



Article

Joint Element and Power Optimization in NOMA-RIS-Assisted Indoor Near-Field Communications

Periyakarupan Gurusamy Sivabalan Velmurugan ^{1,*}, Vinoth Babu Kumaravelu ^{2,*}, Samikkannu Rajkumar ³, Arthi Murugadass ⁴, Mathan Nanjan Suresh ¹ and Samarendra Nath Sur ⁵

¹ Department of Electronics and Communication Engineering, Thiagarajar College of Engineering, Madurai 625015, Tamil Nadu, India; mnsece@tce.edu

² School of Electronics Engineering, Vellore Institute of Technology, Vellore 632014, Tamil Nadu, India

³ Department of Electronics and Communication Engineering, Chennai Institute of Technology, Chennai 600069, Tamil Nadu, India; rajkumars.ece@citchennai.net

⁴ School of Computer Science and Engineering, Vellore Institute of Technology, Vellore 632014, Tamil Nadu, India; arthi.m@vit.ac.in

⁵ Department of Computer Science and Engineering, Sikkim Manipal Institute of Technology, Sikkim Manipal University, Majitar 737136, Sikkim, India; samarendra.s@smit.smu.edu.in

* Correspondence: pgsvels@tce.edu (P.G.S.V.); vinothbabu.k@vit.ac.in (V.B.K.)

Abstract

Reconfigurable intelligent surfaces (RIS) equipped with extremely large aperture arrays (ELAA) are emerging as a key technology for enhancing beamforming gain, spatial multiplexing, and angular resolution in sixth-generation (6G) wireless networks. When combined with non-orthogonal multiple access (NOMA), RIS can further improve spectral efficiency, system throughput, and energy efficiency. However, most existing studies on RIS-aided NOMA assume far-field propagation, where the incident wavefronts are approximately planar. In contrast, RIS-ELAA systems operating at millimeter wave (mmWave) experience spherical wavefronts in the radiative near-field regions. Also, it creates spatial non-stationarity and distance-dependent phase curvature. These effects invalidate the conventional monotonic path-loss assumption and make fairness-oriented NOMA design more challenging. This paper proposes a joint element and power optimization (JEPO) algorithm for near-field RIS-ELAA-assisted indoor NOMA systems, in which the RIS is dynamically partitioned into user-specific subarrays performing near-field phase synthesis toward the near user (NU) and far user (FU). The reversed far-to-near successive interference cancellation (SIC) ordering, governed by an effective FU channel gain greater than an effective NU channel gain, is formally established, and a closed-form optimal power allocation is derived by reducing the max-min fairness condition to a scalar quadratic in the target signal-to-interference-plus-noise ratio (SINR), eliminating iterative power search. Simulation results confirm that JEPO consistently outperforms four baseline schemes across transmit power, NU distance, angular separation, and RIS aperture size, with the largest gain observed at $\theta_{\text{NU}} \approx 40^\circ$ where fixed-partition baselines collapse to near-zero fairness while JEPO maintains robust performance.

Keywords: non-orthogonal multiple access; reconfigurable intelligent surface; near-field communication; joint element and power optimization



Academic Editors: Evangelia Filiopoulou, Mara Nikolaidou, Teta Stamati, Cleopatra Bardaki, Georgia Dede, Alexandra Gasparinatu and Elena Politi

Received: 18 June 2026

Revised: 12 July 2026

Accepted: 14 July 2026

Published: 16 July 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\) license](https://creativecommons.org/licenses/by/4.0/).

1. Introduction

With the transition to sixth-generation (6G) networks, the deployment of extremely large aperture array (ELAA) antennas is expected to introduce a major paradigm shift in

near-field communication (NFC) [1]. The fundamental distinction between the far-field and near-field regions is the wavefront structure; a planar wavefront dominates in the far-field, whereas a spherical wavefront dominates in the near-field. Hence, the propagating wave in the near-field exhibits two benefits, such as (i) high-rank line-of-sight (LoS) channels, which may even provide full rank to improve spatial multiplexing gain and (ii) beam focusing, which makes the energy of the wireless channels centralize on the specific location that depends on the given angle and distance parameters [2].

RIS is gaining attention as an effective solution for creating programmable wireless environments in 6G networks. It offers a cost-efficient and energy-saving approach by eliminating the need for complex active radio-frequency chains. Using an array of affordable passive scattering elements, RIS can alter the phase, amplitude, or polarization of incoming electromagnetic waves. This converts the normally unpredictable and challenging wireless channel into a controllable, software-based propagation medium. As a result, the network can bypass non-line-of-sight (NLoS) blockages, reduce co-channel interference, and establish high-quality virtual links. In the radiative near-field (Fresnel) region, the effectiveness of an RIS increases exponentially because spherical wavefront propagation occurs [3].

Non-orthogonal multiple access (NOMA) has emerged as an important multiple access technique for modern wireless systems because of its ability to significantly enhance spectral efficiency compared with orthogonal access methods and massive connectivity. The fundamental operation of NOMA involves superposition coding at the transmitter and successive interference cancellation (SIC) at the receiver, enabling the users to mitigate interference and decode their intended signals. The novel concept of near-field NOMA is proposed, where the unique near-field beam focusing enables NOMA to be carried out in both angular and distance domains in contrast to far-field NOMA. Users in the same angular direction can be further separated in the distance domain through spherical wavefront focusing [4]. This spherical wavefront propagation creates highly localized beam-focusing advantages, which can flip the usual channel strength relationships, allowing a far user (FU) to achieve a stronger effective channel gain than the near user (NU). As a result, near-field NOMA uses a reversed order for SIC, employing multi-focal control to ensure fair user data rates and improve spectral efficiency across shared spatial channels. Recent research has also extended near-field signal processing to emerging applications such as vehicle localization using vehicle-to-everything (V2X) sidelink communications and joint localization and sensing with large-aperture arrays, highlighting the increasing importance of accurate near-field propagation modeling and spatial signal processing in future 6G systems [5,6]. However, these studies primarily focus on localization and sensing performance rather than fairness-oriented resource optimization in RIS-assisted near-field NOMA systems. The joint optimization of RIS and NOMA has become an important area of research for managing interference and leveraging spatial non-stationarity in near-field 6G systems.

Organization

The remainder of this paper is organized as follows: Section 2 reviews the literature on near-field communications, RIS hardware, and NOMA resource allocation. Section 3 describes our indoor system model and confirms the near-field channel boundaries using the Fresnel approximation. Section 4 explains our max-min fairness problem and introduces the JEPO algorithm, including the greedy element-flipping strategy and the closed-form power allocation. Section 5 presents MATLAB simulation results comparing JEPO with baseline methods. Finally, Section 6 concludes the paper and suggests directions for future work.

2. Related Works

In this section, the existing works on near-field channel modeling, sensing, and optimization, RIS structural and hardware elements optimization, RIS-assisted NOMA and resource allocation matrix, and dynamic subarray partitioning and spatial optimization are comprehensively discussed and summarized.

2.1. Near-Field Channel Modeling, Sensing, and Optimization

In NFC, the channel modeling is a challenging one. The authors of [7] recently carried out the channel estimation of NFC using the bi-linear pattern detection technique under extremely large-scale multiple input multiple output MIMO (XL-MIMO) systems. Further, the problem of optimal beam focusing in the near-field becomes nonconvex, and it is addressed using the semi-definite relaxation (SDR) method in [8]. In a near-field environment, ELAA exploits multiple tasks, such as sensing an unknown target using radar and for the users' communication. By incorporating dynamic metasurface antennas (DMAs) in the near-field environment, it will improve the wireless power transfer (WPT) in the Fresnel region, hence supporting the charging of multiple devices [9]. In emergency scenarios such as natural disasters and in flooded areas, establishing communications becomes a challenging task; in such scenarios, a dynamic actor-critic model is used to ensure fairness among the users as proposed in [10].

2.2. RIS Structural and Hardware Elements Optimization

Instead of considering all the elements of RIS, choosing the optimum number of elements can improve the system rate and energy efficiency, as demonstrated in [11]. Furthermore, holography-based RIS indeed increases beamforming gain, sharpens the main lobe, and improves focusing gain, especially in the near field, which is explored in [12].

2.3. RIS-Assisted NOMA and Resource Allocation Matrix

Optimum power allocation among the NOMA users and eavesdroppers is performed in a near-field environment using imperfect resolution and beam focusing in [13]. Further, the channel quality in the NFC can be improved by estimating the quantized channel gain using a bit allocation scheme as detailed in [14]. Moreover, using the RIS in a NOMA scheme, the accuracy of channel state information (CSI) can be improved through the bit-allocation scheme in the feedback mechanism, also supported by [14]. Hybrid RIS systems, as evaluated in [15], consist of both active and passive RIS elements that further enhance the system rate and reliability while deploying the NOMA scheme with optimal power allocation.

2.4. Dynamic Subarray Partitioning and Spatial Optimization

Recent studies in intelligent vehicular networks show that RIS-assisted NOMA can significantly enhance vehicle-to-infrastructure (V2I) reliability by overcoming dead zones and harsh urban propagation conditions. In particular, blind RIS-based fixed NOMA schemes in [16] have demonstrated superior outage and throughput performance due to the large passive array gain, even without perfect channel knowledge. An alternative approach to the dynamic RIS element partitioning problem is to employ learning-based optimization techniques, such as the deep reinforcement learning (DRL) framework proposed in [17]. DRL-based methods can effectively adapt to dynamic wireless environments by learning RIS control policies through repeated interactions with the environment. However, these methods generally require an offline training phase, a large number of training samples, and periodic retraining when the propagation environment or network configuration

changes. In contrast, the proposed JEPO algorithm is a deterministic optimization framework that directly combines greedy RIS element assignment with the closed-form power allocation derived in Proposition 1. Consequently, JEPO does not require offline training, labeled datasets, or model updates, making it computationally efficient and readily deployable for practical near-field RIS-assisted NOMA systems. While DRL offers adaptability for highly dynamic scenarios, the proposed JEPO algorithm provides a low-complexity, training-free solution with predictable convergence and consistent performance for the considered static and quasi-static indoor environments.

2.5. Motivation and Challenges

Most of the existing RIS-NOMA research works rely on the far-field assumption, where the wavefront impinging on the RIS is approximated as planar. Under this assumption, user channels decay monotonically with distance, enabling simple power-domain NOMA with clear near-user (NU)/far-user (FU) ordering. However, in many practical scenarios, such as indoor hot spots operating in millimeter wave (mmWave) and sub-THz communications, the transmitter and receiver are located within the Fresnel region of the RIS. In such a near-field scenario, the impinging wavefront becomes spherical, and the received gain varies non-monotonically with distance. Consequently, a user positioned far from the RIS may experience a stronger channel if it lies near the focal point. This fundamentally alters the conventional NOMA user ordering and necessitates new resource-allocation strategies and power allocation for user fairness in near-field environments. In particular, the joint optimization of dynamic RIS element partitioning and NOMA power allocation for max-min fairness in indoor near-field communications remains largely unexplored.

To bridge this gap, this paper proposes a JEPO framework for RIS-assisted near-field NOMA systems. Unlike existing near-field studies that primarily focus on channel modeling, localization, sensing, or beamforming [5,6], the proposed JEPO algorithm jointly optimizes dynamic RIS subarray partitioning and closed-form NOMA power allocation using a low-complexity greedy optimization framework. By effectively exploiting the spatial non-stationarity of near-field propagation, the proposed method achieves improved max-min fairness without requiring iterative convex optimization or data-driven learning.

2.6. Contributions

The main contributions of this work on near-field RIS-assisted NOMA systems are summarized as follows.

- **Near-field RIS-assisted NOMA framework:** A near-field ELAA-RIS-assisted NOMA transmission framework is developed for indoor mmWave communications operating at $f_c = 28$ GHz. Based on the second-order Fresnel approximation, the proposed cascaded channel model explicitly captures spherical-wave propagation and distance-dependent phase curvature. Furthermore, the operating region is validated using the uniform-power distance (d_{UP}) and Rayleigh distance (d_R), confirming that all users operate within the radiative near-field regime.
- **Near-field SIC ordering and fairness optimization:** Unlike conventional far-field NOMA systems, user ordering is governed by near-field beam-focusing gains rather than propagation distance alone. Accordingly, a near-field transmission framework employing far-to-near SIC decoding is established, and the corresponding max-min fairness optimization problem is formulated by jointly optimizing the binary RIS element assignment and NOMA power allocation.
- **Joint Element and Power Optimization (JEPO):** A low-complexity Joint Element and Power Optimization (JEPO) algorithm is proposed to solve the resulting mixed-integer non-convex optimization problem. The algorithm combines greedy RIS element

flipping with a closed-form power allocation obtained by transforming the fairness condition into a quadratic equation in the target SINR, thereby avoiding iterative convex optimization and data-driven training.

- Theoretical analysis: The computational complexity and convergence properties of the proposed JEPO algorithm are analyzed. A finite-convergence proof is established based on the monotonic improvement of the fairness objective over a finite feasible RIS partition space. Furthermore, the computational complexity is shown to be approximately $\mathcal{O}(K.M)$ using incremental channel updates, making the proposed algorithm computationally attractive for practical ELAA-RIS deployments.
- Performance evaluation and practical validation: The proposed JEPO framework is extensively evaluated against four representative benchmark schemes: (i) all RIS elements assigned to the FU with equal power allocation [18], (ii) equal RIS partition with equal power allocation [19], (iii) equal RIS partition with optimal power allocation [20], and (iv) orthogonal multiple access (OMA) [21]. Numerical results investigate the effects of transmit power, user distance, angular separation, and RIS aperture size on user fairness. In addition, an exhaustive-search benchmark for a 4×4 RIS demonstrates the near-optimal performance of JEPO, while Monte Carlo simulations over random indoor geometries confirm the robustness of the proposed algorithm under diverse deployment scenarios. Finally, the practical impact of finite-resolution RIS phase quantization is discussed to bridge the gap between the ideal continuous-phase assumption and practical hardware implementations.

3. System Model

Table 1 lists the symbols and notations used throughout the proposed near-field RIS-assisted NOMA system. An indoor downlink NOMA scenario is considered in which the AP is mounted on the wall, and a 2D uniform rectangular array (URA) RIS-ELAA comprises $M = M_x \times M_z$ passive reflectors deployed to serve two single-antenna users, namely a NU and a FU whose direct LoS links to the AP are obstructed by an indoor partition, making the RIS a sole communication pathway. The NU is positioned at distance $d_{\text{NU}} = 2$ m at azimuth angle $\theta_{\text{NU}} = 45^\circ$ off-boresight, while the FU is located at $d_{\text{FU}} = 8$ m along the boresight direction $\theta_{\text{FU}} = 0^\circ$ of the RIS aperture. The overall system configuration is illustrated in Figure 1. Since the system operates in the mmWave band with RIS-ELAA, both the AP-to-RIS and RIS-to-user links fall within the radiative near-field region, where spherical wavefronts are dominant. The near-field operating regime is validated by confirming that both users lie between the uniform-power distance $d_{\text{UP}} \approx 0.27$ m and the Rayleigh distance $d_{\text{R}} \approx 54$ m of the 32×32 RIS at $f_c = 28$ GHz, establishing the uniform spherical wave (USW) model as the appropriate channel representation throughout. Within this regime, the RIS exhibits beam-focusing capability, the ability to concentrate energy toward a specific (angle, distance) location. Unlike the far-field, where both users sharing the same angular direction would be indistinguishable and could not be spatially separated by conventional beamforming, the near-field spherical wavefront structure allows the RIS to independently focus energy toward each user's distinct spatial position. The coordinates of the ELAA-RIS are given by [22].

Table 1. List of Symbols and Notations used in the Proposed Near-Field RIS-assisted NOMA System.

Notation/Variable	Description
M	Total number of passive reflecting RIS elements ($M = M_x \times M_z$).
M_x, M_z	Number of RIS elements along the horizontal (x -axis) and vertical (z -axis) directions.
d_x, d_z	Element spacing along the horizontal and vertical directions of the URA.
λ	Carrier wavelength.

Table 1. Cont.

Notation/Variable	Description
f_c	Carrier frequency (28 GHz).
α	Path-loss exponent.
β_0	Channel power gain at the reference distance of 1 m.
r, θ, φ	Spherical coordinates representing distance, azimuth angle, and elevation angle.
r_{AR}	Distance between the access point (AP) and the RIS origin.
r_u	Distance between the RIS and user u , where $u \in \{NU, FU\}$.
$\theta_{AR}, \varphi_{AR}$	Azimuth and elevation angles from the AP to the RIS.
θ_u, φ_u	Azimuth and elevation angles from the RIS to user u .
$\mathbf{P}_r(m_x, m_z)$	Cartesian coordinates of the (m_x, m_z) th RIS element.
ψ_{m_x, m_z}	Near-field phase response of the (m_x, m_z) th RIS element.
$\mathbf{a}^{NF}(r, \theta, \varphi)$	Two-dimensional near-field array response vector.
$\mathbf{a}_x^{NF}, \mathbf{a}_z^{NF}$	One-dimensional near-field array response vectors along the x - and z -axes.
β_{AR}	Large-scale fading coefficient of the AP-to-RIS link.
β_{RU}	Large-scale fading coefficient of the RIS-to-user link.
$\mathbf{g}$	Near-field channel vector between the AP and the RIS.
$\mathbf{h}_u$	Near-field channel vector between the RIS and user u .
$\mathbf{v}$	RIS phase-shift vector, $\mathbf{v} = [e^{j\phi_1}, \dots, e^{j\phi_M}]^T$.
Θ	Diagonal RIS phase-shift matrix, $\Theta = \text{diag}(\mathbf{v})$.
h_{eff}^u	Effective cascaded near-field channel gain of user u .
P_{max}	Total available transmit power budget at the AP.
$P_{\text{NU}}, P_{\text{FU}}$	Transmit powers allocated to the NU and FU, respectively.
$\sigma_{\text{NU}}^2, \sigma_{\text{FU}}^2$	Noise power variances at the NU and FU receivers.
$C_{\text{NU}}, C_{\text{FU}}$	Achievable capacities (bps/Hz) of the NU and FU, respectively.
$s_{m,u}$	Binary RIS element assignment variable indicating whether element m is assigned to user u .
ϕ_m	Optimized phase shift applied at the m th RIS element.
C^*	Target balanced user rate under max-min fairness criterion ($C^* = C_{\text{NU}} = C_{\text{FU}}$).
γ^*	Optimal SINR threshold corresponding to C^* , where $\gamma^* = 2^{C^*} - 1$.
A, B, D	Intermediate coefficients used in the quadratic power-allocation equation.
K	Number of outer greedy element-flipping iterations required for convergence.

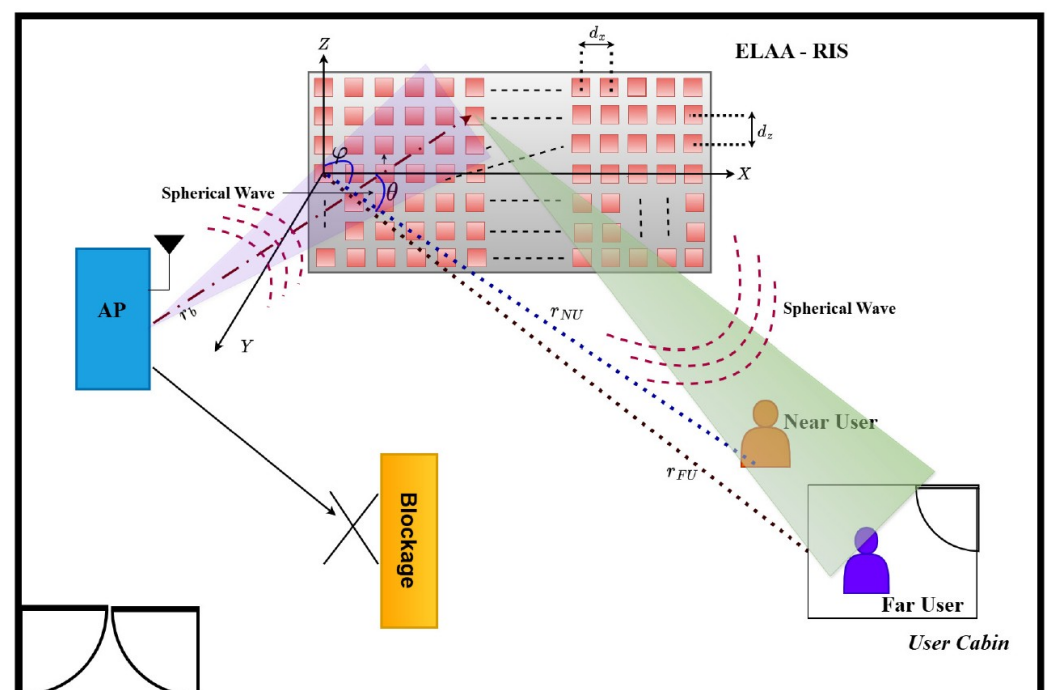


Figure 1. Proposed RIS-assisted NOMA networks for indoor communications.

$$\mathbf{P}_r(m_x, m_z) = ((m_x - 1)d_x, 0, (m_z - 1)d_z) \quad (1)$$

Any point in the space can be described in spherical form by distance r , azimuth angle θ , and elevation angle φ given by

$$\mathbf{P}(r, \theta, \varphi) = (r \cos \theta \sin \varphi, r \sin \theta \sin \varphi, r \cos \varphi) \quad (2)$$

The spherical distance from RIS element (m_x, m_z) to a point (r, θ, φ) is given by

$$r_{m_x, m_z}(r, \theta, \varphi) = \|\mathbf{P}(r, \theta, \varphi) - \mathbf{P}_r(m_x, m_z)\| \quad (3)$$

Substituting the spherical coordinate representation in (2) into the Cartesian distance expression in (1) and expanding the Euclidean norm, the squared distance between the user and the (m_x, m_z) th RIS element is obtained as [21]

$$r_{m_x, m_z}^2 = (r \cos \theta \sin \varphi - (m_x - 1)d_x)^2 + (r \sin \theta \sin \varphi)^2 + (r \cos \varphi - (m_z - 1)d_z)^2 \quad (4)$$

Under the second-order Fresnel approximation, the distance from the origin of the r_{m_x, m_z} th RIS element to any point in space can be expanded as linear and quadratic terms corresponding to x-axis as $Q_x = \frac{(m_x - 1)^2 d_x^2 (1 - \cos^2 \theta \sin^2 \varphi)}{2r}$, and z-axis as $Q_z = \frac{(m_z - 1)^2 d_z^2 \sin^2 \varphi}{2r}$ around the reference distance r as follows:

$$r_{m_x, m_z} \approx r - (m_x - 1)d_x \cos \theta \sin \varphi - (m_z - 1)d_z \cos \varphi + Q_x + Q_z \quad (5)$$

To obtain a separable URA response (Kronecker structure), the mixed xz term in the second-order Fresnel expansion is neglected. The phase term for r_{m_x, m_z} is given by

$$\psi_{m_x, m_z}(r, \theta, \varphi) = -\frac{2\pi}{\lambda} r_{m_x, m_z}(r, \theta, \varphi) \quad (6)$$

The near-field array response in the RIS at a point (r, θ, φ) , can be written as a Kronecker product [21]. Under the second-order Fresnel approximation and by neglecting the mixed xz in the distance expansion, the near-field phase response of the planar RIS becomes separable along the horizontal and vertical axes. Consequently, the two-dimensional URA response can be expressed as the Kronecker product of the corresponding one-dimensional array responses [21].

$$\mathbf{a}^{\text{NF}}(r, \theta, \varphi) = \mathbf{a}_x^{\text{NF}}(r, \theta, \varphi) \otimes \mathbf{a}_z^{\text{NF}}(r, \varphi) \quad (7)$$

For the near-field system model shown in Figure 1, the distance between AP and RIS is denoted by r_{AR} and the distance between RIS and NU/FU is denoted by r_u , where $u \in (\text{NU}, \text{FU})$. The spherical geometry and Fresnel expansion for the near-field array response between AP and RIS are given by

$$\mathbf{a}_{AR}^{\text{NF}}(r_{AR}, \theta_{AR}, \varphi_{AR}) = \mathbf{a}_x^{\text{NF}}(r_{AR}, \theta_{AR}, \varphi_{AR}) \otimes \mathbf{a}_z^{\text{NF}}(r_{AR}, \varphi_{AR}) \quad (8)$$

The term $\mathbf{a}_x^{\text{NF}}(r_{AR}, \theta_{AR}, \varphi_{AR})$ in (8), which is defined by

$$\mathbf{a}_x^{\text{NF}}(r_{AR}, \theta_{AR}, \varphi_{AR}) = \exp \left(-j \frac{2\pi}{\lambda} \left(-(m_x - 1)d_x \cos \theta_{AR} \sin \varphi_{AR} + \frac{(m_x - 1)^2 d_x^2 (1 - \cos^2 \theta_{AR} \sin^2 \varphi_{AR})}{2r_{AR}} \right) \right) \quad (9)$$

Similarly, $\mathbf{a}_z^{\text{NF}}(r_{AR}, \varphi_{AR})$ is defined by

$$\mathbf{a}_z^{\text{NF}}(r_{AR}, \varphi_{AR}) = \exp \left(-j \frac{2\pi}{\lambda} \left(-(m_z - 1)d_z \cos \varphi_{AR} + \frac{(m_z - 1)^2 d_z^2 \sin^2 \varphi_{AR}}{2r_{AR}} \right) \right) \quad (10)$$

Now, the near-field channel vector $\mathbf{g} \in \mathbb{C}^{M \times 1}$ between AP and RIS is given by

$$\mathbf{g} = \beta_{AR} e^{-j\frac{2\pi}{\lambda} r_{AR}} \mathbf{a}_{AR}^{\text{NF}}(r_{AR}, \theta_{AR}, \varphi_{AR}) \quad (11)$$

where $\beta_{AR} = \sqrt{\frac{\beta_0}{r_{AR}^\alpha}}$ is the large-scale fading coefficient between AP and RIS, β_0 is the channel power at the reference distance of 1 m and α is the path loss exponent. The spherical geometry and Fresnel expansion for the near-field array response between RIS and NU/FU are given by

$$\mathbf{a}_{RU}^{\text{NF}}(r_u, \theta_u, \varphi_u) = \mathbf{a}_x^{\text{NF}}(r_u, \theta_u, \varphi_u) \otimes \mathbf{a}_z^{\text{NF}}(r_u, \varphi_u) \quad (12)$$

The term $\mathbf{a}_x^{\text{NF}}(r_u, \theta_u, \varphi_u)$ in (12), which is defined by

$$\mathbf{a}_x^{\text{NF}}(r_u, \theta_u, \varphi_u) = \exp \left(-j\frac{2\pi}{\lambda} \left[-(m_x - 1)d_x \cos \theta_u \sin \varphi_u + \frac{(m_x - 1)^2 d_x^2 (1 - \cos^2 \theta_u \sin^2 \varphi_u)}{2r_u} \right] \right) \quad (13)$$

Similarly, $\mathbf{a}_z^{\text{NF}}(r_u, \varphi_u)$ is defined by

$$\mathbf{a}_z^{\text{NF}}(r_u, \varphi_u) = \exp \left(-j\frac{2\pi}{\lambda} \left[-(m_z - 1)d_z \cos \varphi_u + \frac{(m_z - 1)^2 d_z^2 \sin^2 \varphi_u}{2r_u} \right] \right) \quad (14)$$

Now, the near-field channel vector $\mathbf{h}_u \in \mathbb{C}^{1 \times M}$ between RIS and NU/FU is given by

$$\mathbf{h}_u = \beta_{RU} e^{-j\frac{2\pi}{\lambda} r_u} \mathbf{a}_{RU}^{\text{NF}}(r_u, \theta_u, \varphi_u) \quad (15)$$

where $\beta_{RU} = \sqrt{\frac{\beta_0}{r_u^\alpha}}$ is the large-scale fading coefficient between RIS and NU/FU. Let the RIS phase vector $\mathbf{v} = [e^{j\phi_1}, \dots, e^{j\phi_M}]^T$ and $\Theta = \text{diag}(\mathbf{v})$. The cascaded effective near-field channel for the AP-RIS-User is given by,

$$h_{eff}^u = \mathbf{h}_u^H \Theta \mathbf{g} \quad (16)$$

Achievable Rate for NOMA Users

In near-field NOMA, the channel strength is non-monotonic with respect to distance, and hence the SIC technique order is far-to-near. This reversal arises because the FU is located near the focal point of the RIS and experiences a stronger effective cascaded channel gain than the NU, i.e., $|h_{eff}^{\text{FU}}|^2 > |h_{eff}^{\text{NU}}|^2$ despite being positioned farther from the RIS [21]. Consequently, the FU first decodes the message intended for the NU, removes it via SIC, and then decodes its own data. Meanwhile, the NU directly detects its signal while treating the FU signal as interference. It is important to note that although the JEPO algorithm partitions the RIS elements into subarrays focused toward each user's location, this does not reduce the system to a space-division multiple access (SDMA) architecture. Unlike SDMA, where independent beams serve users on orthogonal spatial channels, the near-field RIS subarrays in JEPO focus energy toward spatially distinct locations within a shared propagation environment. Since both users receive superimposed signals from all RIS elements simultaneously, power-domain NOMA with SIC remains necessary to decode the intended signals, and the element partitioning acts as a beamforming complement rather than a replacement for NOMA. The achievable capacity of the NU in the near-field RIS-ELAA-assisted NOMA system is given by

$$C_{\text{NU}} = \log_2 \left(1 + \frac{|h_{eff}^{\text{NU}}|^2 P_{\text{NU}}}{|h_{eff}^{\text{NU}}|^2 P_{\text{FU}} + \sigma_{\text{NU}}^2} \right) \quad (17)$$

The capacity expression for the FU in the near-field RIS-ELAA-assisted NOMA is given by

$$C_{\text{FU}} = \log_2 \left(1 + \frac{|h_{\text{eff}}^{\text{FU}}|^2 P_{\text{FU}}}{\sigma_{\text{FU}}^2} \right) \quad (18)$$

where $P_u, u \in (\text{NU}, \text{FU})$ and $\sigma_u^2, u \in (\text{NU}, \text{FU})$ are the power allocated and noise power associated with u th user.

4. Problem Formulation and Proposed Solution

To improve the fairness among the users in the downlink transmission of near-field RIS-ELAA-assisted NOMA systems, it is necessary to jointly optimize both the RIS elements and the NOMA power allocation. Unlike conventional far-field NOMA models, the near-field environment introduces spherical wavefronts and spatially non-stationary channel characteristics, making the effective cascaded channel sensitive to the user position and element-level phase profiles. As a result, the fairness among the users can be improved, whereas the traditional fixed RIS element partition and power allocation fail to provide balanced performance of NU and FU. In this section, the JEPO algorithm is introduced and captures the coupling between dynamic RIS element allocation and NOMA power distribution, with the goal of maximizing user-rate fairness under practical system constraints.

Let $s_{m,u} \in \{0, 1\}$ denote the assignment of RIS element $m \in (1, \dots, M)$. Each element can serve one user at a time $s_{m,\text{NU}} + s_{m,\text{FU}} = 1$ and the phase information of the RIS takes the form: $\phi_m = \begin{cases} -\angle h_{\text{NU}}(m) - \angle g(m), & \text{if } s_{m,\text{NU}} = 1, \\ -\angle h_{\text{FU}}(m) - \angle g(m), & \text{if } s_{m,\text{FU}} = 1. \end{cases}$. The resulting JEPO for the near-field RIS-ELAA-assisted NOMA users is given by

$$\max_{s_{m,u}, \mathbf{v}, P_{\text{NU}}, P_{\text{FU}}} \min(C_{\text{NU}}, C_{\text{FU}}) \quad (19a)$$

$$\text{s.t. } s_{m,\text{NU}} + s_{m,\text{FU}} = 1, s_{m,u} \in \{0, 1\}, \forall m \quad (19b)$$

$$|v_m| = 1, \forall m \quad (19c)$$

$$P_{\text{NU}} + P_{\text{FU}} = P_{\text{max}} \quad (19d)$$

$$P_{\text{NU}} \geq 0, P_{\text{FU}} \geq 0 \quad (19e)$$

where P_{max} is the total power budget of AP. Equation (19c) corresponds to unit-modulus constraints on RIS phase shifts. Due to the binary assignment, nonlinear phase coupling, and coupled capacity expression, the JEPO algorithm is non-convex and NP-hard. This non-convex and NP-hard problem can be solved using a low-complexity heuristic algorithm known as the greedy element flipping method.

4.1. Greedy Element Assignment

A greedy element-flipping algorithm is employed to solve JEPO, achieving balanced user rates in the near-field RIS-ELAA-assisted NOMA systems. The algorithm begins by assigning all RIS elements to the FU to maximize its initial beamforming gain. Then, each RIS element is examined individually by tentatively flipping its assignment from the FU to the NU, after which the cascaded channels are recomputed, the NOMA power allocation is updated in closed form, and the resulting fairness metric is evaluated. If a flip leads to an improvement in fairness, it is accepted; otherwise, the previous assignment is retained. This element-by-element update continues iteratively until no further improvement in the fairness objective is achieved, yielding an efficient and low-complexity solution to the joint allocation problem. The overall procedure is summarized in Algorithm 1. The convergence

threshold $\varepsilon = 10^{-4}$ is adopted as the stopping criterion of the outer iterative optimization. Specifically, the JEPO algorithm terminates when the improvement in the fairness metric between two successive outer iterations becomes smaller than ε . In addition, a minimum subarray size $M_{min} = 4$ is enforced during the greedy element-flipping process, ensuring that each user is assigned at least four RIS elements. This constraint prevents degenerate RIS partitions in which one user receives too few reflecting elements for effective near-field beam focusing.

Algorithm 1 Joint Element and Power Optimization (JEPO)

Input: AP–RIS channel $\mathbf{g}$, RIS–user channels $\mathbf{h}_{\text{NU}}, \mathbf{h}_{\text{FU}}$, total power P_{max}

Initialize:

Assign all RIS elements to FU: $s_{m,\text{FU}} = 1, s_{m,\text{NU}} = 0, \forall m$

Compute initial phase shifts ϕ_m

Compute effective channels $h_{\text{eff}}^{\text{NU}}, h_{\text{eff}}^{\text{FU}}$

Compute initial power allocation $(P_{\text{NU}}, P_{\text{FU}})$

Compute initial fairness $F = \min(C_{\text{NU}}, C_{\text{FU}})$

repeat

for $m = 1$ to M **do**

 Flip the assignment of RIS element m : $s_{m,\text{NU}} \leftarrow 1, s_{m,\text{FU}} \leftarrow 0$

 Update RIS phase profile.

 Update effective channels $h_{\text{eff}}^{\text{NU}}, h_{\text{eff}}^{\text{FU}}$

 Update power allocation:

$$P_{\text{FU}}^* = \frac{\gamma^* \sigma_{\text{FU}}^2}{|h_{\text{eff}}^{\text{FU}}|^2}, \text{ and } P_{\text{NU}}^* = P_{\text{max}} - P_{\text{FU}}^*$$

 Compute fairness metric: $F_{\text{temp}} = \min(C_{\text{NU}}, C_{\text{FU}})$

if $F_{\text{temp}} > F + \epsilon$ **then**

 Accept element flip, Update $F \leftarrow F_{\text{temp}}$

else

 Revert element flip

end if

end for

until no improvement in fairness

Output: RIS element assignment $s_{m,u}$ and power allocation $(P_{\text{NU}}, P_{\text{FU}})$

4.2. Convergence Analysis

The proposed JEPO algorithm is guaranteed to converge in a finite number of iterations to a locally optimal RIS partition. Let $F^{(k)} = \min(C_{\text{NU}}^{(k)}, C_{\text{FU}}^{(k)})$ denote the fairness objective after the k -th outer iteration. A candidate RIS element flip is accepted only if it improves the fairness objective by at least the convergence threshold ϵ , i.e.,

$$F^{(k+1)} > F^{(k)} + \epsilon \quad (20)$$

Therefore, the objective value increases monotonically throughout the optimization process. Since each RIS element is assigned exclusively to either the NU or the FU, the RIS partition is represented by a binary assignment vector. Consequently, the feasible search space contains a finite number of admissible partitions. The algorithm terminates after a finite number of iterations when no admissible single-element flip satisfying the acceptance criterion exists. At this point, the obtained RIS partition is locally optimal with respect to the adopted greedy neighborhood search.

Proposition 1. Closed-Form NOMA Power Allocation

To maximize the minimum user rate in the near-field RIS-ELAA-assisted NOMA system, the NOMA power allocation between the NU and FU must be optimized jointly with the RIS element assignment. While the element assignment is handled by the greedy flipping strategy, the power allocation sub-problem admits an exact closed-form solution at each iteration, which avoids the need for iterative numerical solvers and keeps the overall algorithm computationally efficient. Specifically, the optimal power split is obtained by exploiting the structure of the max-min fairness objective: at the optimum, the two user rates must be equal, since any imbalance could be corrected by redistributing power toward the weaker user to improve the minimum rate. FU and NU power allocation can be obtained by fixing $C_{\text{NU}} = C_{\text{FU}} = C^*$, and by using the total power constraint $P_{\text{NU}} + P_{\text{FU}} = P_{\text{max}}$. The FU rate expression is written as,

$$C^* = \log_2 \left(1 + \frac{|h_{\text{eff}}^{\text{FU}}|^2 P_{\text{FU}}}{\sigma_{\text{FU}}^2} \right) \quad (21)$$

Let $\gamma^* = 2^{C^*} - 1$, the power allocation for FU is obtained as

$$P_{\text{FU}} = \frac{\gamma^* \sigma_{\text{FU}}^2}{|h_{\text{eff}}^{\text{FU}}|^2} \quad (22)$$

By substituting the expression for P_{FU} from (22) into the NU achievable capacity expression, a quadratic equation in terms of the target SINR γ^* is obtained as follows (with the detailed algebraic intermediate steps provided in Appendix A):

$$\gamma^{*2} \left(\frac{|h_{\text{eff}}^{\text{NU}}|^2}{|h_{\text{eff}}^{\text{FU}}|^2} \sigma_{\text{FU}}^2 \right) + \gamma^* \left(\sigma_{\text{NU}}^2 + \frac{|h_{\text{eff}}^{\text{NU}}|^2}{|h_{\text{eff}}^{\text{FU}}|^2} \sigma_{\text{FU}}^2 \right) - |h_{\text{eff}}^{\text{NU}}|^2 P_{\text{max}} = 0 \quad (23)$$

Let $A = \frac{|h_{\text{eff}}^{\text{NU}}|^2}{|h_{\text{eff}}^{\text{FU}}|^2} \sigma_{\text{FU}}^2$, $B = A + \sigma_{\text{NU}}^2$ and $D = |h_{\text{eff}}^{\text{NU}}|^2 P_{\text{max}}$, the Equation (23) becomes

$$A\gamma^{*2} + B\gamma^* - D = 0 \quad (24)$$

Taking the positive root of the quadratic equation $\gamma^* = \frac{-B \pm \sqrt{B^2 + 4AD}}{2A}$, the optimal power allocation for FU is given by

$$P_{\text{FU}}^* = \frac{\gamma^* \sigma_{\text{FU}}^2}{|h_{\text{eff}}^{\text{FU}}|^2} \quad (25)$$

Similarly, for NU, it is given by

$$P_{\text{NU}}^* = P_{\text{max}} - P_{\text{FU}}^* \quad (26)$$

For the solution to be physically valid, the feasibility conditions are as follows:

- $P_{\text{FU}}^* \geq 0$, since $\gamma^* > 0$, $\sigma_{\text{FU}}^2 > 0$ and $|h_{\text{eff}}^{\text{FU}}|^2 > 0$
- $P_{\text{NU}}^* \geq 0$, requires $\gamma^* \leq \frac{P_{\text{max}} |h_{\text{eff}}^{\text{FU}}|^2}{\sigma_{\text{FU}}^2}$, i.e., FU's SNR ceiling must not be exceeded
- $|h_{\text{eff}}^{\text{FU}}|^2 > |h_{\text{eff}}^{\text{NU}}|^2$, SIC validity for near-field condition

4.3. Complexity Analysis

The computational complexity of the proposed JEPO algorithm is governed by an outer convergence loop and an inner element-flipping loop. Let K denote the number of outer iterations required until no further improvement in the fairness objective is observed. During each outer iteration, the algorithm sequentially examines all M RIS elements.

A brute-force recomputation of the effective cascaded channels in (16) requires an M -element vector inner product, resulting in a computational complexity of $\mathcal{O}(M)$ per element evaluation and an overall complexity of $\mathcal{O}(K.M^2)$.

However, since only a single binary assignment variable is modified during each candidate flip, the effective cascaded channels can be updated incrementally by adjusting only the contribution of the flipped RIS element. Consequently, the channel update complexity is reduced from $\mathcal{O}(M)$ to $\mathcal{O}(1)$ per candidate evaluation. Furthermore, the optimal NOMA power allocation is obtained directly from the closed-form expression derived in Proposition 1, eliminating the need for iterative optimization. Therefore, the overall computational complexity of the proposed JEPO algorithm is reduced to $\mathcal{O}(K.M)$, where K is typically much smaller than M in practical implementations. Since the algorithm converges in a small number of outer iterations, the proposed JEPO framework remains computationally efficient even for large-scale ELAA-RIS deployments.

The proposed JEPO algorithm is developed as a practical low-complexity heuristic for solving the mixed-integer non-convex optimization problem in (19), whose exact global optimization becomes computationally prohibitive for practical ELAA-RIS sizes due to the combinatorial nature of the binary RIS element assignment. Consequently, deriving a closed-form approximation ratio or global optimality guarantee for this class of problems is beyond the scope of the present work. Instead, the proposed JEPO algorithm guarantees monotonic improvement of the fairness objective and converges in a finite number of iterations to a locally optimal RIS partition with respect to the adopted greedy neighborhood search. Furthermore, the exhaustive-search comparison presented in Section 5 demonstrates that the proposed algorithm closely approaches the globally optimal solution for a small 4×4 RIS while maintaining significantly lower computational complexity, thereby validating its effectiveness for practical large-scale RIS deployments.

For comparison, the exhaustive-search method can theoretically identify the globally optimal RIS partition. However, their computational complexity grows exponentially with the number of RIS elements, rendering them computationally infeasible for the practical 32×32 and 42×42 ELAA-RIS configurations considered in this work. Moreover, optimization techniques such as semidefinite relaxation (SDR) and successive convex approximation (SCA) are primarily designed for continuous optimization variables. Although they can be extended to certain mixed-integer formulations through relaxation, such approaches generally incur substantially higher computational complexity and do not scale well for large ELAA-RIS configurations. Consequently, the proposed JEPO algorithm provides an effective trade-off between computational complexity and fairness performance, making it well-suited for practical near-field RIS-assisted NOMA systems where exact optimization methods are computationally prohibitive.

4.4. Practical Impact of Discrete RIS Phase Shifts

In formulating the max-min optimization problem in (19a), the RIS phase shifts are assumed to be continuously controllable, i.e., $\phi_m \in [0, 2\pi)$, which provides the theoretical performance upper bound of the proposed near-field RIS-assisted NOMA system. In practical RIS implementations, however, PIN-diode or varactor-based reflecting elements typically provide a finite number of discrete phase states (e.g., 1-bit or 2-bit phase quantization). Let B denote the phase resolution in bits. The available phase set is given by

$$\mathcal{F}_B = \left\{ 0, \frac{2\pi}{2^B}, \dots, \frac{2\pi(2^B - 1)}{2^B} \right\}. \quad (27)$$

After obtaining the continuous phase solution from the proposed JEPO algorithm, each RIS element can be mapped to its nearest discrete phase state through a simple quantization

operation. Although this mapping introduces phase quantization errors that slightly reduce the beam-focusing gain, the greedy element assignment and closed-form power allocation of JEPO remain directly applicable without any modification to the optimization framework. Therefore, only a final-phase quantization step is required before implementation. It is well known that increasing the phase resolution from 1-bit to 2-bit substantially reduces quantization loss and improves beam-focusing performance. Consequently, the proposed continuous-phase optimization can be regarded as an upper performance bound, while practical RIS hardware with 2-bit quantization is expected to achieve performance close to this bound. A detailed performance evaluation under discrete-phase RIS hardware is an interesting direction for future work.

5. Simulation Results

In this section, extensive MATLAB simulations are presented to evaluate the performance of the proposed JEPO algorithm under various near-field communication scenarios. All numerical results are obtained under the assumption of perfect CSI for the cascaded AP-RIS-user links. This assumption provides an ideal performance upper bound and enables a clear assessment of the proposed optimization framework. In practical deployments, however, channel estimation errors, pilot contamination, hardware impairments, and user mobility may introduce CSI uncertainty, which can degrade the achievable fairness and throughput. Therefore, the numerical results presented in this section should be interpreted as the upper-bound performance of the proposed scheme, while the investigation of robust JEPO design under imperfect CSI is left for future work.

The simulation parameter used in MATLAB R2024b for evaluating the performance of the RIS-ELAA-assisted NOMA system is shown in Table 2. Under the assumption of simulation parameters, the distance satisfies the Fresnel near-field boundary $d_{\text{Fresnel}} = \frac{2D^2}{\lambda}$. The simulation framework in Table 2 confirms that both users are well within the radiative near-field (Fresnel) region, as their positions (1 m to 6 m) lie clearly between the uniform-power distance ($d_{\text{UP}} \approx 0.27$ m) and the Rayleigh distance ($d_{\text{R}} \approx 54$ m). This validation requires spherical wavefront modeling, since planar approximations would introduce significant phase errors in the indoor channel matrix.

The individual user rates, C_{NU} and C_{FU} , as a function of the JEPO iterations for two RIS apertures, namely 32×32 and 42×42 , are illustrated in Figure 2. At the initial iteration, where all RIS elements are allocated to the FU, the NU achieves a considerably lower rate because of its off-boresight near-field location, whereas the FU operates close to its maximum attainable rate. As the JEPO algorithm progressively reallocates RIS elements and jointly optimizes the NOMA power allocation, the NU rate increases monotonically for both RIS configurations. For the 32×32 RIS, the NU rate reaches ≈ 7 bps/Hz after about 22 iterations, while the larger 42×42 RIS attains the same rate in fewer iterations and ultimately achieves a slightly higher final rate of about 7.6 bps/Hz. In contrast, the FU rate remains nearly constant throughout the optimization process, indicating that the improvement in fairness is achieved with negligible degradation in FU performance. Furthermore, the larger RIS aperture consistently provides higher rates for both users, demonstrating the benefit of increased near-field beam-focusing capability. These results confirm that the combination of near-field RIS-ELAA operation and the proposed JEPO algorithm effectively enhances the disadvantaged NU performance while preserving the service quality of the FU.

The consistent upward trend of the NU rate across iterations shows that the greedy element-flipping technique offers stable convergence within the 20-iteration limit. Additionally, Figure 2 challenges the common zero-sum idea of element sharing. Because near-field beam focusing tightens electromagnetic energy at specific 3D points, elements assigned to the NU become completely decoupled from the FU. This spatial non-stationarity enables

JEPO to quickly increase the FU's rate without reducing the NU's performance. Moreover, the larger-aperture enhancement directly measures the array's gain capabilities using sharper near-field spatial-focusing lenses.

Table 2. Simulation Parameters.

Parameter	Value
Carrier frequency, f_c	28 GHz
RIS configuration	32×32 and 42×42 URA
RIS element spacing	$\lambda/2$
RIS location	bottom left element at $(0, 0, 0)$ in x - z plane
Number of elements, M	1024 (32×32), 1764 (42×42)
AP position	$(-5, 0, 0)$ m
NU position	$d_{\text{NU}} = 2$ m, $(\theta_{\text{NU}} = 45^\circ, \phi_{\text{NU}} = 0^\circ)$
FU position	$(0, 0, 8)$ m, $(\theta_{\text{FU}} = 0^\circ, \phi_{\text{FU}} = 0^\circ)$
Path-loss exponent, α	2
Uniform-power distance, d_{UP}	≈ 0.27 m
Rayleigh distance, d_R	≈ 54 m
Maximum transmit power, P_{max}	1 W (0 dBW)
Noise variance, σ_u^2	10^{-2}
Convergence threshold, ϵ	10^{-4}
JEPO maximum iterations	20
Minimum elements per user, M_{min}	4
Monte Carlo runs	500

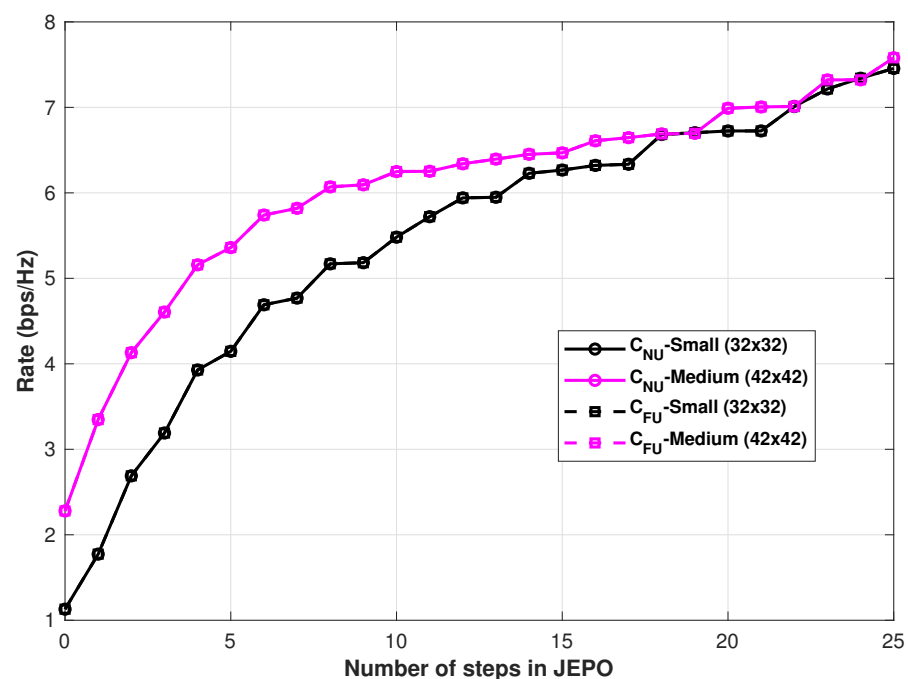


Figure 2. Individual user rates C_{NU} and C_{FU} versus number of JEPO steps for small (32×32) and medium (42×42) aperture RIS configurations.

To validate the near-optimality of the proposed greedy element-flipping strategy, Figure 3 compares JEPO against the exhaustive search upper bound for a small 4×4 RIS ($M = 16$), for which all $2^{16} = 65,536$ binary element assignments can be enumerated. The exhaustive search identifies the globally optimal fairness value of ≈ 1.981 bps/Hz, shown as the red dashed horizontal line. The proposed JEPO algorithm begins at an initial fairness of 1.801 bps/Hz (all elements assigned to the FU) and converges monotonically to 1.981 bps/Hz within eight greedy element-flipping steps, achieving an optimality gap of exactly 0.0%. This result confirms that the greedy element-flipping mechanism, despite its low polynomial complexity of $\mathcal{O}(K \cdot M^2)$, finds the globally optimal element assignment for this

configuration without resorting to exhaustive enumeration. The rapid convergence within eight steps compared to 65,536 evaluations required by exhaustive search demonstrates the efficiency of the proposed approach. While the optimality guarantee cannot be extended analytically to larger RIS sizes where exhaustive search is computationally infeasible, this result provides strong empirical evidence that the greedy strategy identifies near-optimal or optimal solutions in practice, consistent with the complexity analysis established in Proposition 1. The exhaustive-search benchmark serves as the global optimum for the 4×4 RIS configuration. The close agreement between the exhaustive-search and JEPO results indicates that the proposed greedy algorithm incurs only a negligible optimality gap for small-scale RIS systems, while avoiding the exponential computational complexity associated with exhaustive search.

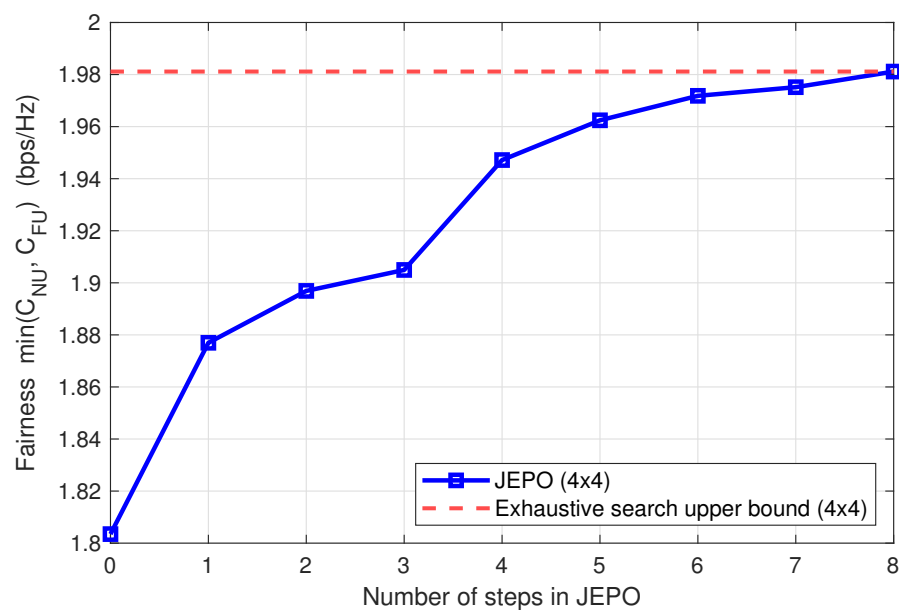


Figure 3. Fairness $\min(C_{NU}, C_{FU})$ versus number of JEPO steps compared with the exhaustive search upper bound for a 4×4 RIS.

To rigorously evaluate the proposed JEPO scheme, four baseline methods are considered. (i) All elements to the FU with equal power allocation, representing the initialization of the JEPO algorithm. (ii) Equal element split with equal power allocation, where the RIS elements are equally partitioned between the NU and FU, isolating neither element assignment nor power optimization. (iii) Equal element split with optimal power allocation, where the RIS elements remain equally partitioned while the NOMA power allocation is optimized using (24) and (25), thereby isolating the gain achieved solely through power optimization. (iv) OMA partition, where users are served in orthogonal time slots using an equal RIS element split, providing a benchmark to quantify the spectral efficiency gain of NOMA over orthogonal multiple access. Figure 4 illustrates the fairness performance, $\min(C_{NU}, C_{FU})$, as a function of the transmit power $P_{\max}$ ranging from -10 dBW to 10 dBW for two RIS aperture configurations, namely 32×32 and 42×42 , comparing the proposed JEPO algorithm with the four baseline schemes.

Across the entire transmit power range, the proposed JEPO algorithm consistently achieves the highest fairness for both RIS aperture sizes, confirming that the joint optimization of RIS element assignment and NOMA power allocation is essential for maximizing user-rate fairness in near-field RIS-assisted NOMA systems. Furthermore, increasing the RIS aperture from 32×32 to 42×42 uniformly improves the fairness of all schemes because the larger RIS provides higher array gain and finer near-field beam-focusing capability. The improvement is particularly significant for the proposed JEPO scheme, demonstrating

its ability to effectively exploit the additional spatial degrees of freedom offered by larger ELAA-RIS deployments.

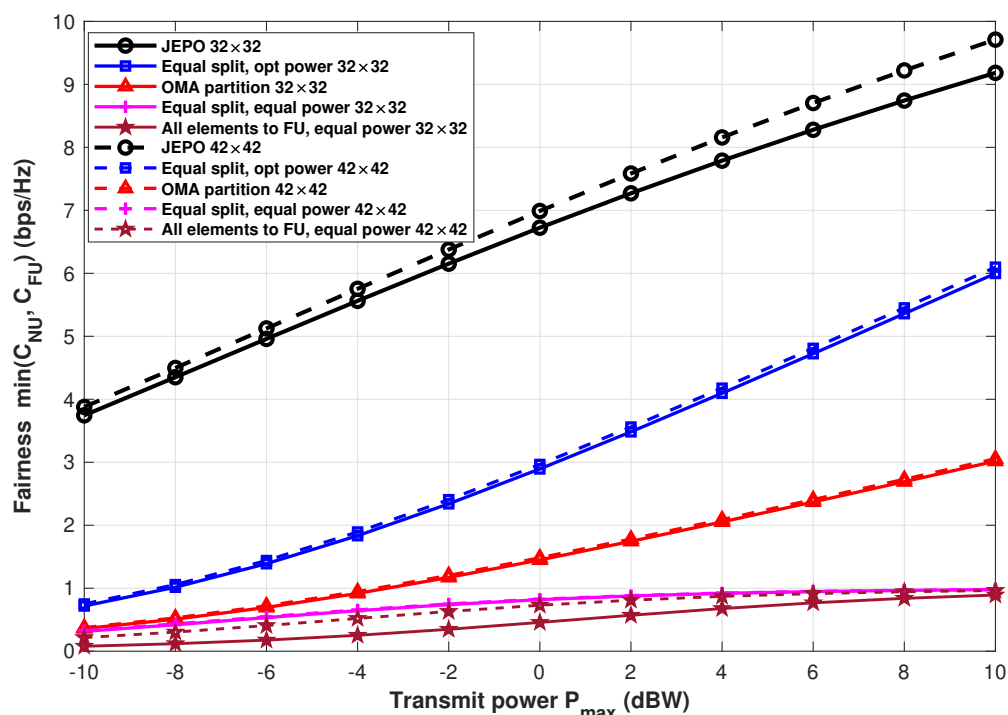


Figure 4. Fairness $\min(C_{NU}, C_{FU})$ versus transmit power P_{max} for different RIS aperture sizes, namely 32×32 and 42×42 , comparing the proposed JEPO scheme with baseline methods.

At $P_{max} = 0$ dBW, the proposed JEPO scheme achieves fairness values of ≈ 6.7 bps/Hz and 7.0 bps/Hz for the 32×32 and 42×42 RIS configurations, respectively, whereas the equal-split with optimal power allocation baseline achieves only about 2.9 bps/Hz and 3.0 bps/Hz. This substantial performance gap demonstrates that optimizing the NOMA power allocation alone cannot fully exploit the near-field propagation characteristics without intelligent RIS element assignment. Similarly, the OMA partition baseline achieves only about 1.5 bps/Hz for the 32×32 RIS and 1.6 bps/Hz for the 42×42 RIS at the same transmit power, confirming the clear spectral efficiency advantage of power-domain NOMA with SIC over orthogonal transmission.

The equal-split with equal-power and all-elements-to-FU baselines remain below 1 bps/Hz throughout most of the transmit power range for both RIS configurations, indicating that neither fixed RIS partitioning nor equal power allocation can efficiently utilize the additional transmit power under interference-limited near-field conditions. In contrast, all schemes exhibit monotonically increasing fairness with increasing transmit power, although the proposed JEPO algorithm demonstrates the steepest growth rate. This improvement is attributed to the greedy element-flipping strategy, which dynamically reallocates RIS elements to enhance the effective cascaded channel of the weaker user while simultaneously determining the optimal NOMA power allocation through the proposed closed-form solution. An additional observation from Figure 4 is that the performance gap between the proposed JEPO algorithm and the baseline schemes is consistently maintained for both RIS aperture sizes. This demonstrates that the proposed algorithm not only provides superior fairness under a fixed RIS size but also scales effectively with increasing aperture dimensions, making it well suited for practical ELAA-assisted near-field wireless communication systems.

To assess the robustness of the proposed JEPO algorithm beyond the deterministic geometry considered in Figure 4, Monte Carlo simulations are performed over $N_{geo} = 200$

independent spatial realizations. For each realization, the NU distance is uniformly distributed over $d_{\text{NU}} \sim \mathcal{U}[1, 4]$ m and its azimuth angle over $\theta_{\text{NU}} \sim \mathcal{U}[-60^\circ, 60^\circ]$. Similarly, the FU distance and azimuth angle are generated as $d_{\text{FU}} \sim \mathcal{U}[6, 10]$ m and $\theta \sim \mathcal{U}[-30^\circ, 30^\circ]$, respectively. In addition, the AP–RIS distance and path-loss exponent are independently varied according to $d_{\text{AR}} \sim \mathcal{U}[4, 6]$ m and $\alpha \sim \mathcal{U}[1.8, 2.4]$. The JEPO element assignment and power allocation are recomputed for every realization and transmit-power value, and the reported fairness is averaged over all realizations.

The average fairness obtained from Monte Carlo simulations over randomly generated indoor geometries and propagation parameters for two RIS aperture configurations, namely 32×32 and 42×42 , is shown in Figure 5. For both RIS aperture sizes, the proposed JEPO algorithm consistently achieves the highest average fairness over the entire transmit-power range. For the 32×32 RIS, the average fairness increases from ≈ 1.4 bps/Hz at $P_{\text{max}} = -10$ dBW to about 4.4 bps/Hz at $P_{\text{max}} = 10$ dBW. Increasing the aperture to 42×42 further improves the corresponding fairness from ≈ 1.5 bps/Hz to 4.5 bps/Hz. This consistent improvement is attributed to the larger array gain and enhanced near-field spatial-focusing capability provided by the 42×42 RIS. Among the benchmark schemes, the equal-split with optimal power allocation achieves the second-highest average fairness. However, its performance remains considerably below JEPO for both aperture sizes. At $P_{\text{max}} = 10$ dBW, this baseline achieves ≈ 2.9 bps/Hz and 3.0 bps/Hz for the 32×32 and 42×42 RIS configurations, respectively, compared with ≈ 4.4 bps/Hz and 4.5 bps/Hz achieved by JEPO. This performance gap demonstrates that power optimization alone cannot fully compensate for a fixed RIS element partition under randomly varying near-field user geometries. The OMA partition also benefits from the larger RIS aperture but remains below the corresponding NOMA-based equal-split optimal-power scheme, confirming the spectral-efficiency advantage of NOMA with SIC. The equal-split with equal-power and all-elements-to-FU baselines provide the lowest average fairness because they lack either adaptive element assignment, optimized power allocation, or both. Their relatively small improvement with increasing RIS size further indicates that a larger aperture alone cannot be fully exploited without an adaptive optimization strategy.

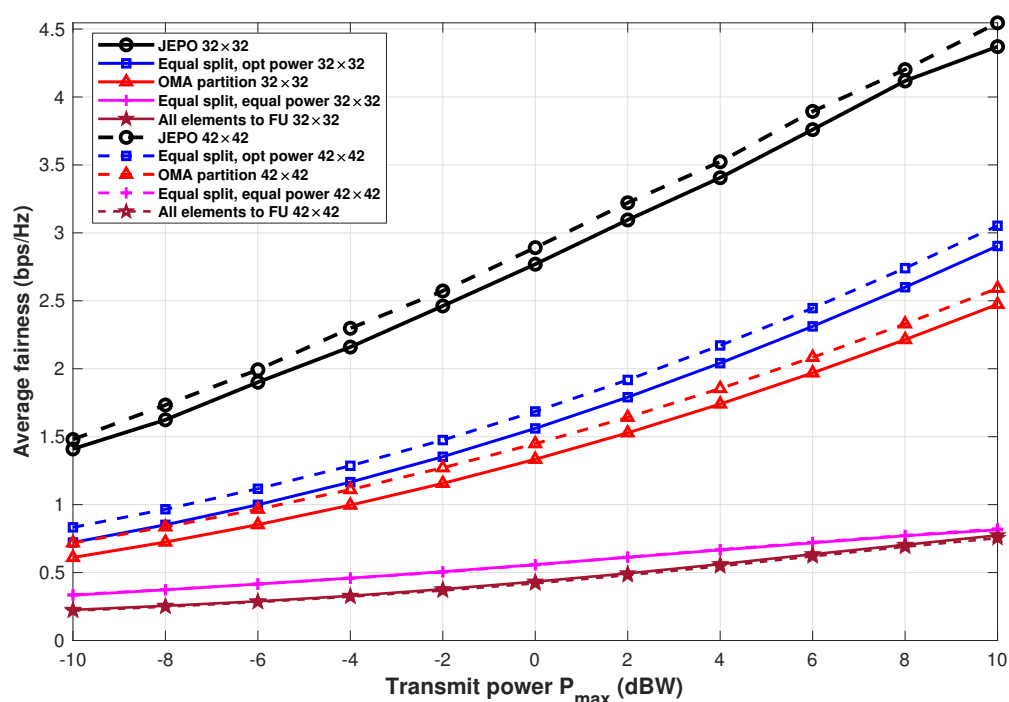


Figure 5. Average fairness versus transmit power obtained from Monte Carlo simulations over random indoor user geometries for two RIS aperture sizes, namely, 32×32 and 42×42 RIS.

Overall, the Monte Carlo results demonstrate that the performance gain of JEPO is not restricted to the favorable deterministic user arrangement adopted in the initial evaluation. The proposed algorithm maintains its fairness advantage across random indoor deployments and for both RIS aperture sizes, confirming its robustness to geometry variations and its ability to effectively utilize the additional spatial degrees of freedom provided by larger ELAA-RIS configurations.

The fairness metric $\min(C_{\text{NU}}, C_{\text{FU}})$ as a function of the NU distance d_{NU} , varying from 1 m to 6 m, with the FU fixed at $d_{\text{FU}} = 8$ m on the boresight axis and the NU located at $\theta_{\text{NU}} = 45^\circ$ off-boresight, is illustrated in Figure 6 for two RIS aperture configurations, namely 32×32 and 42×42 . Both users operate within the radiative near-field (Fresnel) region of the RIS, bounded by the uniform-power distance $d_{\text{UP}} \approx 0.27$ m and the Rayleigh distance $d_{\text{R}} \approx 54$ m for the 32×32 RIS, thereby validating the applicability of the uniform spherical wave (USW) channel model and the Fresnel approximation throughout the considered distance range. The larger 42×42 RIS possesses a larger Fresnel region while remaining well within the near-field operating regime for all simulated user locations. The proposed JEPO algorithm consistently achieves the highest fairness across the entire distance range for both RIS aperture configurations. For the 32×32 RIS, the fairness decreases from ≈ 7.7 bps/Hz at $d_{\text{NU}} = 1$ m to about 4.5 bps/Hz at $d_{\text{NU}} = 6$ m, whereas the 42×42 RIS provides slightly higher fairness over most of the considered distances, reaching ≈ 8.3 bps/Hz at $d_{\text{NU}} = 1$ m and 4.8 bps/Hz at $d_{\text{NU}} = 6$ m. This overall reduction in fairness with increasing NU distance is primarily attributed to the combined effects of increasing propagation loss and the gradual reduction in near-field beam-focusing gain as the NU moves farther away from the RIS. The larger RIS aperture offers additional array gain and finer spatial focusing, resulting in a consistent, although moderate, improvement in fairness compared with the 32×32 configuration. Among the benchmark schemes, the equal element split with optimal power allocation achieves the second-best performance for both RIS sizes, indicating that optimal NOMA power allocation alone improves fairness but cannot compensate for a fixed RIS element partition. The fairness curves of this baseline exhibit noticeable fluctuations with the NU distance because the equal RIS partition cannot adapt to the distance-dependent spatial characteristics of the near-field channel. Consequently, even with the closed-form optimal power allocation obtained from Proposition 1, the effective beamforming gain remains suboptimal. The consistently large performance gap between the proposed JEPO algorithm and the equal-split optimal-power scheme demonstrates that adaptive RIS element assignment contributes more significantly to fairness enhancement than power optimization alone. Similarly, the OMA partition baseline follows a comparable distance-dependent trend but achieves uniformly lower fairness than the corresponding NOMA-based schemes, confirming the spectral efficiency advantage provided by superposition coding and SIC. The equal split with equal power and all-elements-to-FU baselines maintains the lowest fairness throughout the distance range for both RIS configurations because neither adaptive RIS partitioning nor optimized power allocation is employed. These results highlight that static RIS allocation strategies are unable to efficiently exploit the spatially varying characteristics of near-field propagation.

It is also observed that several baseline schemes exhibit non-monotonic variations with the NU distance. These fluctuations arise from the distance-dependent phase evolution of the spherical wavefronts in the near-field region, which periodically changes the constructive and destructive combination of the cascaded AP-RIS-user channel. In contrast, the proposed JEPO algorithm continuously updates the RIS element assignment according to the instantaneous user geometry and jointly optimizes the NOMA power allocation. As a result, it maintains consistently higher fairness across all user locations and effec-

tively exploits the additional spatial degrees of freedom offered by larger RIS apertures, demonstrating its scalability for ELAA-assisted near-field NOMA systems.

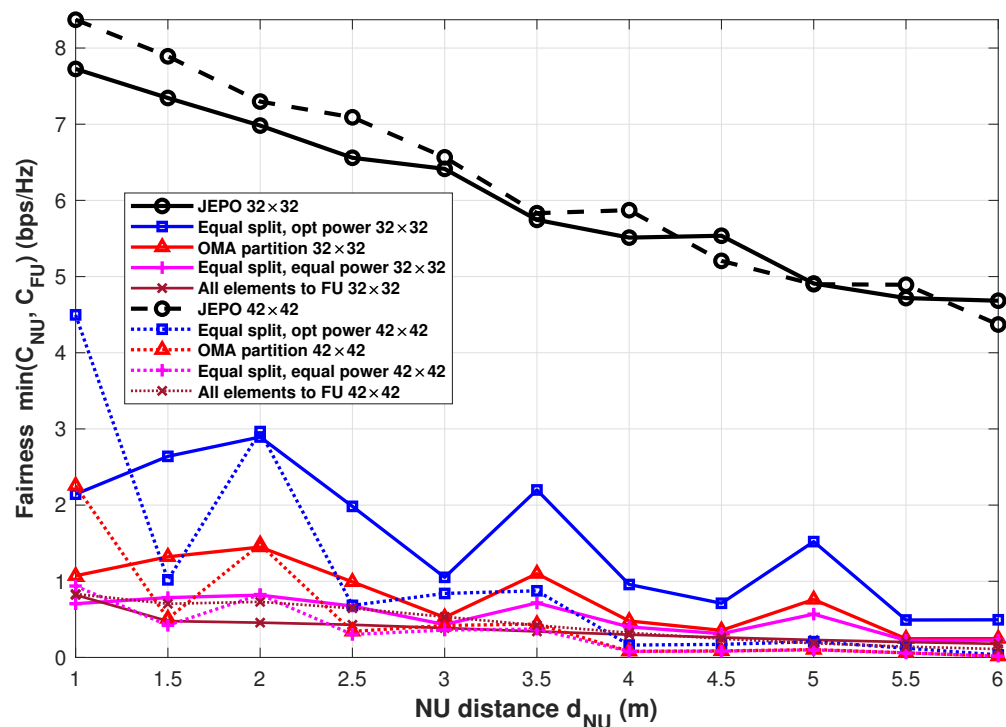


Figure 6. Fairness $\min(C_{NU}, C_{FU})$ versus NU distance d_{NU} for different RIS aperture sizes, namely 32×32 and 42×42 , comparing the proposed JEPO scheme with baseline methods.

The fairness metric $\min(C_{NU}, C_{FU})$ as a function of the azimuth angular separation θ_{NU} ranging from 0° to 60° in 5° increments, with the NU fixed at $d_{NU} = 2$ m and the FU fixed at $d_{FU} = 8$ m on the boresight axis ($\theta_{FU} = 0^\circ$), is shown in Figure 7 for two RIS aperture configurations, namely 32×32 and 42×42 . This comparison is included to evaluate the effect of RIS aperture size on angular-domain fairness performance in the proposed near-field RIS-assisted NOMA system. The proposed JEPO scheme achieves the highest fairness across the entire angular range for both RIS configurations. For the 32×32 RIS, JEPO maintains a fairness value of ≈ 7.0 – 8.0 bps/Hz, while the 42×42 RIS provides a further improvement, especially for smaller and moderate angular separations. This improvement is due to the larger aperture providing higher array gain and finer near-field spatial focusing. Even when the NU moves away from the boresight direction, the proposed greedy element-flipping mechanism dynamically reallocates RIS elements toward the NU and jointly optimizes the NOMA power allocation using Proposition 1. As a result, JEPO maintains robust fairness performance compared with all baseline schemes.

The equal element split with optimal power allocation achieves the second-best performance, particularly for small angular separations. However, its fairness decreases significantly as θ_{NU} increases, and it exhibits strong non-monotonic variations. This behavior indicates that power allocation alone cannot compensate for the phase mismatch caused by a fixed RIS partition in the near-field region. Although the 42×42 RIS improves the performance of this baseline at several angular positions, the performance still drops sharply at larger angular separations because the RIS element assignment remains static. The OMA partition baseline follows a similar trend but provides lower fairness than the corresponding NOMA-based equal-split optimal-power scheme. This confirms the spectral efficiency advantage of NOMA with SIC over orthogonal transmission. The equal-split with equal-power and all-elements-to-FU baselines remain close to or below 1 bps/Hz over

most of the angular range for both RIS sizes, showing that static RIS allocation without power optimization is not sufficient to support balanced user rates in near-field NOMA systems. An important observation from Figure 7 is that around $\theta_{\text{NU}} \approx 40^\circ$, most baseline schemes suffer a severe fairness degradation, whereas the proposed JEPO scheme maintains a fairness of about 7 bps/Hz for both 32×32 and 42×42 RIS configurations. This degradation in the fixed-partition baselines is caused by angle-dependent spherical-wave phase variation, which can lead to destructive combining for certain NU locations. In contrast, JEPO avoids this performance collapse by adaptively modifying the RIS element assignment according to the user geometry.

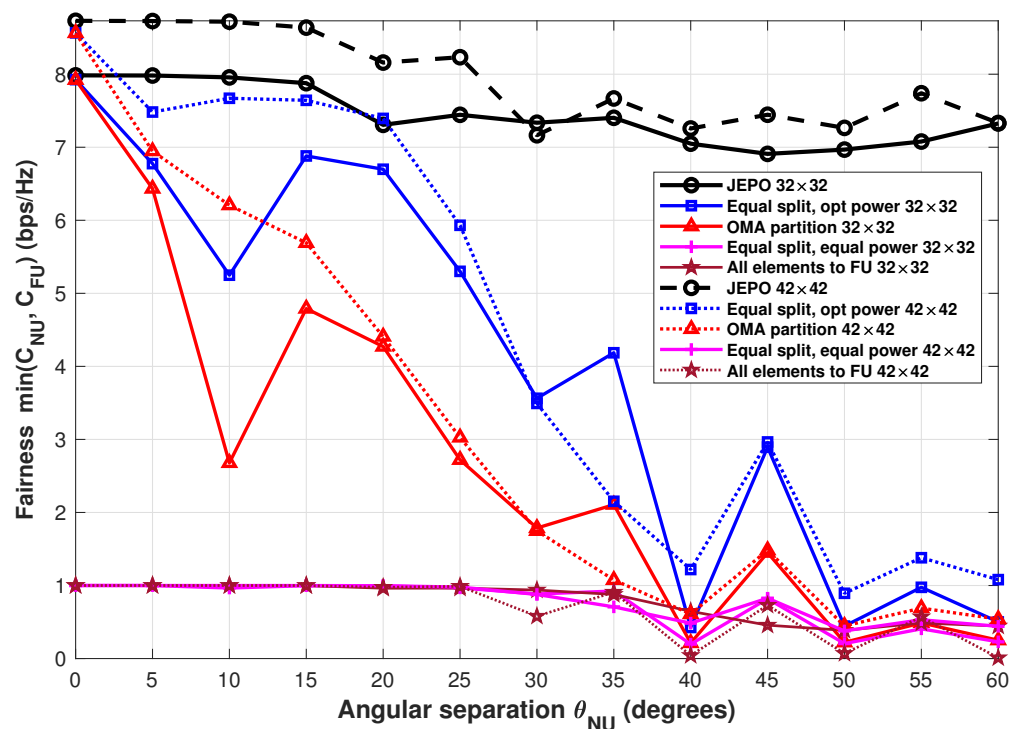


Figure 7. Fairness $\min(C_{\text{NU}}, C_{\text{FU}})$ versus angular separation θ_{NU} for different RIS aperture sizes, namely 32×32 and 42×42 , comparing the proposed JEPO scheme with baseline methods.

Overall, the results demonstrate that the proposed JEPO algorithm is robust to angular displacement and scales effectively with RIS aperture size. The 42×42 RIS generally provides higher fairness than the 32×32 RIS, confirming that larger ELAA-RIS apertures can further improve near-field beam focusing and user-rate fairness when combined with adaptive element and power optimization. The numerical results presented in this section are obtained under several commonly adopted assumptions for theoretical performance evaluation, including perfect CSI, continuous RIS phase shifts, passive lossless RIS elements, single-antenna users, two-user NOMA transmission, a static indoor environment, and the absence of a direct AP–user link. These assumptions allow the proposed JEPO framework to be evaluated under an idealized setting and establish an upper performance bound for fairness optimization in near-field RIS-assisted NOMA systems. In practical deployments, however, channel estimation errors, finite-resolution phase shifters, hardware impairments, element losses, user mobility, direct AP–user propagation, and multi-user scenarios may reduce the achievable performance. Nevertheless, the proposed optimization framework remains applicable after incorporating these practical effects into the system model, and extending the proposed JEPO algorithm to such realistic scenarios constitutes an important direction for future research.

6. Conclusions

In this paper, the JEPO algorithm is proposed to maximize user-rate fairness in RIS-ELAA-assisted NOMA systems operating in the radiative near-field region of indoor mmWave environments at 28 GHz. The cascaded near-field channel model is derived under the second-order Fresnel approximation for the AP-to-RIS and RIS-to-user links, with both users validated within the USW operating region bounded by $d_{UP} \approx 0.27$ m and $d_R \approx 54$ m. The validity of power-domain NOMA with reversed far-to-near SIC ordering, governed by the condition $|h_{\text{eff}}^{\text{FU}}|^2 > |h_{\text{eff}}^{\text{NU}}|^2$, is formally established by demonstrating that RIS element partitioning provides beam-focusing complementarity rather than spatial orthogonality, making SIC necessary for residual interference management. The JEPO algorithm jointly optimizes the binary RIS element assignment via greedy element flipping and the NOMA power allocation via the closed-form Proposition 1, which reduces the max-min fairness condition to a scalar quadratic in γ^* , eliminating iterative power search. The complexity is established as $\mathcal{O}(K \cdot M^2)$, reducible to $\mathcal{O}(K \cdot M)$ with incremental updates, where $K \ll M$, contrasting with the $\mathcal{O}(2^M)$ exhaustive search. Simulation results confirm that JEPO consistently outperforms all baseline methods across transmit power, NU distance, angular separation, and RIS aperture size, with the largest gain observed at $\theta_{\text{NU}} \approx 40^\circ$ where fixed-partition baselines collapse to near-zero fairness. The present work can be extended to multi-user scenarios, active-RIS configurations, imperfect CSI conditions, physical layer security, and full non-uniform spherical wave (NUSW) channel modeling.

Although this work provides a comprehensive investigation of fairness optimization for near-field RIS-assisted NOMA systems, several practical aspects remain open for future research. These include robust optimization under imperfect CSI, discrete-phase RIS architectures, hardware impairments, passive reflection losses, multi-antenna users, multi-user NOMA scenarios, direct AP–user links, and dynamic indoor environments with user mobility. Investigating these practical considerations will further improve the applicability of the proposed JEPO framework in realistic 6G indoor communication systems.

Author Contributions: Conceptualization, P.G.S.V. and V.B.K.; methodology, P.G.S.V. and V.B.K.; software, P.G.S.V.; validation, P.G.S.V., V.B.K. and S.R.; formal analysis, P.G.S.V. and V.B.K.; investigation, P.G.S.V. and S.R.; resources, V.B.K. and A.M.; data curation, P.G.S.V.; writing—original draft preparation, P.G.S.V.; writing—review and editing, V.B.K., S.R., A.M., M.N.S. and S.N.S.; visualization, P.G.S.V.; supervision, V.B.K. and S.N.S.; project administration, V.B.K.; funding acquisition, V.B.K. and S.N.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: All data are available from the corresponding author upon reasonable request.

Acknowledgments: The authors would like to express their sincere gratitude to Sundarrajan Jayaraman Thiruvengadam from the Department of Electronics and Communication Engineering, Presidency University, Bengaluru, India for his invaluable mentorship and guidance throughout this research.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

6G	Sixth-Generation wireless networks
AP	Access Point
AWGN	Additive White Gaussian Noise
BS	Base Station

CSI	Channel State Information
DMA	Dynamic Metasurface Antenna
ELAA	Extremely Large Aperture Array
FU	Far User
IoT	Internet of Things
ISAC	Integrated Sensing and Communication
JEPO	Joint Element and Power Optimization
LoS	Line-of-Sight
MATLAB	Matrix Laboratory
MIMO	Multiple Input Multiple Output
mmWave	Millimeter Wave
NFC	Near-Field Communication
NLoS	Non-Line-of-Sight
NOMA	Non-Orthogonal Multiple Access
NU	Near User
NUSW	Non-Uniform Spherical Wave
OMA	Orthogonal Multiple Access
RIS	Reconfigurable Intelligent Surface
SDMA	Space Division Multiple Access
SIC	Successive Interference Cancellation
SINR	Signal-to-Interference-plus-Noise Ratio
SNR	Signal-to-Noise Ratio
sub-THz	Sub-Terahertz
UPW	Uniform Plane Wave
URA	Uniform Rectangular Array
USW	Uniform Spherical Wave
V2I	Vehicle-to-Infrastructure
WPT	Wireless Power Transfer
XL-MIMO	Extra-Large Scale Multiple Input Multiple Output

Appendix A. Derivation of the Quadratic Equation in (23)

Substituting $P_{\text{FU}} = \frac{\gamma^* \sigma_{\text{FU}}^2}{|h_{\text{eff}}|^2}$ in NU rate expression in (17) results

$$\gamma^* = \frac{|h_{\text{eff}}^{\text{NU}}|^2 P_{\text{NU}}}{|h_{\text{eff}}^{\text{NU}}|^2 P_{\text{FU}} + \sigma_{\text{NU}}^2} \quad (\text{A1})$$

Simplifying (A1) with $P_{\text{NU}} = P_{\text{max}} - \frac{\gamma^* \sigma_{\text{FU}}^2}{|h_{\text{eff}}^{\text{FU}}|^2}$ results in

$$\gamma^* \left(\frac{|h_{\text{eff}}^{\text{NU}}|^2 \gamma^* \sigma_{\text{FU}}^2}{|h_{\text{eff}}^{\text{FU}}|^2} + \sigma_{\text{NU}}^2 \right) = |h_{\text{eff}}^{\text{NU}}|^2 \left(P_{\text{max}} - \frac{\gamma^* \sigma_{\text{FU}}^2}{|h_{\text{eff}}^{\text{FU}}|^2} \right) \quad (\text{A2})$$

The Equation (A2) can be rearranged as

$$\gamma^{*2} \left(\frac{|h_{\text{eff}}^{\text{NU}}|^2 \sigma_{\text{FU}}^2}{|h_{\text{eff}}^{\text{FU}}|^2} \right) + \gamma^* \left(\frac{\sigma_{\text{FU}}^2 |h_{\text{eff}}^{\text{NU}}|^2}{|h_{\text{eff}}^{\text{FU}}|^2} + \sigma_{\text{NU}}^2 \right) = |h_{\text{eff}}^{\text{NU}}|^2 P_{\text{max}} \quad (\text{A3})$$

For notation simplicity, define $A = \frac{|h_{\text{eff}}^{\text{NU}}|^2 \sigma_{\text{FU}}^2}{|h_{\text{eff}}^{\text{FU}}|^2}$, $B = A + \sigma_{\text{NU}}^2$ and $D = |h_{\text{eff}}^{\text{NU}}|^2 P_{\text{max}}$. This appendix provides the intermediate algebraic steps leading from (23) to (24).

References

1. Zhang, H.; Shlezinger, N.; Guidi, F.; Dardari, D.; Eldar, Y.C. 6G Wireless Communications: From Far-Field Beam Steering to Near-Field Beam Focusing. *IEEE Commun. Mag.* **2023**, *61*, 72–77. [\[CrossRef\]](#)
2. Mu, X.; Xu, J.; Liu, Y.; Hanzo, L. Reconfigurable Intelligent Surface-Aided Near-Field Communications for 6G: Opportunities and Challenges. *IEEE Veh. Technol. Mag.* **2024**, *19*, 65–74. [\[CrossRef\]](#)
3. Liu, Y.; Wang, Z.; Xu, J.; Ouyang, C.; Mu, X.; Schober, R. Near-Field Communications: A Tutorial Review. *IEEE Open J. Commun. Soc.* **2023**, *4*, 1999–2049. [\[CrossRef\]](#)
4. Zuo, J.; Mu, X.; Liu, Y. Near-Field Non-Orthogonal Multiple Access Communications. *IEEE Trans. Wirel. Commun.* **2024**, *23*, 7600–7616. [\[CrossRef\]](#)
5. Decarli, N.; Guerra, A.; Giovannetti, C.; Guidi, F.; Masini, B.M. Near-Field Localization of Vehicles Based on V2X Sidelink Communication. In Proceedings of the 2023 IEEE International Conference on Communications Workshops (ICC Workshops), Rome, Italy, 28 May–1 June 2023; pp. 1343–1348. [\[CrossRef\]](#)
6. Wang, Z.; Ramezani, P.; Liu, Y.; Björnson, E. Near-Field Localization and Sensing With Large-Aperture Arrays: From Signal Modeling to Processing. *IEEE Signal Process. Mag.* **2025**, *42*, 74–87. [\[CrossRef\]](#)
7. Wang, H.; Guo, P.; Li, X.; Wen, F.; Wang, X.; Nallanathan, A. MBPD: A robust algorithm for polar-domain channel estimation in near-field wideband XL-MIMO systems. *IEEE Internet Things J.* **2025**, *12*, 18461–18470. [\[CrossRef\]](#)
8. Sun, P.; Wang, B. Near-Field Beam Focusing for Integrated Sensing and Communication Systems. *IEEE Internet Things J.* **2025**, *12*, 18643–18650. [\[CrossRef\]](#)
9. Zhang, H.; Shlezinger, N.; Guidi, F.; Guerra, A.; Dardari, D.; Imani, M.F.; Eldar, Y.C. Near-Field Beam Focusing for Wireless Power Transfer With Dynamic Metasurface Antennas. *IEEE Internet Things J.* **2025**, *12*, 18596–18605. [\[CrossRef\]](#)
10. Zhang, C.; Hou, J.; Chen, C.; Li, G. Enhanced resource orchestration in near-field and far-field NOMA communications for emergency IoT applications. *IEEE Internet Things J.* **2025**, *12*, 18520–18531. [\[CrossRef\]](#)
11. Zappone, A.; Renzo, M.D.; Xi, X.; Debbah, M. On the Optimal Number of Reflecting Elements for Reconfigurable Intelligent Surfaces. *IEEE Wirel. Commun. Lett.* **2021**, *10*, 464–468. [\[CrossRef\]](#)
12. Singh, S.; Singh, K.; Singh, S.K.; Shin, H.; Duong, T.Q. Beamforming design towards sum-rate maximization for holographic active RIS-aided uplink near-field communications. *IEEE Internet Things J.* **2025**, *12*, 18582–18595. [\[CrossRef\]](#)
13. Zhuo, B.; Gu, J.; Zhang, G.; Yang, H. Imperfect resolution of nearfield beamfocusing for NOMA-aided physical-layer security. *IEEE Internet Things J.* **2025**, *12*, 18471–18483. [\[CrossRef\]](#)
14. Ma, L.; Yang, H.; Cai, T.; Yang, Y. RIS-NOMA Networks Under Near-Field: Limited Feedback Design. *IEEE Internet Things J.* **2025**, *12*, 18532–18545. [\[CrossRef\]](#)
15. Kumaradasa, C.; Kumar, D.; Rajatheva, N.; Bhatia, V. On Performance of Hybrid RIS-Aided NOMA Network. In Proceedings of the 2025 IEEE Wireless Communications and Networking Conference (WCNC), Milan, Italy, 24–27 March 2025; pp. 1–6. [\[CrossRef\]](#)
16. Kumaravelu, V.B.; Selvaprabhu, P.; Han, D.S.; Sarker, M.A.; Periyakarupan Gurusamy Sivabalan, V.; Sundarrajan; Jayaraman, T.; Murugadass, A.; Evangeline, C.S. Blind reconfigurable intelligent surface-aided fixed non-orthogonal multiple access for intelligent vehicular networks. *J. Wirel. Commun. Netw.* **2023**, *2023*, 83. [\[CrossRef\]](#)
17. Gevez, Y.; Tek, Y.I.; Basar, E. Dynamic RIS Partitioning in NOMA Systems Using Deep Reinforcement Learning. *Front. Antennas Propag.* **2024**, *2*, 1418412. [\[CrossRef\]](#)
18. Ding, Z.; Schober, R.; Poor, H.V. On the Impact of Phase Shifting Designs on IRS-NOMA. *IEEE Wirel. Commun. Lett.* **2020**, *9*, 1596–1600. [\[CrossRef\]](#)
19. Khaleel, A.; Basar, E. A Novel NOMA Solution with RIS Partitioning. *IEEE J. Sel. Top. Signal Process.* **2022**, *16*, 70–81. [\[CrossRef\]](#)
20. Yang, G.; Xu, X.; Liang, Y.-C. Intelligent Reflecting Surface Assisted Non-Orthogonal Multiple Access. *IEEE Trans. Wirel. Commun.* **2021**, *20*, 1828–1842. [\[CrossRef\]](#)
21. Lei, J.; Mu, X.; Zhang, T.; Liu, Y. RIS Assisted Near-Field NOMA Communications: A Security-Fairness Trade-Off. *IEEE Trans. Veh. Technol.* **2025**, *74*, 11656–11661. [\[CrossRef\]](#)
22. Manikas, A. *Differential Geometry in Array Processing*; Imperial College Press: London, UK, 2004.

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.