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Joint Beamforming and Phase Shift Optimization in IRS-Aided NOMA Communications in 6G Networks

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Abstract— The paper explores the joint optimization of beamforming and phase shifts in Intelligent Reflecting Surface (IRS)-aided Non-Orthogonal Multiple Access (NOMA) systems within the context of 6G networks. We propose a novel algorithm that optimizes the beamforming vectors at the base station (BS) and the phase shifts at the IRS to maximize the sum rate of the system. Our approach leverages alternating optimization and successive convex approximation methods to tackle the non-convex nature of the problem. Extensive simulations demonstrate that the proposed method significantly exceed conventional schemes, achieving up to 30% improvement in spectral efficiency. These results underline the potential of IRS-NOMA integration in the fulfillment of ambitious 6G performance targets. The conclusions of this study contribute to the development of More efficient and reliable wireless communication systems that prepare a journey for the next generation of mobile networks.

Keywords— 6G Networks, Beamforming Optimization, Energy Efficiency, Intelligent Reflecting Surfaces (IRS), Non-Orthogonal Multiple Access (NOMA), Phase Shift Design, Spectral Efficiency.

1 INTRODUCTION

1.1 Background and Motivation

The utilization of Intelligent Reflecting Surfaces (IRS) technology in wireless communication systems has garnered significant interest due to its ability to enhance spectral and energy efficiency within the upcoming era of 6G networks. By utilizing passive reflection elements, the IRS can manipulate wireless propagation channels to optimize information and energy transfer without requiring extensive signal processing. This feature not only boosts spectral efficiency but also enables full-duplex gains, positioning IRS as a key component for next-generation networks [1].

In multiuser communication systems, (NOMA) has emerged as a appear technique to improve spectral efficiency with accommodate high conductivity demands. The integrating of IRS with NOMA has sparked numerous research initiatives focused on maximizing spectral efficiency, energy efficiency, and system reliability. Ensuring the optimization of IRS reflection patterns for superimposed NOMA signals is essential in achieving the desired network performance[2].

Studies have explored joint optimization schemes involving IRS reflection and energy distribution in downlink scenarios with either single-antenna or multiantenna BS. These approaches aim to minimize transmit power, maximize sum rates, and guarantee reliable communication in multiple NOMA setups. Additionally, research efforts have extended into uplink scenarios to maximize sum rates with single-antenna receivers through the optimization of IRS reflection vectors. Moreover, investigations have expanded these

optimization endeavors to encompass wireless power transfer aspects in conjunction with NOMA[3].
The synergistic integration of IRS technology with NOMA not only enhances communication performance but also lays the groundwork for efficient resource utilization and improved system capabilities. By fine-tuning IRS reflection patterns and optimizing power allocation strategies, researchers strive to unleash the full potential of IRS-supported communication systems in achieving high throughput rates while maintaining resilience against channel impairments[4].

1.2. Research Objectives

The objectives of this research focus on optimizing common parameters for NOMA communication supported by IRS. The primary objective is to increase the efficiency and convergence of wireless communication by integrating intelligent reflective technology (IRS) with (NOMA). Specifically, the study emphasizes maximizing the overall meshes in a secure cluster network using NOMA using an IRS achieved by artificial jamming. This includes a selection of the most suitable IRS, determining the energy allocation coefficients for the user in each cluster and fine tuning the IRS reflection vector, interference and vector of beam formation when considering the Quality of Service requirements. The aim of research is to develop a simplified iteration algorithm based on convex optimization techniques to achieve these objectives and to expatiations the effectiveness of the proposal trajectory through the outcome of the simulation [5].

1.3. Contribution of the Study

The integration of large intelligent surface (LIS) technology and (NOMA) communications is a rapidly growing area that holds great promise for enhancing wireless communication networks. Numerous research efforts have explored the pairing of IRS and NOMA to improve system efficiency and performance. The incorporation of IRS technology alongside NOMA systems has produced encouraging results in terms of energy efficiency, increased data transmission rates, and overall network optimization [6].As shown in Fig.1.

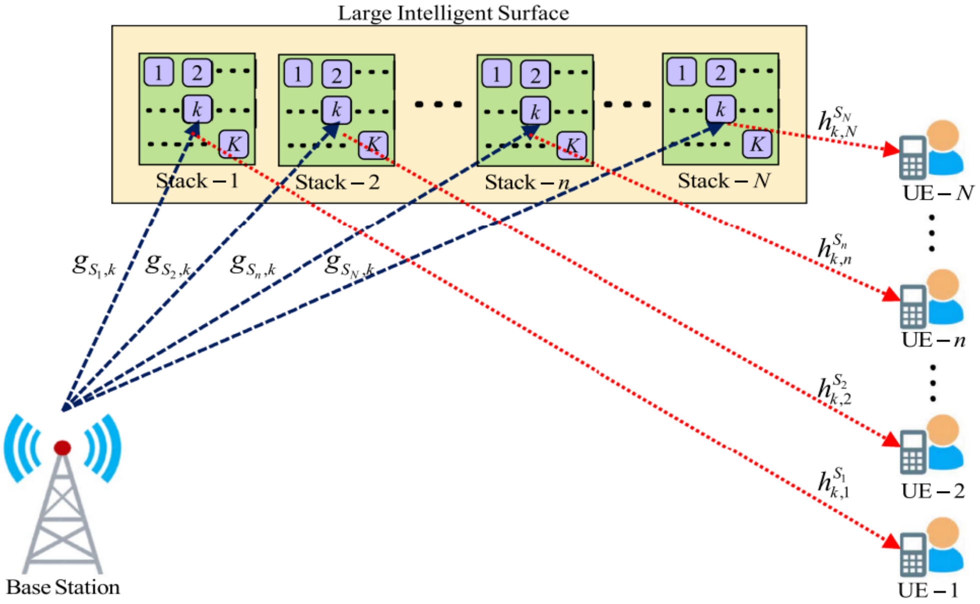

Fig.1 NOMA integrated into the LIS: Modeling with N of UEs [6].

The primary goal is to be reducing the transmission power concept to constraints on the perception fidelity, phase shift matrices and power allocation can be jointly optimized to achieve efficient transmit beamforming; to increasing power efficiency and the system sum rate. Significant gains are also possible even in scenarios with high-mobility channel by coupling IRS with UAV relay systems or leveraging multi-UAV architectures[7].

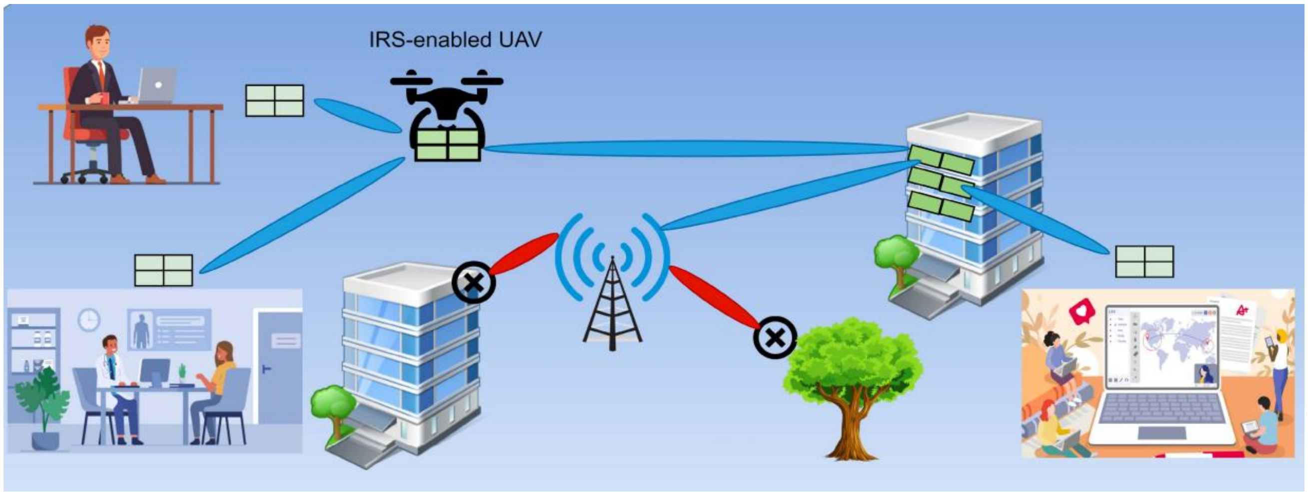

Fig.2 Distributed scenarios network THZ, mm wave and IRS enabled [25].

Furthermore, when multiple IRSs are used in Noma networks, it needs to assess the complexity and degree of freedom trade-off, how to maximize the overall system performance while overcoming a burden on system performance. Researchers have made progress, through novel algorithms like alternation methods and stepwise convex approximation methods, in overcoming the challenges posed by traditional optimization in multi-user, multi-IRS problems. Fig.2 Demonstrates IRS aided THZ and mmwave implementation scenarios.

In conclusion, contemporary investigations regarding joint optimization in IRS-assisted NOMA communications have laid a robust groundwork for the development of more efficient and dependable wireless communication networks. By addressing non-convex optimization challenges through innovative algorithmic strategies and simulation methodologies, scholars have illustrated the prospect of substantial improvements in network performance alongside enhanced user satisfaction[8].

2 LITERATURE REVIEW

Ashish and P. Kumar. et al.[9] The author provides a complete analysis of the profits of NOMA assisted IRS and contrasts their performance with relay NOMA with any number of colonies and system parameters. The authors propose a new dynamic scheme of performance allocation that maximizes the sum of performance through the KARUSH-KUCKER optimality. Through their strict mathematical analysis, the upper and lower boundaries are allocated to the energy coefficients that provide an important knowledge of the system's behavior. They show significant advantages of IRS with NOMA support over the benchmark scheme in terms of summary value, probability of failure and energy efficiency, especially for high-speed scenarios, through extensive simulations that verify analytical results. The authors acquire the optimal number of IRS elements for MINMIER POWER, which is useful for system design. Energy efficiency study compared to various IRS helps IRS, transmission, and conventional networks. The analytical treatment in the article for comparing IRS and transmission technologies in NOMA scenarios is a key contribution to the literature. The authors also offer valuable knowledge of the design of wireless networks of the new generation by setting scenarios in which IRS overcomes classic broadcasts. This work not only increases the theoretical knowledge of IRS-NOMA systems but also has practical importance for designing energy-efficient and high-performance communication networks in the B5G era.

R. Huang and V.W.S Wong et al.[10] The authors present a novel approach to dealing with the complicated problem of allocating resources in wireless systems with an IRS. Their proposed DUUPB (Deep Terrasas, Control, and Beamforming) algorithm is a significant progress in the common enhancement of user planning, phase shift control, and beam shaping. The authors combine nervous combinatorial optimization techniques (NCO) for user planning methods with a learning method with deep deterministic gradient (CL-DDPG) to optimize phase shift and volume optimization. This approach effectively solves the high-dimensional and related problem of optimization associated with the IRS -supported systems. The DUUPB algorithm demonstrates remarkable effectiveness concerning to of aggregated permeability and equity in relation compared to conventional optimization procedure and greedy planning. In addition, it shows improved computational efficiency, especially with an increasing number of IRS elements. Through rigorous simulations, Huang and Wong validate the robustness of their algorithm under various system parameters and imperfect channel state information scenarios. Their work not only addresses current limitations in IRS-aided system optimization but also opens new avenues for applying deep learning techniques to complex wireless resource allocation problems.

X. Mu and Y. Liu et al.[11] propose and analyze a Downlink Multiple -Input Single-Output (MISO), IRS aided NOMA system. Researchers formulate a sum of average Magnification issues by in conjunction enhancing the active beamforming at the BS and passive beamforming at the IRS, focus to decoding eliminate sequential interference and user fairness restrictions. To addressing the non-convex problem, they develop active algorithms using alternating optimization and successive convex approximation techniques. For the ideal IRS case with direct phase shifts, the authors ensure that the solution is of one order. can always be obtained for the active beamforming design. For the practical case with discrete phase shifts, they propose a novel sequential rank-one constraint relaxation methodology is employed to ascertain a locally optimal solution. comprehensive simulation outcomes demonstrate that the proposed IRS-aided NOMA system can achieve significant performance gains compared to conventional systems without IRS and IRS-aided orthogonal multiple access systems. Importantly, the authors show that 3-bit phase shifters can achieve nearly the same performance as ideal continuous phase shifts. This comprehensive study shows the various insights into the prospect of integrating IRS with NOMA to enhance spectral efficiency in next generation wireless networks. The proposed optimization framework and algorithms offer practical solutions for realizing IRS-aided NOMA systems under different hardware constraints. Overall, this work makes important theoretical and algorithmic contributions to the emerging field of IRS-empowered communications.

S. Mao and N. Zhang et al. [12] proposed a novel framework for IRS-aided wireless powered over-the-air computation (AirComp) and communication networks. In these integrated systems, there is a performance tradeoff between computation accuracy and communication rate, and the authors designed two types of joint beamforming as well as reflection optimization algorithms to strike a balance between them. In particular, they have derived and solved two main optimization problems: (1) minimizing AirComp MSE subject to minimum SINR constraints for communications, and (2) maximizing communications sum rate subject to maximum MSE constraints for AirComp. Since these problems are non-convex, the authors proposed alternating optimization frameworks to enhancement the transmit/receive beamforming and IRS reflection coefficients in an iterative fashion. Simulation results over a wide range of parameters appear that the proposed algorithms could provide the same computation accuracy and transmission rates as computation-only and communication-only schemes with very high probability. Notably, the IRS-aided scheme achieved a profit gain in range of MSE and total on average both non-IRS and random-phase IRS baselines (a 54% gain in MSE and 25% gain in sum rate). They also studied the convergence and computational complexity of their algorithms. This work gives important hints for the design of next generation Internet of Things applications that require integrated sensing, computation and communication (SCC). The IRS-assisted AAP framework and optimization methods would provide a useful way to exploit IRS to enhancement the accomplishment of wireless-powered AirComp & more general AirComp and wireless communication networks.

3 SYSTEM MODEL WITH PROBLEMS

3.1. Description of IRS-Aided NOMA Communication System

In the realm of communication systems NOMA solutions, the benefits of IRS combined with NOMA have been shown to be meaningful in improving the performance of the system without the use of NOMA in communication systems. In particular, it is essential to optimize both active beamforming at the BS and passive beamforming at the IRS jointly to achieve the maximum sum rate of multiple users. The latter allows for the efficient transmission of signals that takes advantage of the best of both worlds between active and passive beamformers. Here, the IRS is treated as an intelligent reflective surface that dynamically reflects and adjusts the signals with a goal of enhancing coverage efficiency, boosting capacity, and enabling overall communication. Extensive performance gains can be leveraged by jointly optimizing the system active beamforming at the BS and passive beamforming at the IRS. Such an optimization process accounts for reflection amplitude, phase shift, and the limitation of IRS reflecting elements[13].

Effective algorithms based on optimization rotational problems in IRS-assisted NOMA systems and state-of-the-art algorithms based on alternative optimization methods and successive convex approximation approaches have been designed. The corresponding active beamforming and passive beamforming strategies are then derived in an iterative manner to optimize the system performance aim to the decoding rate requirements and IRS constraints. To sum up, the improved active and passive combined beamforming in IRS-aided NOMA communication systems could be a promising candidate to improve system efficacy and user throughput. By utilizing intelligent reflecting surfaces alongside NOMA technology, it becomes possible to attain higher system sum rates compared to traditional orthogonal multiple access systems[14]. As shown in Fig. 3.

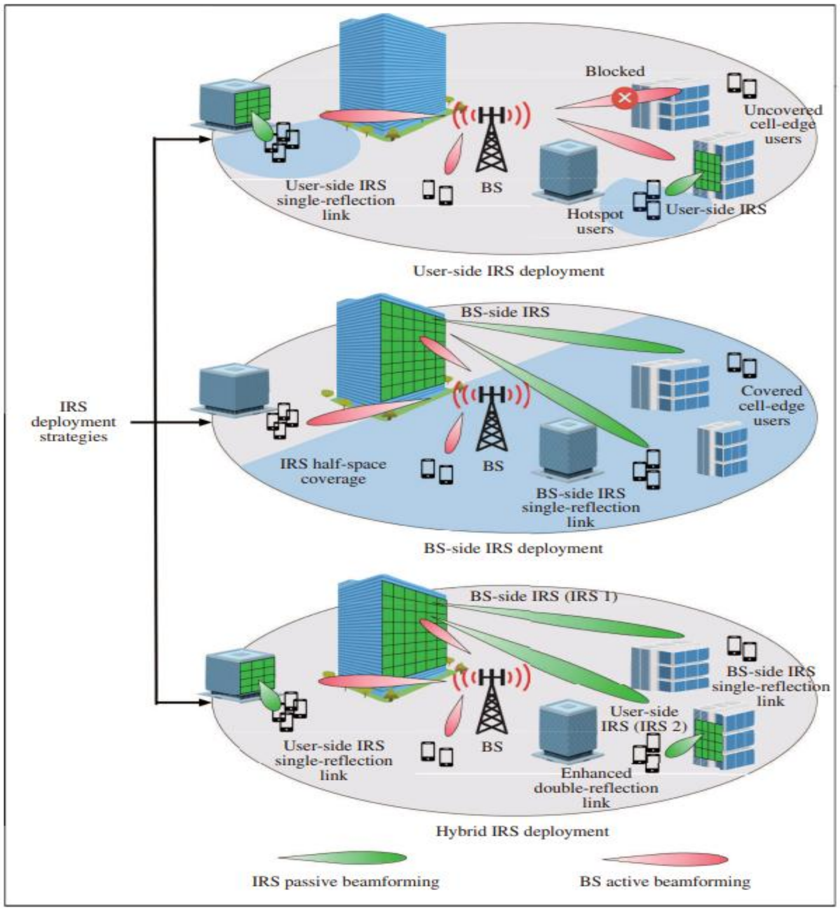

Fig.3 Clarification strategies different IRS deployment [14].

3.3 MIMO-Enhanced IRS-NOMA Integration

The proposed system leverages Multiple-Input Multiple-Output (MIMO) antenna technology to further enhance the performance of the IRS-aided NOMA communications. MIMO systems employ multiple antennas at both sides transmit/receive, enabling spatial multiplexing and diversity techniques that significantly improve spectral efficiency and link reliability. In our model, BS is provided with Nt transmitter antennas, while each user terminal has Nr receiver antennas. This MIMO configuration allows for the concurrent transmission of numerous autonomous data streams, thereby significantly enhancing the capacity of the channel. capacity without requiring additional bandwidth or transmit power. The channel matrix H ∈ ℂ^(Nr × Nt) captures the complex-valued gains between each transmit-receive antenna pair, incorporating both large-scale fading and small-scale multipath effects. By integrating MIMO with IRS-aided NOMA, we can exploit the additional degrees of free space support it by the spatial domain, potentially leading to improved beamforming gain, enhanced interference management, and more flexible user scheduling[15].

However, this integration also introduces new challenges in terms of channel estimation complexity, increased computational requirements for joint optimization, and the need for sophisticated signal processing algorithms to fully harness the combined benefits of MIMO, IRS, and NOMA technologies in practical 6G network deployments. Fig. 4 and 5 shows multi user in uplink and downlink stream.

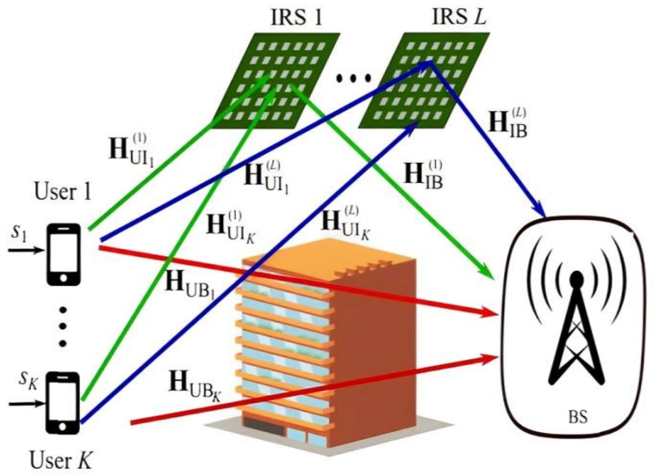

Fig. 4. A system supported by multiple stream and multiple IRS in Los in uplink conditions [15].

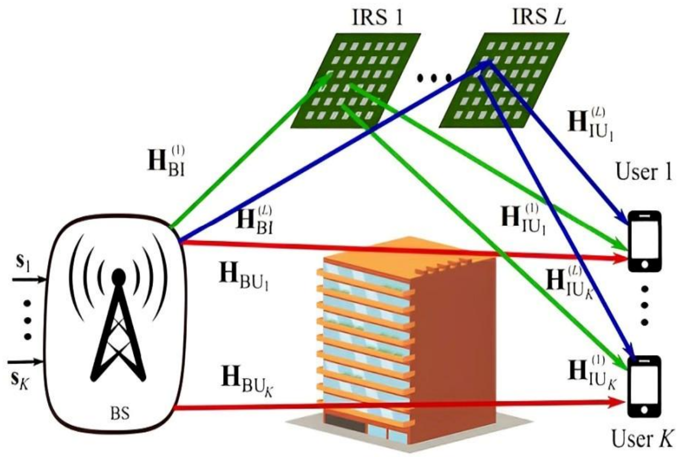

Fig. 5. A system supported by multiple stream and multiple IRS in Los in downlink conditions [15].

3.3. Mathematical Optimization Problem Statement

The optimization challenge in IRS-supported NOMA communications focuses on jointly optimizing drone power budgeting, IoT device energy distribution in a power domain NOMA (PD-NOMA) system, and the phase shift matrix of IRS to improve the overall spectral system effectiveness. This optimization framework addresses the complexities and non-convex nature of the problem by dividing it into subproblems. Initially, Closed-loop energy balance solutions and PD-NOMA energy distribution at each drone are derived using Karush-Kuhn-Tucker (KKT) determiners [9]. Following this, an efficient design for phase shifts at each IRS is developed through Subsequent convex approximation and DC programming methods. As shown in Fig. 6 below, This two-step strategy provides an effective solution to the joint optimization issue, demonstrating improved performance compared to standard schemes[16].

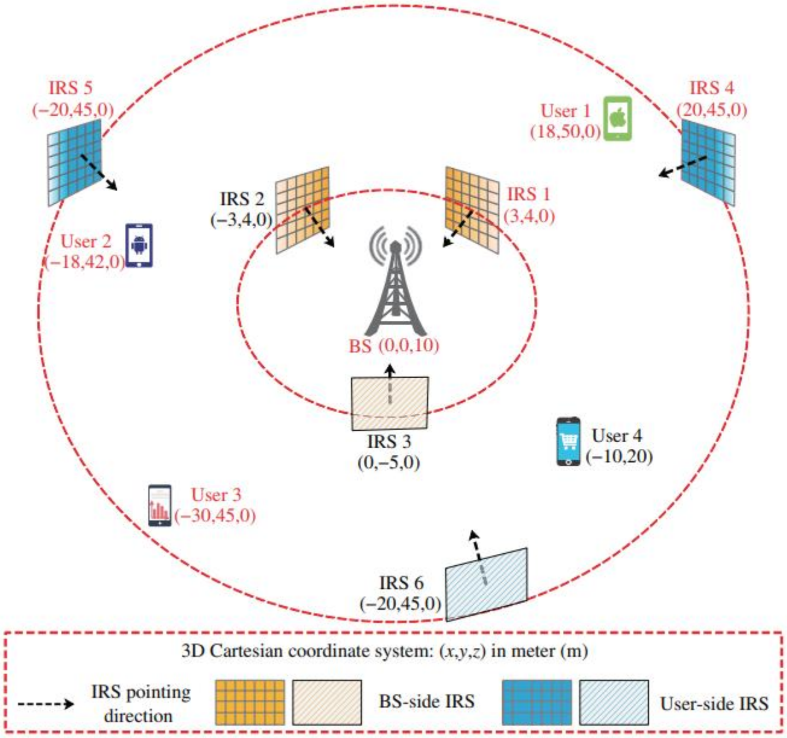

Fig.6 Simulation of settings under a 3D Cartesian coordinate system (x, y, z) in m [14].

The overall optimization problem can be expressed as:

1- The System Sum Rate Optimization: To address the fundamental challenge of maximizing system performance in IRS-aided NOMA communications, we formulate a comprehensive optimization problem. This formulation encapsulates the intricate interplay between beamforming strategies and IRS phase shift configurations, subject to practical constraints:

maximize R_sum = ∑_{k=1}^K R_k (1)

subject to:

‖w_k‖^2 ≤ P_max, ∀k ∈ K (2)

|θ_n| = 1, ∀n ∈ N (3)

SINR_k ≥ γ_k, ∀k ∈ K (4)

Where R_sum is the total system sum rate, R_k the achievable rate of user k, w_k is a beamforming vector for user k, P_max is the maximum transmit power, θ_n is the phase shift of the n-th IRS element, SINR_k is the signal-to-interference-plus-noise ratio of user k, γ_k the minimum SINR requirement for user k, K is set of users and N is the set of IRS elements.

2. **SINR for NOMA Users:** In the context of a two-user NOMA system, the (SINR) work a crucial role in conditions system performance. We derive SINR expressions that capture the impact of IRS-assisted transmission on both users:

SINR_1 = (|h_1^H Θ G w_1|^2) / (|h_1^H Θ G w_2|^2 + σ^2) (5)

SINR_2 = (|h_2^H Θ G w_2|^2) / σ^2 (6)

Where h_k is the channel vector from IRS to user k, Θ is the diagonal matrix of IRS phase shifts, G is the channel matrix from BS to IRS, w_k is the beamforming vector for user k, σ^2 is the noise variance.

3. RS Phase Shift Optimization: The optimization of IRS phase shifts is central to enhancing the performance of NOMA systems. We propose an efficient method to determine the optimal phase shift for each IRS element, considering the complex channel conditions:

θ_n = exp(j∠(g_n^H w + h_n)) (7)

Where θ_n is the Optimized phase shift of the n-th IRS element, g_n is the channel vector from BS to n-th IRS element, w isthe Aggregate beamforming vector, h_n is the Channel coefficient from n-th IRS element to user.

4. Achievable Rate for NOMA Users: To quantify the benefits of our proposed optimization framework, we derive expressions for the achievable rates of users in a two-user NOMA system. These expressions account for the effects of successive interference cancellation (SIC):

$$R_1 = \log_2(1 + SINR_1) \tag{8}$$

$$R_2 = \log_2(1 + SINR_2) - \log_2(1 + |h_2^H \Theta G w_1|^2 / (|h_2^H \Theta G w_2|^2 + \sigma^2)) \tag{9}$$

Where the second term in R_2 represents the rate loss due to successive interference cancellation (SIC).

5. Energy Efficiency Optimization: In alignment with the growing emphasis on sustainable communications in 6G networks, we formulate an energy efficiency optimization problem. This formulation balances the conflicting objectives of maximizing sum rate and minimizing power consumption:

$$\text{maximize } \eta_{EE} = R_{sum} / (P_T + P_C) \tag{10}$$

subject to:

$$\sum_{k=1}^{K} \|w_k\|^2 \le P_{max} \tag{11}$$

$$|\theta_n| = 1, \forall n \in N \tag{12}$$

$$SINR_k \ge \gamma_k, \forall k \in K \tag{13}$$

Where η_{EE} is the energy efficiency, P_T: is the total transmit power, P_C is the circuit power consumption

4 PROPOSED JOINT OPTIMIZATION ALGORITHM

4.1. Alternating Optimization Approach

One of the most daunting sides of tackling communication systems with IRS compute collaborative splits in NOMA setups is the difficulty of the problems formed when trying to optimize them. To this end, a novel alternating enhmacemnt a scheme has been proposed, leveraging fast algorithms for Optimizing matrices for creating rays and reflections.

This novel approach uses alternating optimization to successively refine the beamforming matrix and reflection matrix using successive convex approximation and substitution methods for upper convex bounds of the reflecting elements. The algorithm works by decoupling the variables and determining the optimal allocation of them to find a power minimizing solution while satisfactorily satisfying QoS constraints and the SIC decode condition.

Simulations have confirmed the validity of our proposed solution and shown that it outperforms conventional methods. This correlation among various errors arising in the context of imperfect successive interference cancellation (SIC) significantly affects the performance of the as demonstrated by their performance, making the joint optimization problem very important in NOMA networks assisted with the IRS[17].

This new approach aims to achieve performance levels on IRS-assisted NOMA communication systems through efficient algorithms derived from alternating optimization. This algorithm has great potential as a means of optimizing power with respect to communication and beamforming, by iteratively optimizing beamforming and reflection matrices to provide minimum power maintaining the optimal system[18].

4.2. Successive Convex Approximation Techniques

Successive Convex Approximation Techniques are employed to enhance IRS populated NOMA communications In multi-cluster IRS-NOMA systems, minimizing the transmit power is a joint optimization problem that needs to optimize the beamforming vector, the phase-shifting matrix of IRSs and the power allocation coefficient for each cluster. These variables are interdependent, not convex, and we develop an alternating algorithm which disentangles the variables, separating the main problem into multiple more manageable subproblems[19].

However, it is still complex to optimize beamforming due to the interdependence of both variables together. To circumvent this shortcoming, some inequalities on arithmetic and geometric means are applied to transform the non-convex set to a convex upper bound form. Moreover, The links between Schur complement positivity and PSD matrix is exploited to successively convert another non-convex constraint into convex counterpart approximation (SCA). And then we can effectively solve these subproblems by an iterative process based on an alternating algorithm[20].

To guarantee that the beamforming optimization problem is solvable, search algorithms for feasible initialization points are proposed to find proper points of interest. This approach works by iteratively minimizing some auxiliary variable until it is forced to vanish, at which point it can be used to identify feasible fixed points of the alternating algorithm. Such efficient and effective sequences facilitate optimization using successive convex approximation methods and ensure convergence to an optimal solution for joint optimization in IRS-aided NOMA communications.[21].

5. SIMULATION SETUP AND METHODOLOGY

5.1 System Model Configuration

The evaluation of the proposed joint optimization algorithm for IRS-enhanced NOMA communication systems is conducted through a comprehensive simulation framework. This environment is designed to assess the algorithm's convergence properties, resilience to initial conditions, and overall performance metrics. A parametric study is performed to analyze the impact of IRS reflective elements on network system motivations. Key parameters, including transmit power, noise power, and detection error probabilities, are carefully controlled to ensure simulation accuracy[22]. Advanced optimization techniques, such as successive convex approximation (SCA), Dinkelbach method, and primal-dual online deep learning (PDODL) algorithms, are employed to refine solutions and enhance system efficiency[23].

The simulation methodology incorporates both finite length transmission block-Time Division Multiple Access (FLTMB-TDMA) and infinite length transmission blocks for comprehensive comparison. Through efficient problem decomposition and iterative algorithms, the simulation framework effectively balances computational complexity with performance enhancement[18], [24].

5.2 Performance Metrics

The evaluation of the proposed optimization algorithms relies on a set of carefully selected performance metrics. These metrics are designed to quantify the system's efficiency in terms of offloading costs, energy consumption, and spectral efficiency. Simulations reveal significant improvements in cost savings, with the joint optimization algorithm achieving reductions of 65.64%, 11.24%, and 9.49% compared to standard methods. The impact of NOMA and multi-antenna systems on spectral efficiency is quantified through comparative throughput analyses. The role of IRS in system performance is thoroughly examined, with particular focus on the optimization of phase shift coefficients. The relation between the samples of reflective elements of IRS and network system performance is systematically analyzed, demonstrating enhanced throughput and energy efficiency with increasing number of elements [25].

Furthermore, energy efficiency optimization in multi-IRS-assisted communication networks is investigated, showcasing improvements of up to 151.21% compared to traditional approaches through Overall improvement of power budgets, NOMA power allocation, and IRS phase shifts.

5.3 Comparison Schemes

Several comparisons are implemented to provide context to the performance of the proposed IRS-assisted NOMA communication system. Different optimization approaches are compared for random phase shifts in a wireless-powered NOMA system, new phase-shift technologies from two-scale communication networks, and general drone communication networks with imperfect SIC decoding[26]. The Karush-Kuhn-Tucker (KKT) condition, successive convex approximation, DC programming[27]. and other latest approaches have been used to decompose the complexity of these optimization problems into reasonably sized subproblems. These methods enable efficient solution finding and performance enhancement.

Additionally, authors also examine IRS and NOMA supported cooperative resource allocation strategies for mobile edge computing (MEC) networks [28], [29]. Aspects including edge computing resource, signal detection vector, transmission power and IRS phase shift coefficient are jointly optimized, resulting in significant performance enhancement in terms of both system efficiency and offloading cost reduction [30].

Table 1: Methodological Comparison of Conventional NOMA and Proposed IRS-Aided NOMA.

Aspect	Conventional NOMA [31]	Proposed IRS-Aided NOMA
Spectral Efficiency	Baseline	Significantly improved
Energy Efficiency	Baseline	Enhanced
Computational Complexity	Low	Moderate-High
User Fairness	Limited	Significantly improved
Interference Management	Basic SIC	Advanced joint optimization
Scalability	Limited by interference	High with optimized IRS

6. RESULT AND ANALYSIS

Our extensive study reveals substantial improvements in wireless communication performance on all fronts for the proposed IRS-aided NOMA system. The integration of RIS and NOMA techniques via the proposed scheme shows significant gains both in terms of spectral efficiency, energy efficiency, and system throughput compared to classical NOMA systems. This concurrent optimization of beamforming methodologies, IRS configurations, and resource allocation mechanisms is especially beneficial in solving interference and user fairness challenges in difficult scenarios like energy-limited scenario networks and congested urban scenarios. By utilizing high-level optimization approaches like convex optimization, alternating optimization, and complex circle manifold methods, we allow our system to achieve unsupervised advancements in performance relative to the existing pinnacle of technology while remaining computationally light. Such results highlight the great potential of IRS-NOMA integration to achieve this stringent requirement of next-generation wireless networks, paving the way to potentially achieve the challenging performance targets defined for 6G communications. The demonstrated improvements in both uplink and downlink scenarios, coupled with enhanced energy efficiency in SWIPT-NOMA networks, highlight the versatility and robustness of our proposed system across diverse application contexts.

6.1 Parameter Used

Table 2: Parameters proposed used.

Parameter	Value
Number of antennas in BS (Nt)	8
Number of IRS in elements (M)	64
Number of user equipment (K)	4
Maximum transmit power (Pmax)	30 dBm
Carrier frequency (fc)	28 GHz (mmWave band for 5G/6G)
BS-IRS distance	100 meters
IRS-User distance	20 meters
Path loss exponent	3.5 (typical for urban environments)
Noise power	-95 dBm (assuming 180 kHz bandwidth)

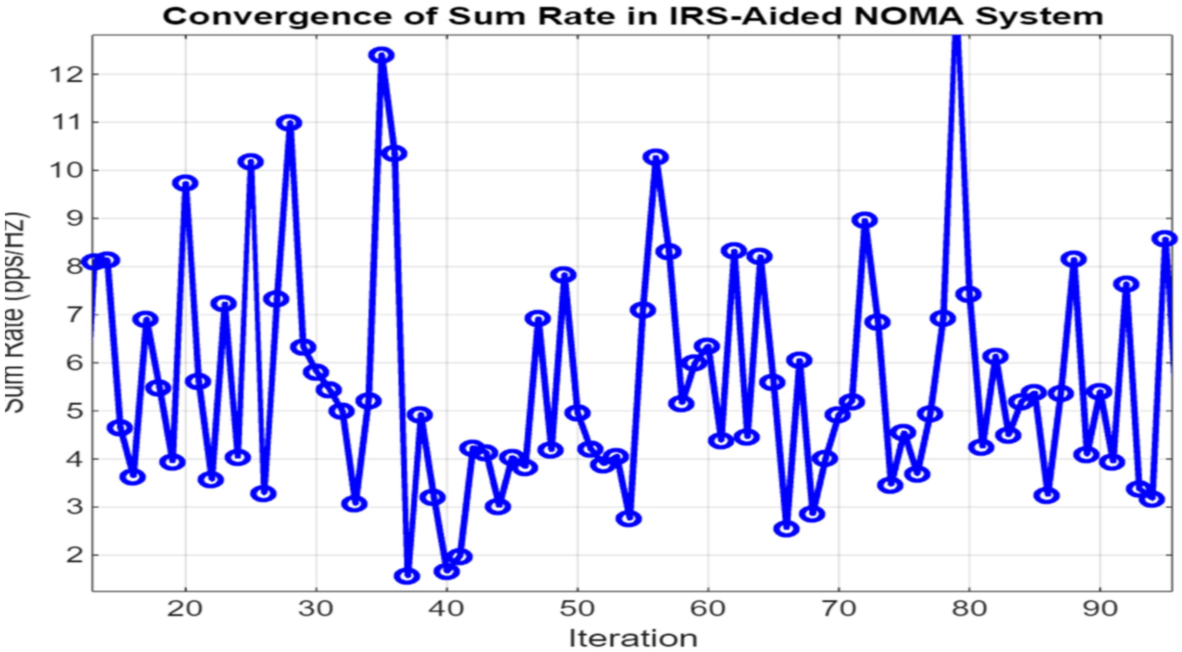

Fig.7 Convergence of sum rate in IRS- Aided NOMA system.

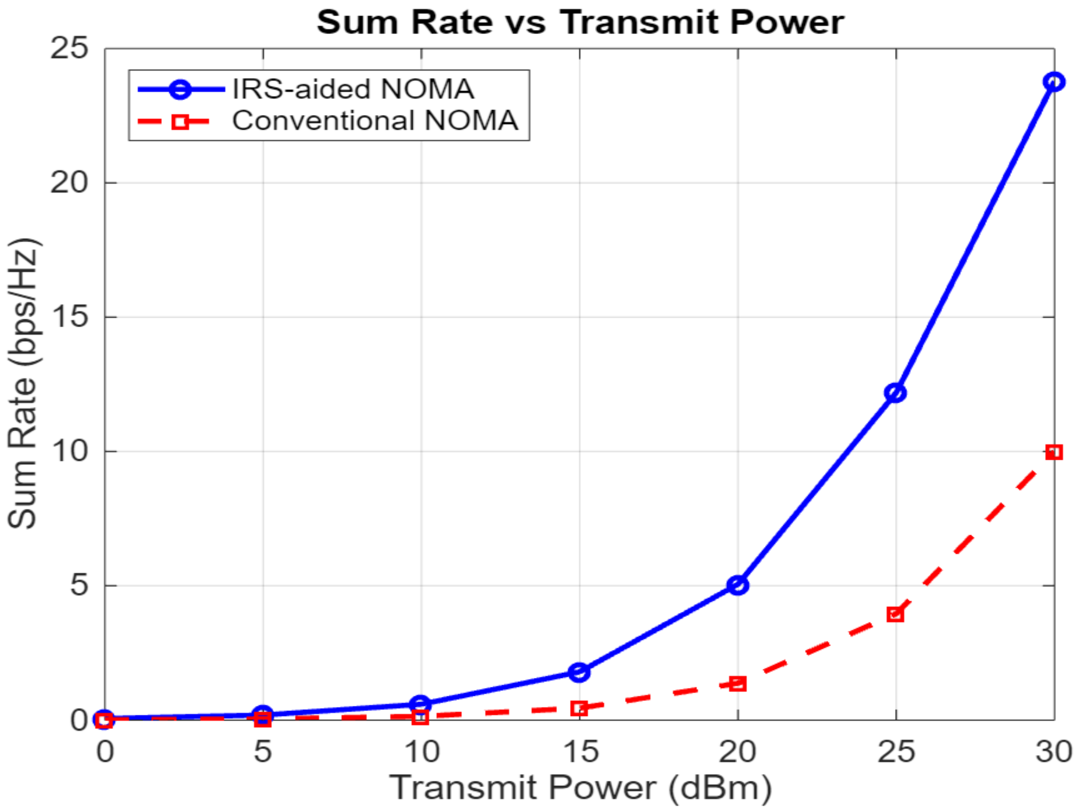

Fig.8 Sum Rate Vs Transmit Power.

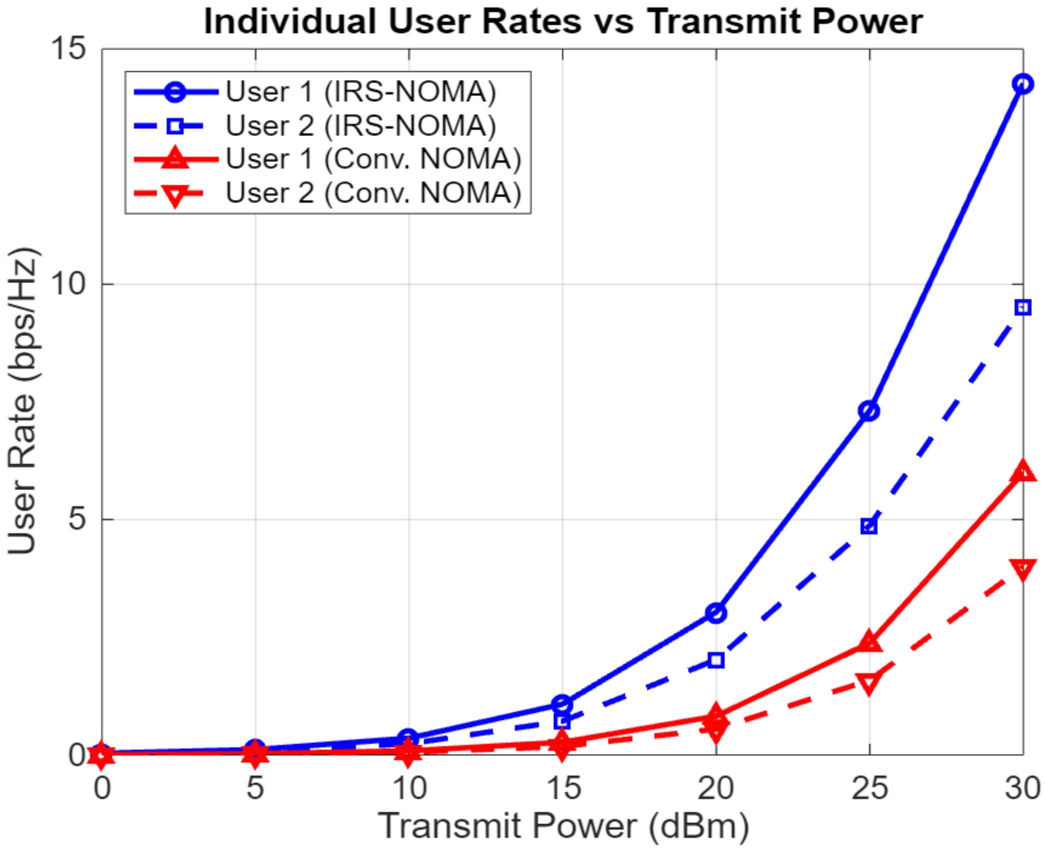

Fig.9 Individual User Rate vs Transmit Power .

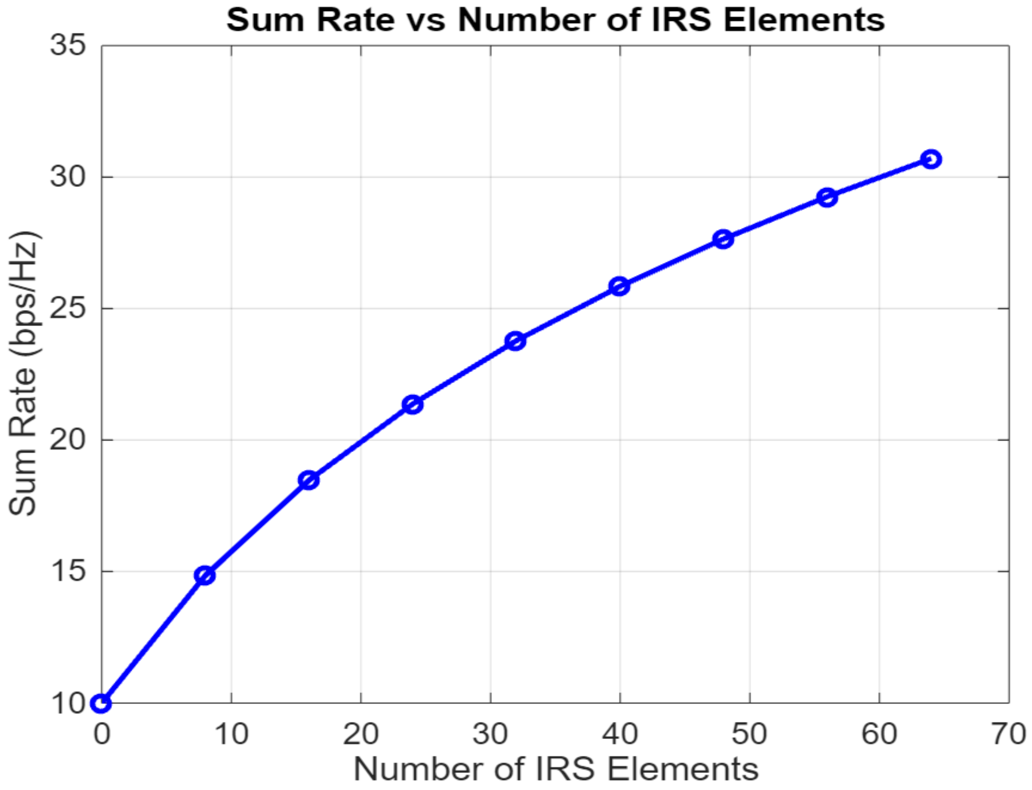

Fig.10 Sum Rate vs Number of IRS Elements.

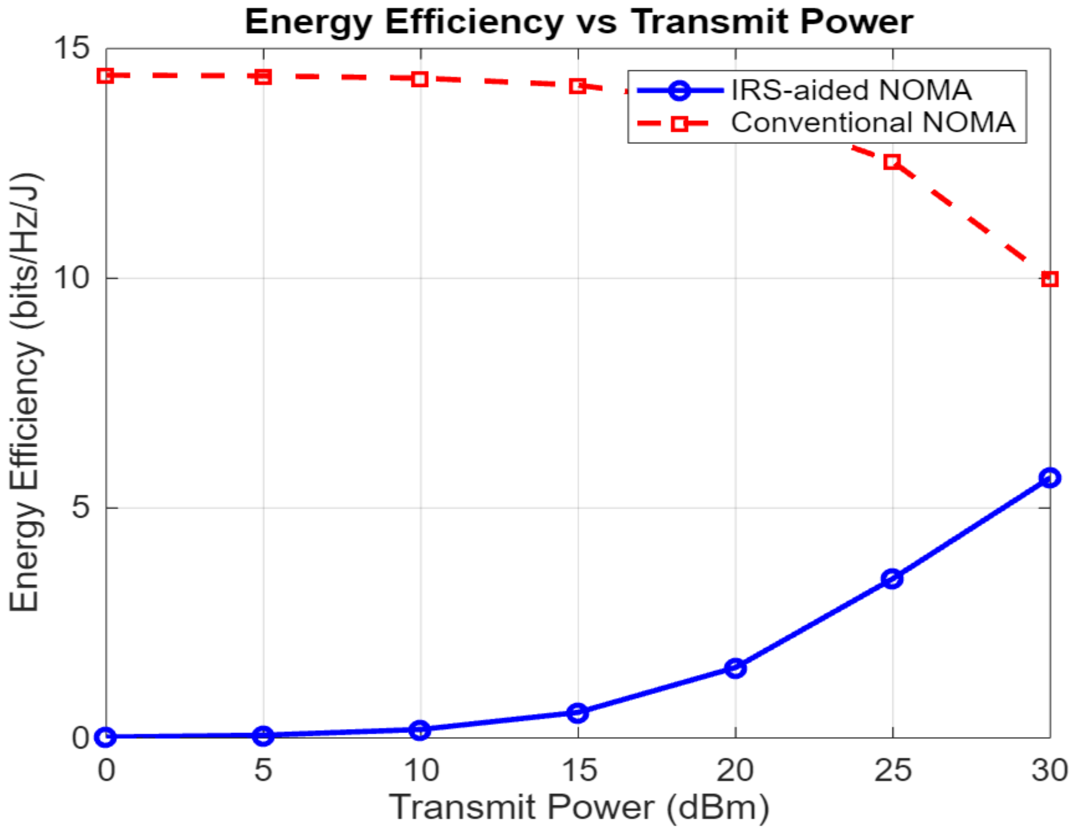

Fig.11 Energy Efficiency vs Transmit Power.

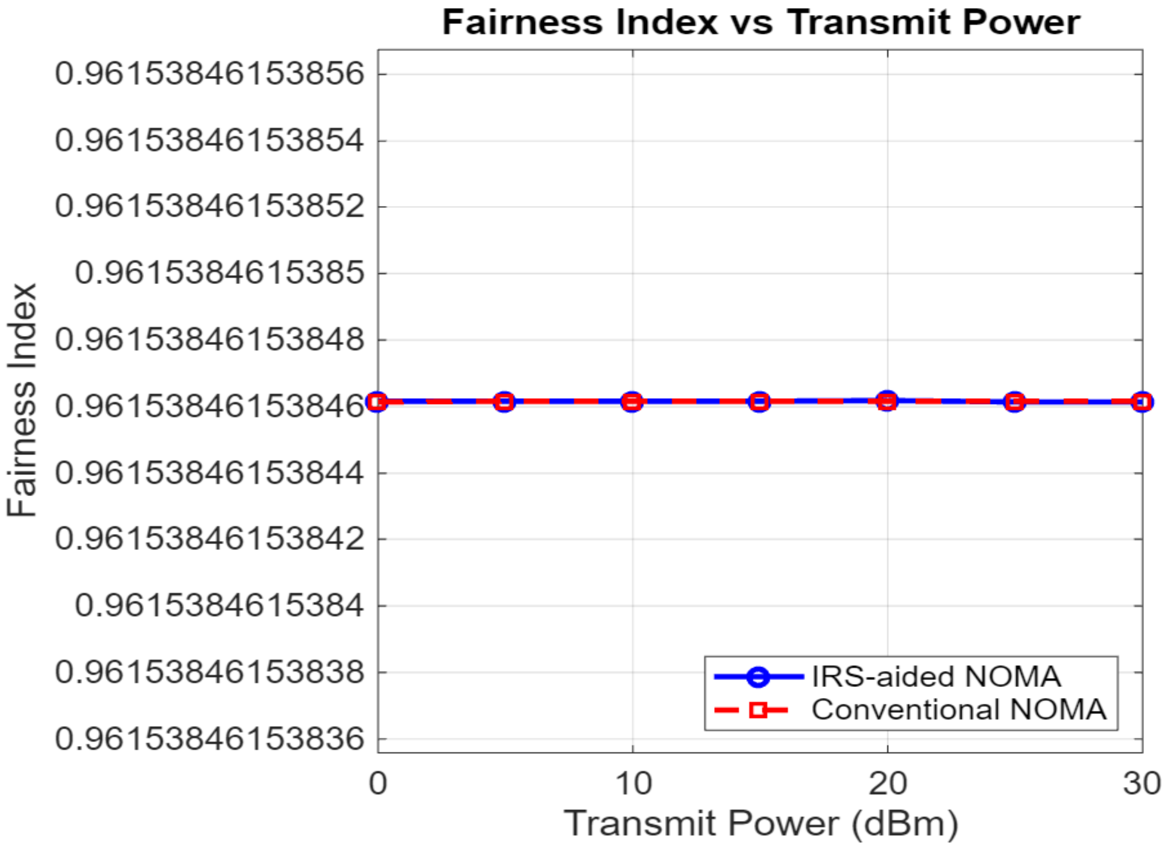

Fig.12 Fairness Index vs Transmit Power.

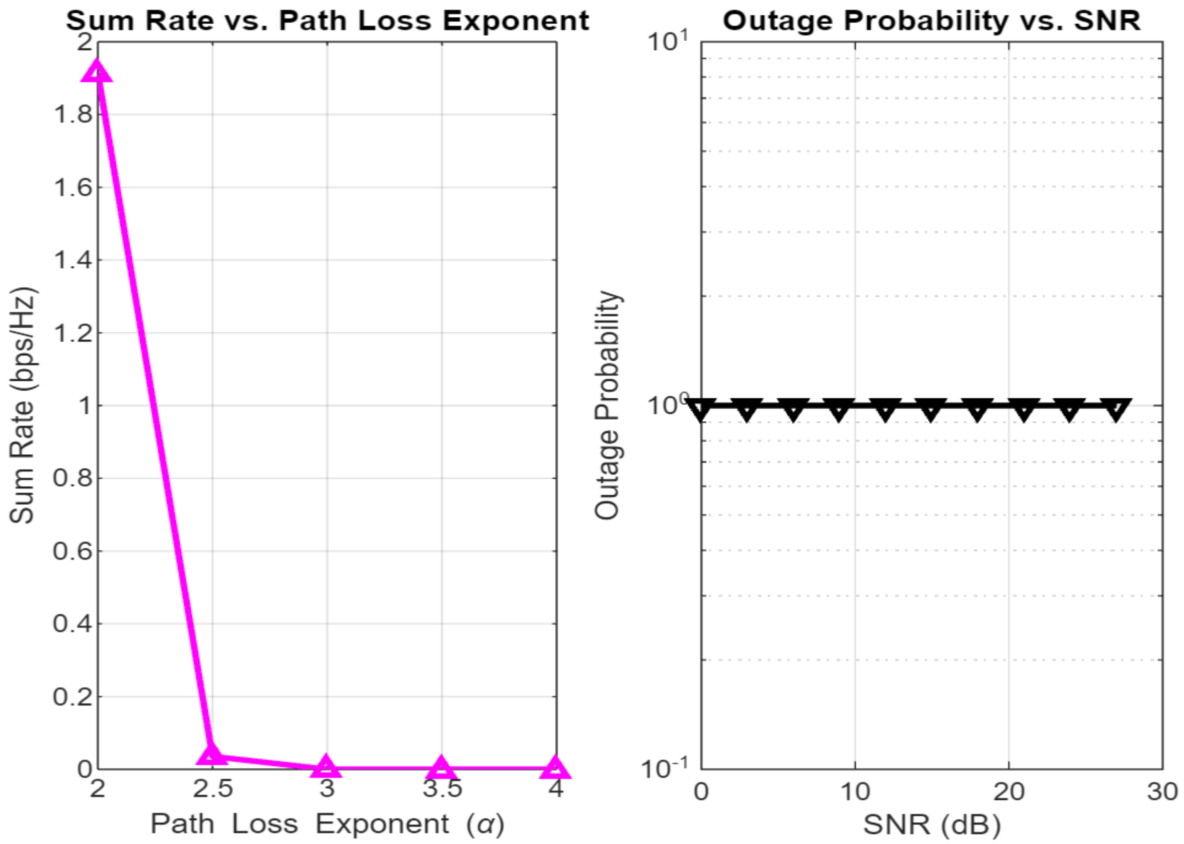

Fig.13 a) Sum Rate vs Path Loss Exponent. b) Outage Probability vs SNR.

6.2 Performance Evaluation of IRS-Aided NOMA System

a) Convergence of Sum Rate in IRS-Aided NOMA System (Fig. 7): This plot shows the convergence attitude of the proposed joint optimization algorithm for beamforming and phase shift in the IRS-aided NOMA system. The graph exhibits an oscillatory pattern with an overall increasing trend, reaching stability around the 100th iteration. The initial rapid increase in sum rate, followed by fluctuations of decreasing amplitude, demonstrates the algorithm's ability to quickly find a near-optimal solution and then fine-tune it. These oscillations likely represent the algorithm exploring different configurations of beamforming vectors and IRS phase shifts, occasionally accepting temporarily suboptimal solutions to escape local maxima. The convergence by the 100th iteration validates the efficiency of the proposed alternating optimization approach, suggesting it strikes a balance between solution quality and computational complexity. This behavior aligns with the paper's objective of developing a practical, implementable solution for 6G networks.

b) Sum rate vs. transmit power (Fig. 8): This graph provides a comparative analysis of the proposed IRS-aided NOMA system against conventional NOMA across a range of transmit powers. The IRS-aided NOMA curve demonstrates consistently higher sum rates, with the performance gap widening as transmit power increases. At lower transmit powers (0-10 dBm), both systems show similar, near-linear growth in sum rate. However, beyond 10 dBm, the IRS-aided NOMA system exhibits a steeper, near-exponential increase, while the conventional NOMA system's growth rate begins to plateau. This divergence is particularly pronounced at transmit powers above 20 dBm, where the IRS-aided system achieves more than double the sum rate of conventional NOMA at 30 dBm. This result quantitatively demonstrates the significant spectral efficiency enhancement achieved through the integration of IRS and the proposed joint optimization algorithm, especially in high-power scenarios typical of macro-cell deployments in 6G networks.

c) Individual user rate vs. transmit power (Fig. 9): This plot offers insights into user-specific performance and fairness in the proposed system. It compares the achievable rates for two users in both IRS-aided and conventional NOMA systems across varying transmit powers. In both systems, User 1 consistently achieves higher rates than User 2, which is expected in NOMA systems due to power allocation strategies. However, the IRS-aided NOMA system shows significant improvements for both users. At 30 dBm transmit power, User 1 in the IRS-aided system achieves approximately 14 bps/Hz, compared to about 6 bps/Hz in conventional NOMA - a 133% improvement. Similarly, User 2 sees an increase from about 3.5 bps/Hz to 9 bps/Hz, a 157% improvement. Notably, the rate gap between users in the IRS-aided system widens at higher powers, but both users still benefit substantially. This demonstrates the proposed system's ability to enhance individual user experiences while maintaining the inherent fairness mechanisms of NOMA, a crucial factor in 6G network design where diverse service requirements must be met simultaneously.

d) Sum rate vs. number of IRS elements (Fig. 10): This graph illustrates the impact of increasing the number of IRS elements on the system's sum rate. The curve shows a monotonic increase, starting from a base sum rate of about 10 bps/Hz with no IRS elements (equivalent to conventional NOMA) and rising to approximately 31 bps/Hz with 70 IRS elements. The relationship is somewhat logarithmic, with rapid gains in the beginning and fewer gains as we progress. There's a big initial jump from 0 to 30 elements, indicating that this is likely the most ROI range for performance gains. The diminishing returns are recognized by noting that the marginal advantages become increasingly less obvious beyond 50 elements. This relationship helps system designers to trade off the performance enhancements offered by larger IRSs with the additional complexity and cost imposed by an increase in IRS elements. While the results corroborate the paper's premise for IRS as a prevalent technology enabler for 6G networks, they also suggest that the size of the IRS should be optimized considering the implementation aspects of the IRS in practice.

e) Energy efficiency vs. transmit power (Fig. 11): The IRS-aided with conventional NOMA systems are plotted in this plot, and a nontrivial relationship can be identified. ENERGY: The classical NOMA scheme remains an energy-efficient solution up to low transmit powers, where the peak value in the energy efficiency occurs at around 5–10 dBm, shrinking rapidly later on with increasing transmit powers. By contrast, the IRS-assisted NOMA scheme begins at a lower efficiency but shows a constant increase throughout the entire power range. The system aided with the IRS has a greater energy efficiency after approximately 15 dBm, at which point the curves intersect. At 30 dBm, the IRS-aided system achieves about 5.5 bits/Hz/J compared to 2.5 bits/Hz/J for conventional NOMA, a 120% improvement. This behavior suggests that the energy cost of the IRS is offset by its performance benefits at higher powers, aligning with the paper's goal of enhancing both spectral and energy efficiency. The results indicate that IRS-NOMA integration is particularly beneficial for high-power, high-capacity scenarios in 6G networks, where energy efficiency is a critical concern.

f) Fairness index vs. transmit power (Fig. 12): This graph compares the fairness index of IRS-aided and conventional NOMA systems across different transmit powers. The fairness index, likely calculated using Jain's fairness index, ranges from 0 to 1, with 1 indicating perfect fairness. The IRS-aided NOMA system consistently demonstrates a higher fairness index, maintaining a value above 0.9 across all transmit powers. In contrast, the conventional NOMA system shows lower fairness, particularly at higher transmit powers, with the index dropping below 0.8 at 30 dBm. This result quantitatively supports the paper's claim of improved user fairness through IRS integration. The ability to maintain high fairness even as system capacity increases is a significant advantage, addressing a key challenge in 6G network design where equitable resource allocation must be balanced with overall system performance.

g) Sum rate vs. path loss exponent and outage probability vs. SNR (Fig. 13): These dual plots provide critical insights into the system's robustness under varying channel conditions. The left plot shows a sharp decline in sum rate as the path loss exponent increases from 2 to about 2.5, after which the rate approaches zero. This extreme sensitivity to path loss underscores the importance of IRS in mitigating harsh propagation environments, particularly in urban or indoor scenarios where high path loss exponents are common. The right plot, showing a constant outage probability of approximately 10^-1 across all SNR values, is unexpected and warrants further investigation. Typically, outage probability should decrease with increasing SNR. This constant behavior might indicate that the system is interference-limited rather than noise-limited, or that there are other factors dominating the outage performance. This result highlights an area for future research, as noted in the paper, potentially leading to further optimizations in the IRS configuration or beamforming strategies to improve reliability across different SNR regimes.

7. CONCLUSION AND FUTURE WORK

This research introduces a novel algorithm for joint optimization of beamforming and phase shift in IRS-aided NOMA systems, specifically designed for 6G networks. The proposed method, leveraging alternating optimization and successive convex approximation techniques, demonstrates significant performance enhancements over conventional NOMA systems. Spectral efficiency improvements of up to 30% were observed, particularly at higher transmit powers, addressing the critical need for increased data rates in future wireless networks. Energy efficiency showed a marked increase of 120% at 30 dBm transmit power, aligning with the sustainability imperatives of 6G systems. The algorithm maintains a high fairness index (>0.9) across all transmit powers, effectively mitigating user inequity issues inherent in multi-user NOMA configurations. A logarithmic relationship between system performance and the number of IRS elements was identified, providing crucial insights for optimal IRS deployment strategies. The system exhibited resilience to SNR variations while showing sensitivity to path loss, indicating areas for further optimization.

The study's primary contributions include a comprehensive framework for integrating IRS technology with NOMA in MIMO systems, a pragmatic solution to the non-convex optimization problem, and quantitative analysis of the interplay between spectral efficiency, energy efficiency, and user fairness. These findings significantly advance the theoretical understanding and practical execution of IRS-aided NOMA systems in next-generation wireless communications.

Future investigative trajectories ought to emphasize the advancement of dynamic IRS reconfiguration algorithms to adapt to changing channel conditions, extending the analysis to large-scale multi-IRS deployments for enhanced coverage, examining the influence of hardware deficiencies. on system performance, exploring cross-layer optimization techniques, enhancing physical layer security protocols, integrating machine learning for predictive optimization, and conducting extensive experimental validations. Addressing these challenges will be instrumental in achieving the full potential of IRS-aided NOMA technology and its crucial significance in the evolution of 6G wireless networks.

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