IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received 6 June 2022, accepted 16 July 2022, date of publication 28 July 2022, date of current version 5 August 2022.
Digital Object Identifier 10.1109/ACCESS.2022.3194539

RESEARCH ARTICLE

An Optimum Weighted Energy Efficiency Approach for Low Complexity Power Allocation in Downlink NOMA

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This research was supported by Taif University Researchers Supporting Project Number (TURSP-2020/147), Taif University, Taif, Saudi Arabia. The work of Mohamed Elwekeil is supported by the H2020 Marie Skłodowska-Curie Actions (MSCA) Individual Fellowships (IF) project IUCCF, grant 844253.

ABSTRACT Non-orthogonal multiple access (NOMA) has emerged as a significant technique for 5G wireless networks because it increases device connectivity, spectral efficiency, and energy efficiency. The advantages of the NOMA system rely on the employed resource allocation schemes, which include power allocation (PA) and subcarrier user assignment (SUA). Therefore, this paper concentrates on suggesting a PA approach called a weighted energy efficiency power allocation (WEE-PA) approach to maximize the total weighted energy efficiency (WEE) in the NOMA system. Also, the proposed WEE-PA approach boosts the fairness between users, the minimum user rate in the system, the outage probability, and the average data rate per weak user. Therefore, the PA optimization problem defines as an optimization problem with a total power constraint and a set of dynamic PA parameters to maximize the WEE and ensure user fairness. The original optimization problem separates into two sub-problems, and an iterative approach is employed to solve these two sub-problems alternatingly and reduce the computational complexity. Since the optimization problem is non-convex, the sequential quadratic programming (SQP) technique is applied to resolve it and find the corresponding optimal solution. Our simulations confirm that using our proposed WEE-PA algorithm to allocate mutual resources furnishes better results than existing PA schemes.

INDEX TERMS Non-orthogonal multiple access (NOMA), power allocation (PA), subcarrier user assignment (SUA), weighted energy efficiency (WEE).

I. INTRODUCTION

With the rapid growth of the internet-of-things (IoT) and the enormous expansion of users and their high requirements of data rate and capacity, new multiplexing techniques and resource allocation mechanisms are in demand. One of the key techniques that satisfy these requirements in communication systems is non-orthogonal multiple access (NOMA) [1].

The associate editor coordinating the review of this manuscript and approving it for publication was Khaled Rabie.

There are many advantages that NOMA offers over orthogonal multiple access (OMA) techniques, for instance enhanced spectrum efficiency (SE), improved energy efficiency (EE), extremely high attainable data rates, minimum transmission latency, improved user fairness, enormous device connectivity, and compatibility with other techniques [2]–[5].

The NOMA scheme employs power domain (PD-NOMA) or code domain (CD-NOMA) multiplexing to permit various users to use the same frequency or time resources. The PD-NOMA is the subject of this paper. In the PD-NOMA, different power levels are assigned to many users based on their channel condition. Also, superposition coding (SC) techniques are employed in the PD-NOMA at the sender sides to transmit numerous users' message signals based on the variation of their channel gain characteristics. Then, at the receiver end, each user utilizes the successive interference cancellation (SIC) approach to decode their signal from the entire acquired signal [6]–[10].

In NOMA systems, resource allocation includes power allocation (PA) and subcarrier user assignment (SUA), also referred to as user pairing (UP), both of which are critical to achieving high performance. Consequently, PA and SUA for NOMA systems have been investigated in various research studies in the literature, e.g., [11]–[46]. UP means which subcarrier is selected for certain paired users. Conversely, PA means how the base station (BS) distributes its total power budget between the subcarriers and how the power of each subcarrier is distributed among the users using the same subcarrier. PA has many objectives, such as maximizing the overall system capacity, enhancing the spectral efficiency (SE), increasing the user data rate, reducing the outage probability, improving the data rate of weak users, enhancing the SIC performance, improving the user fairness, minimizing the power consumption, and improving energy efficiency (EE).

This paper concentrates on the PA problem. Specifically, we present a new PA algorithm to enhance the total weighted energy efficiency (WEE) and guarantee fairness between users. Concerning the UP problem, we involve previous existing algorithms which are the conventional user pairing (CUP) algorithm [12] and the worst subcarrier first (WSF) algorithm [24] with the proposed PA algorithm.

Subsequently, the paper contributions are summarized as follows:

- Formulating a model for optimizing the PA problem in the downlink NOMA system to maximize the total WEE.
- Introducing the weighted energy-efficient power allocation (WEE-PA) algorithm to improve the WEE, the user fairness, the data rate per weak user, the minimum user rate, and the outage probability of the realized system.
- The optimization problem of the suggested WEE-PA algorithm is separated into two sub-problems and solved in two iterative matched steps to reduce the complexity that results from the increased number of variables. We employ the sequential quadratic programming (SQP) approach to tackle the PA issue in NOMA.

The remaining part of the paper is prepared as follows. The previous studies of the NOMA resource allocation approaches are introduced in Section II. The model of downlink NOMA scheme and the optimization problem for maximizing the total WEE are discussed in Section III. The proposed WEE-PA for the NOMA system is presented in Section IV. In Section V, the computational complexity is studied. In Section VI, simulation outcomes are carried out. Finally, our conclusions are displayed in Section VII.

II. RELATED WORKS

The NOMA system's resource allocation issue has been addressed in different researches to reach various execution criteria. For an example of UP algorithms, the random pairing algorithm is proposed in [11] as a low complexity scheme. However, it ends up with a sub-optimal throughput since it ignores the users' channel characteristics.

Two UP techniques, specifically fixed-power-allocation NOMA (F-NOMA) and cognitive-radio-inspired NOMA (CR-NOMA) are suggested in [12] to recognize the users' channel gains. The results of [12] reveal that the NOMA strategy produces a greater sum-rate relative to OMA systems. The F-NOMA also named the CUP algorithm. In the CUP algorithm, each subcarrier selects two users; one with the maximum channel gain and the second with the worst channel gain from the total available users, and removes the selected users from the following selection.

Two UP methods, uniform channel gain difference (UCGD) pairing and hybrid UP, have been presented in [13], followed by a modified M-users pairing scheme, to lower the mid-users pairing problem and obtain capacity increases, particularly if imperfect SIC is employed. A virtual-UP is executed in [14] to usage the spectrum of unpaired users in NOMA systems. A divide and next-largest-difference-based UP algorithm (D-NLUPA) is implemented in [15] to maintain fairness among the NOMA clusters and guarantee that the sum-rate improvement for every cluster is higher than a certain threshold.

In [16]–[21], the matching theory is investigated, as a solution to the UP in NOMA systems, where appropriate solutions are found with adequate complexities. A modified resource allocation algorithm with small complexity for user grouping and PA optimization is introduced in [22]. An SUA algorithm for the NOMA system is introduced in [23] to develop SE by raising the total system sum-rate and preserving large channel gain distinction between the joined users per subcarrier to improve the SIC implementation. Two SUA algorithms for the NOMA system, namely "worst subcarrier first based subcarrier-user assignment algorithm" (WSF-SUAA) and "spectral efficiency maximization-based subcarrier-user assignment algorithm" (SEM-SUAA) are implemented in [24]. These algorithms aim to improve SE, enhance the data rate of weak users, improve the fairness between users, and reduce the outage probability. The WSF-SUAA hangs on sorting subcarriers in ascending order according to the user with the worst channel gain of each subcarrier before the SUA to prevent choosing a user with the worst channel gain with any subcarrier. Also, The WSF-SUAA improves the spectral efficiency, the data rate of weak users, and the fairness between users.

For the PA schemes, a low complexity PA algorithm called fixed power allocation (FPA) is investigated in [25] but this algorithm is inefficient because of the inconsideration of users' channel states in defining power levels. Also, a full search power allocation (FSPA) algorithm is introduced in [25] to achieve the best performance of the NOMA system but it suffers from high computational complexity. In [25] and [26], the fractional transmit power allocation (FTPA) algorithm is investigated to achieve good performance with less complexity than FSPA and strike a balance between the FPA and FSPA algorithms. But it needs a previous simulation to evaluate a certain parameter to enhance the overall performance.

In [27], the theoretic discussions and algorithmic answers for how to mutually optimize PA and channel distribution in the NOMA system are presented to enhance the system throughput and fairness relative to OMA. A fair-NOMA is introduced in [28], [29] to prove that the two mobile paired users can achieve an information capacity higher than or equivalent to the information capacity with OMA, regardless of the user selection rules. An optimal PA scheme for the downlink NOMA scheme is investigated in [30], [31], where the objective is to enhance the NOMA total throughput schemes.

In [32], a modern three-stride resource allocation approach is used to handle the challenges of sum-rate maximization and conflict among user fairness and sum-rate performance in the downlink multi-carrier NOMA (MC-NOMA) scheme. The user association algorithms and the closed-form solutions for PA for multi-cell NOMA systems are investigated in [33] to enhance the total sum rate and outage probability.

In [34], an analytical solution of the optimal PA is derived for weighted sum-rate (WSR) maximization in NOMA schemes under power consumption restrictions and quality-of-service (QoS) restrictions. Furthermore, in [35], the WSR problem in the presence of a maximum power restriction for the NOMA system is solved by optimizing PA via the Karush-Kuhn-Tucker (KKT) criteria and applying a greedy user selection algorithm as the best set of scheduling multiplexed users. An iterative PA algorithm for MC-NOMA while considering user priority is investigated in [36] to determine the best solution for maximizing the WSR. Moreover, a novel approach for jointly optimizing the subcarrier allocation and PA problems is introduced in [37], [38] to maximize the WSR in MC-NOMA under the cellular power constraints.

The energy-effective planning for the forthcoming generations of wireless communications is of supreme interest because of the great growth of data traffic and wireless terminals. Consequently, strategies for allocating resources that advance the EE in the NOMA system are grown as an essential topic in the wireless research community. Specifically, an optimum user PA solution using KKT conditions is presented in [39] to maximize EE in the NOMA system while considering defective channel state knowledge at the transmitter and user QoS restriction.

A method that depends on multi-objective optimization to assign resources in the downlink of a multi-user NOMA (MU-NOMA) system is investigated in [40] to enhance SE and EE where users' QoS necessities, transmit power budget, and SIC constraints are satisfied. Moreover, in [20] and [41], the optimal PA methods for various NOMA systems, containing two-user NOMA, MU-NOMA, and MC-NOMA systems are investigated. Also, these PA strategies follow different execution measures, for example, the max-min fairness, sum rate, and EE accompanied by user weights and QoS restrictions.

Also, in most cases, the optimal NOMA PA schemes presented in [20] and [41] provide analytical solutions. On the other hand, convex optimization techniques are used to determine it numerically.

Furthermore, the optimization of EE and fairness between users to find the optimal subcarrier allocation and PA parameters is investigated in [42] for the downlink MC-NOMA system. Moreover, a new UP algorithm named the ''worst-case user first subcarrier allocation'' (WCUFSA) algorithm is proposed to avoid the distribution of the channel with a low channel state and recognize the largest performance in distributing a greater channel state to allow a subcarrier to users.

Moreover, the WEE maximization in the NOMA system is investigated in [43]–[46] for deriving the optimal energy-efficient PA expression. The WEE is specified as a proportion of the WSR to the total power consumption and is adopted with user weights to obtain user fairness and priorities.

III. SYSTEM MODEL AND PROBLEM FORMULATION

The Multi-input-multi-output (MIMO) techniques can provide the advantages of spatial multiplexing and/or spatial diversity, which enhance the system's performance, improve the transmission capacity, and decrease the interference by equipping more antenna, but we assume the worst scenario which is a single-input-single-output (SISO) NOMA scheme. Consequently, the downlink NOMA scheme model in the SISO scenario is described in this part. Furthermore, the issue of maximizing total EE using user weights (i.e., WEE) and guaranteeing user fairness are expressed.

A. SYSTEM MODEL

The downlink model of the NOMA system is described in Fig. 1. The BS simultaneously transmits data signals to a group of users K. The BS uses a single antenna for both transmission and reception [26]–[53]. The entire usable bandwidth B is uniformly distributed between S subcarriers. The bandwidth of any subcarrier is equal to $Bs = \frac{B}{S}$. The set of all subcarriers and users are represented by $k = \{1, 2, \cdots, K\}$ and $s = \{1, 2, \ldots, S\}$, respectively. The BS is supposed to have complete channel state information (CSI).

According to the NOMA rules, the BS distributes varying levels of power to each subcarrier based on its CSI. Also, multiple users can share a single subcarrier. Furthermore, each user can get data from various subcarriers. To decrease the excessive multiple-access, we assume that each user can employ only one subcarrier, and each subcarrier can be allotted to N users, where N is the number of paired users on the subcarrier s. Accordingly, the whole number of users is $K = NS$ [18], [23], [24], and [42]. Also, the BS divides its total transmit power P_T among subcarriers such that

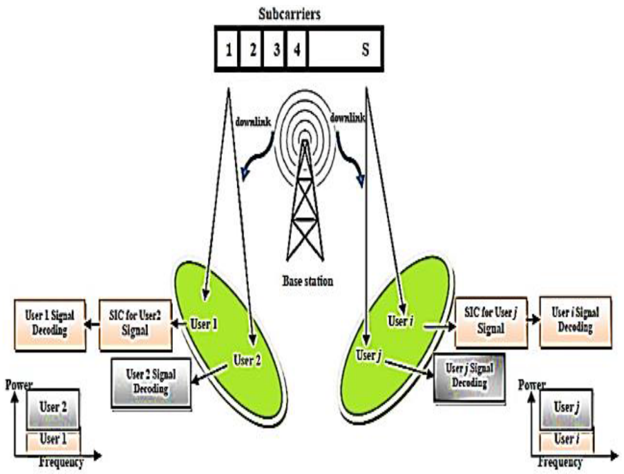

FIGURE 1. **The downlink model of the NOMA system [24].**

$P_T = \sum_{s=1}^{S} P_s$, where P_s is the power per subcarrier s. Then, the power for each subcarrier s is distributed among its multiplexed users (i.e., paired users) so that fairness is attained between users.

Subsequently, the signal transferred from the BS to the users multiplexed on subcarrier s is expressed as in [17], [18], [20], [24], and [42]:

$$x_s = \sum_{k=1}^{N} \sqrt{P_{s,k}} M_{s,k} \tag{1}$$

where $P_{s,k}$ is the power assigned to user k over subcarrier s and $M_{s,k}$ is the information signal transmitted from the BS to user k over subcarrier s. The received signal of user k over subcarrier s is represented as in [17], [18], [20], [24], and [42]:

$$\begin{aligned} y_{s,k} &= h_{s,k} x_s + Z_{s,k} \\ &= \sqrt{P_{s,k}} h_{s,k} M_{s,k} + \sum_{i=1, i \neq k}^{N} \sqrt{P_{s,i}} h_{s,k} M_{s,i} + Z_{s,k} \end{aligned} \tag{2}$$

where $h_{s,k} = g_{s,k} d_k^{-\gamma}$ is the channel gain coefficient from the BS to the k$^{\text{th}}$ user on subcarrier s, $g_{s,k}$ is assumed to have Rayleigh fading channel gain, d_k is the distance between the BS and user k, and γ is the path loss exponent. $Z_{s,k} \sim CN\left(0, \sigma_s^2\right)$ is the "complex additive white Gaussian noise" (AWGN) at user k with zero mean and variance $\sigma_s^2 = N_0 \frac{B}{S}$, where N_0 is the noise-power-spectral-density.

According to the PD-NOMA concept, the SIC approach is used to detect MU signals at the recipient side, where the descending order of channel gains normalized by noise is an essential part of implementing the SIC operation. Specifically, assume $\Gamma_{s,k} = \frac{|h_{s,k}|^2}{\sigma_s^2}$ be the channel gain normalized by noise ratio (CNR) of user k over subcarrier s. Assume that the CNRs of the multiplexed users on the subcarrier s are arranged in descending order according to Γ as $\Gamma_{s,1} \geq \ldots \Gamma_{s,k} \geq \ldots \Gamma_{s,N}$. Thus, $\Gamma_{s,1}$ is the CNR of the strongest user, while $\Gamma_{s,N}$ is the CNR of the weakest user on the same subcarrier s.

Therefore, user 1 (the user with the greatest channel gain on subcarrier s) can decode other users' signals first, then separate them from the composite received signal. Then, user 1 can decode its data signal $M_{s,1}$ unaccompanied by any intrusion from other users. On the other hand, the user N (the user with the worse channel gain on the same subcarrier s) can decode its information signal $M_{s,N}$ immediately unaccompanied by applying the SIC operation, and other users' signals are regarded as an intrusion. Also, the BS will allow a higher power to the users with lower CNRs to ensure fairness and simplify the SIC procedure between the paired users in NOMA, i.e., $P_{s,1} \leq \ldots \leq P_{s,k} \leq \ldots \leq P_{s,N}$.

Consequently, the obtained signal to interference plus noise ratio (SINR) of the user k on subcarrier s after implementing the SIC process is given by [17], [18], [20], [24], and [42]:

$$\begin{aligned} SINR_{s,k} &= \frac{P_{s,k} \left|h_{s,k}\right|^2}{\sum_{i=1, i \neq k}^{k-1} P_{s,i} \left|h_{s,k}\right|^2 + \sigma_s^2} \\ &= \frac{P_{s,k} \Gamma_{s,k}}{\sum_{i=1, i \neq k}^{k-1} P_{s,i} \Gamma_{s,k} + 1} \end{aligned} \tag{3}$$

where $\sigma_s^2 = E[\left|Z_{s,k}\right|^2$ denotes the noise power on subcarrier s.

Thus, the data rate of user k on the subcarrier s is represented as [17], [18], [20], [24], and [42]:

$$\begin{aligned} R_{s,k} &= B_s \log_2 \left(1 + SINR_{s,k}\right) \\ &= B_s \log_2 \left(1 + \frac{P_{s,k} \Gamma_{s,k}}{\sum_{i=1, i \neq k}^{k-1} P_{s,i} \Gamma_{s,k} + 1}\right) \end{aligned} \tag{4}$$

As the number of users participating per subcarrier increases, all users except the one whose signals decoded in the last stage of the SIC will suffer from severe interference, which means that their QoS degrades. Thus, the SIC is difficult to implement in a general case with more than two users per subcarrier. So, to reduce the additional complexity of SIC operations on the receiver side, we will suppose that each user can utilize one subcarrier and only $N = 2$ users' pair on the same subcarrier [23], [24], [41], [42], [50], and [53]. Consequently, the number of users is supposed to be twice the number of subcarriers ($K = 2S$) [18], [20], [23], [24], [41], [42], [50], and [53].

Accordingly, we suppose that the CNRs of the paired users which are the strong user (user 1) and weak user (user 2) on the same subcarrier s are $\Gamma_{s,1}$ and $\Gamma_{s,2}$, respectively. Later, the obtainable data rates of the user 1 and the user 2 on the same subcarrier s can be expressed, respectively as [18], [20], [23], [41], and [42]:

$$\begin{aligned} R_{s,1} &= B_s \log_2 \left(1 + P_{s,1} \Gamma_{s,1}\right), \\ R_{s,2} &= B_s \log_2 \left(1 + \frac{P_{s,2} \Gamma_{s,2}}{P_{s,1} \Gamma_{s,2} + 1}\right) \end{aligned} \tag{5}$$

Next, the total sum-rate for subcarrier s is described as [18], [20], and [41]:

$$R_s = R_{s,1} + R_{s,2}$$

$$= B_s \log_2\left(1 + P_{s,1}\Gamma_{s,1}\right) + B_s \log_2\left(1 + \frac{P_{s,2}\Gamma_{s,2}}{P_{s,1}\Gamma_{s,2}+1}\right) \quad (6)$$

To attain fairness between two multiplexed users, $P_{s,1} < P_{s,2}$. Consequently, we assume that $P_{s,1} = \alpha_s P_s$ and $P_{s,2} = (1-\alpha_s)P_s$, where $0 < \alpha_s < 0.5$ is a dynamic PA parameter [25], [26]. Accordingly, the total sum-rate for subcarrier s can be expressed as:

$$R_s(P_s, \alpha_s) = B_s \log_2\left(1 + \alpha_s P_s \Gamma_{s,1}\right) + B_s \log_2\left(1 + \frac{(1-\alpha_s)\, P_s \Gamma_{s,2}}{\alpha_s P_s \Gamma_{s,2}+1}\right) \quad (7)$$

Next, the whole system sum-rate is represented by:

$$R_T(P_s, \alpha_s) = \sum_{s=1}^{S} R_s \quad (8)$$

Moreover, we introduce the weight factors $w_{s,1}$ and $w_{s,2}$ to the paired users on the same subcarrier s to adjust the user priority when allocating resources and recognize the user fairness. The value of $w_{s,1}$ and $w_{s,2}$ must be satisfied the conditions of $w_{s,2} > w_{s,1}$, and $1 < \frac{w_{s,2}}{w_{s,1}} < \frac{\Gamma_{s,1}}{\Gamma_{s,2}}$. Because when $w_{s,2} > w_{s,1}$, the data rate of the weak user will be enhanced with a large value with respect to the data rate of the strong user. Consequently, the value of the fairness index improves.

Thus, the total system weighted sum-rate (WSR) can be expressed as [20], [35]–[38], and [41]:

$$R_{T,weighted}(P_s, \alpha_s) = \sum_{s=1}^{S} w_{s,1}R_{s,1} + w_{s,2}R_{s,2} \quad (9)$$

Due to the daily increase of wireless information transfer, the energy dissipation of wireless systems has been quickly rising. Consequently, obtaining the trade-off between large data throughput and energy preservation is essential in the future mobile communication schemes.

EE in bits-per-joule is specified as the proportion of the obtainable sum-rate to the total power consumption [18], [20], [39], [41], and [42]. Therefore, the total system EE can be described as:

$$EE_T(P_s, \alpha_s) = \frac{R_T(P_s, \alpha_s)}{P_T + P_C} \quad (10)$$

where P_C is the circuits' and SIC's power consumption on all subcarriers. Then, the total weighted EE (WEE) is expressed as [20], [41], and [43]–[46]:

$$EE_{T,weighted}(P_s, \alpha_s) = \frac{R_{T,weighted}(P_s, \alpha_s)}{P_T + P_C} \quad (11)$$

B. PROBLEM FORMULATION

In this subsection, the issue of optimizing PA in the downlink NOMA scheme is studied. Consequently, maximizing the total WEE for the NOMA system by using the optimum PA algorithm is our objective. Therefore, the optimization problem is formulated as follows:

$$\begin{aligned} \textit{Objectives}: \ \textit{max} \quad & EE_{T,weighted}(P_s, \alpha_s) \\ \textit{Subject to} \quad & C_1 : \sum_{s=1}^{S} P_s \le P_T, \\ & C_2 : P_s \ge 0, \quad \forall s \\ & C_3 : 0 < \alpha_s < 0.5, \quad \forall s \end{aligned} \quad (12)$$

The constraint C_1 assures the total power restrictions for the BS. The constraint C_2 ensures that the allocated power to each subcarrier is a non-negative value. C_3 specifies the range of the dynamic PA parameter used by each subcarrier to ensure the low allocated power associated with the strong user and the high allocated power associated with the weak user (i.e., ensure fairness among the two paired users per subcarrier).

Since this optimization problem is non-convex, the global optimum solution is hard to be obtained in polynomial time. Also, the computational complexity will be increased because of the presence of more than one variable. Thus, to solve this optimization problem efficiently, it is divided into two sub-problems which are solved through two iterative matched steps. One sub-problem is used to optimize the PA to each subcarrier (i.e., P_s) and the other sub-problem is used to optimize the PA to each user per subcarrier (i.e., $P_{s,1} = \alpha_s P_s$ and $P_{s,2} = (1-\alpha_s)P_s$).

IV. WEIGHTED ENERGY EFFICIENCY-POWER ALLOCATION ALGORITHM FOR NOMA SYSTEM

In this part, we concentrate on optimizing the PA to improve the total WEE and assure user fairness in the NOMA system. The execution of the NOMA system relies on selecting the paired users over a particular subcarrier, distributing the total BS power between the subcarriers, and allocating the subcarrier's power to the paired users. We consider that the two paired users are assigned to the subcarrier involving one of the related-UP algorithms presented in the related works for the SUAA which are the CUP algorithm [12] and the WSF-SUAA [24]. So, we concentrate in this paper on the PA aspect.

Specifically, we present a PA method to resolve the problem of maximizing total WEE by optimizing PA. So, we divide this problem into two sub-problems with two iterative matched steps. Therefore, firstly, we initiate α_s as constant and obtain the optimum value of P_s^*. Secondly, we obtain the optimum value of α_s in terms of the value of P_s^* that is optimized previously.

The proposed WEE-PA algorithm steps can be described in detail as follows:

1) STEP 1: OPTIMIZING THE SUBCARRIER's POWER

To optimize the power allocated to each subcarrier (P_s^*), we initiate the value of $\alpha_{s-old} = \alpha_s = 0.2$ and make it constant over all subcarriers. So, the power of the strong user and the weak user becomes $P_{s,1} = 0.2P_s$ and $P_{s,2} = 0.8P_s$, respectively. Then, the total WEE for the NOMA system in (11) becomes a function in one variable (P_s), which is represented as equation (13), shown at the bottom of the page.

Then, the resulting optimization problem in (12) is relaxed to the first sub-problem and described as follows:

$$\begin{aligned} Objectives:\ max \quad & EE_{T,weighted}(P_s) \\ Subject\ to \quad & C_1: \sum_{s=1}^{S} P_s \le P_T, \\ & C_2: P_s \ge 0, \quad \forall s \end{aligned} \tag{14}$$

The optimization sub-problem in (14) is a non-convex and nonlinearly constrained programming problem. Thus, the sequential quadratic programming (SQP) algorithm is employed in this paper to obtain the best solution [54]. The SQP is one of the most effective and fastest methods for modeling the nonlinearly constrained optimization and non-convex problems into quadratic programming sub-problems [55]. It appropriates for small or large problems and outperforms any other nonlinear programming approach related to efficiency, precision, and percentage of successful answers across a great number of examination difficulties [56]. The SQP algorithm gets close to a local minimum within a limited iteration. At every main iteration, an approximation is formed of the Hessian of the Lagrangian function employing a quasi-Newton modernizing approach [57]. The SQP algorithm merges the objective and restriction functions into a merit function and tries to reduce the merit function subject to relaxed restriction to obtain a feasible solution.

Therefore, the optimization sub-problem in (14) converts to a form proportion to the SQP algorithm form [54] to obtain the optimum value of P_s, which is described as:

$$\begin{aligned} Objectives:\ min \quad & -EE_{T,weighted}(P_s) \\ Subject\ to \quad & C_1: P_T - \sum_{s=1}^{S} P_s \ge 0, \\ & C_2: P_s \ge 0, \quad \forall s \end{aligned} \tag{15}$$

2) STEP 2: OPTIMIZING THE DYNAMIC POWER ALLOCATION PARAMETER USED BY EACH SUBCARRIER S

After obtaining the optimum value of the power per subcarrier P_s, we set $P_{s-new} = P_s$ that is computed in step1.

Then, we convert the total WEE for the NOMA system in (11) to a function in a new variable ($\alpha_{s-new} = \alpha_s$) to optimize the PA between the two paired users per subcarrier. Consequently, the total WEE is expressed as equation (16), shown at the bottom of the page

Algorithm 1 Proposed WEE-PA Algorithm

1: *Initialization*: **Set** Tolerance $\epsilon > 0$, Repetition number $= 0$.
2: **Set** $\alpha_{s-old} = \alpha_s = 0.2\ \forall s$.
3: **Solve (15) with the SQP algorithm to find** the optimum value of the variable (P_s).
4: **Set** $P_{s-new} = P_s$ that is computed in the step 3.
5: **Solve (18) with the SQP algorithm to find** the optimum value of the variable (α_{s-new}).
6: **Calculate** *error* $= L_2norm\,(\alpha_{s-new} - \alpha_{s-old})$
7: **If** *error* $< \epsilon$, then
8: **End the algorithm**.
9: **else**
10: **Set** α_{s-old} *in step* 2 $= \alpha_{s-new}$ *that computed in step* 5.
11: **Repeat** steps from **step 3 to step 6**.
12: **End if**
13: ***End of the Algorithm.***

Then, the resulting optimization problem in (12) is relaxed to the second sub-problem and converted into:

$$\begin{aligned} Objectives:\ max \quad & EE_{T,weighted}(\alpha_{s-new}) \\ & C_3: 0 < \alpha_{s-new} < 0.5, \quad \forall s \end{aligned} \tag{17}$$

The optimization sub-problem in (17) is a non-convex and nonlinearly constrained programming problem. Therefore, the SQP algorithm is employed, then the optimization

$$EE_{T,weighted}(P_s) = \frac{R_{T,weighted}(P_s)}{P_T + P_C} = \frac{\sum_{s=1}^{S}\left(w_{s,1}B_s \log_2\left(1+\alpha_{s-old}P_s\Gamma_{s,1}\right) + w_{s,2}B_s\log_2\left(1+\frac{(1-\alpha_{s-old})P_s\Gamma_{s,2}}{\alpha_{s-old}P_s\Gamma_{s,2}+1}\right)\right)}{P_T+P_C} \tag{13}$$

$$EE_{T,weighted}(\alpha_{s-new}) = \frac{R_{T,weighted}(\alpha_{s-new})}{P_T + P_C} = \frac{\sum_{s=1}^{S}\left(w_{s,1}B_s \log_2\left(1+\alpha_{s-new}P_{s-new}\Gamma_{s,1}\right) + w_{s,2}B_s\log_2\left(1+\frac{(1-\alpha_{s-new})P_{s-new}\Gamma_{s,2}}{\alpha_{s-new}P_{s-new}\Gamma_{s,2}+1}\right)\right)}{P_T+P_C} \tag{16}$$

sub-problem in (17) is transformed into:

$$Objectives: \ min \ -EE_{T,weighted}(\alpha_{s-new})$$
$$C_3 : 0 < \alpha_{s-new} < 0.5, \quad \forall s \quad (18)$$

Later, the optimum value of α_{s-new} is obtained. The two matched steps of the proposed WEE-PA algorithm are repeated several times until the error among two successive solutions is less than a specified tolerance. So, we perform the following steps after the two matched steps:

a) Calculate the error which equals to $\|\boldsymbol{\alpha}_{s-new} - \boldsymbol{\alpha}_{s-old}\|_2$. The second norm of variable x is defined as the square root of the sum of the squares of the values in each dimension. Consequently, the error is expressed as:

$$error = \|\boldsymbol{\alpha}_{s-new} - \boldsymbol{\alpha}_{s-old}\|_2 \quad (19)$$

b) If the error < tolerance, the algorithm is stopped. But if not, $\boldsymbol{\alpha}_{s-old}$ *in step* $1 = \boldsymbol{\alpha}_{s-new}$ *that computed in step* 2, next, step 1 and step 2 are repeated.

The pseudo-code that follows the proposed WEE-PA algorithm's steps is demonstrated in Algorithm 1.

V. COMPLEXITY ANALYSIS

The complexity of the proposed WEE-PA algorithm that depends on the SQP algorithm for finding its solution is discussed in this section. The complexity evaluates in terms of the total number of iterations of the SQP algorithm, which is essential for converging to the optimal solution. The total number of iterations of the SQP algorithm relies on the maximum number of function evaluations allowed, the whole number of available subcarriers S, and the number of paired users per subcarrier s in the NOMA system [55]. The total number of iterations rises if the number of subcarriers rises. Therefore, the number of iterations of the optimization sub-problem in (15) employing the SQP algorithm in the first step of the proposed WEE-PA algorithm is almost equal to $O\left(S * (number\ of\ multiplexedusers\ per\ subcarrier)^2\right) = O\left(S * 2^2\right) = O(4S)$.

Hereafter, we note that the number of iterations of the optimization sub-problem in (18) employing the SQP algorithm in the second step of the proposed WEE-PA algorithm is almost equal to the number of iterations in the first step of the proposed WEE-PA algorithm. Thus, the total number of iterations of the proposed WEE-PA algorithm after two matched steps are almost equal to $2 * O(4S)$. Then, the two matched steps are repetitively several times until the error in the last step is smaller than the tolerance. Consequently, the complexity (i.e., the total number of iterations) of the proposed WEE-PA algorithm is almost equal to:

$$The\ Complexity = 2 * \ Number\ of\ repetition * O(4S) \quad (20)$$

In order to investigate the complexity of the proposed WEE-PA algorithm, the average run time versus the number of subcarriers for $P_T = 2w, P_T = 6w, P_T = 12w$ is shown in Fig. 2. This figure shows the average run time for the proposed WEE-PA algorithm when it is implemented using

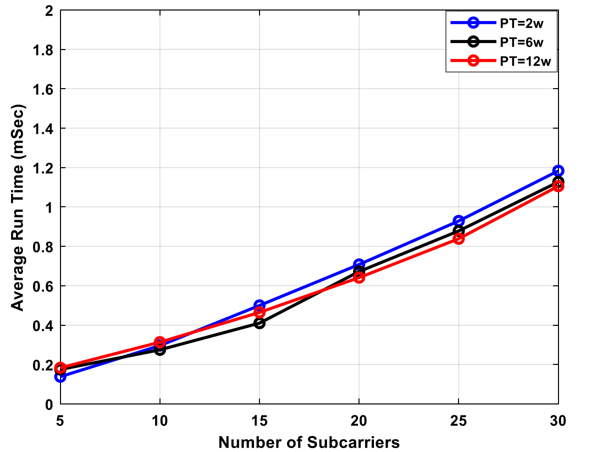

FIGURE 2. Average run time versus the number of subcarriers for $P_T = 2w, P_T = 6w, P_T = 12w$.

MATLAB 2018 software on Windows 10 using Intel(R)-Core (TM) i5-6300U CPU, and RAM of 8.00 GB. In addition, the average run time of the proposed WEE-PA algorithm is computed for 1000-channel realization. As shown in Fig. 2, when the number of subcarriers increases, the algorithm's average run time rises. It is noteworthy that the change in the total transmitted power does not affect the complexity of the proposed WEE-PA algorithm significantly. Consequently, Fig. 2 proves that the complexity of the proposed WEE-PA algorithm depends on the number of subcarriers as previously calculated in (20) and doesn't depend on the total transmitted power (P_T).

VI. SIMULATION RESULTS AND DISCUSSION

The proposed WEE-PA algorithm's performance in the downlink NOMA scheme is evaluated through the simulation results. In our simulations, we realize one BS that positioned in the cell center, and the user terminals are scattered randomly in a circular range with a radius of 500 m, and the smallest distance between a certain user and the BS is $d_k = 50m$ [18], [34], and [41]. The value of the path loss exponent is set to be $\gamma = 2$ [20], and [41], [42]. We suppose that the total power budget of the BS is $P_T = 12w$ and the circuit power consumption is $P_C = 1w$ [18], [20], and [41], [42]. A multipath frequency-selective-Rayleigh-fading channel is considered [23], and [24]. The noise power is represented by $\sigma_s^2 = N_0 \frac{B}{S}$, where $N_0 = -174$dBm/Hz is the noise-power-spectral-density and the $B = 5\,MHz$ is the total system bandwidth [18], [20], and [41], [42]. We set the value of tolerance as $\epsilon = 10^{-3}$. The weight factors of the two paired users on the same subcarrier s are set to be $w_{s,1} = 0.9$, and $w_{s,2} = 1.1 \forall s$, where these values satisfy the condition of $1 < \frac{w_{s,2}}{w_{s,1}} < \frac{\Gamma_{s,1}}{\Gamma_{s,2}}$ to avoid a collapse of the SIC process and ensure fairness [20], and [41].

MATLAB's optimization toolbox is used in our simulations to implement the SQP algorithm by using fmincon function. The results shown below are averaged over 1000-channel realizations.

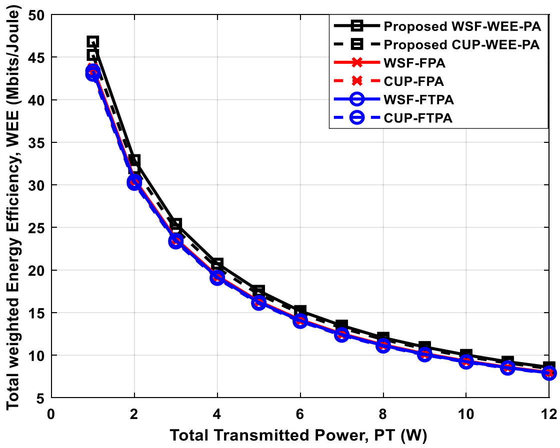

FIGURE 3. The total weighted energy efficiency versus the total transmitted power of the BS for $S = 5$ subcarriers and $K = 10$ users.

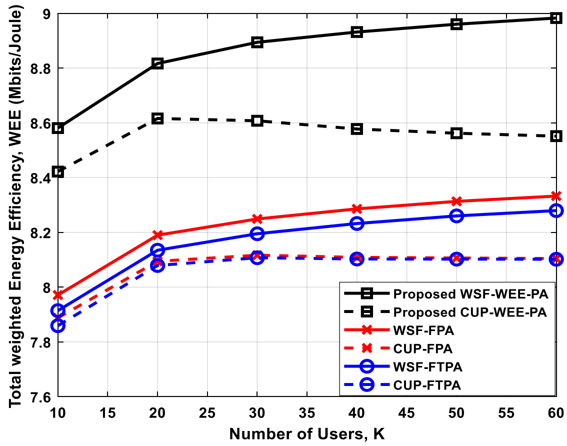

FIGURE 4. The total weighted energy efficiency versus the number of users for $P_T = 12w$.

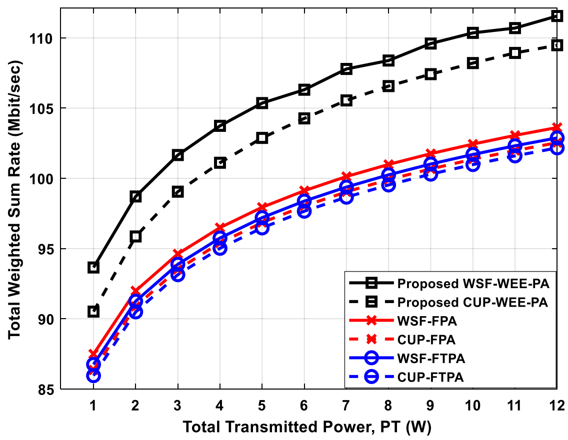

FIGURE 5. The total weighted sum rate versus the total transmitted power of the BS for S = 5 subcarriers and K = 10 users.

To prove the performance gain of the proposed WEE-PA algorithm, we contrast it with two PA algorithms as benchmarks. The first benchmark algorithm is the FPA algorithm [25], in which the BS distributes the total transmit power equally between the available subcarriers. Later, the FPA algorithm is employed to divide the power per subcarrier s among its two paired users, where $P_{s,1} = o.2P_s$, and $P_{s,2} = 0.8P_s$. The second is the FTPA algorithm [25], [26], in which the BS splits the total transmit power equally among available subcarriers. Next, the FTPA algorithm is adopted to apportion the power per subcarrier s among its two paired users with a decay power-distribution factor equal to 0.2.

For the SUA algorithms, we employ the CUP algorithm [12] and the WSF-SUAA [24] with all PA algorithms. So, CUP-WEE-PA, CUP-FPA, and CUP-FTPA represent the CUP algorithm associated with the proposed WEE-PA algorithm, FPA algorithm, and FTPA algorithm, respectively. On the other hand, WSF-WEE-PA, WSF-FPA, and WSF-FTPA represent the WSF algorithm associated with the proposed WEE-PA algorithm, FPA algorithm, and FTPA algorithm, respectively. Most of the simulation results are displayed against the total transmitted power of the BS (P_T) for $S = 5$ subcarriers and $K = 10$ users, and against the number of users for $P_T = 12w$.

Fig. 3 and Fig. 4 demonstrate the total weighted energy efficiency (WEE) versus the total transmitted power of the BS and the number of users, respectively. We observe that the proposed WEE-PA algorithm with any SUA algorithms succeeded in achieving the PA optimization goal to advance the total WEE of the NOMA scheme. Therefore, as the number of users rises or the value of the total transmitted power rises, the proposed WSF-WEE-PA and CUP-WEE-PA algorithms perform better in maximizing WEE compared to WSF-FPA, CUP-FPA, WSF-FTPA, and CUP-FTPA algorithms. The total WEE decreases as the total transmitted power of the BS increases, as shown in Fig. 3, due to the inverse relationship shown in (11). In Fig 4, when the number of users increases, the WEE value increases for the schemes using the WSF algorithm in the SUA operation (i.e., WSF-WEE-PA, WSF-FPA, and WSF-FTPA) because the WSF algorithm prevents choosing a user with the worst channel gain with any subcarrier. Consequently, the paired users selected for each subcarrier have better channel gain, the total weighted sum rate increases, and the WEE value raises. On the other hand, when the number of users increases, the WEE value decreases approximately for the schemes that use the CUP algorithm in the SUA process (i.e., CUP-WEE-PA, CUP-FPA, and CUP-FTPA) because the CUP algorithm doesn't consider which subcarrier starts the SUA process. Also, the subcarriers at the later stages are left with limited options to select paired users which leads to assigning users with low channel gains over the subcarriers. So, when the number of users increases, the paired users selected for each subcarrier may have worse channel gain, the total weighted sum rate decreases, and the WEE value decreases.

The total weighted sum rate versus the total transmitted power of the BS and the number of users is presented in Fig. 5 and Fig. 6, respectively. We note that with varying the number of users or varying the value of total

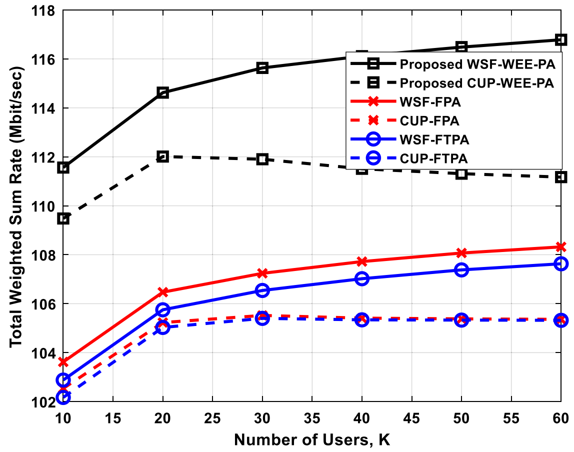

FIGURE 6. The total weighted sum rate versus the number of users for $P_T = 12w$.

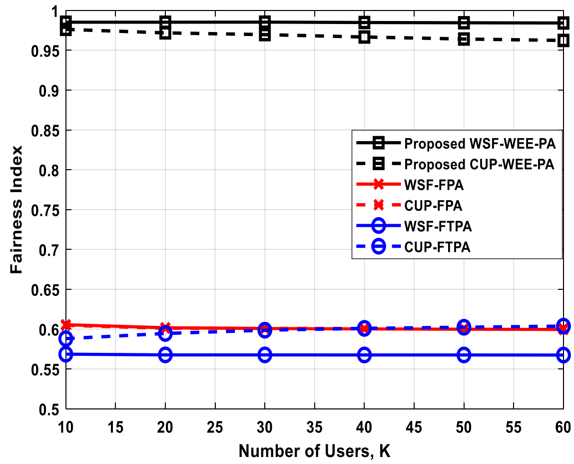

FIGURE 8. The fairness index versus the number of users for $P_T = 12w$.

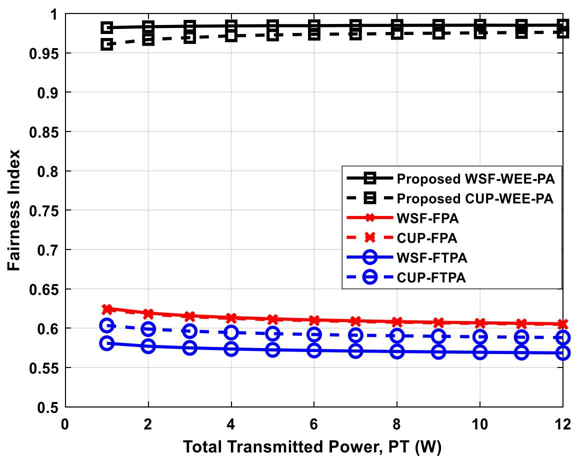

FIGURE 7. The fairness index versus the total transmitted power of the BS for $S = 5$ subcarriers and $K = 10$ users.

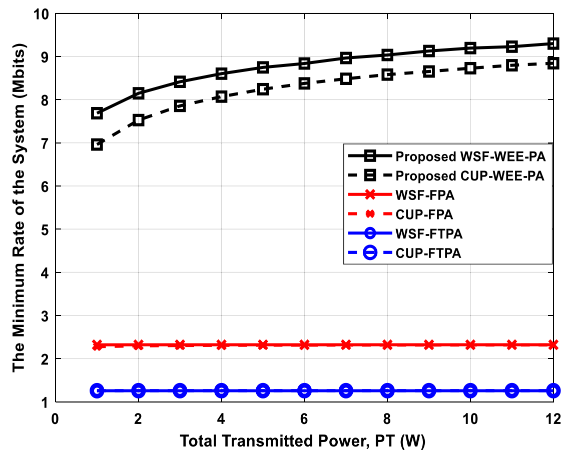

FIGURE 9. The minimum rate of the system versus the total transmitted power of the BS for $S = 5$ subcarriers and $K = 10$ users.

transmitted power, the proposed WSF-WEE-PA and CUP-WE-PA algorithms give a noticeably higher weighted sum-rate compared to WSF-FPA, CUP-FPA, WSF-FTPA, and CUP-FTPA algorithms. This is because the total WEE and the total WSR have a direct relationship, as shown in (11). Also, the proposed WSF-WEE- PA and CUP-WEE-PA algorithms give a higher WEE compared to the considered benchmark algorithms, as shown in Fig. 3 and Fig. 4. As demonstrated in Fig 6, when the number of users increases, the total WSR value of the schemes using the WSF algorithm in the SUA process (i.e., WSF-WEE-PA, WSF-FPA, and WSF-FTPA) rises. Because the selected paired users per subcarrier have better channel gain increasing the total weighted sum rate. Also, when the number of users increases, the total WSR value for schemes using the CUP algorithm in the SUA process (i.e., CUP-WEE-PA, CUP-FPA, and CUP-FTPA) reduces approximately. Because the selected paired users for each subcarrier may have worse channel gain resulting in a reduction in the total weighted sum rate.

The fairness index versus the total transmitted power of the BS and the number of users is displayed in Fig. 7 and Fig. 8, respectively. The fairness index aims to ensure that resources are allocated fairly among users in the system due to introducing the weighting factors $w_{s,1}$ and $w_{s,2}$ and suggesting the value of α_s in the optimization PA problem.

The fairness index (FI) concerning the data rate of users is denoted by [23], [24], and [58]:

$$FI = \frac{(\sum_{k=1}^{K} R_k)^2}{K \sum_{k=1}^{K} (R_k)^2} \tag{21}$$

Fig. 7 and Fig. 8 prove that the WSF-WEE-PA and CUP-WEE-PA algorithms are much larger than the WSF-FPA, CUP-FPA, WSF-FTPA, and CUP-FTPA algorithms in FI as a result of guaranteeing user fairness in building the problem of PA of optimization.

Fig. 9 and Fig. 10 demonstrate the minimum user rate of the NOMA system versus the total transmitted power of the BS and the number of users, respectively. It is noticeable that implementing the proposed WEE-PA algorithm with any SUA algorithms greatly enhances the minimum user rate than other PA algorithms and works better with the

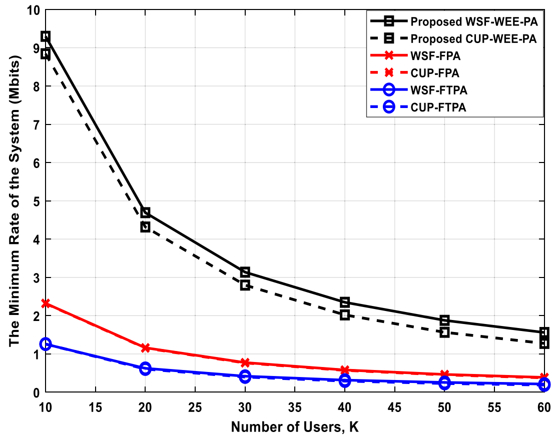

FIGURE 10. The minimum rate of the system versus the number of users for $P_T = 12w$.

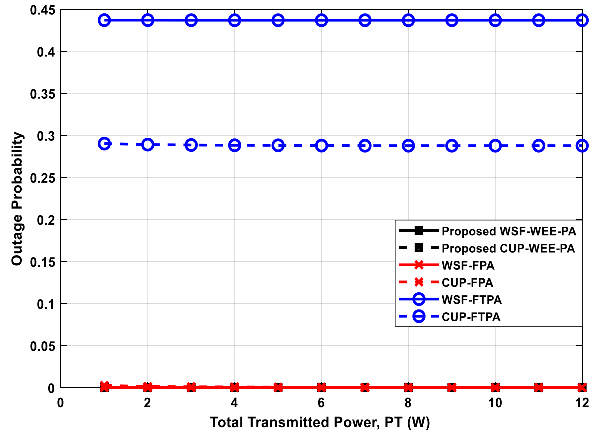

FIGURE 12. The outage probability versus the total transmitted power of the BS for S = 5 subcarriers and K = 10 users.

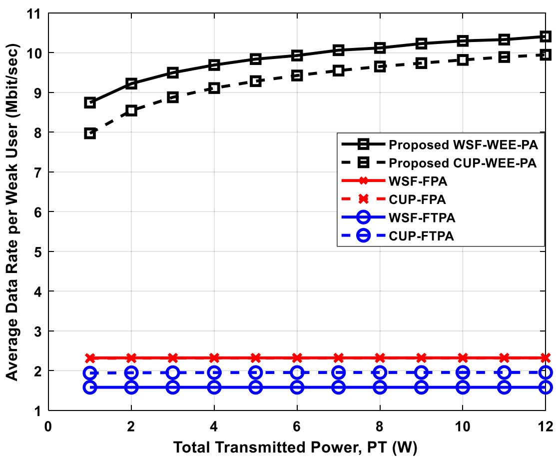

FIGURE 11. The average data rate per weak user versus the total transmitted power of the BS for $S = 16$ subcarriers and $K = 32$ users.

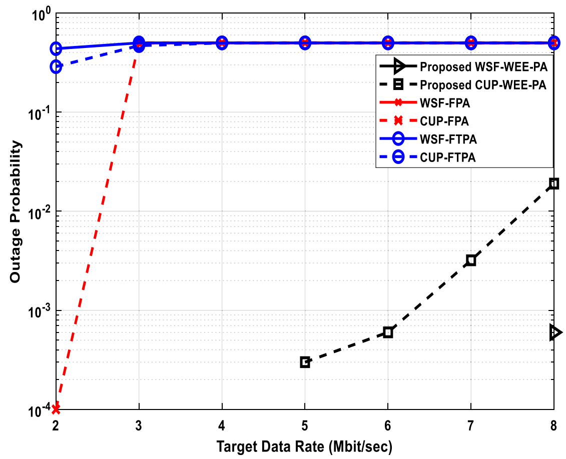

FIGURE 13. The outage probability versus the target data rate for S = 5 subcarriers, K = 10 users, and $P_T = 12w$.

WSF algorithm. As demonstrated in Fig. 10, the NOMA system's minimal user rate reduces with increasing the number of users. Because the power resource is constant, the power allocated to each user decreases with growing number of users.

The average data rate per weak user versus the total transmitted power of the BS is exposed in Fig. 11. This figure shows that the proposed WEE-PA algorithm with the WSF and CUP algorithms has substantially greater average data rates per weak user than other related PA algorithms. Because it ensures fairness in resource allocation and increases total WSR and total WEE for the NOMA system.

Fig. 12 studies the outage probability against the total transmitted power of the BS. The outage probability is defined as the probability that the simulated user's data transmission rate will not reach the target data rate of 2 Mbps/Hz.

There is no outage for the proposed WEE–PA algorithm and the FPA algorithm. Since the data rate values of the paired users are not smaller than the target data rate (2 Mbps/Hz) for all total transmitted power values, as shown previously in Fig. 9 and Fig. 10. On the other side, the FTPA provides considerably high outage probability, especially with the CUP algorithm.

To further prove the efficiency of the proposed WEE–PA in enhancing the outage probability than the other PA algorithms, the outage probability versus the different value of the target data rate for $S = 5$ subcarriers, $K = 10$ users, and $P_T = 12w$ is investigated and presented in Fig.13. This figure proves that the outage probability of both FTPA and FPA increases sharply to 0.5 as the target data rate becomes higher than 2 Mbps/Hz. Conversely, the outage probability of the CUP-WEE-PA algorithm is less than 10^{-3} for a target data rate lower than 7 Mbps/Hz, and there is no outage occurred with the WSF-WEE-PA for all simulated values of the target data rate.

VII. CONCLUSION

This paper suggests an approach for solving the PA problem in the downlink NOMA scheme to improve the weighted energy efficiency (WEE) and ensure fairness between users through using the user's weight factors. Therefore, the optimization problem is formulated in terms of PA among subcarriers and PA between the paired users per subcarrier under the restrictions of total power and the dynamic PA parameter range to ensure user fairness. The proposed weighted energy efficiency power allocation (WEE-PA) algorithm is investigated to resolve the optimization problem by relaxing it into two sub-problems to decrease the computation complexity caused by introducing more than one variable in the optimization problem. Moreover, the two sub-problems solve through two iterative matched steps. The first sub-problem aims to optimize the PA of each subcarrier. Besides, the second sub-problem aims to optimize the PA between the two paired users of each subcarrier. Because the optimization problem is non-convex, the sequential quadratic programming (SQP) technique is applied to reach the optimum solution. The simulation results expose that applying the proposed WEE-PA algorithm to any subcarrier-user assignment algorithms is better than the considered benchmark PA schemes. The proposed WEE-PA algorithm can enhance the NOMA system performance in terms of the WEE, the fairness among users, the minimum user rate of the system, the average data rate per weak user, and the outage probability.

ACKNOWLEDGMENT

The authors would like to acknowledge the support received from Taif University Researchers Supporting Project Number (TURSP-2020/147), Taif university, Taif, Saudi Arabia.

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