mathbf{h}_{m,1,i}{}^H\mathbf{\Theta}_i\mathbf{g}_m|^2+\sigma^2}, \forall m \in \mathcal{M}$. Accordingly, $\text{SINR}_{2,m} = \min\{\text{SINR}_{2,m}^1, \text{SINR}_{2,m}^2\}, \quad \forall m \in \mathcal{M}$.

B. Problem Formulation

To study the performance of the considered IRS-aided MC-NOMA system, we formulate a power-minimization problem that attempts to minimize the overall transmit power to meet a set of quality-of-service (QoS) requirements, as follows:

$$\textbf{P1:} \underset{p_{j,i}\forall j\forall i,\theta_i}{\text{minimize}} \quad P_t = \sum_{i=1}^{K/2} \left(p_{1,i} + p_{2,i}\right) \tag{2a}$$

$$\text{subject to} \quad \text{SINR}'_{j,f} \geq \gamma_{\min}, \forall j \in \{1,2\}, \forall f \in \mathcal{F} \tag{2b}$$

$$\text{SINR}_{j,m} \geq \gamma_{\min}, \forall j \in \{1,2\}, \forall m \in \mathcal{M}. \tag{2c}$$

$$(1), |\theta_{i,m}| \leq 1, \forall i, \forall m. \tag{2d}$$

The QoS constraints in (2b) and (2c) represent the minimum SINR requirements for IRS-free and IRS-assisted users, respectively. In particular, three aspects determine the performance of the MC-NOMA IRS-aided system model. These aspects are: 1) forming the clusters that can be served with the aid of the IRS units, i.e., IRS-assignment; 2) determining the users that can be served in each channel, i.e., grouping strategy; and 3) proposing an efficient approach to provide sub-optimal solutions to the joint and non-convex optimization problem **P1.** It is worth mentioning that the optimal IRS assignment/clustering approaches can be achieved by combining them with the resource allocation problem. Such a combination can be formulated as a mixed integer non-linear programming (MINLP) problem. However, due to the combinatorial nature of MINLP problems, we propose a two-stage, low-complexity solution. Specifically, in the first stage, we propose a competitive IRS-assignment/clustering approach that captures the system requirements. In the second stage, we develop an iterative algorithm to solve the optimization problem.

III. IRS Assignment, Grouping Strategy, And The Proposed Solution

Now, we develop an algorithm for IRS-assignment and grouping strategy. Based on these algorithms, we propose a solution to **P1.**

A. IRS-assignment and Grouping Strategy

1) IRS Selection: As the number of available IRS units is less than that of the available channels, forming the clusters that can be served by IRS, i.e., IRS-aided clusters, has a direct influence on the overall system's performance. Since the channel gains have a considerable impact on the QoS of each user, we propose an IRS selection criterion, which suggests dividing the users based on their channel strengths into two sets of users: the cell-center and cell-edge users. To be specific, the users are sorted based on their channel conditions such that

$$\underbrace{||h_1||^2 \cdots \geq ||h_{2F}||^2}_{\text{cell-center users}} \underbrace{\geq ||h_{2F+1}||^2 \geq \cdots \geq ||h_K||^2}_{\text{cell-edge users}}, \tag{3}$$

where h_k is the channel coefficient between the BS and the U_k. The ordering in (3) indicates that the cell-center users have stronger channel conditions than the cell-edge users, and thus, can be served without using IRS. Therefore, such users (i.e., cell-center users) can be grouped into clusters, which are referred to as IRS-free clusters. On the other hand, the users with weaker channel conditions, i.e., the cell-edge users, can be served using the available IRS units, and they are referred to as IRS-assisted clusters. The sets of the cell-center and cell-edge users are denoted as $\mathcal{A}$ and $\mathcal{B}$, respectively.

2) IRS-assignment and Grouping Strategy: The proposed clustering strategy should be determined taking into account whether the cluster is IRS-free or IRS-assisted cluster. In particular, the proposed clustering approach for IRS-free clusters is similar to that in the conventional NOMA-based clustering approach [10]. Specifically, the users with diverse channel conditions are grouped, which allows for a successful SIC implementation. Generally, the IRS units are attached to the ceilings and coated on the tops of buildings [1] [2]. This, as a result, enables users to have direct links with IRS units, and thus, it is assumed that each user can establish LOS links with all IRS units. In particular, there are two key factors that affect the IRS-assignment and clustering algorithms, which are 1) the distance between each user and the available IRS; and 2) the correlation between channels of users. Specifically, the proposed IRS assignment should associate each IRS-aided cluster with its nearest IRS unit. In addition, as the users in each cluster share the same phase shift matrix, the users with higher channel correlation should be grouped together.

Accordingly, to solve this challenging clustering problem, we consider an illustrative example to shed some light on the key facts when considering the IRS assignment and clustering approach. We summarize the key steps of determining the joint IRS assignment and clustering in the following:

1. For IRS_m unit, $\forall m \in \mathcal{M}$, the cell-edge users are ordered according to their distances to the IRS_m. The nearest user to the m^{th} IRS unit is reserved to be served by that IRS unit. For example, considering the m^{th} IRS unit, the users are ordered as follows:

$$|d_{m\to 2F+4}| \leq |d_{m\to 2F+2}| \leq |d_{m\to 2F+3}| \leq |d_{2F+1}| \leq \cdots \leq |d_{m\to K}| \leq |d_{m\to K-1}|, \tag{4}$$

where $d_{m\to i}, \forall m \in \mathcal{M}$, denotes the distance between IRS_m and $U_i, \forall i \in \{2F+1, \cdots, K\}$. This ordering indicates that U_{2F+4} is the nearest user to the m^{th} IRS, and thus IRS_m is reserved to serve U_{2F+4}. Accordingly, U_{2F+4} is removed from the cell-edge users set, and IRS_m is removed from the available IRS set, and such a user is denoted as $u_{1,m}$. This process continues until all IRS units are associated with their corresponding nearest users.

2. Since the users within each cluster utilize the same phase shift matrix, the users with higher channel correlation should be grouped together. Accordingly, for IRS_m, the correlation between the channel of the $u_{1,m}$ and the channel of other users can be evaluated as $\text{Corr}_{1,j}^{m} = \frac{|\mathbf{h}_{1,i}\mathbf{h}_{r,i}|}{|\mathbf{h}_{1,i}||\mathbf{h}_{r,i}|}, \forall m$. With this, the user with a higher correlation to $u_{1,m}$ is assigned to IRS_m. This process continues until each IRS unit is associated with two users.

B. The Proposed Algorithm

Considering the IRS-assignment and clustering approaches presented in the previous subsection, the performance of the developed system can now be assessed by solving the optimization problem $\mathbf{P1}$. However, solving this problem is challenging due to the fact that $\mathbf{P1}$ is non-convex in nature, and the power allocation and reflection coefficient matrix should be jointly optimized. While most of the existing IRS-aided systems have exploited the AO approach to solve the original power minimization optimization frameworks, we propose a simple sequential convex approximation (SCA) algorithm to solve the problem. With this SCA approach, each non-convex term is approximated with a linear (convex) term, and thus, the problem can be iteratively solved until convergence.

Note that the power allocation and phase shift matrix optimization over each channel are independent of other channels. This enables us to minimize the transmit power over each channel (i.e., cluster) separately from the other. With this, the optimization problem $\mathbf{P1}$ becomes:

$$\mathbf{P2:}\ \underset{p_{j,i},\theta_i,\forall i,}{\text{minimize}} \quad p_{1,i} + p_{2,i} \tag{5a}$$

$$\text{subject to} \quad \begin{cases} \text{SINR}'_{j,m} \geq \gamma_{\min}, & \text{IRS-free clusters} \\ \text{SINR}_{j,m} \geq \gamma_{\min}, & \text{IRS-aided clusters} \end{cases} \tag{5b}$$

Note that the minimum rate constraint for the IRS-free clusters can be written as

$$p_{1,f}|h'_{1,f}|^2 \geq \gamma_{\min}\big(\sigma^2\big), \forall f \in \mathcal{F}, \tag{6a}$$

$$p_{2,f}|h'_{2,f}|^2 \geq \gamma_{\min}\big(p_{1,f}|h'_{2,f}|^2 + \sigma^2\big), \forall f \in \mathcal{F}, \tag{6b}$$

$$p_{2,f}|h'_{1,f}|^2 \geq \gamma_{\min}\big(p_{1,f}|h'_{1,f}|^2 + \sigma^2\big), \forall f \in \mathcal{F}. \tag{6c}$$

To deal with the non-convexity issue of (2c), we assume that $|\mathbf{h}_{m,j,i}{}^{H}\mathbf{\Theta}_i\mathbf{g}_m|^2 = |\mathbf{q}_{m,j,i}\theta_m|^2$, where $\mathbf{q}_{m,j,i} = \mathbf{h}_{m,j,i}^{H}\text{diag}(\mathbf{g}_m)$, and $\theta_m = [\beta_{1,m}e^{j\theta_{1,m}}, \beta_{2,m}e^{j\theta_{2,m}}, \cdots, \beta_{L,m}e^{j\theta_{L,m}}]^T$ [11]. Also, for notation simplicity, the term $\mathbf{q}_{j,m}$ refers to $\mathbf{q}_{m,j,i}$. Now, we apply SCA to deal with the non-convexity issues of minimum rate requirements of the IRS-aided clusters. Accordingly, we introduce a set of positive slack variables such that

$$|\mathbf{q}_{j,m}^{H}\theta_m|^2 \geq \Gamma_{j,m}^2, \forall j \in \{1,2\}, \forall m \in \mathcal{M}, \tag{7}$$

$$p_{j,m}\Gamma_{j,m}^2 \geq \zeta_{j,m}, \forall j \in \{1,2\}, \forall m \in \mathcal{M}. \tag{8}$$

Accordingly, the non-convex constraint is written as

$$\zeta_{1,m} \geq \gamma_{\min}(\sigma^2), \tag{9a}$$

$$\zeta_{2,m} \geq \gamma_{\min}(\zeta_{1,m} + \sigma^2). \tag{9b}$$

We deal with the non-convexity problem in (7) by approximating each term with its first-order Taylor series expansion as follows:

$$\begin{aligned} &|\mathbf{q}_{j,m}^{H}\theta_m^{(t)}|^2 + 2|\mathbf{q}_{j,m}^{H}\theta_m^{(t)}| \\ &\big[\Re(\mathbf{q}_{j,m}^{H}\theta_m) - \Re(\mathbf{q}_{j,m}^{H}\theta_m^{(t)}), \Im(\mathbf{q}_{j,m}^{H}\theta_m) - \Im(\mathbf{q}_{j,m}^{H}\theta_m^{(t)})\big] \\ &\geq \Gamma_m^{j,m(t)} + 2\Gamma_{j,m}{}^{(t)}(\Gamma_{j,m}{}^{(t)} - \Gamma_{j,m}{}^{(t)}), \end{aligned} \tag{10}$$

where the superscript t denotes the t^{th} iteration. Similarly, the constraint in (8) can be written as

$$\begin{aligned} &p_{j,m}^{(t)}\Gamma_{j,m}^{2}{}^{(t)} + \Gamma_{j,m}^{2}{}^{(t)}(p_{j,m} - p_{j,m}^{(t)}) + \\ &2p_{j,m}^{(t)}\Gamma_m{}^{(t)}(\Gamma_{j,m} - \Gamma_{j,m}{}^{(t)}) \geq \zeta_{j,m}. \end{aligned} \tag{11}$$

With this slack variable, our optimization can be now written as

$$\mathbf{P3:}\ \underset{p_{j,i}\forall j\forall i,\theta_i}{\text{minimize}} \quad p_{1,i} + p_{2,i} \tag{12a}$$

$$\text{subject to} \quad \begin{cases} (6a), (6b), (6c), \\ (9a), (9b), (10), (11), (2d). \end{cases} \tag{12b}$$

Since the power minimization problem, $\mathbf{P2}$, is solved via an iterative algorithm based on SCA, the complexity of the proposed solution depends on solving the approximated optimization problem $\mathbf{P3}$ at each iteration. In particular, $\mathbf{P3}$ is a linear problem, and thus, its complexity at each iteration is upper-bounded by $\mathcal{O}(n^2m)$ [12], where n and m are the numbers of the optimization parameters and the dimensions of $\mathbf{P3}$, respectively. Accordingly, the overall complexity of solving $\mathbf{P2}$ can be expressed as $\mathcal{O}(n^2m\log(\frac{1}{\epsilon}))$, where ϵ is the required accuracy. With this, it is obvious that utilizing the SCA algorithm has a lower complexity when compared to the conventional AO algorithm. This is due to the fact that AO requires decoupling the optimization parameters, thus, solving the problem in two steps. This, as a result, introduces higher complexity as well as higher computational time.

IV. SIMULATION RESULTS

This section studies the performance of the considered IRS-aided MC-NOMA system with the proposed IRS-assignment user clustering approaches. In particular, the performance of this system is compared with that of two benchmark schemes, which are the conventional MC-NOMA system (i.e., IRS-free MC-NOMA system), and the IRS-aided MC-NOMA with random IRS-assignment and clustering strategy. In this simulation, we consider a BS, which is located at the origin, i.e., $(x_{BS}, y_{BS}) = (0, 0)$, and communicates with ten users, i.e., $K = 10$, and the users are randomly distributed in a circle of radius of 50 meters, where the noise variance is assumed to be -90 dBm. Furthermore, the number of IRS units is assumed to be 3, i.e., $M = 3$, which are randomly distributed inside the circle. Each IRS unit is equipped with 8 reflecting elements, i.e., $L = 8$. The number of channels is assumed to be 5, i.e., $N = 5$.

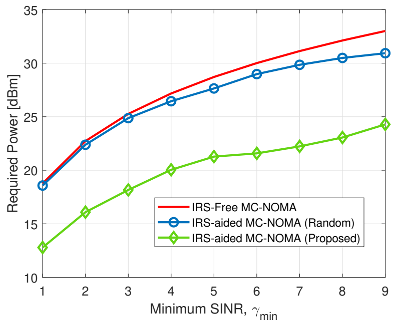

Fig. 2: The required transmit power against the minimum SINR requirements, $M = 3$.

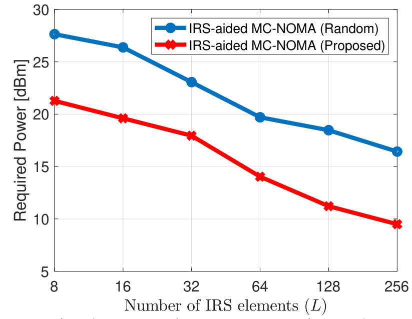

Fig. 4: The required transmit power against the number of IRS elements, L.

Fig. 2 shows the minimum required power versus a set of minimum SINR requirements for the proposed IRS-assignment and clustering strategy against other benchmark schemes. It is obvious that the performance of the IRS-aided MC-NOMA with the proposed algorithms outperforms that of the random IRS-assignment. This is due to the fact that the proposed approaches search for the best IRS-assignment and clustering strategy, while the random approaches group the users without considering their channel conditions. Accordingly, higher transmit power is required to meet similar QoS constraints.

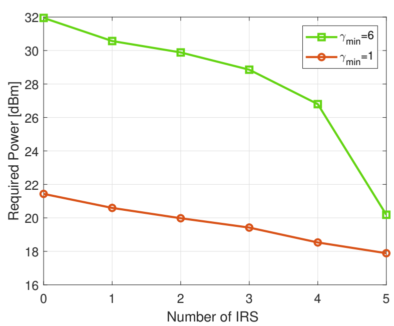

Fig. 3: The required transmit power against the number of IRS for the proposed IRS-assignment strategy.

In addition, Fig. 3 depicts that the required transmit power decreases with the increase of the IRS units. This is due to the fact that a larger number of IRS units implies that more clusters can be assisted with the available IRS units, and thus, minimum transmit power is required. Fig. 4 demonstrates the impact of the number of IRS elements, L, on the required transmit power. As seen in Fig. 4, the required transmit power declines with the increase of the IRS elements, for both the competitive and random IRS assignment.

V. Conclusion

This paper considered an IRS-aided MC-NOMA system with several IRS units being less than the number of channels. Accordingly, the users are categorized into two groups according to their channel strengths: cell-center and cell-edge users. Competitive IRS-assignment and grouping algorithms were developed to assign the available IRS units to the IRS-aided clusters and determine the users in each cluster. In addition, we developed an optimization framework to minimize the transmit power under a set of QoS constraints. In particular, a simple SCA approach was developed to solve the original non-convex power-minimization problem. Simulation results revealed that the IRS-aided MC-NOMA system with the proposed IRS-assignment and clustering strategy outperforms the benchmark schemes regarding the required minimum transmission power to achieve the same set of QoS constraints.

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