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Spectral Efficiency Enhancement for Reconfigurable Intelligent Surface Assisted MIMO System

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Abstract

Reconfigurable intelligent surfaces (RISs) have emerged as promising contenders for enabling sixth-generation (6G) physical wireless platforms. RISs fine-tune wireless networks to optimize the spectrum and energy use. This article explores the design challenge of a joint beamforming strategy for increasing throughput at the Access Point (AP) and RIS. This challenging problem is addressing through creating an iterative algorithm that applied the Duality Theory and the Alternative Optimization technique called the Duality Alternating Optimization (DAO) algorithm. The joint beamforming design challenge is established for the proposed network to maximize all User Equipment (UEs) throughput. Additionally, the study offers a collaborative beamforming system to address the formulated challenge. Due to the raising issues including non-convexity and difficulty with variable coupling, the proposed Algorithm divides the optimization problem of the coupled variables into four distinct optimization sub-problems by introducing new supporting variables. The alternative optimization strategy handles the issue sequentially by iteratively updating these new variables, the active beamformer, and the passive beamformer. Finally, the simulation results indicate that the study achieved about a 30% spectrum boost over the standard network without RIS for a certain system

Keywords: 6G networks, active/ non-active beamforming, Reconfigurable intelligent surfaces (RISs), non-convex optimization problems.

الخلاصة:. ظهرت الاسطح الذكية القابلة لاعادة الهيكلة كتقنية واعدة لتمكين الجيل السادس من الاتصالات اللاسلكية، حيث يتم استخدام هذه الاسطح لتحسين كلا من كفاءة الطيف والطاقة. هذا البحث يناقش مشاكل التصميم الخاصة بتشكيل الحزمة التي تساعد في زيادة معدل ارسال البيانات لكلا من الاسطح الذكية ونقاط الوصول على حد سواء. تم تطوير خوارزمية تكرارية قليلة التعقيد لمعالجة هذه المشكلة الصعبة الغير خطية، حيث يتم استخدام نظرية التماثل مع تقنية النمذجة بالتبادل، سميت هذا الخوارزمية بـ DAO. نظرا لكون هذه المشكلة غير خطية وذات متغيرات مقترنة معا لذلك تم تقسيم خوارزمية التحسين المقترحة الى اربعة مسائل ثانوية باستخدام متغيرات جديدة كعامل مساعد. حيث تتعامل ستتراتيجية التحسين التكرارية مع المشكلة بالتسلسل من خلال التحديث المتكرر للمتغيرات الجديدة و تشكيل الحزمة النشطة والغير نشطة. تشير نتائج المحاكاة الى تحقيق زيادة في كفاءة الطيف الكهرومغناطيسي بنسبة ٣٠% تقريبا مقارنة بالنظام القياسي الخالي من الاسطح الذكية لضروف عمل معينة للنظام.

1. INTRODUCTION

Numerous novel solutions have been proposed to address the requirement for a huge increase in network capacity during the next decade, including "Multiple-Input Multiple-Output" (MIMO) networking, "millimeter-wave" (mmWave) networking, and ultra-dense networks [1]–[3]. Nevertheless, the power usage and hardware cost have increased significantly for using these technologies. As a result of the substantial power-hungry Radio Frequency, (RF) chains recovered the network systems that employed MIMO and mm-Wave technologies in ultra-dense networks [4], [5]. This challenge is addressed through presenting unique technology termed RIS which is a potential power solution for cost-effectiveness to enhance the characteristics of wireless systems [6]–[9]. RIS is a relatively new hardware technology that has the potential ability to significantly reduce energy consumption [10],

[11]. RIS is a programmable flat surface containing a large number of small metallic patch elements. The RIS element is dipoles that are simply produced and independent digital controlled to modulate the incident signals reflection amplitudes, phases, polarization, and frequency responses [12]. When the RIS is used appropriately, it can consume significantly less energy than standard Amplify-and-Forward (AF) relays [13].

The following sections highlight the primary benefits of including RIS in future wireless networks. Firstly, each metallic patch unit can synchronously adjust its reflecting coefficients via an intelligent controller which allows additional desirable and interfering signals constructively and destructively to the intended UE respectively [14], [15]. For example, [16] demonstrated that the received Signal-to-Noise Ratio (SNR) grows quadratically with the RIS reflective elements number when one RIS-aided system is deployed which is commonly identified as the squared power gain. In multiple UEs networks, interference between UEs can be notably reduced by enhancing the AP /RIS beamforming concurrently. Secondly, due to the modest structure size of a metal patch unit, a standard RIS can connect massive metallic patch units which leads to substantial beamforming gain for system performance enhancement. Next, as each unit contains components such as Positive-Intrinsic-Negative (PIN) diodes [17], and "varactor diodes", it is possible to implement either discrete or continuous RIS phase control. Thus, RIS consumes significantly less energy than an active antenna with an RF chain. Based on the advantages mentioned above, more effort has been expended on developing RIS in wireless systems. Several studies using RIS are conducted in various fields including channel estimation, joint RIS beamforming, and AP transmit beamforming optimization. In [18] the authors presented a novel method for optimizing the energy efficiency of a multiuser Multiple-Input Single-Output" (MISO) system by adjusting the APs transmitted power and the phase shifts reflector of the RIS. A RIS-assisted single-cell cellular system was investigated in [16], the authors sought to minimize transmitting power at the AP by enhancing AP/RIS beamforming which assumes that the RIS phase shifts may be modified constantly. The authors of [19] used deep reinforcement learning to examine the joint design of AP/RIS beamforming. In [20], the authors discussed how RIS-assisted joint processing coordinated multipoint transmission from various AP to aid the lowest achievable rate of numerous cell-edge UEs. The mean-square error technique is used to transform the max-min formula (a non-convex problem) into a convex equivalent procedure which simplifies the task of an efficient near-optimal iterative algorithm.

The current study aims to tackle the complex challenge of joint beamforming scheme design regarding throughput improvement at the AP and RIS levels. Consequently, the main objective is to enhance the RISs reflection-beamforming, as well as AP-transmission beamforming to maximize channel throughput while adhering to the total power constraint. Unlike [20], which relies on "mean-square error" and the sub-gradient method, our suggested algorithm uses Duality Theory[1] and Quadratic forms. The following outlines the contributions to the paper:

- This paper discusses the downlink of a wireless network. A multiple-AP antenna connects with the UE of a single antenna via a RIS with a phase-shifted broadcast signal. A RIS's reflection beamforming is utilized through intelligent surfaces with a finite reflecting element.
- The study recommends optimizing the AP/RIS beamforming to increase channel throughput. The joint beamforming design challenge is established for the proposed network to maximize all UEs' throughput. Additionally, the study offers a collaborative beamforming system to address the formulated challenge prompted by the solutions mentioned in ref. [21].
- The study employs the Duality Theory and the Quadratic function in the suggested approach to decouple the joint beamforming design. The throughput will then converge to a locally optimal solution.

This paper was organized as follows: Section 1 is the introduction. Section 2 describes the multiuser MIMO system with programmable RIS constructions and the targeted channel throughput challenge formulation. In Section 3 proposed Algorithm for beamforming design is developed. Section 4 discusses the simulation results. The conclusion of the work is done in Section 5.

Notations**:** The capital letters like (M,…, N) denote scalar constants. Small latter like (k,…..r)) denote scalar variables. Vectors are represented by bold small latter like (**h)**, where the $\mathbf{h}_k$ means the kth element of **h.** Capital bold latter implies matrix-like **F.** Diag $(\cdot)$ denotes the diagonal operation**.** We use tr(.), $(.)^H$ indicates the matrixes' trace and conjugate transpose (Hermitian), respectively. As well as we use $\mathbb{C}$, Rel, $\otimes$, R denote for complex, real number, and Kronecker product, real matrix respectively.

[1] A theorem regarding the connection between the results of primal and dual linear-optimization problems.

2. SYSTEM MODEL AND FORMULATION OF THE PROBLEM

This study examines a RIS-assisted multiuser multiple antennas wireless system, as illustrated in Fig (1), which comprises |Ap| numbers of APs equipped with M antenna components to service the downlink of K- UEs with a single antenna. The AP is aided by R numbers of RIS, and each contains N reflective elements. The direct path to the K-th user is expressed through a channel matrix with complex vectors, $\mathbf{F}_{a,k} \in \mathbb{C}^{N\times K}$. $\mathbf{h}_{r,k} \in \mathbb{C}^{N\times 1}$ denotes the surface-UE path, and $\mathbf{G}_{a,r} \in \mathbb{C}^{M\times N}$ is the MIMO AP-RIS links channel matrix[2]. Diagonal matrix $\mathbf{\Phi}_r \in \mathbb{C}^{N\times N}$ is received signal phase shift at the RIS, where $\mathbf{\Phi}_r = \sqrt{\eta}$ diag $(\Phi_{r1},\ldots \Phi_{rn})$, $\forall r \in R$. The reflection amplitude of an element can theoretically be modified for various purposes including performance optimization and channel acquisition [22]. However, practically it is too expensive to contemplate an independent controller of the phase shift and amplitude of the reflection concurrently. An individual element is often considered to maximize signal reflection for simplicity's sake. The study assumes discrete-value (finite-number) phase shifts for the RIS's element phase shifts to facilitate practical implementation. If the study employs b-bits[3] to characterize the phase-shift levels, then the number of these levels will be 2^b [23]. Assuming that the discrete phase-shift levels in the range $[0; 2\pi]$ are uniformly quantized for simplicity. Finally, , the discrete phase shift values set will be as follows at each RIS element [24],

$$\boldsymbol{\Phi}_{r,n} \in \left\{0, \frac{\pi}{2^{b-1}}, \ldots, (2^b - 1)\frac{\pi}{2^{b-1}}\right\}, \quad \forall \mathrm{r} \in \mathrm{R}, \forall \mathrm{n} \in \mathrm{N}$$

at the AP, the transmitted baseband symbols are represented as follows [23] , [15],

$$\mathrm{x} = \sum_{k=1}^{K} \mathbf{V}_{a,k} \mathrm{S}_k \tag{1}$$

where S_k is the transmitted symbol to the k-th user (k=1, …. K) , and $\mathbf{V}_{a,k}$ is a baseband beamformer vector for the k-th user, $\mathbf{V}_{a,k} \in \mathbb{C}^{M\times K}$ for m=1, ... M. The received signal at the k-th mobile terminal can be characterized in the following fashion using the system model stated previously,

$$\boldsymbol{y_k} = \underbrace{\sum_{a\in|Ap|} \mathbf{F}_{a,k}^{H}\mathbf{V}_{a,k}\mathbf{S}_k + \sum_{a\in|Ap|}\sum_{r\in|R|} \mathbf{H}_{r,k}^{H}\mathbf{\Phi}_r^{H}\mathbf{G}_{a,r}\mathbf{V}_{a,k}\mathbf{S}_k}_{\text{useful-signal}} + \underbrace{\sum_{a\in|Ap|}\sum_{\substack{i\in|K|\\ i\neq k}} \mathbf{F}_{a,k}^{H}\mathbf{V}_{a,i}\mathbf{S}_i + \sum_{a\in|Ap|}\sum_{\substack{i\in|K|\\ i\neq k}}\sum_{r\in|R|} \mathbf{H}_{r,k}^{H}\mathbf{\Phi}_r^{H}\mathbf{G}_{a,r}\mathbf{V}_{a,i}\mathbf{S}_i}_{\text{interference-signal}} + \mathbf{n}_k \ldots (2)$$

where $\boldsymbol{n}_k \sim \mathrm{CN}(0, \sigma^2)$ is the additive white gaussian noise at the receiver for the kth -UE, and the useful signal includes both direct Ap–UE and indirect AP-RIS-UE paths. Next, study uses the symbols, $\mathbf{\Phi}, \mathbf{G}_r$ and $\boldsymbol{V_k}$, for respectively $diag.\{\mathbf{\Phi_1}, \mathbf{\Phi_2}, \ldots \mathbf{\Phi}_{\boldsymbol{R}}\}$, $\mathbf{G}_{\boldsymbol{r}}{}^{\boldsymbol{T}} = [\mathbf{G}_{\mathbf{1},\boldsymbol{r}}{}^{\boldsymbol{T}}, \mathbf{G}_{\mathbf{2},\boldsymbol{r}}{}^{\boldsymbol{T}}, \ldots \mathbf{G}_{\boldsymbol{AP},\boldsymbol{r}}{}^{\boldsymbol{T}}]$, and $\mathbf{V}_{\boldsymbol{k}}{}^{\boldsymbol{T}} = [\mathbf{V}_{\mathbf{1},\boldsymbol{k}}{}^{\boldsymbol{T}}, \mathbf{V}_{\mathbf{2},\boldsymbol{k}}{}^{\boldsymbol{T}}, \ldots \mathbf{V}_{\boldsymbol{AP},\boldsymbol{k}}{}^{\boldsymbol{T}}]$, the last expression for the received signal y_k in (2) may be simplified into, $\sum_{a\in|Ap|}\sum_{i\in|K|}\left(\mathbf{F}_{a,k}^{H} + \mathbf{H}_k^{H}\mathbf{\Phi}_r^{H}\right)\mathbf{V}_i \mathrm{S}_{a,i} + \mathbf{n}_k$. In addition, the study uses the notation $\mathbf{Q}_k$ to denote the equivalent channel for the useful signal such that,

$$\mathbf{Q}_k^H = \mathbf{F}_k^H + \sum_{r\in|R|} \mathbf{H}_k^H \mathbf{\Phi}_r^H \mathbf{G}_r \tag{3}$$

The received signal and the Signal-to-Interference-plus-Noise Ratio (SINR) at UE- k are then represented in the following manner [23] [25],

$$\boldsymbol{y_k} = \sum_{\boldsymbol{i}=1}^{\boldsymbol{k}} \mathbf{Q}_k^{H}\mathbf{V}_i\mathbf{S}_i + \boldsymbol{n_k} \tag{4}$$

$$\mathbf{\Gamma}_k(\mathbf{\Phi}, \mathbf{V}) = \frac{\mathbf{V}_k^{H}\mathbf{Q}_k\mathbf{Q}_k^{H}\mathbf{V}_k}{\sum_{\substack{i\in|K|\\ i\neq k}} \mathbf{V}_i^{H}\mathbf{Q}_k\mathbf{Q}_k^{H}\mathbf{V}_i + \mathbf{n}_k} \tag{5}$$

Finally, the sum rate (Nat/s/Hz) per UE- k is shown as [23],[26]

$$\mathrm{R_t} = \sum_{k\in k} \ln(1+\mathbf{\Gamma}_k) \tag{6}$$

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[2] Without lossing of generality, we consider that all channels' Channel State Information (CSI) is precisely known at the AP and RIS.

[3] It's worth noting that the discrete phase shifter's quantization loss significantly grows as N increases. For scenarios with a big N, we choose high-order quantization.

The primary goal is to improve the RISs reflection-beamforming $\mathbf{\Phi}$ and AP-transmission beamforming $\mathbf{V}$ to increase channel throughput while maintaining the total energy constraint. The joint beamforming design challenge is established for the proposed network to maximize all UEs' throughput. Additionally, the study offers a collaborative beamforming system to address the formulated challenge, prompted by the solutions mentioned in ref [21]. The design problem for transmission/reflection beamforming can be described as follows [21]:

$\mathcal{P}0$:

$$\max_{\mathbf{\Phi},\mathbf{V}} \sum_{k\in|K|} \ln(1+\Gamma_k) \quad (7)$$

s.t:

$$\boldsymbol{\Phi}_{r,n} \in \left\{0, \frac{\pi}{2^{b-1}}, \dots, \frac{(2^b-1)\pi}{2^{b-1}}\right\}, \qquad \forall r \in R, \forall n \in N \quad (7a)$$

$$\mathrm{tr}\left(\mathbf{V}_k \mathbf{V}_k^H\right) \leq P_{max}, \quad (7b)$$

where P_{max} denotes the AP maximum allowed transmitting power. The phase shift limitation of the reflecting element is defined in the constraint of equation (7a). Regarding to the restrictions in eq. (7a) and (7b), the optimization issue presented in eq. (7) is a significantly complex problem challenge.

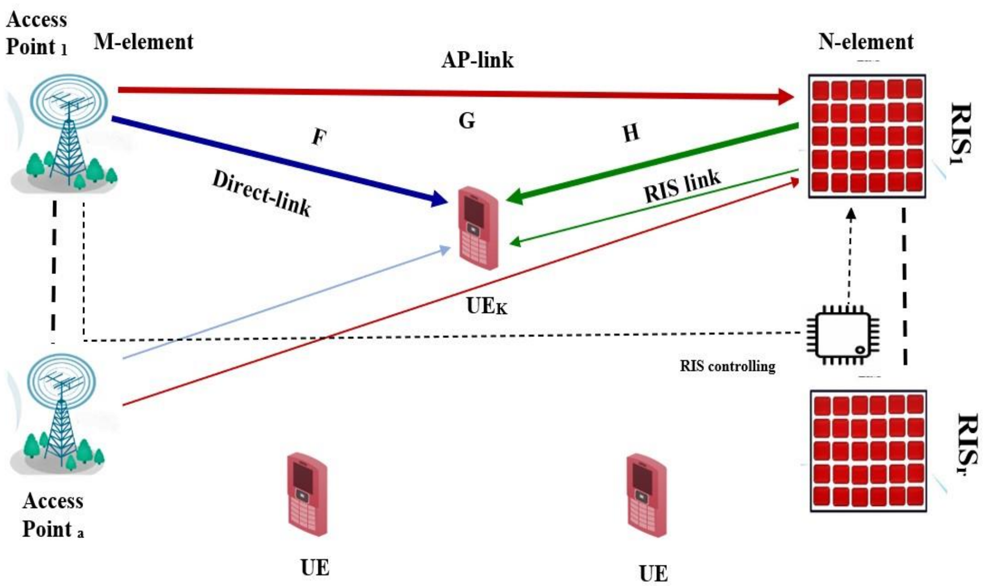

Figure 1 Model of the proposed multiple RISs schemes.

3. THE PROPOSED BEAMFORMING ALGORITHM

Utilizing the Duality theory, the logarithm function in eq. (7..) can be approached using the equation highlighted below, i.e., the dual formulation technique provided in reference [20] for decomposing the logarithms based on a new supporting variable, namely $\mu_k^1 \in \mathbb{R}^{n\times k}$. On the other hand, the optimization problem $\mathcal{P}_0$ in (7) is similar to the following statement [20],

$\mathcal{P}1$:

$$\max_{\mathbf{\Phi},\mathbf{V},\mu_k^1} \sum_{k\in|K|} \ln(1+\mu_k^1) - \sum_{k\in|K|} \mu^1{}_k + \sum_{k\in|K|} (1+\mu_k^1)\,\Gamma_k(\mathbf{\Phi},\mathbf{V}) \quad (8)$$

$$\text{s.t.:}\quad \mathbf{\Phi}_{r,n} \in \left\{0, \frac{\pi}{2^{b-1}}, \dots, \frac{(2^b-1)\pi}{2^{b-1}}\right\}, \forall r \in R, \forall n \in N \tag{8a}$$

$$\text{tr}\left(\mathbf{V}_k \mathbf{V}_k^H\right) \leq \text{Pmax} \tag{8b}$$

It is clear that in $\boldsymbol{\mathcal{P}}_1$**,** eq. (8a) is the constraint on $\mathbf{\Phi_{r,n}}$ and eq.(8b) is the constraint on $\mathbf{V_{a,k}}$. This dilemma inspires us to employ the Quadratic transform technique to disentangle the problem $\boldsymbol{\mathcal{P}_1}$ optimization variable from its connection. It is worth noting that using the traditional Dinkelback cannot be employed due to the dimensional complexity of this fractional problem. For this reason, additional supporting variables have been included namely, µ2 and µ3 which supplied to solve the AP beamforming design **V** iteratively (separately) using the alternate optimization approach [27]**.** This mediated through fixing the RIS's reflection beamforming **Φ** to solve over **V** and then fixing **V** to solve over **Φ** until convergence occurs. Consequantly, the optimization problem $\boldsymbol{\mathcal{P}_0}$ can be solved for **V, Φ**, µ1, µ2 and µ3 at a low level of complexity as shown in Fig (2). The flow chart of the proposed transmission/reflection beamforming Algorthim namly DAO which is based on Duality Theory and Quadratic Transform**.** Precisly, subsequent sub-problems are needed to be solved, e.g., the study needs to solve sub-problem-I to update μ_k^{1*} using V*, Φ*, and $\frac{\partial \mathcal{P}\mathbf{1}}{\partial \mu_k^1} = \mathbf{0}$. Then, updating variables, $\mathbf{\Phi}^*$and µ1* the problem in eq. (7) written as,

Ƥ 2:

$$\max_{\mathbf{V}} \quad \sum_{k\in|K|} \ln(1 + \mathbf{\Gamma}_k(\mathbf{\Phi}^*, \mathbf{V})) \tag{9}$$

s.t.:

$$\mathbf{\Phi}_{r,n} \in \left\{0, \frac{\pi}{2^{b-1}}, \dots, \frac{(2^b-1)\pi}{2^{b-1}}\right\}, \qquad \forall r \in R, \forall n \in N \tag{9a}$$

$$\text{tr}\left(\mathbf{V}_k \mathbf{V}_k^H\right) \leq P_{max} \tag{9b}$$

Following that, using the Quadratic transform approach outlined in [21] and the vectors $\mu_k^2 \in \mathbb{C}^K$, the problem in (9) can be represented in a reduced form with one constraint as follows,

Ƥ 2:

$$\max_{\mathbf{V}} \quad \sum_k 2\sqrt{1+\mu_k^{1*}}\ Rel.\{\mu_k^2 \mathbf{Q}_k^H \mathbf{V}_k^H\} - \sum_k \mu_k^{2H}\left(\sum_{\substack{i\in|K|\\ i\neq k}} \mathbf{V}_i^H \mathbf{Q}_k \mathbf{Q}_k^H \mathbf{V}_i + 1\right) \tag{10}$$

s.t.:

$$\text{tr}\left(\mathbf{V}_k \mathbf{V}_k^H\right) \leq P_{max} \tag{10a}$$

where the notation $Rel.\{\ .\ \}$ represents the real part of the complex number inside the bracket.

3.1 AP-Transmission beaforming updating

The next sub-problems (**2** and **3**) are considered to optimize $\mathbf{V}_k$ and μ_k^2 in eq. (10) alternatively. First, fixing **V** and find μ_k^{2*} by setting $\frac{\partial P2,a}{\partial \mu_k^2} = 0$, where it is possible to update the optimal μ_k^2 as follows [26],

$$\mu_k^{2*} = \frac{\sqrt{1+\mu_k^{1*}}\mathbf{Q}_k^H \mathbf{V}_i}{\sum_{\substack{i\in|K|\\ i\neq k}} \mathbf{V}_i^H \mathbf{Q}_k \mathbf{Q}_k^H \mathbf{V}_i + n_k} \quad \dots \ (11)$$

Second, fixing μ_k^2 to update **V*** in $\boldsymbol{\mathcal{P}}_2$, thus sake of simplicity using the new objective function $\boldsymbol{\mathcal{P}}_3$ which is formulated as follows,

Ƥ3:

$$\max_{\mathbf{V}} \ -\mathbf{V}^H \mathbf{E}\,\mathbf{V} + 2\ Rel.\{U^H \mathbf{V}\} - \mathbf{Z} \quad \dots \ (12)$$

$$\text{s.t.:} \quad \mathbf{V}^H \mathbf{A}\,\mathbf{V} \leq P_{max} \quad \dots \ (12a)$$

$$\text{where } \mathbf{E} = \mathrm{Ik} \otimes \sum_k \mathbf{Q}_k \mu_k^2 \mu_k^{2H} \mathbf{Q}_k^H$$

$$\mathbf{Z} = \sum_k \mu_k^{2H} n_k \mu_k^2 ,$$

$$U^T = [u_1, u_2, \ldots u_k], \; u_k = \mu_2^H \mathbf{Q}_k^H V_k,$$

$$A = I_k \otimes \mathbf{E}.$$

Eventually, the AP-transmission beamforming can be updated via any package for disciplined convex programs as discussed in ref. [28] since the study have semidefinite programming (SDP) constraints in eq. (12).

3.2 RIS-Reflection beamforming updating

The next task is to update the variable μ^3_k for fixed $\mathbf{V*}$ and μ_k^{1*} using the objective function that expressed as follows,

Ƥ4;

$$\max_{\Phi} \sum_k (1 - \mu_k^{1*}) \, \mathbf{\Gamma}_k(\mathbf{\Phi}, V^*) \tag{13}$$

$$\text{s.t.}; \quad \mathbf{\Phi}_{r,n} \in \left\{0, \frac{\pi}{2^{b-1}}, \ldots, \frac{\pi(2^b-1)}{2^{b-1}}\right\}, \quad \forall r \in R, \forall n \in N \tag{13a}$$

Additionally, Due to unsolved the addressed challenging in this case, the study turns to Quadratic transformation with a new variable μ_k^3. As a result, the problem in (13) can be stated as [21],

Ƥ5;

$$\max_{\Phi} \sum_k 2\sqrt{1 + \mu 1 *} \; Rel\,\{\mu_k^{3H} \mathbf{W}_k\} - \mu_k^{3H} \Big(\sum_{\substack{i \in |K| \\ i \neq k}} \mathbf{W}_i \mathbf{W}_i^H + n_k\Big) \mu_k^3 \; \ldots \tag{14}$$

s.t.;

$$\mathbf{\Phi}_{r,n} \in \left\{0, \frac{\pi}{2^{b-1}}, \ldots, \frac{(2^b-1)\pi}{2^{b-1}}\right\}, \forall r \in R, \forall n \in N \tag{14a}$$

Where

$$\mathbf{W}_k = \sum_{a \in |AP|} (\mathbf{F}_{a,k}^H + \mathbf{H}_k \mathbf{\Phi}^H \mathbf{G}_a) V_k \tag{15}$$

Following that, similar to the preceding approach, subproblem $\boldsymbol{P}_5$ in (14) can be further subdivided into two more minor problems and solved as follows: first determine _μ_k^{3*} for fixed $\mathbf{\Phi}$ via $\frac{\partial P5}{\partial \mu 3K} = 0$,

$$\mu_k^{3*} = \frac{\sqrt{1 + \mu^{1*}} \mathbf{W}_k(\mathbf{\Phi})^*}{\sum_{\substack{i \in |K| \\ i \neq k}} \mathbf{W}_i(\mathbf{\Phi})^* + n_k} \tag{16}$$

Next, $\boldsymbol{P}_5$ can be further reduced to the following expression,

Ƥ6;

$$\max_{\Phi} \; - \mathbf{\Phi}^H ß \, \mathbf{\Phi} + 2\, Rel.\{\mathbf{\Phi}^H \mathbf{b}\} - \mathbf{a} \tag{17}$$

s.t.;

$$\mathbf{\Phi}_{r,n} \in \left\{0, \frac{\pi}{2^{b-1}}, \ldots, \frac{(2^b-1)\pi}{2^{b-1}}\right\}, \quad \forall r \in R, \forall n \in N \tag{17a}$$

where,

$$ß = \sum_a \sum_k \mathrm{diag}(\mu_k^{3H} \boldsymbol{H}_k^H) \boldsymbol{G}a,r \boldsymbol{V}a,k \,(\boldsymbol{G}a,r\boldsymbol{V}a,k)H,$$

$$b=\sum_a \sum_k \sqrt{1+\mu 1*}\ \mathrm{diag}(\mu_k^{3H} H_k^H)\ GaVa,k-\sum_a \sum_k \mu_k^{3H} F_{a,k}^H V_{a,k}^*(\mu_k^{3H} F_{a,k}^H V_{a,k}^*)$$

$$\mathbf{a} = \sum_k |\sum_a \mu_k^{3H} F_{a,k}^H V_k|2 + \sum_k \mu_k^{3H} n_k \mu_k^3 -2\sum_k \sqrt{1+\mu 1*}\ Rel.\{\sum_a \mu_k^{3H} F_{a,k}^H V_k\}.$$

Due to the SDP restrictions that existed in eq (17) , any package can modify the RIS-reflection beamforming for disciplined convex programs [28]. The flowchart of Algorithm 1 in Fig (2) illustrates the overall methods for resolving all of the suggested Algorithm's subproblems, particularly the DAO which is based on Duality Theory and Quadratic Transformation beamforming.

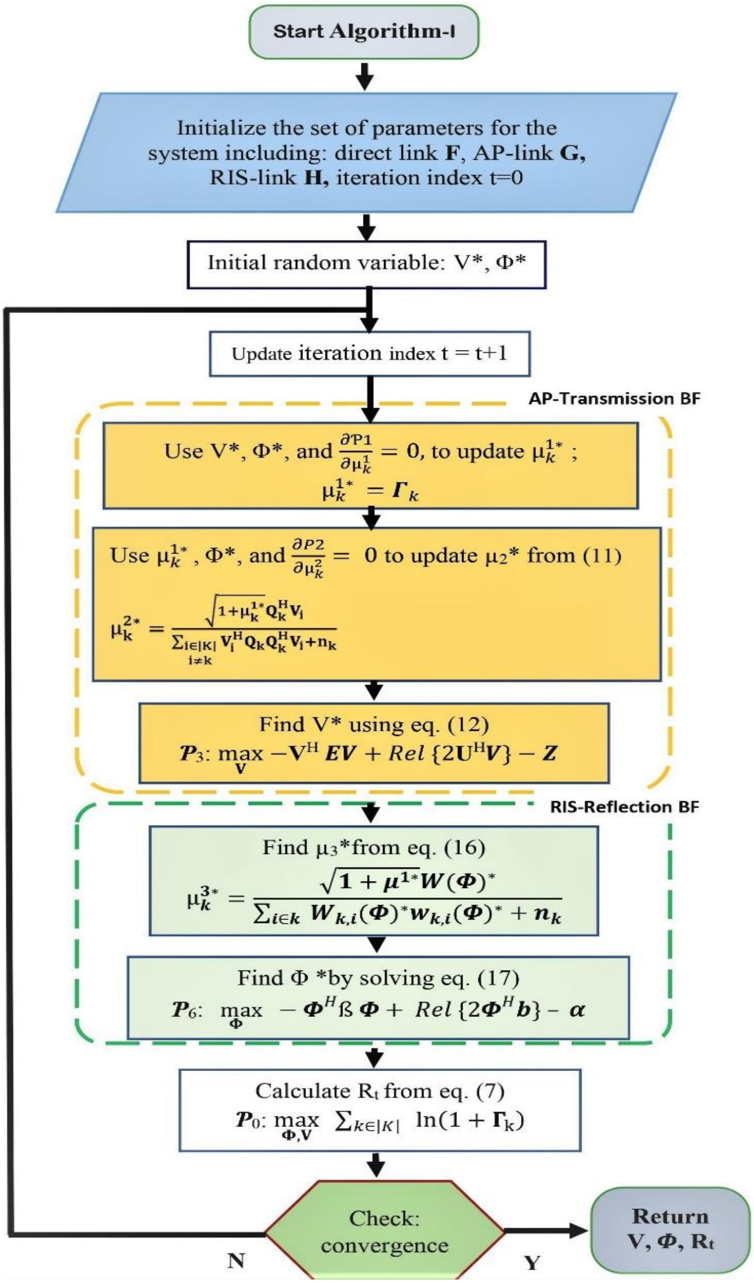

Figure.2 The flowchart of the proposed algorithm.

4. NUMERICAL RESULTS

The numerical result of the suggested RIS-enhanced multiuser MIMO communication system is reported in the this section. Unless expressly stated otherwise, the system parameters are defined in table-I. The path loss on a large scale has been calculated for various situations, as indicated in table-I. For small-scale fading, the study assumed that the AP-RIS and RIS-UE links followed the Rayleigh fading principle, whereas the AP-UE link follows the Rician fading principle. Additionally, the angle of arrival/departure is assumed to be random within the range [0, 2π]. Phase shifters take only a limited number of discrete values for practical RIS execution. Demonstrating the performance gain achieved by the RIS in the transmission system, a comparison between our proposed Algorithm to the following baseline schemes has been applied:

- Traditional MIMO system without employing RIS technique.
- No LoS path scenario, i.e., blockage scenario. MATLAB software has been employed in the simulation.

Table I. System parameters' setting for numerical simulations.

Parameter	Setting
Total transmit power	$P_t =$ 2 dB or 32 dBm [24]
Path loss exponent	2.3, 2.5 and 3.5
Channel model	Rician fading for LoS rays and Rayleigh fading for NLOS rays
Power loss in RF chains	P^{UE} =12 dBm [15]
Power loss in baseband network	P^{RIS} =12 dBm [15]
Power loss in the switch network	P^{AP} = 9 dB
Noise power	$n^2 = -100$ dBm
Phase-shifters quantize digits (b)	3 bits
Number of RIS elements N	[10 - 180]
Base station antenna number M	4 elements
Number of users	[5 - 55] users
Number of AP	20

The spectral efficiency of proposed system is compared to N-element in RIS while retaining the transmit power of the AP at 0 dBm which expressed in fig. 3. Clearly, increses N increases leads to improved the spectral performance of the RIS-based system when the signal intensity increased due to the RIS's summation of the reflected beams. For instance, increasing the size of the surface element N from 30 to 160 elements can improve the UE rate by approximately 30% (from 9 to 13 bps/Hz).
Fig. 4 plots the spectral efficiency versus the transmit power of the AP. It can be seeing that the sum-rate increases exponentially rather than linearly, as in fig. 3, because increasing N can improve only the RIS-assisted link. Contrary, the AP-UE path and the RIS-assisted path received assistance when the power transferred by the AP grows.

4.1 Analysis of the Complexity;

According to the approximate complexity for updating the variables, $\mathbf{V}, \mathbf{\Phi}, \mu_k^1, \mu_k^2,$ and μ_k^3, the overall complexity of Algorithm-1 for each iteration is in the order of $\mathcal{O}(T_{12}(|Ap|\ M\ K\ )^2 + T_{22}(|R|\ N\ )^2 + |Ap|\ M\ K + (|R|\ K\ )^2\ (\ |R|\ K + 1)^{2.5})$, where T_{12} and T_{22} are the number of iterations required to solve eq. 12 and eq.17, respectively. Finally, Fig 5 adds the analysis of the complexity of the proposed algorithm convergence speed where the simulation has been conducted to compare this algorithm (the suggested DAO Algorithm) with some reference algorithm as benchmarks. The spectrum efficiency tends to be stable after almost nine iterations, which verifies the short execution time of the proposed beamforming approach.
It is worth noting that, employing RIS technique for MIMO wireless communications achieve a multiple figure of merits and these benefits can be achieved at a very little complexity. Instead of acquiring the direct channel state information in case of the conventional MIMO scheme, in RIS aided system the scheme will acquire almost the same dimensional matrix, but for the effective channel (the direct and reflected vectors as a one cascaded vector). In addition, as depicted in fig. 5 the complexity of the passive reflecting beamforming is the same for conventional analog beamforming without employing RIS technology. In addition, as depicted in fig. 4 the

complexity (in terms of the number of required iteration for convergence) of the passive reflecting beamforming is the same for conventional analog beamforming (without employing RIS technology).

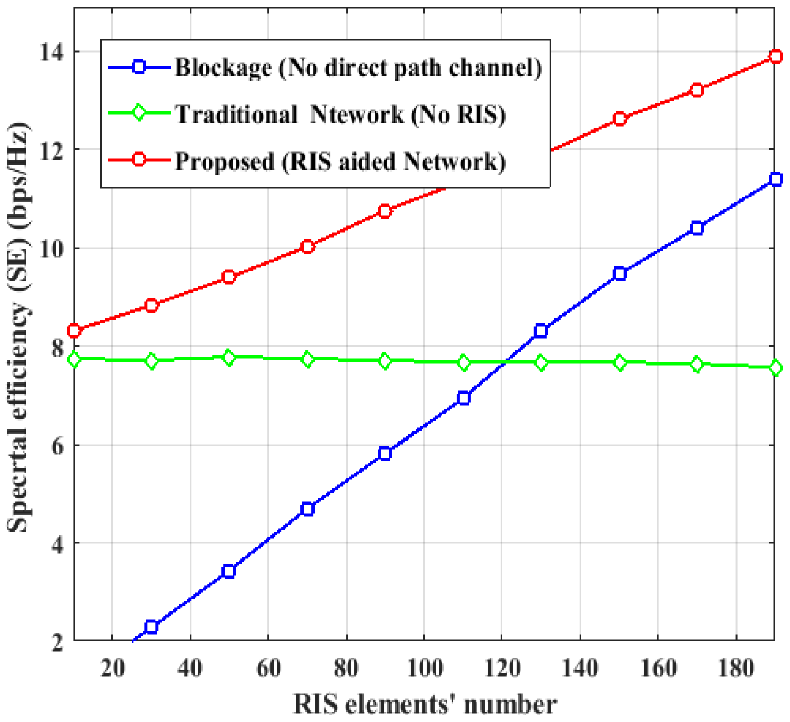

Figure 3 SE versus number of IRS' elements N.

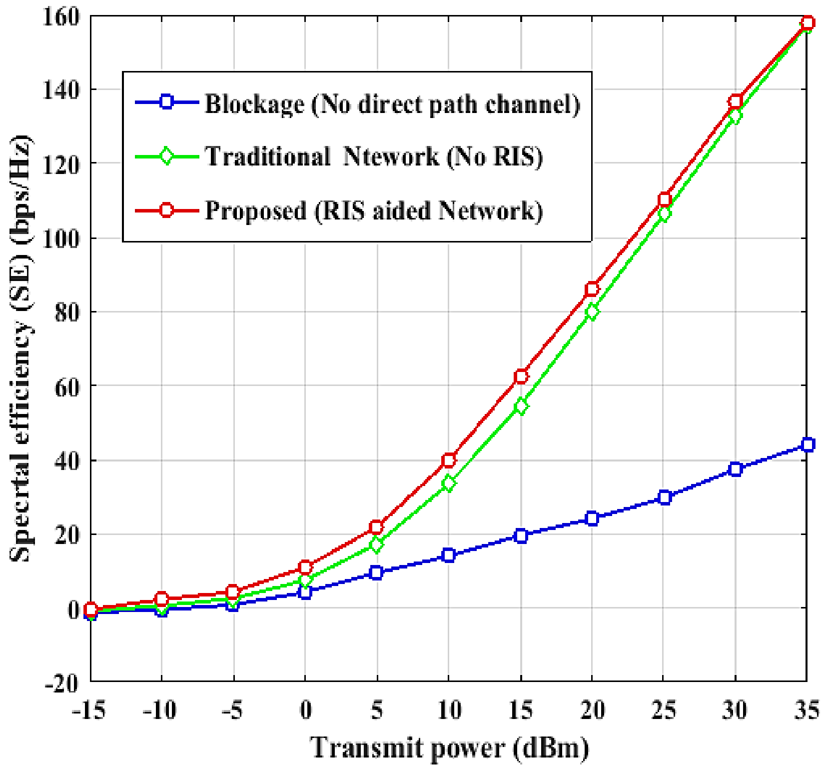

Figure 4 spectral efficiency versus AP's maximum transmit power P_{max}.

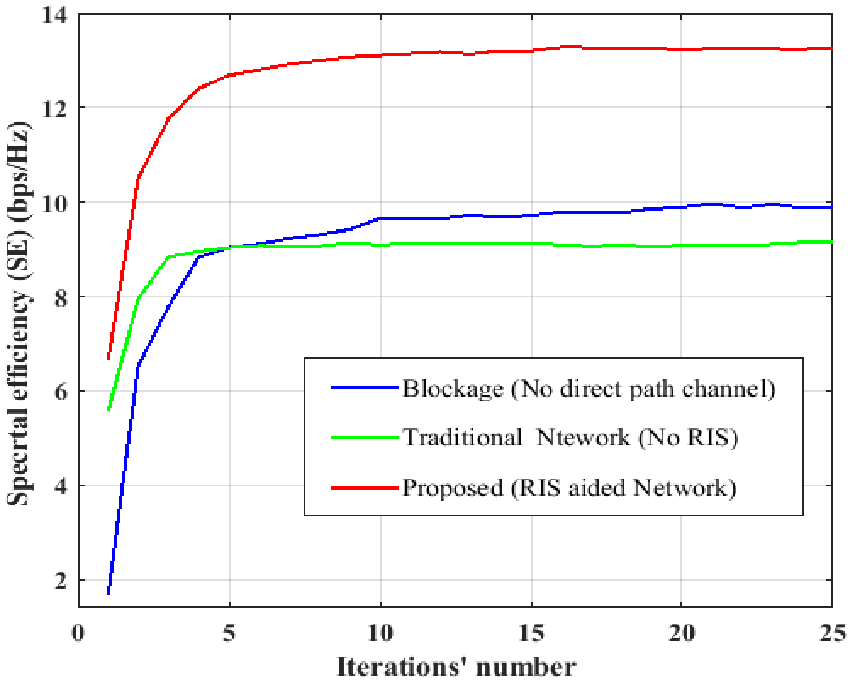

Figure 5 The proposed Algorithm's convergence performance

5. CONCLUSION

The presnt study builds an AP/RIS beamforming system with a discrete level phase shifter for the non-active reflection-BF challenge using Duality Theory and Quadratic approaches. A wireless network's downlink is addressed in detail, and a multiple-antenna AP interfaces with the equipment of single-antenna UEs to expand network capacity while consuming low power. As a result, the joint beamforming design challenge for the proposed network is defined to provide a near-optimal sum rate for all UEs. Additionally, the study offers a collaborative beamforming system to address the formulated challenge prompted by the solutions mentioned in ref [21]. For this purpose, the study suggested to solve this problem by using a Duality Theory and Quadratic method through decouple the design of joint beamforming. The simulation results indicated that the proposed Algorithm achieved nearly 30% spectrum boost over the conventional network (without RIS). This enhancement is mediated via the scheme's specified RIS elements scenario. The obtained result shows significant higher capacity than a conventional wireless communication network. Besides, the results show that the complexity (in terms of the number of required iteration for convergence) of the passive reflecting beamforming almost is the same for conventional analog beamforming (without employing RIS technology). Therefore, more qualitative and quantitative resreaches are required in term of Max-Min Fair spectral-efficient beamforming strategy and the effects of multipath signals.

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