8th Iranian Conference on Signal Processing and Intelligent Systems (ICSPIS 2022), December 28-29, University of Science and Technology of Mazandaran

Phase Shift Design for Intelligent Reflecting Surfaces under Practical Reflection Models in NOMA Network

Fatemeh Ghalgarzadeh, Mahdi Majidi
Department of Electrical and Computer Engineering
University of Kashan
Kashan, Iran
f.ghalgar97@grad.kashanu.ac.ir
m.majidi@kashanu.ac.ir

Rashid Mirzavand
Department of Electrical and Computer Engineering
University of Alberta
Edmonton, Canada
mirzavan@ualberta.ca

***Abstract*— Intelligent reflecting surface (IRS) with wireless channel reconfiguration capability has been proposed as a promising technology to improve the performance of future wireless networks. IRS is able to achieve massive connectivity, as well as high energy and spectral efficiency with the aid of non-orthogonal multiple access (NOMA) technique. However, IRS in practical systems faces serious challenges such as discrete phase shift configuration, the dependence of reflection amplitude on phase shift, as well as dependence on incident and reflection angles. Hence, we consider a downlink NOMA system assisted by an IRS under practical reflection models and maximize the sum rate by optimizing the IRS phase shift configuration. Since the corresponding optimization problem is non-convex, two exhaustive search and genetic algorithm methods are used to solve the problem. Simulation results show that increasing the number of IRS elements improves the sum rate, and on the contrary, significantly increases the problem-solving time in the exhaustive search method and makes it inefficient. In comparison the genetic algorithm is able to effectively solve the problem in less time than the exhaustive search method. Moreover, a simple but efficient phase aligning algorithm is also proposed in single-user case as a suboptimal solution of problem.**

Keywords—Intelligent reflecting surface; non-orthogonal multiple access; practical reflection models; genetic algorithm; phase aligning algorithm.

I. INTRODUCTION

The destructive effects of natural wireless propagation, including attenuation and scattering, as well as the ineffectiveness of uncontrollable channel models to meet the requirements of future wireless networks, have led researchers to create a programmable and intelligent wireless environment [1, 2]. A leading technology to achieve a reconfigurable wireless channel is intelligent reflecting surface (IRS) [2, 3]. IRS is a planar antenna array, which contains many passive reflecting elements with ability to control the phase, amplitude, frequency, and even polarization of the input wave [2]. In previous works, ideal reflection models for IRS are mainly considered, in which a continuous phase shift configuration, constant reflection amplitude, and no dependence on incident and reflection angles are assumed. However, a practical IRS might not satisfy any of these conditions. In [4], a practical phase shift model is presented, where the reflection amplitude is nonlinearly dependent on its phase shift, and the transmit power of a multiple-input single-output (MISO) system with an IRS based on this model is minimized by jointly designing the transmit and reflect beamforming. The aim of [5] is to achieve the desired quality-of-service (QoS) of users with minimum transmit power in an IRS-aided downlink system, where the unit cell radiation pattern depends on the incident, and reflection angle. Furthermore, in [6], a practical model is adopted for IRS considering the dependence of the reflection amplitude on the input angle.

With the aim of improving the spectral efficiency (SE) and connectivity of users in IRS-assisted wireless networks, the non-orthogonal multiple access (NOMA) technique is utilized [7]. The main idea of NOMA is to allocate one resource block, e.g. subcarrier, time slot, and code, to multiple users. Therefore, the number of users supported by NOMA is greater than the number of resource blocks. hence, the use of NOMA increases SE and supports massive connectivity [8]. In [9], the throughput maximization of an IRS-aided downlink NOMA system by jointly optimizing the resource allocation, decoding order, and IRS reflection coefficients is investigated. In [10], the transmit power of a NOMA network enhanced by IRS is minimized under the unit reflection amplitude, and discrete phase shifting constraint for IRS elements. In [11], a MISO IRS-assisted NOMA system is considered, and the transmit and reflect beamforming are jointly optimized in terms of the sum rate over the users. In [12], the performance of the IRS-NOMA system is studied in two simple but efficient phase shifting designs; In the first design, the phase shift of each element is adjusted so that the phase of the cascaded channel via that element is zero, and in the second design the phase shifts are discrete and randomly chosen. In [13], a multi-cluster NOMA network is designed, where an IRS is deployed in each cluster due to the non-line-of-sight (NLoS) propagation feature of communication from the base station (BS) to cell edge user, and the power allocation, beamforming vector and IRS phase shifting matrix of each cluster are jointly optimized so that the total transmit power is minimized.

In this paper, a single-input single-output (SISO) NOMA system is considered, where an IRS under practical reflection models is exploited to enhance the downlink communication from the BS to the users. We maximize the sum rate of all users by formulating an optimization problem to configure IRS. The corresponding optimization problem is non-convex and is solved in two specific single-user and two-user cases. the simple single-user case provides a useful perspective for solving the problem. Furthermore, the general multi-user case can be achieved by using the two-user case, and the user pairing concept [10].

II. System Model

In this paper, an IRS-assisted downlink NOMA system is considered, where a single-antenna BS is assisted by an IRS with Q reflecting elements to serve K single-antenna users (see Fig. 1). The direct path between the BS and each user is blocked by existing obstacles and has NLoS propagation feature. Therefore, an IRS is deployed to aid communication, which has the line-of-sight (LoS) links with the BS and users.

As shown in Fig. 1, the IRS is located in xy plane and contains Q_x elements along the x-axis (columns) and Q_y elements along the y-axis (rows). In addition, the first element is located at the coordinate origin, and elements are indexed row-by-row by $q \in [1, Q]$ [14]. Therefore, the location of the q-th element is expressed as

$$\boldsymbol{l}_q = [i(q)d, j(q)d, 0]^T, \tag{1}$$

where d denotes the element spacing and $i(q) = \mathrm{mod}(q-1, Q_x)$ and $j(q) = [(q-1)/Q_x]$ show the horizontal and vertical indices of the q-th element, respectively. The $\mathrm{mod}(.,.)$ operator calculates the remainder of dividing the first argument by the second argument, and $[.]$ is the integer component of the input [14]. If a plane wave impinges on the IRS from the (ϕ, θ) direction, the array response vector that determines the phase shift of the IRS elements relative to the first element is

$$\boldsymbol{a}(\phi,\theta) = \sqrt{G(\phi,\theta)}\left[e^{j\boldsymbol{k}(\phi,\theta)^T\boldsymbol{l}_1}, \dots, e^{j\boldsymbol{k}(\phi,\theta)^T\boldsymbol{l}_Q}\right]^T, \tag{2}$$

where ϕ and θ represent the azimuth and elevation angles, respectively. $G(\phi,\theta)$ denotes the directivity pattern of the BS antenna in (ϕ,θ) direction, and $\boldsymbol{k}(\phi,\theta) = \kappa[\sin(\theta)\cos(\phi), \sin(\theta)\sin(\phi), \cos(\theta)]^T$ is the wave vector, where κ represents the wave number [14]. Moreover, it is assumed that the IRS has digital coding with two voltage levels. Therefore, the total number of possible configurations for the IRS is 2^Q. But if the BS and users are considered in the xz plane, the array response vector can be simplified by dropping the dependence on ϕ as

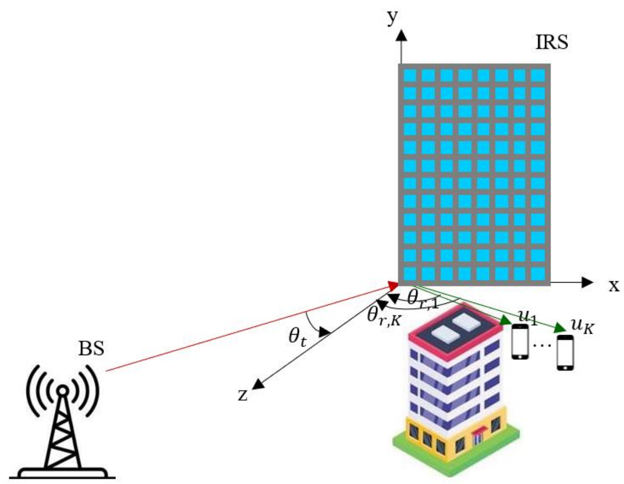

Fig. 1. : IRS-assisted NOMA system.

$$\boldsymbol{a}(\theta) = \sqrt{G(\theta)}\left[e^{j\kappa d\sin(\theta)i(1)}, \dots, e^{j\kappa d\sin(\theta)i(Q)}\right]^T, \tag{3}$$

where the phase shifts only depend on the horizontal indices $i(q)$, which means that the received signals of all elements of an IRS column are the same. Therefore, the phase shifts applied by the elements of a column are the same and the total number of configurations is reduced to 2^{Q_x}.

Let $x = \sum_{k=1}^{K}\sqrt{p_k}s_k$ be the transmit signal of the BS, where p_k represents the power allocated to the k-th user and s_k denotes the symbol transmitted to the k-th user. In addition, the equivalent channels of the BS to IRS, IRS to user k, and BS to user k are indicated by $\boldsymbol{h}_t \in \mathbb{C}^{Q\times 1}$, $\boldsymbol{h}_{r,k}^H \in \mathbb{C}^{1\times Q}$, and $h_{d,k} \in \mathbb{C}$, respectively. Therefore, the signal received at the k-th user is

$$y_k = \left(h_{d,k} + \boldsymbol{h}_{r,k}^H\boldsymbol{\Omega}\boldsymbol{h}_t\right)x + z_k, k = 1, \dots, K, \tag{4}$$

where $z_k \sim \mathcal{CN}(0,\sigma^2)$ represents the complex additive white Gaussian noise (AWGN) at the k-th user's receiver. Moreover, $\boldsymbol{\Omega}$ is the IRS phase shift matrix, which is defined as

$$\boldsymbol{\Omega}\left(\boldsymbol{\Psi}_t, \boldsymbol{\Psi}_{r,k}, \mathbf{v}\right) \triangleq g\left(\boldsymbol{\Psi}_t, \boldsymbol{\Psi}_{r,k}\right)\mathrm{diag}(\mathbf{v}), \tag{5}$$

where $\mathbf{v} = \left[v_1, \dots, v_Q\right]^T$ with $v_q = \tau_q e^{j\beta_q}$ is the reflection coefficient vector of IRS; β_q and τ_q denote phase shift and reflection amplitude of the q-th element, respectively. Exploiting the physics-based model proposed in [5], $\boldsymbol{\Omega}$ depends on the incident and reflection angles, as well as the polarization of impinging wave. This dependence is represented in (5) by the function $g\left(\boldsymbol{\Psi}_t, \boldsymbol{\Psi}_{r,k}\right)$, which is

$$g(\boldsymbol{\Psi}_t, \boldsymbol{\Psi}_{r,k}) = \frac{j4\pi L^2}{\lambda^2} \tilde{g}(\boldsymbol{\Psi}_t, \boldsymbol{\Psi}_{r,k}) \times \operatorname{sinc}\left(\frac{\kappa L A_x(\boldsymbol{\Psi}_t, \boldsymbol{\Psi}_{r,k})}{2}\right) \times \operatorname{sinc}\left(\frac{\kappa L A_y(\boldsymbol{\Psi}_t, \boldsymbol{\Psi}_{r,k})}{2}\right) \tag{6}$$

Where L and λ denote the length of IRS elements, and wavelength, respectively. $\boldsymbol{\Psi}_t = (\theta_t, \phi_t, \varphi_t)$ is the angle-of-arrival (AoA), where φ_t denotes the polarization of the incident wave. Also, $\boldsymbol{\Psi}_{r,k} = (\theta_{r,k}, \phi_{r,k})$ indicates the angle-of-departure (AoD) for the k-th user. $A_i(\boldsymbol{\Psi}_t, \boldsymbol{\Psi}_{r,k}) = A_i(\boldsymbol{\Psi}_t) + A_i(\boldsymbol{\Psi}_{r,k})\,; i \in \{x, y\}$ with $A_x(\boldsymbol{\Psi}) = \sin(\theta)\cos(\phi)$ and $A_y(\boldsymbol{\Psi}) = \sin(\theta)\sin(\phi)$. Furthermore, $\tilde{g}(\boldsymbol{\Psi}_t, \boldsymbol{\Psi}_{r,k})$ is given in (7), where $c(\boldsymbol{\Psi}_t) = A_z(\boldsymbol{\Psi}_t)/\sqrt{A_{x,y}^2(\boldsymbol{\Psi}_t) + A_z^2(\boldsymbol{\Psi}_t)}$, $A_{x,y}(\boldsymbol{\Psi}_t) = \cos(\varphi_t)\, A_x(\boldsymbol{\Psi}_t) + \sin(\varphi_t)\, A_y(\boldsymbol{\Psi}_t)$ and $A_z(\boldsymbol{\Psi}_t) = \cos(\theta_t)$ [5].

Based on the practical phase shift model presented in [4], the reflection amplitude is a nonlinear function of the phase shift and is expressed as

$$\tau_q(\beta_q) = (1 - \tau_{min}) \left(\frac{\sin(\beta_q - \zeta) + 1}{2}\right)^{\alpha} + \tau_{min} \tag{8}$$

where $\tau_{min} \geq 0$ is the minimum amplitude, $\zeta \geq 0$ represents the difference between $-\pi/2$ and the phase where τ_{min} occurs, and $\alpha \geq 0$ is a parameter to control the slope of the function curve [4].

III. Problem Formulation

The goal of this paper is to find the IRS phase shift configuration with the maximum sum rate assuming the total transmit power, $P_T = \sum_{k=1}^{K} p_k$, is fixed. This can be realized by formulating and solving an optimization problem in two specific single-user and two-user cases.

A. Single-user case

According to Shannon's formula, the achievable rate in this case is expressed as

$$R(\mathbf{v}) = W \log_2(1 + \gamma(\mathbf{v})) \tag{9}$$

where W is the bandwidth and $\gamma(\mathbf{v})$ denotes the signal-to-noise ratio (SNR) for the reflection coefficient vector $\mathbf{v}$, which is

$$\gamma(\mathbf{v}) = \frac{|h_d + \boldsymbol{h}_r^H \boldsymbol{\Omega}(\boldsymbol{\Psi}_t, \boldsymbol{\Psi}_r, \mathbf{v}) \boldsymbol{h}_t|^2 P_T}{\sigma^2} \tag{10}$$

Therefore, the optimization problem is formulated as

$$\max_{\{\beta_q\}_{q=1}^{Q}} \quad R(\mathbf{v}) \tag{11}$$

$$s.t. \quad v_q = \tau_q(\beta_q) e^{j\beta_q}, q = 1, \dots, Q \tag{12}$$

$$\beta_q = \beta_{q+Q_x} = \cdots = \beta_{q+(Q_y-1)Q_x}, q = 1, \dots, Q_x \tag{13}$$

$$\beta_q \in B, q = 1, \dots, Q, \tag{14}$$

where B represents the set of possible phase shifts and constraint (13) indicates that the phase shifts of the elements in a column are the same. The above problem is a non-convex problem and also, for large IRSs, solving it by exhaustive search method is very time-consuming. Therefore, in this subsection, two genetic and phase aligning algorithms have been used to achieve the optimal IRS configuration.

The optimization variable in the above problem is the IRS phase shift configuration. But assuming that the phase shifts of the elements of a column are the same, the dimensions of the problem are reduced to one row. On the other hand, due to the presence of two voltage levels, only one bit is needed to specify the phase shift of each element. Therefore, in the genetic algorithm, the variable is defined as a bit string of length Q_x. Furthermore, the fitness function maps each IRS phase shift configuration to the corresponding achievable rate at the receiver.

Based on the phase aligning algorithm in [15], the phase shift applied by each element of the IRS is adjusted so that the received signal of the user by that element is in phase with the received signal by the direct path. However, in this paper, the phase shift values for IRS elements are limited, and also the phase shifts of all elements in a column are considered the same. Therefore, in this paper, the phase aligning algorithm is defined in such a way that the phase shift for the elements of each column of the IRS is chosen to minimize the phase difference between the received signal of the user by this column and the received signal by the direct path.

B. Two-user case

In this subsection, a simple case with $K = 2$ users is considered. According to the NOMA protocol, less power is allocated to the user with stronger channel. Therefore, the successive interference cancellation (SIC) technique is performed in the receiver of the user who has a stronger channel to remove the interference of the user with the weaker channel. The user with stronger channel first decodes the user's signal who has a weaker channel and removes it from its observation signal to decode its own signal. While, the user with the weaker channel to decode its own signal treats the signal of the user with the stronger channel as interference. In IRS-NOMA systems, due to the dependence of the channel power gains on the IRS

$$\tilde{g}(\boldsymbol{\Psi}_t, \boldsymbol{\Psi}_{r,k}) = c(\boldsymbol{\Psi}_t) \times \left\| \begin{bmatrix} \cos(\varphi_t)\cos(\theta_{r,k})\sin(\phi_{r,k}) - \sin(\varphi_t)\cos(\theta_{r,k})\cos(\phi_{r,k}) \\ \sin(\varphi_t)\sin(\phi_{r,k}) + \cos(\varphi_t)\cos(\phi_{r,k}) \end{bmatrix} \right\|_2 \tag{7}$$

phase shift configuration, the user in which the SIC technique is performed changes depending on the IRS configuration and is obtained as

$$\bar{k}(\mathbf{v}) = \arg\max_{k\in\{1,2\}} \left|h_{d,k} + \boldsymbol{h}_{r,k}^{H}\boldsymbol{\Omega}\left(\boldsymbol{\Psi}_t, \boldsymbol{\Psi}_{r,k}, \mathbf{v}\right)\boldsymbol{h}_t\right|^2. \quad (15)$$

In order to guarantee the successful implementation of SIC in user $\bar{k}$, the achievable rate in user $\bar{k}$ to decode the signal of another user $\left(k \in \{1,2\}, k \neq \bar{k}\right)$, $R_{k\neq\bar{k}\to\bar{k}}$, must not be less than the achievable rate at user k to decode its own signal, $R_{k\neq\bar{k}\to k\neq\bar{k}}$ [9, 11].

$$R_{k\neq\bar{k}\to\bar{k}} \geq R_{k\neq\bar{k}\to k\neq\bar{k}}, \quad (16)$$

where $R_{k\neq\bar{k}\to\bar{k}}$ and $R_{k\neq\bar{k}\to k\neq\bar{k}}$ are expressed as

$$R_{k\neq\bar{k}\to\bar{k}}(\mathbf{v}) = W\, log_2\left(1 + \frac{p_{k\neq\bar{k}}\left|h_{d,\bar{k}} + h_{e2e,\bar{k}}\right|^2}{p_{\bar{k}}\left|h_{d,\bar{k}} + h_{e2e,\bar{k}}\right|^2 + \sigma^2}\right) \quad (17)$$

$$R_{k\neq\bar{k}\to k\neq\bar{k}}(\mathbf{v}) = W\, log_2\left(1 + \frac{p_{k\neq\bar{k}}\left|h_{d,k\neq\bar{k}} + h_{e2e,k\neq\bar{k}}\right|^2}{p_{\bar{k}}\left|h_{d,k\neq\bar{k}} + h_{e2e,k\neq\bar{k}}\right|^2 + \sigma^2}\right) \quad (18)$$

where $h_{e2e,k} = \boldsymbol{h}_{r,k}^{H}\boldsymbol{\Omega}\left(\boldsymbol{\Psi}_t, \boldsymbol{\Psi}_{r,k}, \mathbf{v}\right)\boldsymbol{h}_t$ represents the end-to-end channel via IRS for the k-th user. Thus, the sum rate of two users can be expressed as

$$R_{sum}(\mathbf{v}) = \sum_{k=1}^{2} R_{k\to k}(\mathbf{v}). \quad (19)$$

Since the user $\bar{k}$ to decode its own signal, first decodes the signal of the other user and removes it from its observation signal, $R_{\bar{k}\to\bar{k}}$ is expressed as

$$R_{\bar{k}\to\bar{k}}(\mathbf{v}) = W \log_2\left(1 + \frac{p_{\bar{k}}\left|h_{d,\bar{k}} + h_{e2e,\bar{k}}\right|^2}{\sigma^2}\right). \quad (20)$$

In addition, fractional transmit power allocation (FTPA) is used as the power allocation technique. Based on the FTPA scheme, the allocated power to each user depends on the channel gains of all users and is given as

$$p_k = P_T \frac{(|h_k|^2/\sigma_k^2)^{-\delta}}{\sum_{j=1}^{K}\left(\left|h_j\right|^2/\sigma_j^2\right)^{-\delta}}, \qquad k = 1, \dots, K \quad (21)$$

where h_k denotes the channel gain of the k-th user and σ_k^2 the noise power at the receiver of the k-th user. Moreover, $0 \leq \delta \leq 1$ is the decay coefficient, which the case of $\delta = 0$ indicates equal power allocation to all users, and as δ increases, more power is allocated to the weaker user (in terms of channel conditions) [16]. In this paper, $\delta = 1$ is considered and also due to the creation of an additional path by the IRS, the channel gain of each user is defined as the sum of the gains of the direct channel and IRS cascaded channel. On the other hand, since the noise power of the receiver is the same for all users and is equal to σ^2, the power allocated to the k-th user is expressed as

$$p_k = P_T \frac{\left|h_{d,k} + h_{e2e,k}\right|^{-2}}{\sum_{j=1}^{K}\left|h_{d,j} + h_{e2e,j}\right|^{-2}}. \quad (22)$$

Therefore, the corresponding optimization problem is formulated as

$$\max_{\{\beta_q\}_{q=1}^{Q}} \quad R_{sum}(\mathbf{v}) \quad (23)$$

$$s.t. \quad R_{k\neq\bar{k}\to\bar{k}} \geq R_{k\neq\bar{k}\to k\neq\bar{k}} \quad (24)$$

$$v_q = \tau_q\left(\beta_q\right)e^{j\beta_q}, q = 1, \dots, Q \quad (25)$$

$$\beta_q = \beta_{q+Q_x} = \cdots = \beta_{q+(Q_y-1)Q_x}, \mathrm{q} = 1, \dots, Q_x \quad (26)$$

$$\beta_q \in B, q = 1, \dots, Q, \quad (27)$$

which is a non-convex problem. Therefore, the genetic algorithm is used for suboptimal solving the problem. Furthermore, in order to evaluate the performance of the genetic algorithm, the problem is solved by exhaustive search method as well. The optimization variable and the fitness function in the genetic algorithm are defined similarly to the single-user case.

IV. Simulation Results

Downlink communication from a BS composed of a directional antenna to K single-antenna users is considered, which is improved by a practical IRS. It is assumed that the BS antenna is directed towards the IRS and the users' antenna is omnidirectional. Moreover, the NOMA scheme is adopted as a multiple access technique. The channel gain for each effective path as $h_i = \sqrt{\bar{h}_i\hat{h}_i}\tilde{h}_i, i \in \{t, r, d\}$ depends on the path loss related to the distance $\bar{h}_i$, large-scale shadowing $\hat{h}_i$, and the small-scale fading $\tilde{h}_i$, where the BS-IRS, IRS-user, and BS-user paths are represented by t, r, and d subscripts, respectively. The propagation environment is considered as

TABLE I. VALUES OF SYSTEM PARAMETERS.

parameter	value	parameter	value	parameter	value
f_c	$30\, GHz$	W	$20\, MHz$	ζ	0.43π
d_x	$\lambda/2$	N_0	$-174\, dBm/Hz$	$(\hat{h}_d, \hat{h}_t, \hat{h}_r)$	$(-80, 0, 0)\, dB$
d_y	$\lambda/2$	N_F	$6\, dB$	ρ_t	$1.5 \times 10^3\lambda$
L_{uc}	$0.8d_x$	P_T	$5\, W$	ρ_r	$(0.5, 0.8) \times 10^3\lambda$
Q_y	12	τ_{min}	0.2	θ_t	$\pi/6$
B	$\{0, \pi\}$	α	1.6	θ_r	$(\pi/4, \pi/3)$

free space, and as a result, the path loss is modeled as $\bar{h}_i = \left(\frac{\lambda}{4\pi\rho_i}\right)^2$, where ρ_i denotes the distance. The direct link between BS and users is heavily (strongly) shadowed, while links from BS to IRS and IRS to users are LoS. In addition, Rayleigh fading is considered for all channels, i.e., $\tilde{h}_i \sim \mathcal{CN}(0,1)$. The noise power at the receivers is modeled as $\sigma^2 = WN_0N_F$, where N_F and N_0 denote the noise figure and the power spectral density of the noise, respectively [5]. The values used for system parameters are presented in TABLE I.

A. *Single-user case*

In this case, it is assumed that the user is at a distance of $0.5 \times 1000\lambda$ from the IRS and at an elevation angle of $\theta_r = \pi/4$. By varying the number of IRS columns, Q_x, the maximum achievable rate is obtained by the three proposed methods. In Fig. 2, the maximum achievable rate for different values of Q_x is shown for each of the proposed methods.

From Fig. 2, it is observed that as the number of IRS columns increases, the achievable rate increases. Moreover, the curves of the proposed methods almost match each other, while for large IRSs, the time to solve the problem using the genetic algorithm is almost half the time required in the exhaustive search method, and the phase aligning algorithm achieves the solution 10 thousand times faster than the genetic algorithm.

B. *Two-user case*

Similar to the single-user case, Fig. 3 shows the maximum sum rate of users for different Q_x using both exhaustive search and genetic algorithm methods. User 1 and 2 are placed at a distance of 0.5×1000λ and 0.8×1000λ from the IRS and angles of π/4 and π/3, respectively.

Fig. 3 shows the improvement of the sum rate of users with the increase of Q_x. On the contrary, by increasing the number of IRS columns, the problem-solving time increases and the exhaustive search method becomes inefficient. But the genetic

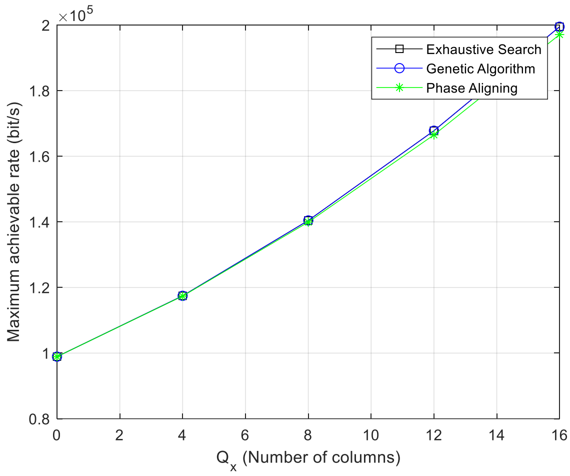

Fig. 2. Maximum achievable rate versus the number of IRS columns ($Q_x = 0$ shows the case without IRS).

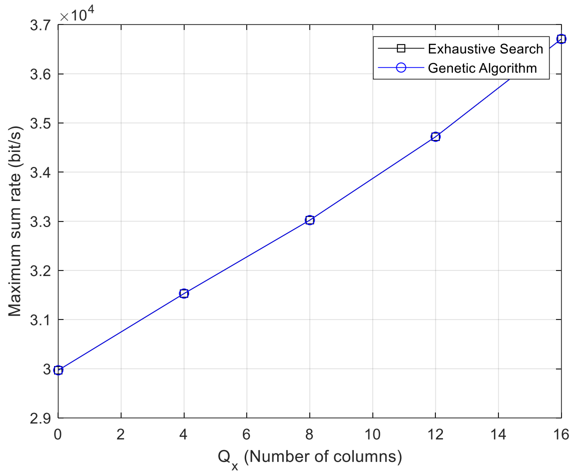

Fig. 3. Maximum sum rate versus the number of IRS columns ($Q_x = 0$ shows the case without IRS).

algorithm can solve the problem in about half the required time in the exhaustive search method, while, the curves of these two methods have a slight difference with each other. Thus, the genetic algorithm is an efficient method to solve the problem for large IRSs.

V. Conclusion

In this paper, an IRS-assisted downlink NOMA system was considered, where a practical IRS was deployed to assist communication from a single-antenna BS to multiple single-antenna users. The aim of this paper is to optimize the IRS phase shift configuration in terms of the sum rate. The corresponding optimization problem was non-convex and to solve it, two exhaustive search and genetic algorithm methods have been presented. Moreover, the phase aligning algorithm was also proposed in single-user case for suboptimal solving the problem. The simulation results showed the time-consuming and ineffectiveness of the exhaustive search method for large IRSs, while the proposed suboptimal algorithms are able to provide similar performance in less time. In the future works, the performance of the system for the larger IRSs and more number of phase shift levels can be investigated.

References

[1] C. Liaskos, S. Nie, A. Tsioliaridou, A. Pitsillides, S. Ioannidis, and I. Akyildiz, "A new wireless communication paradigm through software-controlled metasurfaces," *IEEE Communications Magazine*, vol. 56, no. 9, pp. 162-169, 2018.

[2] W. Long, R. Chen, M. Moretti, W. Zhang, and J. Li, "A promising technology for 6G wireless networks: Intelligent reflecting surface," *Journal of Communications and Information Networks*, vol. 6, no. 1, pp. 1-16, 2021.

[3] 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, 2021.

[4] S. Abeywickrama, R. Zhang, Q. Wu, and C. Yuen, "Intelligent reflecting surface: Practical phase shift model and beamforming optimization," *IEEE Transactions on Communications*, vol. 68, no. 9, pp. 5849-5863, 2020.

[5] M. Najafi, V. Jamali, R. Schober, and H. V. Poor, "Physics-based modeling and scalable optimization of large intelligent reflecting surfaces," *IEEE Transactions on Communications,* vol. 69, no. 4, pp. 2673-2691, 2020.

[6] Z. Salman-Taheri and M. Majidi, "Analytical solution of 3D beamforming problem in wireless communication networks using intelligent reflecting surfaces," in *5'th Conference on Electrical and Computer Engineering Technology (ETECH 2020)*, Tehran, October 2020.

[7] Y. Liu *et al.*, "Reconfigurable intelligent surfaces: Principles and opportunities," *IEEE Communications Surveys & Tutorials,* vol. 23, no. 3, pp. 1546-1577, 2021.

[8] Z. Ding, X. Lei, G. K. Karagiannidis, R. Schober, J. Yuan, and V. K. Bhargava, "A survey on non-orthogonal multiple access for 5G networks: Research challenges and future trends," *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 10, pp. 2181-2195, 2017.

[9] 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, 2020.

[10] 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, 2020.

[11] X. Mu, Y. Liu, L. Guo, J. Lin, and N. Al-Dhahir, "Exploiting intelligent reflecting surfaces in NOMA networks: Joint beamforming optimization," *IEEE Transactions on Wireless Communications,* vol. 19, no. 10, pp. 6884-6898, 2020.

[12] Z. Ding, R. Schober, and H. V. Poor, "On the impact of phase shifting designs on IRS-NOMA," *IEEE wireless communications letters,* vol. 9, no. 10, pp. 1596-1600, 2020.

[13] X. Xie, F. Fang, and Z. Ding, "Joint optimization of beamforming, phase-shifting and power allocation in a multi-cluster IRS-NOMA network," *IEEE Transactions on Vehicular Technology,* vol. 70, no. 8, pp. 7705-7717, 2021.

[14] E. Björnson, "Optimizing a binary intelligent reflecting surface for OFDM communications under mutual coupling," in *WSA 2021; 25th International ITG Workshop on Smart Antennas*, 2021: VDE, pp. 1-6.

[15] Ö. Özdoğan and E. Björnson, "Deep learning-based phase reconfiguration for intelligent reflecting surfaces," in *2020 54th Asilomar Conference on Signals, Systems, and Computers*, 2020: IEEE, pp. 707-711.

[16] F. Fang, H. Zhang, J. Cheng, and V. C. Leung, "Energy-efficient resource allocation for downlink non-orthogonal multiple access network," *IEEE Transactions on Communications,* vol. 64, no. 9, pp. 3722-3732, 2016.