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Self-Sustainable Multi-IRS-Aided Wireless Powered Hybrid TDMA-NOMA System

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ABSTRACT Intelligent reflecting surface (IRS) has been recently integrated with emerging communication technologies to meet the demanding requirements of communication systems. This paper investigates the deployment of multi-IRS units in a hybrid time-domain multiple access (TDMA) and non-orthogonal multiple access (NOMA) system, referred to as a multi-IRS-aided hybrid TDMA-NOMA system. In particular, a self-sustainable scenario is proposed, in which the IRS units can harvest energy from the radio frequency signal to feed them-self with the required energy. With this self-sustainable IRS-aided hybrid TDMA-NOMA system, the available time is fragmented into a set of time slots, in which an IRS unit is assigned to serve a cluster of users during each time slot. Meanwhile, the remaining unassigned (i.e., idle) IRS units harvest energy to feed themselves with the required energy, which addresses the energy limitation challenge related to conventional communication systems. Specifically, we propose an efficient algorithm to group the users in clusters and, thus, assign an appropriate IRS unit for each cluster. To examine the capabilities of the proposed self-sustainable multi-IRS-aided hybrid TDMA-NOMA system, a resource allocation framework is formulated aiming to minimize the transmit power at the base station under a set of quality-of-service (QoS) constraints. Such QoS constraints include the minimum required rate for each user and the minimum harvested energy at each IRS. However, since the considered optimization problem is not convex, and the coupled nature of the design parameters (i.e., the per-user power allocation and per-IRS reflection phase matrix), solving such a problem is challenging. Thus, we develop an efficient iterative algorithm, based on the sequential convex approximation, to solve the original optimization problem. Simulation results reveal that the proposed self-sustainable IRS-aided TDMA-NOMA system with the proposed clustering approach and IRS assignment consumes less power while achieving the sustainability of IRS units compared to benchmark approaches.

INDEX TERMS Intelligent Reflecting Surface (IRS), Non-Orthogonal Multiple Access (NOMA), Hybrid TDMA-NOMA.

I. INTRODUCTION

Recently, intelligent reflecting surface (IRS) has been identified as a promising solution to support the stringent requirements of future communication systems, including 6G and beyond [1]. An IRS unit contains a set of passive reflecting elements (mirrors). Each reflecting element has a controllable phase shift feature, which can reflect the incident signal towards the intended users

[2]. Accordingly, IRS has the potential capabilities to reconfigure the electromagnetic environment [1]. This can also be viewed as a remote base-station that can be deployed along with the existing base-station to improve the quality-of-service (QoS) of communication systems [3]. With this, IRS can offer several advantages, i.e., establishing virtual line-of-sight (LoS) to circumvent obstacles between communication ends, extending the signal coverage, and improving channel rank conditions [4]. In particular, due to its low cost and ease of deployment, the IRS technology is able to play a key role in the deployment of Internet-of-things (IoT) networks [5], where a massive number of users with diverse channel conditions need to be simultaneously connected and served [3] [4].

Furthermore, non-orthogonal multiple access (NOMA) has been considered as a promising paradigm for efficient spectrum utilization, thus meeting the massive connectivity of IoT networks [6]. Unlike the well-known conventional orthogonal multiple-access (OMA) techniques, NOMA exploits an orthogonal resource block (RB), time or frequency, to serve more than one user through power-domain superposition coding (SC) [7]. With SC, users with lower channel gains are encoded with higher power levels compared to those experiencing better channel conditions [8]. In fact, such power encoding strategy enables the fairness between users while ensuring the successful implementation of successive interference cancellation (SIC) [9]. In SIC, stronger users decode the messages intended for weaker users before decoding their own messages. With these key features, NOMA has been integrated with various OMA techniques [9], known as hybrid OMA-NOMA systems, to expand their potential capabilities and facilitate the NOMA deployment in dense networks. In such hybrid systems, an orthogonal RB is dedicated to serving a group of users (i.e., cluster). Then, the power domain multiplexing, offered by the NOMA technique, is exploited to serve the users in each cluster. Therefore, hybrid OMA-NOMA systems offer additional degrees of freedom while mitigating the practical limitations of deploying NOMA in dense networks [10]. The hybrid OMA-NOMA systems include hybrid time-division multiple access (TDMA)-NOMA systems and hybrid orthogonal frequency division multiple access (OFDMA)-NOMA systems [10].

Recently, several research directions have been identified to investigate the integration of IRS technology in a set of multiple access (MA) techniques, referred to as IRS-aided MA techniques. Such IRS-aided MA techniques should be able to deal with the practical challenges of employing MA in dense networks, and thus, improve the QoS of the communication system. In particular, IRS-aided MA techniques include IRS-aided multi-antenna techniques [11] [12], [13], and IRS-aided NOMA systems [14] [15]. To be specific, different IRS-aided NOMA configurations have been studied in the literature. For example, a multi-user single-input single-output (SISO) IRS-aided NOMA system is investigated under new channel statistics in [14], in which every two users are grouped into a cluster. In [16], a multi-cell SISO IRS-aided system was considered, where a single IRS is utilized to serve a group of users within each cell. In particular, a resource allocation technique is proposed to maximize the sum rate of the system. In addition, the capacity regions between IRS-aided OMA and NOMA systems have been characterized in [17]. Another SISO IRS-aided NOMA system has been studied in [18], in which a power minimization problem is formulated and solved for IRS-aided OMA and IRS-aided NOMA systems under a set of QoS constraints. Furthermore, the authors in [19] has considered an uplink transmission scheme assisted by hybrid TDMA-NOMA system. Specifically, the available time is divided into a set of time slots, where each group of two users communicates with the BS at each time slot. However, the sustainability of the IRS units has not been considered. It is worth noting that IRS-aided hybrid TDMA-NOMA systems have several advantages over other IRS-aided MA techniques [20]. For example, the time-fragmentation, offered by TDMA implies that all IRS units can be available at each time slot, which as a result, introduces an additional degree of freedom. Specifically, such IRS availability is non-affordable when considering hybrid OFDMA-NOMA systems, in which the available IRS should be allocated for each orthogonal RB. On the other hand, the time division of TDMA allows for dividing the available time for transmissions into sub-time slots. Accordingly, each group of users (cluster) can be served during each time slot by exploiting the power domain multiplexing technique offered by NOMA with the aid of the available IRS units. Furthermore, such a hybrid system mitigates the practical limitations of deploying stand-alone NOMA in dense networks. Specifically, since the users are grouped into clusters, SIC is required to be deployed for a small number of users.

While IRS, itself, consists of passive elements that reflect the signal without amplifying it, the set of controllers of such passive elements consume energy [21] [22]. The consumed power grows exponentially with the increase of the number of reflecting elements [22]. Accordingly, the energy consumption of the IRS should be carefully considered when investigating the potential role of IRS deployment in communication systems for two main reasons [23]. First, since IRS units are typically mounted at the top of high buildings, coated on walls, or carried by aerial platforms [2], empowering them with conventional electrical resources can be a challenge in terms of cost and practical implementations. Second, considering the environmental perspectives, the increase in power consumption increases the emission of CO_2, which as a result, has undesirable impacts on the environment.

These drawbacks limit the massive deployment of IRS in IoT networks, where a large number of IRS units should be utilized. Based on the above, the implementation of self-sustainable IRS units has been recently proposed as a promising solution to handle the energy consumption issue in IRS-aided systems [21]. With a self-sustainable approach, an IRS unit can harvest energy from the received radio frequency (RF) signal by employing simultaneous power and information transfer (SWIPT). In particular, a few works have investigated the wireless empowering of IRS through SWIPT, including the works in [21] [22]. In [21], [22], it was assumed that the reflecting elements of an IRS are classified into either energy harvesting or communication elements.

MOTIVATION AND CONTRIBUTION

Recently, the hybrid TDMA-NOMA system has been considered as a potential solution to support the massive connectivity in 6G networks while fulfilling the demanding rate requirements [24] [8], [24]–[27]. However, improving the channel conditions between the BS and users in such system becomes of vital importance, especially for cell-edge users [4]. This is due to the fact that some users, i.e., cell-edge users, might suffer from poor channel conditions, and severe blockage might avoid line-of-sight communications. Such circumstances limit the potential capabilities of deploying hybrid TDMA-NOMA in dense networks, where a massive number of users with diverse channel conditions seeks to achieve their QoS requirements. Accordingly, deploying IRS in wireless communication networks, including hybrid TDMA-NOMA system, has been recently identified as a potential candidate to engineer the signal propagation, and thus, supporting the unprecedented requirements of in such systems [4], [14], [28]. However, several design challenges have to be carefully addressed to exploit the underlying benefits of the hybrid TDMA-NOMA IRS-aided system [29]. Firstly, most of the existing works in the literature have assumed that a single IRS is employed to improve the communication between the users and the base station. While this assumption simplifies the analysis of the IRS-aided systems, it limits the potential benefits of deploying multi-IRS units in the system. This is due to the fact that a single IRS with a fixed location would not be able to cover a wide geographical area. Thus, deploying multiple IRSs can be classified as a distinguish solution to overcome the aforementioned challenges. On the other hand, providing energy to the multiple IRS units is considered as one of the major issues that has to be also addressed when considering the hybrid TDMA-NOMA IRS-aided networks. These aspects motivate us to consider a self-sustainable multi-IRS hybrid TDMA-NOMA in this paper. We summarize the main contributions of the paper as follows:

- First, we define the self-sustainable IRS-aided hybrid TDMA-NOMA system. We propose an IRS-assignment strategy that determines the busy and the idle IRS sets at each time slot. Accordingly, the busy IRS unit is utilized to reflect the signal and thus support data communication, while the idle IRS units harvest energy.
- We propose a clustering approach that divides the users into a set of clusters. As such, each time slot is dedicated to serving a cluster with the help of the busy IRS set.
- We formulate a power minimization framework that aims to minimize the transmit power at the base station (BS) while achieving a set of QoS constraints: minimum rate demand at each user and minimum harvested energy per idle IRS units.
- We develop an iterative algorithm based on sequential convex approximation (SCA) to solve the original problem and determine the design parameters.
- To validate the efficiency of the self-sustainable system, we compare its performance with a set of benchmark schemes.

The rest of the paper is organized as follows. Section II configures the self-sustainable IRS-aided hybrid TDMA-NOMA system model and formulates the power minimization framework. Section III presents the proposed algorithms for the IRS assignment and clustering. The set of simulation results is provided in Section IV. Section V concludes the paper.

II. SYSTEM MODEL AND PROBLEM FORMULATION

A. SYSTEM MODEL

We consider a downlink transmission of single-antenna BS, which communicates with N single-antenna users through the support of M IRS units, as shown in Fig. 1. Specifically, the BS is located at $(x_{\mathrm{BS}}, y_{\mathrm{BS}})$, while the n^{th} user, referred to as U_n $\forall n \in \mathcal{N} = \{1, \cdots, N\}$, is located at (x_{U_n}, y_{U_n}). Furthermore, the m^{th} IRS unit (I_m), $\forall m \in \mathcal{M} = \{1, \cdots, M\}$ consists of L reflecting elements, and it is located at (x_m, y_m), where the $\mathcal{I} = \{I_1, I_2, \cdots, I_M\}$ is a set contains all the IRS units. With such a hybrid system, the available time of transmission (T) is equally divided into K time slots, and the users are grouped into clusters. Such that the k^{th} time slot (t_k), i.e., $t_k = \frac{T}{K}$, is dedicated to serve the k^{th} cluster (c_k). To support the communications with the users in c_k, an IRS unit is assigned to support the transmission in time slot t_k, and such an IRS unit is referred to as a busy IRS (I_b). Meanwhile, the remaining IRS units, referred to as idle IRS units, can harvest energy to feed the controllers with the harvested energy. The next section will present the IRS assignment and clustering approach criteria. Accordingly, the BS transmits the superimposed signal x_k at each t_k, such as,

$$x_k = \sqrt{p_{1,k}} s_{1,k} + \sqrt{p_{2,k}} s_{2,k}, \forall k \in \mathcal{K}, \tag{1}$$

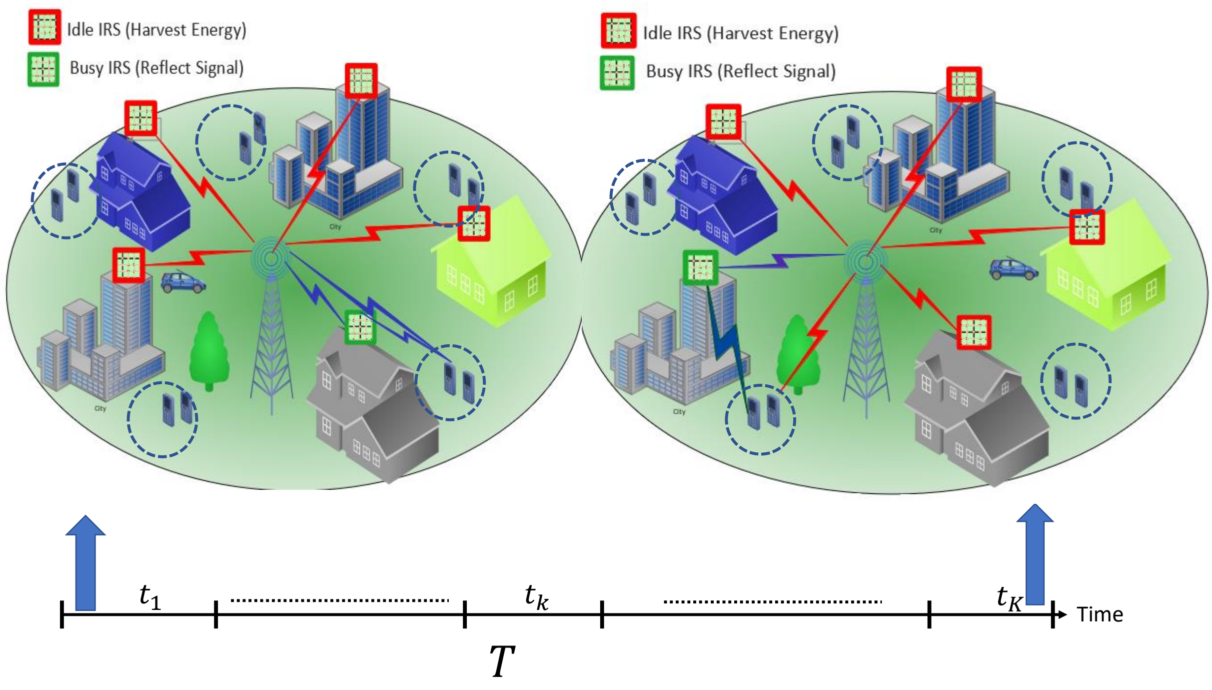

FIGURE 1: Self-Sustainable IRS-aided hybrid TDMA-NOMA system

where $s_{i,k}$ and $p_{i,k}$ denote the symbol intended to the i^{th} user in c_k, referred to as $u_{i,k}$, and the corresponding power allocation, respectively.

Information decoding at users

The received signal at $u_{i,k}$ can be written as

$$r_{i,k} = \left(h_{i,k} + \mathbf{h}_{b,i,k}^{H}\mathbf{\Theta}_b\mathbf{g}_b\right)x_k + n_{i,k}, \forall i \in \{1,2\}, \forall k \in \mathcal{K}, \tag{2}$$

where $\mathbf{h}_{b,i,k}^{H} \in \mathbb{C}^{1\times L}$, and $\mathbf{g}_b \in \mathbb{C}^{L\times 1}$ denote the channels between the busy IRS (i.e., I_b) and $u_{j,i}$, and between the BS and I_b, respectively. Furthermore, $\mathbf{\Theta}_b = \mathrm{diag}[e^{j\theta_{b,1}}, \cdots, e^{j\theta_{b,L}}]$ is the IRS reflection diagonal matrix, where $\theta_{b,l} \in [0, 2\pi]$ is the phase shift of l^{th} reflecting element of I_b. Since the IRS units and the BS are generally pre-deployed and, thus, have a LOS, the channel between BS and I_b can be modeled as a Rician fading channel [30]. Accordingly, the channel model between the BS and each IRS can be modeled as [31],

$$\mathbf{g}_b = \sqrt{C_0 d_b^{-a_0}}\left(\sqrt{\frac{\kappa}{\kappa+1}}\tilde{\mathbf{g}}_b^{\mathrm{LOS}} + \sqrt{\frac{1}{\kappa+1}}\tilde{\mathbf{g}}_b^{\mathrm{NLOS}}\right), \tag{3}$$

where C_0 and a_0 are the reference path loss and the path loss exponent, respectively. Furthermore, d_i is the distance between the BS and I_b, i.e., $d_b = \sqrt{(x_m - x_{\mathrm{BS}})^2 + (y_m - y_{\mathrm{BS}})^2}$. In addition, κ denotes the Rician factor, while $\tilde{\mathbf{g}}_b^{\mathrm{LOS}}$ and $\tilde{\mathbf{g}}_b^{\mathrm{NLOS}}$ denote the LOS and non-line of sight (NLOS) components, respectively. On the other hand, the channels between the BS and each user and between each IRS and each user are characterized as Rayleigh fading. In particular, $h_{i,k} = \sqrt{C_1 d_{i,k}^{-a_1}}\tilde{h}_{i,k}$, where $d_{i,k} = \sqrt{(x_{i,k} - x_{\mathrm{BS}})^2 + (y_{i,k} - y_{\mathrm{BS}})^2}$ is the distance between the BS and $u_{i,k}$. In addition, $\mathbf{h}_{b,2,k} = \sqrt{C_1 d_{b,i,k}^{-a_1}}\tilde{h}_{i,k}$. It is also assumed that the channels are quasi-static, and thus, they remain constant throughout the transmission time. It is worth mentioning that ordering of users has a considerable impact on the SIC process, and thus, it determines the overall performance of the system. Without loss of generality, it is assumed that

$$\left|h_{1,k} + \mathbf{h}_{b,1,k}{}^{H}\mathbf{\Theta}_b\mathbf{g}_b\right|^2 \geq \left|h_{2,k} + \mathbf{h}_{b,2,k}{}^{H}\mathbf{\Theta}_b\mathbf{g}_b\right|^2. \tag{4}$$

With this, the strongest user, i.e., $u_{1,k}$, performs SIC to decode the message intended for the weaker user prior to decoding its own message with the following signal-to-noise and interference ratio (SINR):

$$\mathrm{SINR}_{2,k}^{1} = \frac{p_{2,k}\left|h_{1,k} + \mathbf{h}_{b,1,k}^{H}\mathbf{\Theta}_b\mathbf{g}_b\right|^2}{\left(p_{1,k}\left|h_{1,k} + \mathbf{h}_{b,1,k}^{H}\mathbf{\Theta}_b\mathbf{g}_b\right|^2 + \sigma_{1,k}^2\right)}, \forall k. \tag{5}$$

When the strongest user decodes the message of the weakest user, it subtracts this message of the received signal. Then, the strongest user decodes its message with the following SINR [32]:

$$\mathrm{SINR}_{1,k} = \frac{p_{1,k}\left|h_{1,k} + \mathbf{h}_{b,1,k}^{H}\mathbf{\Theta}_b\mathbf{g}_b\right|^2}{\sigma_{1,k}^2}, \forall k \in \mathcal{K}. \tag{6}$$

However, the weaker user does not perform SIC and can only decode its message with the following SINR

$$\mathrm{SINR}_{2,k}^{2}=\frac{p_{2,k}\left|h_{2,k}+\mathbf{h}_{b,2,k}^{H}\mathbf{\Theta}_{b}\mathbf{g}_{b}\right|^{2}}{\left(p_{1,k}\left|h_{2,k}+\mathbf{h}_{b,2,k}^{H}\mathbf{\Theta}_{m}\mathbf{g}_{b}\right|^{2}+\sigma_{2,k}^{2}\right)}. \quad (7)$$

Accordingly, the achieved rate for each user can be defined as [33], [34]

$$R_{1,k}=t_k\log(1+\mathrm{SINR}_{1,k}), \quad (8a)$$

$$R_{2,k}=t_k\log(1+\min\{\mathrm{SINR}_{2,k}^{1},\mathrm{SINR}_{2,k}^{2}\}). \quad (8b)$$

Energy harvesting at idle IRS units

While I_b is reserved to support the transmission to the users in c_k, the remaining IRS (i.e., the idle IRS) units can harvest energy during time slot t_k. Note that the set of idle IRS units is denoted as $\mathcal{I}_i$, such as $\mathcal{I}_i \cup I_b=\mathcal{I}$, while I_i denotes an idle IRS unit. Accordingly, the harvested energy at I_i can be written as

$$\mathrm{E}_i=\eta_i t_k p_k |\mathbf{g}_i|^2, \quad \forall I_i\in\mathcal{I}_i, \quad (9)$$

where $\eta_i\in(0,1]$ is the power conversion efficiency, and $p_k=p_{1,k}+p_{2,k}$ is the allocated power to the users in c_k.

B. PROBLEM FORMULATION

Considering the achieved rate for each user and the EH capabilities of the idle IRS units, we aim to minimize the transmit power subject to achieve a set of QoS for the users and the IRS units. Accordingly, we develop the following power minimization framework:

$$\begin{aligned} P_1 \underset{p_{i,k},\theta_b}{\text{minimize}} \quad & \sum_{k=1}^{K} p_k && (10a)\\ \text{subject to} \quad & \mathrm{R}_{i,k}\geq R^{\min}, \forall i\in\{1,2\},\forall k\in\mathcal{K}, && (10b)\\ & \mathrm{E}_m \geq \gamma_m^{\min}, \forall m, m\neq b, && (10c)\\ & (4), && (10d)\end{aligned}$$

where $R^{\min}$ is the minimum rate requirement for $u_{i,k}$. In addition, $\gamma_m^{\min}$ is the minimum harvested energy requirements for I_i. Note that the proposed power minimization framework P_1 ensures the sustainability of the considered IRS units. Specifically, it enables the IRS units to harvest energy for their operational process while achieving the minimum rate requirements of the users. However, solving such an optimization framework is challenging due to several factors. Firstly, the optimization framework is not only convex but also a joint optimization framework, where the power levels for the users and the phase shift matrix for the busy IRS should be jointly optimized. Thus, this coupled nature of the optimization framework introduces additional challenges in solving it. Secondly, selecting the users in each cluster (i.e., clustering) and determining the busy and idle IRS units must be determined prior to solving the problem. We deal with these issues in the following sections.

III. IRS-ASSIGNMENT AND PROPOSED ALGORITHMS

A. IRS-SELECTION AND GROUPING STRATEGY CRITERIA

As the busy IRS (one IRS unit) in our system serves a single cluster at a time while the other idle IRS units harvest energy, selecting the appropriate IRS sets is crucial for the overall performance of the system. In addition, grouping a pair of users at each time slot (clustering) should also be carefully investigated. Accordingly, this paper proposes efficient IRS selection and grouping strategy algorithms. Specifically, the proposed algorithms consider several factors, namely the distances between IRS units and the intended clusters, as well as the channel conditions of users. The proposed IRS-selection and user grouping strategy algorithms are executed as follows:

1. At the first time slot, i.e., t_1, the channel gain between each IRS and each user in the network is determined, i.e., $|\mathbf{h}_{m,n}|^2$, $\forall m\in\mathcal{M},\forall n\in\mathcal{N}$. With this, we select the users with the best channel gains with respect to each IRS and include them in Table 1. The information in Table 1 indicates that U_k and U_{k-2} have the best channel gains with respect to I_1.
2. Accordingly, the correlation between the channels of stronger users for each IRS is now calculated, i.e.,
$$\mathrm{Corr}_m=\frac{|\mathbf{h}_{m,1}\mathbf{h}_{m,2}|}{|\mathbf{h}_{m,1}||\mathbf{h}_{m,2}|},\forall m. \quad (11)$$
3. Then, the users with higher correlation are assigned to that IRS, and such IRS is denoted as the busy IRS, while the others are referred to as the idle IRS. As an illustrative example, assume that
$$\mathrm{Corr}_M=\max.\{\mathrm{Corr}_1.\mathrm{Corr}_2,\cdots,\mathrm{Corr}_M\}.$$
This implies that $I_b=I_M$. Furthermore, the paired users at this time slot are U_{K-1} and U_1. Meanwhile, the set of idle IRS is $\{I_1,I_2,\cdots,I_{M-1}\}$.
4. In the second time slot, the busy IRS from the previous time slot is excluded from the set of available IRS units, i.e.,
$$\mathcal{I}_{t+1}=\mathcal{I}_t\setminus I_b.$$
Similarly, the set of available users is updated as follows:
$$\mathcal{U}_{t+1}=\mathcal{U}_t\setminus\{U_{K-1},U_1\}.$$
5. The steps from 1 to 4 are repeated for all time slots.

IRS	I_1	$\cdots$	I_m	$\cdots$	I_M
	$\|\mathbf{h}_{1,k}\|^2$	$\vdots$	$\|\mathbf{h}_{m,3}\|^2$	$\vdots$	$\|\mathbf{h}_{M,K-1}\|^2$
	$\|\mathbf{h}_{1,k-2}\|^2$	$\vdots$	$\|\mathbf{h}_{m,6}\|^2$	$\vdots$	$\|\mathbf{h}_{M,1}\|^2$

TABLE 1: Channel gains for users with best channel conditions with respect to each IRS.

B. THE PROPOSED SOLUTION

Given the proposed IRS-selection and grouping strategy algorithms, the power minimization framework P_1 can now be solved. However, such a problem is non-convex due to the non-convexity of the constraints. While most of the existing works in the literature exploit an alternating optimization (AO) to deal with the joint nature of the problem, we propose an iterative algorithm based on SCA to solve this power minimization problem. With this, it is obvious that the optimization parameters, namely allocated power and the corresponding reflection matrix, can be evaluated separately for each time slot. This enables us to update P_1 as follows:

$$
\begin{aligned}
P_2: \quad & \underset{p_{j,i}\forall j \forall i, \theta_i}{\text{minimize}} && p_k && \text{(12a)}\\
& \text{subject to} && \text{SINR}_{i,k} \geq \text{SINR}^{\min}, && \text{(12b)}\\
& && \text{E}_m \geq \gamma_m^{\min}, && \text{(12c)}\\
& && (4), && \text{(12d)}
\end{aligned}
$$

where $\text{SINR}^{\min} = 2^{\frac{R^{\min}}{t_k}} - 1$.

For notional simplicity, assume that

$$\mathbf{v}_{b,i,k} = \left[\mathbf{h}_{b,i,k}{}^{H}\text{diag}\,(g_b), \quad h_{i,k}\right].$$

Accordingly [31],

$$|h_{i,k} + \mathbf{h}_{b,i,k}{}^{H}\mathbf{\Theta}_b\mathbf{g}_b|^2 = |\mathbf{v}_{b,i,k}\mathbf{r}_b|^2, \tag{13}$$

where $\mathbf{r}_b = [\beta_{b,1}e^{j\theta_{b,1}}, \cdots, \beta_{b,L}e^{j\theta_{b,L}}, 1]^T$. Note that (12b) can be split into the following set of constraints:

$$
(12b) = \begin{cases}
\frac{p_{1,k}\left|\mathbf{v}_{b,1,k}\mathbf{r}_b\right|^2}{\sigma_{1,k}^2} \geq \text{SINR}^{\min}, & \forall k \in \mathcal{K},\\
\frac{p_{2,k}\left|\mathbf{v}_{b,1,k}\mathbf{r}_b\right|^2}{p_{1,k}\left|\mathbf{v}_{b,1,k}\mathbf{r}_b\right|^2 + \sigma_{1,k}^2} \geq \text{SINR}^{\min} & \forall k \in \mathcal{K},\\
\frac{p_{2,k}\left|\mathbf{v}_{b,2,k}\mathbf{r}_b\right|^2}{\left(p_{1,k}\left|\mathbf{v}_{b,2,k}\mathbf{r}_b\right|^2 + \sigma_{2,k}^2\right.} \geq \text{SINR}^{\min} & \forall k \in \mathcal{K},
\end{cases} \tag{14}
$$

To deal with the non-convexity of the problem, we exploit SCA, at which each non-convex term is approximated with its lower linear (convex-concave) approximation. Accordingly, the approximated convex problem is solved iteratively until the convergence. With this, we introduce a set of non-negative slack variables to deal with the non-convexity issue of (12b) such as,

$$|\mathbf{v}_{b,i,k}\mathbf{r}_b|^2 \geq z_{b,i,k}, \tag{15a}$$

$$z_{b,i,k} \geq \gamma_{b,i,k}{}^2. \tag{15b}$$

Then, we deploy first-order Taylor series expansion to approximate the non-convex terms in (15). The corresponding lower linear (convex-concave) terms, as follows:

$$
\begin{aligned}
&|\mathbf{v}_{b,i,k}\mathbf{r}_b^{(t)}|^2 + 2|\mathbf{v}_{b,i,k}\mathbf{r}_b^{(t)}|\\
&\left[\Re(\mathbf{v}_{b,i,k}\mathbf{r}_b) - \Re(\mathbf{v}_{b,i,k}\mathbf{r}_b^{(t)}),\ \Im(\mathbf{v}_{b,i,k}\mathbf{r}_b) - \Im(\mathbf{v}_{b,i,k}\mathbf{r}_b^{(t)})\right]\\
&\geq z_{b,i,k},
\end{aligned} \tag{16}
$$

$$z_{b,i,k} \geq \gamma_{b,i,k}^{2}{}^{(t)} + 2\gamma_{b,i,k}{}^{(t)}\left(\gamma_{b,i,k} - \gamma_{b,i,k}{}^{(t)}\right), \tag{17}$$

where $(\ )^{(t)}$ represents the t^{th} iteration of $(\ )$. Furthermore, we incorporate an additional new slack variable such as

$$p_{j,k}\gamma_{b,i,k}^2 \geq \zeta_{b,j,i,k}. \tag{18}$$

Similarly, we handle the non-convexity issue of this constraint through first-order Taylor series approximation as follows:

$$
\begin{aligned}
&p_{j,k}^{(t)}\gamma^{2(t)}_{b,i,k} + 2p_{j,k}^{(t)}\gamma_{b,i,k}^{(t)}\left(\gamma_{b,i,k} - \gamma_{b,i,k}^{(t)}\right) +\\
&\gamma^{2(t)}_{b,i,k}\left(p_{j,k} - p_{j,k}^{(t)}\right) \geq \zeta_{b,j,i,k}.
\end{aligned} \tag{19}
$$

With these slack variables, the minimum rate constraints in (12b) can be written as

$$
(12b) = \begin{cases}
\zeta_{b,1,1,k} \geq \text{SINR}^{\min}\left(\sigma_{1,k}\right)\\
\zeta_{b,2,1,k} \geq \text{SINR}^{\min}\left(\zeta_{b,1,1,k} + \sigma_{1,k}\right)\\
\zeta_{b,2,2,k} \geq \text{SINR}^{\min}\left(\zeta_{b,1,2,k} + \sigma_{2,k}\right)\\
(16), (17), (19).
\end{cases} \tag{20}
$$

On the other hand, the SIC constraint in (4) can be written as

$$z_{b,1,k} \geq z_{b,2,k}. \tag{21}$$

Finally, the minimum harvested energy can be written as

$$p_k \geq \frac{\gamma_k^{\min}}{\eta_{i,k}t_k}. \tag{22}$$

Accordingly, the approximated optimization framework can be written as

$$
\begin{aligned}
P2: \quad & \underset{\Gamma}{\text{minimize}} && p_k && \text{(23a)}\\
& \text{subject to} && (20), (21), (22), && \text{(23b)}
\end{aligned}
$$

where Γ is a set that contains all the optimization parameters, i.e., $\Gamma = \{\mathbf{r}_m, z_{b,ik}, p_k, p_{1,k}, p_{2,k}, \gamma_{b,i,k}, \zeta_{b,j,i,k}\}$. The selection of the set of initial values to initiate the iterative algorithm, i.e., $\Gamma^{(0)}$, directly impacts the efficiency of the proposed SCA-based iterative algorithm. Therefore, we select a random power level, i.e., $p_k^{(0)}$. Then, we evaluate the remaining slack variables based on this initial value.

Parameter	Value
Number of users (N)	10
Number of IRS units (M)	5
Number of reflecting elements (L)	8
Path loss exponent (a_0)	3
power conversion efficiency (η)	0.5
Noise Variance (σ^2) [Watt]	10^-6
Total time for transmission (T) [Seconds]	1
Number of time slots (K)	5
Duration of each time slot t_k [Seconds]	0.2

TABLE 2: Simulation Parameters.

IV. SIMULATION RESULTS

In this section, we provide a set of simulations to validate the performance of the proposed IRS-assignment and grouping strategy algorithms for the IRS-aided hybrid TDMA-NOMA system. In particular, we compare the performance of the proposed algorithms against that of random IRS-assignment and grouping strategy algorithms, in which the IRS-assignment and clustering approaches are randomly selected. This simulation assumes that ten users, i.e., $N = 10$, are uniformly distributed within a circle with a radius of 20 meters. In addition, a set of 5 IRS units, i.e., $M = 5$, is randomly distributed within the circle. We provide the set of parameters used in the simulations in Table 2.

To demonstrate the benefits of deploying the hybrid TDMA-NOMA system in the considered self-sustainable IRS-aided system, we compare its performance with that of the conventional TDMA system in Fig. 2. As can be seen in Fig. 2, it is obvious that the hybrid TDMA-NOMA for both random and the proposed IRS assignment outperforms the performance of the conventional TDMA system. This is due to the fact that the time frame in conventional TDMA is divided into shorter time slots, which as a result, requires more power to achieve the same QoS requirements.

Fig. 3 compares the required minimum transmit power against different SINR requirements for the proposed IRS-assignment and grouping strategy approaches and that required for a random IRS-assignment. It can be seen in Fig. 3 that the proposed approach outperforms the random one in terms of the required minimum power. This is because the proposed approach considers the channel conditions of users and thus selects the best IRS (i.e., busy IRS) to serve the users in each time slot. However, the random approach does not impose any constraint either on user grouping or the IRS-assignment. On one hand, this random approach might group uncorrelated users together. On the other hand, such a random approach might select inappropriate IRS (far IRS) for a group of users. This, as a result, leads to

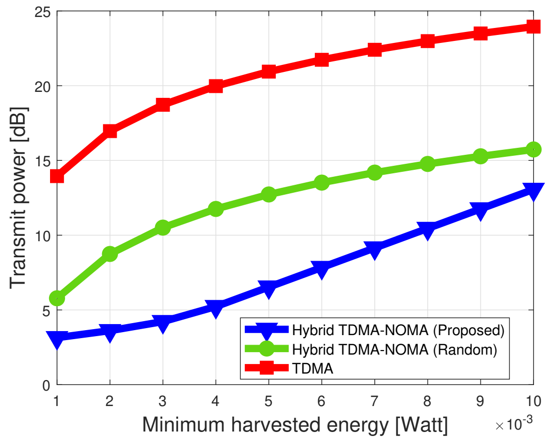

FIGURE 2: Required transmit power against different harvested energy requirements, $\mathrm{SINR}^{\min} = 4$.

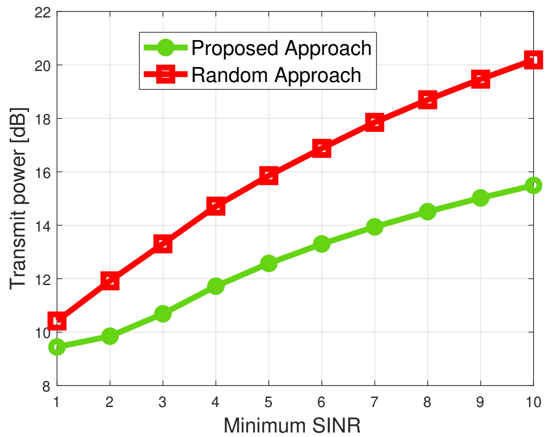

FIGURE 3: Required transmit power against different SINR requirements, $\gamma_m^{\min} = 10^{-4}$ Watt.

higher power consumption, as can be seen in Fig. 3.

Fig. 4 depicts the required transmit power against different harvested energy requirements for the IRS-aided hybrid TDMA-NOMA system and compares the proposed and the random approaches. As it is expected, the minimum required power grows with the increase of the minimum harvested energy requirements for both approaches. This can be justified as harvesting more energy at idle IRS units require more transmit power than the BS. However, our proposed IRS-assignment and grouping strategy approaches satisfy the QoS requirements with lower transmit power consumption compared to that of the random approach.

Finally, the convergence of the proposed SCA algorithm to solve the power minimization is provided in Fig. 5. In particular, the required transmit power against the number of iterations is provided for three-time slots (i.e., clusters). It is shown that the proposed SCA algorithm

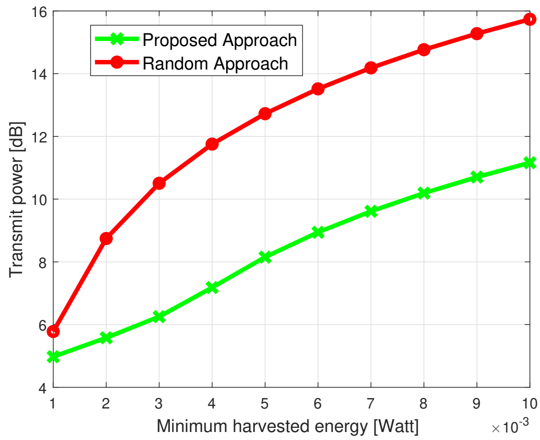

FIGURE 4: Required transmit power against different harvested energy requirements, $\mathrm{SINR}^{\min} = 4$.

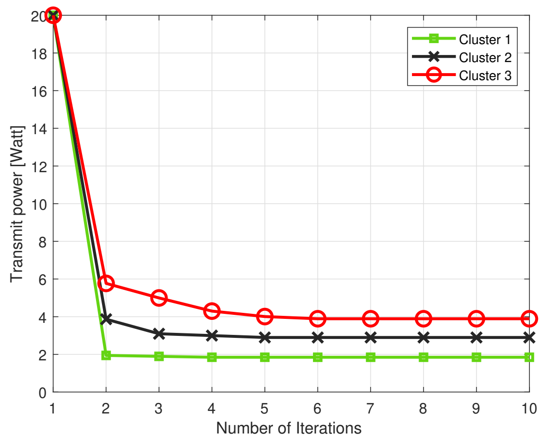

FIGURE 5: The convergence of the proposed SCA for different time slots, $\mathrm{SINR}^{\min} = 5, \gamma_m^{\min} = 10^{-3}$.

converges to the solution with a few iterations.

V. CONCLUSIONS

In this paper, we proposed a self-sustainable IRS-aided hybrid TDMA-NOMA. It was assumed that the available IRS units are divided in each time slot into two sets, busy and idle IRS sets. Specifically, while the busy IRS unit was reserved to support the transmission of the paired users, the idle IRS units were assumed harvesting energy. We also proposed an IRS-assignment and user grouping strategy for the self-sustainable system. Furthermore, we developed a power minimization framework with a set of QoS constraints. An efficient SCA was proposed to solve the original problem. Simulation results revealed that the proposed IRS-assignment and user grouping strategies outperform the random approaches. In addition, it was also confirmed that the proposed SCA algorithm converges to the solution with a few iterations.

REFERENCES

[1] B. Ji, Y. Han, S. Liu, F. Tao, G. Zhang, Z. Fu, and C. Li, "Several key technologies for 6G: Challenges and opportunities," IEEE Communications Standards Magazine, vol. 5, no. 2, pp. 44–51, Jun. 2021.

[2] S. Gong, X. Lu, D. T. Hoang, D. Niyato, L. Shu, D. I. Kim, and Y.-C. Liang, "Toward smart wireless communications via intelligent reflecting surfaces: A contemporary survey," IEEE Communications Surveys & Tutorials, vol. 22, no. 4, pp. 2283–2314, 4th quart., 2020.

[3] Q. Liu, S. Sun, B. Rong, and M. Kadoch, "Intelligent reflective surface based 6G communications for sustainable energy infrastructure," IEEE Wireless Communications, vol. 28, no. 6, pp. 49–55, Dec. 2021.

[4] Q. Wu, S. Zhang, B. Zheng, C. You, and R. Zhang, "Intelligent reflecting surface-aided wireless communications: A tutorial," IEEE Transactions on Communications, vol. 69, no. 5, pp. 3313–3351, Jan. 2021.

[5] Z. Chu, Z. Zhu, X. Li, F. Zhou, L. Zhen, and N. Al-Dhahir, "Resource allocation for IRS-assisted wireless-powered FDMA IoT networks," IEEE Internet of Things Journal, vol. 9, no. 11, pp. 8774–8785, Oct. 2021.

[6] H. Al-Obiedollah, K. Cumanan, A. G. Burr, J. Tang, Y. Rahulamathavan, Z. Ding, and O. A. Dobre, "On energy harvesting of hybrid tdma-noma systems," in Proc. IEEE Global Communications Conference (GLOBECOM), 2019, pp. 1–6.

[7] S. Vanka, S. Srinivasa, Z. Gong, P. Vizi, K. Stamatiou, and M. Haenggi, "Superposition coding strategies: Design and experimental evaluation," IEEE Trans. Wireless Commun., vol. 11, no. 7, pp. 2628–2639, Jul. 2012.

[8] X. Wei, H. Al-Obiedollah, K. Cumanan, W. Wang, Z. Ding, and O. A. Dobre, "Spectral-energy efficiency trade-off based design for hybrid tdma-noma system," IEEE Transactions on Vehicular Technology, vol. 71, no. 3, pp. 3377–3382, Jan. 2022.

[9] S. R. Islam, N. Avazov, O. A. Dobre, and K.-S. Kwak, "Power-domain non-orthogonal multiple access (NOMA) in 5G systems: potentials and challenges," IEEE Commun. Surveys Tuts., vol. 19, no. 2, pp. 721–742, Oct. 2017.

[10] X. Wei, H. Al-Obiedollah, K. Cumanan, M. Zhang, J. Tang, W. Wang, and O. A. Dobre, "Resource allocation technique for hybrid TDMA-NOMA system with opportunistic time assignment," in Proc. IEEE ICC WORKSHOP, 2020, pp. 1–7.

[11] G. Zhou, C. Pan, H. Ren, K. Wang, and A. Nallanathan, "Intelligent reflecting surface aided multigroup multicast MISO communication systems," IEEE Transactions on Signal Processing, vol. 68, pp. 3236–3251, April 2020.

[12] C. Pan, H. Ren, K. Wang, M. Elkashlan, A. Nallanathan, J. Wang, and L. Hanzo, "Intelligent reflecting surface aided MIMO broadcasting for simultaneous wireless information and power transfer," IEEE Journal on Selected Areas in Communications, vol. 38, no. 8, pp. 1719–1734, Jun. 2020.

[13] Y. Han, W. Tang, S. Jin, C.-K. Wen, and X. Ma, "Large intelligent surface-assisted wireless communication exploiting statistical CSI," IEEE Transactions on Vehicular Technology, vol. 68, no. 8, pp. 8238–8242, June 2019.

[14] T. Hou, Y. Liu, Z. Song, X. Sun, Y. Chen, and L. Hanzo, "Reconfigurable intelligent surface aided NOMA networks," IEEE Journal on Selected Areas in Communications, vol. 38, no. 11, pp. 2575–2588, July 2020.

[15] W. Ni, X. Liu, Y. Liu, H. Tian, and Y. Chen, "Resource allocation for multi-cell irs-aided noma networks," IEEE Transactions on Wireless Communications, vol. 20, no. 7, pp. 4253–4268, 2021.

[16] ——, "Resource allocation for multi-cell IRS-aided NOMA networks," IEEE Transactions on Wireless Communications, vol. 20, no. 7, pp. 4253–4268, February 2021.

[17] X. Mu, Y. Liu, L. Guo, J. Lin, and N. Al-Dhahir, "Capacity and optimal resource allocation for IRS-assisted multi-user communication systems," IEEE Transactions on Communications, vol. 69, no. 6, pp. 3771–3786, February 2021.

[18] B. Zheng, Q. Wu, and R. Zhang, "Intelligent reflecting surface-assisted multiple access with user pairing: NOMA or OMA?" IEEE Communications Letters, vol. 24, no. 4, pp. 753–757, January 2020.

[19] D. Zhang, Q. Wu, M. Cui, G. Zhang, and D. Niyato, "Throughput maximization for irs-assisted wireless powered hybrid noma and tdma," IEEE Wireless Communications Letters, vol. 10, no. 9, pp. 1944–1948, 2021.

[20] G. Chen, Q. Wu, C. He, W. Chen, J. Tang, and S. Jin, "Active IRS aided multiple access for energy-constrained IoT systems," IEEE Transactions on Wireless Communications, vol. 22, no. 3, pp. 1677 – 1694, September 2022.

[21] S. Hu, Z. Wei, Y. Cai, C. Liu, D. W. K. Ng, and J. Yuan, "Robust and secure sum-rate maximization for multiuser MISO downlink systems with self-sustainable IRS," IEEE Transactions on Communications, vol. 69, no. 10, pp. 7032–7049, July 2021.

[22] S. Hu, Z. Wei, Y. Cai, D. W. K. Ng, and J. Yuan, "Sum-rate maximization for multiuser MISO downlink systems with self-sustainable IRS," in Proc. IEEE Global Communications Conference (GLOBECOM), 2020, pp. 1–7.

[23] C. Huang, A. Zappone, G. C. Alexandropoulos, M. Debbah, and C. Yuen, "Reconfigurable intelligent surfaces for energy efficiency in wireless communication," IEEE Transactions on Wireless Communications, vol. 18, no. 8, pp. 4157–4170, June 2019.

[24] R. V. Bhat, M. Motani, and T. J. Lim, "Hybrid NOMA-TDMA for multiple access channels with non-ideal batteries and circuit cost," in Proc. International Symposium on Information Theory (ISIT). IEEE, 2018, pp. 1091–1095.

[25] Y. Zhu, X. Yuan, Y. Hu, T. Wang, M. C. Gursoy, and A. Schmeink, "Low-latency hybrid NOMA-TDMA: QoS-Driven design framework," IEEE Transactions on Wireless Communications, Early Access, October 2022.

[26] L. Liu, B. Sun, Y. Wu, and D. H. Tsang, "Latency optimization for computation offloading with hybrid NOMA–OMA transmission," IEEE Internet of Things Journal, vol. 8, no. 8, pp. 6677–6691, 2021.

[27] C. Chaieb, F. Abdelkefi, and W. Ajib, "Deep reinforcement learning for resource allocation in multi-band and hybrid OMA-NOMA wireless networks," IEEE Transactions on Communications, vol. 71, no. 1, pp. 187–198, November 2022.

[28] Z. Ding and H. V. Poor, "A simple design of irs-noma transmission," IEEE Communications Letters, vol. 24, no. 5, pp. 1119–1123, 2020.

[29] Z. Ding, L. Lv, F. Fang, O. A. Dobre, G. K. Karagiannidis, N. Al-Dhahir, R. Schober, and H. V. Poor, "A state-of-the-art survey on reconfigurable intelligent surface-assisted non-orthogonal multiple access networks," Proceedings of the IEEE, vol. 110, no. 9, pp. 1358–1379, 2022.

[30] Z. Li, W. Chen, Q. Wu, K. Wang, and J. Li, "Joint beamforming design and power splitting optimization in IRS-assisted SWIPT NOMA networks," IEEE Transactions on Wireless Communications, vol. 21, no. 3, pp. 2019–2033, September 2021.

[31] J. Zuo, Y. Liu, Z. Qin, and N. Al-Dhahir, "Resource allocation in intelligent reflecting surface assisted NOMA systems," IEEE Transactions on Communications, vol. 68, no. 11, pp. 7170–7183, August 2020.

[32] J. Zhu, Y. Huang, J. Wang, K. Navaie, and Z. Ding, "Power efficient IRS-assisted NOMA," IEEE Transactions on Communications, vol. 69, no. 2, pp. 900–913, 2020.

[33] S. Jiao, F. Fang, X. Zhou, and H. Zhang, "Joint beamforming and phase shift design in downlink UAV networks with IRS-assisted NOMA," Journal of Communications and Information Networks, vol. 5, no. 2, pp. 138–149, 2020.

[34] H. M. Al-Obiedollah, K. Cumanan, J. Thiyagalingam, A. G. Burr, Z. Ding, and O. A. Dobre, "Energy efficient beamforming design for MISO non-orthogonal multiple access systems," IEEE Trans. Commun., vol. 67, no. 6, pp. 4117–4131, Jun. 2019.

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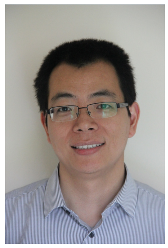

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