Automatika

Journal for Control, Measurement, Electronics, Computing and Communications

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/taut20

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To cite this article: G. Shanmugavel & M. S. Vasanthi (2024) Subcarrier-users nomination process for downlink NOMA system, Automatika, 65:2, 652-661, DOI: 10.1080/00051144.2024.2314937

To link to this article: https://doi.org/10.1080/00051144.2024.2314937

Published online: 13 Feb 2024.

AUTOMATIKA
2024, VOL. 65, NO. 2, 652–661
https://doi.org/10.1080/00051144.2024.2314937

Subcarrier-users nomination process for downlink NOMA system

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ABSTRACT

The non-orthogonal multiple access (NOMA) characteristics of 5G radio access allow for more efficient resource distribution. NOMA improves spectral efficiency by allowing Power domain users to transmit power concurrently with other users of time and spectrum resources. The selection of the subcarrier and the nomination of users to the subcarrier is of the utmost importance to maximize spectral efficiency fairness among the users and improve the data rate of weak users in the downlink NOMA system. The least gain subcarrier First-threshold-based Adaptive user grouping algorithm (LGSF-TBAUGA) has been devised for this purpose. This algorithm maintains a significant channel gain differential based on a threshold, thus avoiding successive interference cancellation (SIC) process imperfections. The computational complexity of the proposed technique is calculated and compared to other approaches. The power coefficients of the selected users are used to allocate power to them. The proposed method improves the weak user data and overall system sum rates. As a result, the spectrum efficiency and user fairness index have been greatly enhanced compared to some existing algorithms.

ARTICLE HISTORY
Received 1 December 2023
Accepted 31 January 2024

KEYWORDS
Subcarrier selection; user grouping; NOMA; computational complexity; spectral efficiency; fairness index

1. Introduction

The motivation for subcarrier selection and user nomination ultimately lies in optimizing system performance, accommodating diverse user requirements, and ensuring efficient use of limited communication resources. The specific strategy employed will depend on the goals and challenges of the communication system in question. The necessity to accommodate a substantial quantity of associated users and diverse Internet of Things (IoT) devices, along with the surge in data traffic resulting from novel applications, has emerged as a critical requirement for 5G cellular networks. These networks must be capable of delivering desired services to this heterogeneous range of users and IoT devices, given the quick expansion of the IoT and the escalating demand for connectivity. Spectral efficiency (SE) has emerged as a paramount concern in 5G wireless networks [1]. In the context of SE, it has been observed that NOMA approaches exhibit superior performance compared to orthogonal multiple access (OMA), particularly in scenarios characterized by fading environments [2]. Despite the relative ease of deployment associated with OMA schemes, their SE is lower, and their radio resources are constrained, hence limiting their ability to cater to the demands of forthcoming networks characterized by a high volume of connections [3]. NOMA exhibits superiority over OMA due to its ability to accommodate multiple users concurrently and on the same frequency channel within a cell [4].

The power-domain non-orthogonal multiple access (PD-NOMA) scheme involves sharing available power among users [5]. Multiuser detection methods, such as SIC, are employed in the receiver end to differentiate the preferred signals. Moreover, PD-NOMA is responsible for managing the distribution of adaptable resources and enhancing the NOMA system's efficacy, encompassing SE, energy efficiency (EE) and fairness among the users. Users who don't have good information about the channel state are given more power to show how PD-NOMA enhances user fairness, while users who have better information about the channel receive less power [6,7].

The rest of the paper is organized as follows: Section 2 represents the related works about Channel assignment and user grouping methods. The system model and mathematical formulation of the sum-rate maximization challenges are presented in Section 3. Section 4 describes the suggested method for selecting subcarriers and grouping users' algorithms, while Section 5 deals with the derivation of the computational complexity of the proposed algorithm. Then, section 6 presents simulation results and analysis. The results are summarized, and the paper's conclusions are drawn in section 7.

2. Related works

Studies have given more attention in the last decade to the issue of how resources are allocated in NOMA

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systems. Users have been paired together, channels have been assigned, and power has been distributed in numerous NOMA-based research [8–11]. Therefore, we selected the subcarrier with paired users in this study and concentrated on the user pair (UP) problem. Many academics have recently turned to UP and power allocation (PA) algorithms in an effort to boost NOMA's SE, EE and user fairness index. In the first UP technique, described as "random pairing" (RP) in [12], the base station (BS) randomly assigns users to available sub-channels. Two UP methods are presented in [13], and the Multi-UP technique is added to increase user capacity while minimizing or eliminating the mid-UP issue. In Conventional user pairing (CUP), the strongest and most weak users are paired; the next strong and the next weak users are considered to pair. Hybrid UP and UCGD stand for "uniform channel gain difference" and "hybrid UP", respectively. Here, we group people with average gains with those with poor ones. Hybrid UP relies on traditional UP for users located on the far edge of the cell when the channel gain variances are significant. A virtual UP is utilized in order to make efficient use of the available spectrum that is accessible to unpaired users in NOMA systems when two far-users have identical amounts of channel gain, and a near-user may utilize the same amount of frequencies [14]. This is done in order to make efficient use of the spectrum that is available to unpaired users. In [15], the channel gain difference between users is increased for user clustering, and deep learning-based power is allocated to users.

User grouping strategy is used in [16–21] to overcome the UP issue of the NOMA systems, yielding viable solutions with affordable complexity. The technique of pairing views the user and subcarriers as a couple of users to be combined to achieve the highest sum-rate. User and subcarrier preference lists must match with channel statuses. In [22], researchers investigated how to improve a downlink multicarrier NOMA network's EE and fairness index by adjusting subcarrier and power assignment parameters. Also recommended is the worst-case user first subcarrier allocation (WCUFSA) algorithm, a novel greedy technique. The differentiated greedy method has a good track record for users with high-quality channels via subcarriers. As a bonus, it stops users from getting channels that have fewer channel attributes. In [23], this study aims to find the best subcarrier selection to feed downlink NOMA systems while minimizing outages and ensuring that all users are treated equally. Then, they suggest a simple greedy-based subcarrier sharing method based on the first principle of the least gain user. In [24], the authors discussed subcarrier selection and user matching technique to improve the spectral efficiency of NOMA.

In [25] discussed the Weighted Sum Rate Maximization (WSRM) and Weighted Sum Energy Efficiency Maximization (WSEEM) challenges while scheduling users and distributing power in Multi-Cell Multi-Carrier NOMA (MCMC-NOMA) networks. The subcarrier user matching technique for downlink NOMA is based on the worst subcarrier first subcarrier user assignment algorithm (WSF-SUAA) [26] is discussed. In [27], we can take a look at Joint subcarrier and power allocation (JSPA). Similar results can be obtained using Lagrangian-duality and dynamic programming (LDDP) by employing a three-way resource allocation approach to tackle the overall system sum-rate improving difficulties. In [28], a NOMA system is investigated to minimize power usage by studying cooperative groups of users.

3. Modelling a system and formulating a problem

This section will elucidate the system model for downlink NOMA systems presently under consideration. We have formulated the challenge of maximizing the sum-rate to further improve the fairness of the system and assure fairness for all users.

3.1. Proposed system model

In Figure 1, we see a diagram of a proposed downlink NOMA system.; in this setup, a base station (BS) delivers data simultaneously to a group of users denoted by $\mathbb{N} = \{1, 2, \ldots, N\}$, where N is the total count of users (also known as the cardinal of the set $\mathbb{N}$; written as $N = \#\mathbb{N}$, with # standing for the cardinal operator). Where the grouped users are assigned to the group of subcarriers that $\mathbb{M} = \{1, 2, \ldots, M\}$, then $M = \#\mathbb{M}$ denotes the total count of subcarriers. Then, the amount of available bandwidth in the system is denoted as W, and is evenly divided into M subcarriers. Then the, each subcarrier bandwidth is $B = \frac{W}{M}$

The channel gain is represented by $|C_g|^2$where $C_g = G_{rf}/\sqrt{1 + d_x^q}$, where, G_rf represents the Rayleigh channel gain, d represents the User distance from BS, x stands for the iteration number represents the user location, which is determined by instinct distance and q represents the path loss coefficient. It is assumed that

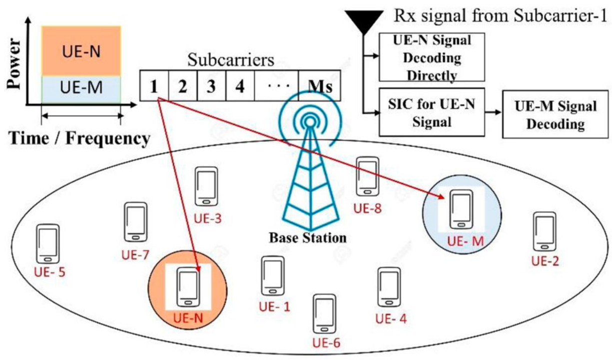

Figure 1. Downlink system architecture proposed for NOMA.

S.No:	Reference	Methods Used	Contributions	Outcomes
1	[25]	Fractional Programming (FP). Successive Pseudo-Convex Approximation (SPCA)	Investigated user scheduling and power allocation in Multi-Cell Multi-Carrier NOMA networks.	Proposed framework shown to be efficient and superior to existing schemes.
2	[15]	User grouping method based on maximum channel gain difference	Proposed power allocation methods improve system sum rate by about 10%	Deep learning power allocation improves sum rate by about 2.2% and 19% compared to other methods. Proposed power allocation methods improve system sum rate by about 10%.
3	[23]	LOUFSA Algorithm for subcarrier allocation User pairing and power allocation mechanisms in NOMA systems	LOUFSA Algorithm for subcarrier allocation User pairing and power allocation mechanisms in NOMA systems A novel lowest-opportunities user first principle for subcarrier allocation.	The LOUFSA algorithm's performance improves as the number of users increases. The LOUFSA algorithm achieves the highest data rate for weak users.
4	[29]	The paper proposes a resource allocation scheme for D2D communications. The scheme includes a vital algorithm for fair resource allocation among D2D pairs.	Fairness in resource allocation among different D2D pairs. Water-filling algorithm for power allocation among allocated subcarriers.	Increasing coherence bandwidth doesn't affect algorithm performance. Increasing SNR per subcarrier improves fairness index.
5	[21]	Heuristic matching algorithm for user-channel matching Particle swarm optimization algorithm for power allocation	Utilized particle swarm optimization algorithm for power allocation. Notable improvement in system throughput (15%) and user fairness 55%.	Notable improvement in system throughput (15%) Significant improvement in user fairness (55%)
6	[20]	Analytical characterization of optimal power allocation with given channel assignment	Provided optimal power allocation in closed or semi-closed form. Proposed a low-complexity method to optimize channel assignment and power allocation.	Consideration of power order constraints in power allocation problems. Proposed method for joint optimization of channel assignment and power allocation
7	[18]	Superposition coding and successive interference cancellation techniques. Low-complexity suboptimal algorithm for subchannel assignment and power allocation	Various new techniques proposed to meet overwhelming data rate requirements.	Proposed algorithms yield better sum rate and energy efficiency performance. Subchannel power allocation achieves better performance than equal power allocation scheme.
8	[17]	Matching algorithm for subchannel assignment and power allocation. Two-sided exchange stable matching. Interior point methods for problem solving	Formulate joint sub-channel and power allocations as a non-convex weighted total sum-rate maximization problem.	The proposed algorithm outperforms orthogonal multiple access and previous non-orthogonal multiple access schemes.
9	[13]	Investigated performance effects of near-far pairing on regions with negligible channel gain differences between users.	Mathematical analysis of exact ergodic sum capacity of a two users pair considering perfect and imperfect SIC.	Increasing number of in-pair users leads to increased SIC imperfection effects.
10	[30]	Non cooperative game resource optimization. Subchannel assignment scheme using matching theory. Power allocation problem decoupled into three subproblems	Decoupling of power allocation problem into three sub problems. Simulation results demonstrating the effectiveness of the proposed resource allocation scheme	Power allocation problem decoupled into three subproblems and solved separately. Simulation results show potency of proposed resource allocation scheme
11	[31]	Sub-channel scheduling. Task assignment. Power allocation.	Proposes a low-complexity algorithm based on matching theory for sub-channel allocation. Derives closed-form solutions for task assignment coefficients and transmit power. Analyzes offloading strategy in both OMA and NOMA schemes.	Offloading strategy can be dynamically and efficiently used with different conditions. No other outcomes or results are mentioned in the abstract.

the channel state information (CSI) is perfectly sent to the BS. The BS allocates a set of subcarriers to a group of users and provides them varied amounts of power based on every subcarrier's CSI. The BS is presumed to be fully conversant with the CSI. The BS allocates a range of subcarriers and transmits powers to a set of users based on the CSI of each subcarrier.

It is presumed each and every subcarrier has been assigned to N_m users, where N_m is the total users who can be multiplexed on subcarrier$m$. Then, the entire amount of users are considered to be $N = N_m M$. Then [4,32], the message that the BS sent to N_m users are grouped to the subcarrier m is denoted by:

$$T_X = \sum_{n=1}^{N} \sqrt{P_{m,n}} X_{m,n} \tag{1}$$

Power allocation for user n on subcarrier$m$ is denoted by $P_{m,n}$. In addition, $X_{m,n}$ Denote the data transferred to user n to the subcarrier$m$.

The resulting signal for user n in subcarrier m can be written as

$$RX_{m,n} = Cg_{m,n}TX + A_{m,n} \quad (2)$$

$$RX_{m,n} = \sqrt{P_{m,n}}Cg_{m,n}X_{m,n} + \sum_{i=1,i\neq n}^{N_m} \sqrt{P_{m,n}}Cg_{m,n}X_{m,i} + A_{m,n} \quad (3)$$

In Equation (3) $Cg_{m,n}$ denotes the channel gain of *nth* user of *mth* subcarrier generated by the BS, and $A_{m,n}$ Mention that the additive white Gaussian noise of *nth* user with mean value is zero and the variance.$\sigma^2 = N_0\frac{W}{M}$, here N_0 represents the noise power spectral density (PSD). With the assumption that the user's channel gains have been normalized due to noise, SIC is used to process the incoming signal from the BS at the receiver end before being arranged from highest to lowest priority as $\frac{|Cg_{m,1}|^2}{\sigma^2} \geq \ldots \geq \frac{|Cg_{m,n}|^2}{\sigma^2} \geq \ldots \geq \frac{|Cg_{m,n_m}|^2}{\sigma^2}$. After that, the BS adjusts the power it gives each user as$P_{m,1} \leq \ldots \leq P_{m,n} \leq \ldots \leq P_{m,n_m}$. According to the SIC process, the strong user (i.e. very weak or less channel gain users the BS allotted more power) decodes first directly, and then the other user's signals are extracted in the superimposed signal. The signal-to-interference noise ratio (SINR) of the user n with respect to subcarrier m after applying the SIC technique [22,29] is given as

$$SINR_{m,n} = \frac{P_{m,n}|Cg_{m,n}|^2}{\sum_{i=1,i\neq n}^{n-1} P_{m,i}|Cg_{m,n}|^2 + \sigma_m^2} \quad (4)$$

The assigned bandwidth of every single subcarrier has been normalized to $1H_z$, and N_0 is consistent with overall subcarriers. Then, the data rate of *nth* user and *mth* subcarrier can be written as

$$DR_{m,n} = log_2(1 + SINR_{m,n}) \quad (5)$$

$$DR_{m,n} = log_2\left(1 + \frac{P_{m,n}|Cg_{m,n}|^2}{\sum_{i=1,i\neq n}^{n-1} P_{m,i}|Cg_{m,n}|^2 + AN_0}\right) \quad (6)$$

Calculate the overall sum rate as

$$SR_T = \sum_{m=1}^{M} SR \quad (7)$$

Where $SR = \sum_{n=1}^{N_m} DR_{m,n}$ The subcarrier's overall sum rate is represented bySR.

3.2. Problem formulation

We represent the $(M \times N)$ subcarrier and users as a matrix $G_{m,n}$ in order to establish a pairing correlation between them. The binary value of $m_{m,n}$ that the user n can be assigned to subcarrier m.

$$G_{m,n} = \begin{bmatrix} m_{1,1} & \ldots & m_{1,n} \\ \ldots & \ldots & \ldots \\ m_{m,1} & \ldots & m_{m,n} \end{bmatrix} \quad (8)$$

$$g_{m,n} = \begin{cases} 1, & \textit{if User n has been allocated to subcarrier m;} \\ 0, & \textit{otherwise;} \end{cases} \quad (9)$$

The main objective of the proposed method is to reduce the SIC as much as possible and simultaneously increase user fairness, total sum rate and system performance. Then to create the optimization issues can be denoted as to enhance the total sum rate of the system: max SR_T

Subject to the following criteria

$$C_1 : \sum_{m=1}^{M}\sum_{n=1}^{N} P_{m,n} \leq P_T$$
$$C_2 : P_{m,n} \geq 0, \forall_{M,n}$$
$$C_3 : \sum_{n=1}^{N} h_{m,n} = N_m, \forall_M$$
$$C_4 : \sum_{m=1}^{M} h_{m,n} = 1, \forall_M$$
$$C_5 : h_{m,n} \in \{0, 1\}, \forall_{M,n}$$

Here P_T is the Maximum power transmission of the base station and each of the users across every subcarrier, subject to the constraints of C1 and C2. C3 ensures that N_m Users are the only ones who can use each subcarrier. C4 demonstrates that all users can only get data via a single subcarrier. C5 makes it necessary to assign subcarriers.

4. Proposed least gain subcarrier first and threshold-based adaptive user grouping algorithm (LGSF-TBAUGA)

The proposed LGSF-TBAUGA assigns users to suitable subcarriers according to its channel gain value. The proposed algorithm will function based on each user's channel gain value. Here N number of users and M number of subcarriers ($M = \frac{N}{2}$) are considered. Two users are considered as a group or pair to assign for subcarrier. The proposed algorithm will perform based on the following steps.

Step-1: Based upon the subcarrier and users, a channel gain matrix is formed, and then the least channel gain user is identified in each subcarrier.
Step-2: The proposed method will operate depending on the channel gain value of each user.
Step-3: In rearranged subcarriers, each subcarrier with the strong gain user (1st user) is identified.
Step-4: Based on the threshold value, the next strong channel gain user (2nd user) is identified in each subcarrier to group a user's. (The selection of the

next strong channel gain users for remaining subcarriers are un-selected users of subcarriers only considered.)

Proposed algorithm (LGSF-TBAUGA)

1: *Initialization*: Form a matrix with channel gain $H = |Cg_{s,k}|^2 \forall_M \in M\ Subcarriers\ n \in N\ users.$

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

3: In every m subcarriers, pick the worst channel gain: $Cg_m^{worst} = \min |cg_{s,k}|^2 \forall_M$

4: Sort m subcarriers in ascending sequence based on Cg_s^{worst}

5: end for

6: for m subcarrier that has been arranged **do**

7: pick up the user to the highest channel gain in m subcarrier that has been arranged. (i.e. strongest gain user): $Cg_{m-sorted}^{worst} = \max |cg_{m-sorted,n}|^2 \forall_M - Sorted$

8: Don't choose the selected user again by any subcarrier, and The chosen user will be deleted from all N users.

9: end for

10: for subcarrier that has been arranged, **do**

11: Fix the Threshold value between the user is 0.2 $if(|cg_m| \geq 0.2)$ users who were still not selected for m subcarrier that has been arranged (i.e. Least gain user): $Cg_{m-sorted}^{worst} = \max |cg_{m-sorted,\ remained\ n}|^2 \forall_M - Sorted$

12: Take the chosen user out of the list of all *N-users* and No need to choose already selected subcarrier once more.**13: end for14:** ***End***

13: end for

14: ***End***

The steps of the proposed LGSF-TBAUGA algorithm are provided in detail with examples.

Step-1, is executed within the matrix($M1$). The least channel gain user is found in all subcarriers in ($M1$). The identified least channel gain users of subcarriers 1, 2, 3 and 4 is 0.11, 0.12, 0.15 and 0.09, respectfully.

$$\begin{bmatrix} Users: & 1 & 2 & 3 & 4 & 5 \\ Subcarrier1: & 0.64 & 0.11 & 0.91 & 0.94 & 0.85 \\ Subcarrier2: & 0.48 & 0.39 & 0.12 & 0.29 & 0.36 \\ Subcarrier3: & 0.15 & 0.98 & 0.57 & 0.6 & 0.96 \\ Subcarrier4: & 0.53 & 0.93 & 0.48 & 0.92 & 0.09 \end{bmatrix.$$
$$\left. \begin{matrix} 6 & 7 & 8 \\ 0.2 & 0.6 & 0.92 \\ 0.87 & 0.53 & 0.85 \\ 0.62 & 0.17 & 0.6 \\ 0.62 & 0.29 & 0.72 \end{matrix} \right] \quad \text{(M1)}$$

Step-2, implemented in($M2$). It shows that the rearranged subcarriers are based of (LGSF). Then, the subcarriers are arranged in ascending order as ($S4$) then ($S1$), ($S2$) and($S3$).

$$\left[\begin{matrix} Users: & 1 & 2 & 3 & 4 & 5 \\ Subcarrier4: & 0.53 & 0.93 & 0.48 & 0.92 & 0.09 \\ Subcarrier1: & 0.64 & 0.11 & 0.91 & 0.94 & 0.85 \\ Subcarrier2: & 0.48 & 0.39 & 0.12 & 0.29 & 0.36 \\ Subcarrier3: & 0.15 & 0.98 & 0.57 & 0.6 & 0.96 \end{matrix} \right.$$
$$\left. \begin{matrix} 6 & 7 & 8 \\ 0.62 & 0.29 & 0.72 \\ 0.2 & 0.6 & 0.92 \\ 0.87 & 0.53 & 0.85 \\ 0.62 & 0.17 & 0.6 \end{matrix} \right] \quad \text{(M2)}$$

Step-3 to find the strong user from M2, in ($S4$) A total 8 users are available. In the strong channel, a gain user should be selected. So user 2nd is selected as a most strong channel gain user in ($S4$). For that, in ($S1$) user 4 is selected, in ($S2$) user 6 is selected, and then in ($S3$)user 2 is the strong channel gain user, but user 2 is already selected from($S4$), so the next unselected strong channel gain user should be selected for ($S3$). User 5 is the unselected strong channel gain user for ($S3$).

$$\left[\begin{matrix} Users: & 1 & 2 & 3 & 4 & 5 \\ Subcarrier4: & 0.53 & 0.93 & 0.48 & 0.92 & 0.09 \\ Subcarrier1: & 0.64 & 0.11 & 0.91 & 0.94 & 0.85 \\ Subcarrier2: & 0.48 & 0.39 & 0.12 & 0.29 & 0.36 \\ Subcarrier3: & 0.15 & 0.98 & 0.57 & 0.6 & 0.96 \end{matrix} \right.$$
$$\left. \begin{matrix} 6 & 7 & 8 \\ 0.62 & 0.29 & 0.72 \\ 0.2 & 0.6 & 0.92 \\ 0.87 & 0.53 & 0.85 \\ 0.62 & 0.17 & 0.6 \end{matrix} \right] \quad \text{(M3)}$$

Step-4 In ($M3$) user 2, user 4, user 6 and user 5 are selected as strong channel gain users of ($S4$), ($S1$), ($S2$), and ($S3$), respectively. So, to select the 2nd user to pair or group to the subcarriers, the already selected users are eliminated. Then, based on the threshold value (consider 0.2 is the threshold value), From among the remaining users of every subcarrier, the subsequent strong user is selected. In ($S4$) user 2 is chosen as a strong user then, based on the threshold value, the next strong user is user 8. For the remaining subcarriers, the next strong users are selected from unselected users. So for ($S4$) user 2(1st user) and user 8(2nd user) is selected and grouped or paired. Likewise ($S1$) user 4(1st user) and user 1(2nd user) is grouped, ($S2$) user 6(1st user) and user 7(2nd user) is grouped and ($S3$) user 5(1st user) and user 3(2nd user) is grouped.

$$\left[\begin{matrix} Users: & 1 & 2 & 3 & 4 & 5 \\ Subcarrier4: & 0.53 & 0.93 & 0.48 & 0.92 & 0.09 \\ Subcarrier1: & 0.64 & 0.11 & 0.91 & 0.94 & 0.85 \\ Subcarrier2: & 0.48 & 0.39 & 0.12 & 0.29 & 0.36 \\ Subcarrier3: & 0.15 & 0.98 & 0.57 & 0.6 & 0.96 \end{matrix} \right.$$

$$\begin{matrix} 6 & 7 & 8 \\ 0.62 & 0.29 & 0.72 \\ 0.2 & 0.6 & 0.92 \\ 0.87 & 0.53 & 0.85 \\ 0.62 & 0.17 & 0.6 \end{matrix}\Bigg] \tag{M4}$$

The subcarrier and users as a matrix $G_{m,n}$ is formed in($M5$).

$$\left[\begin{matrix} Users: & 1 & 2 & 3 & 4 & 5 \\ Subcarrier4: & 0 & 0.93 & 0 & 0 & 0 \\ Subcarrier1: & 0.64 & 0 & 0 & 0.94 & 0 \\ Subcarrier2: & 0 & 0 & 0 & 0 & 0 \\ Subcarrier3: & 0 & 0 & 0.57 & 0 & 0.96 \end{matrix}\right.$$

$$\begin{matrix} 6 & 7 & 8 \\ 0 & 0 & 0.72 \\ 0 & 0 & 0 \\ 0.87 & 0.53 & 0 \\ 0 & 0 & 0 \end{matrix}\Bigg] \tag{M5}$$

According to the proposed algorithm, for each subcarrier, one strongest user and the next strong user are selected based on the threshold value, and these two users are grouped.

5. Computational complexity analysis

The computational complexity of LGSF-TBAUGA is calculated and compared to CUP [13], RP [12], WCUFSA [22] and WSF-SUAA [26].

From the proposed algorithm step-2 and 3, compute the least channel gain from all N users and all subcarriers S.

The total number of steps required to select the least channel among N users in a single subcarrier is:

$$N - 1 \text{ operations} \tag{10}$$

Since there are total M subcarriers, the entire amount of operations to compute the worst channel is

$$M(N - 1) \tag{11}$$

In step 4 the subcarrier are sorted; the number of operations needed to sort one subcarrier is

$$2M \ln M \text{ operations} \tag{12}$$

In step 7, for all subcarriers, a stronger user is determined, which has maximum channel gain among all N users.

For 1 subcarrier, the number of operations needed to compute stronger users is

$$\frac{N-1}{2} \tag{13}$$

Since there are a total of M subcarriers, the total number of operations for computing the strongest user is

$$M\left(\frac{\boldsymbol{N}-1}{2}\right) \tag{14}$$

Finally, in step 11, a comparison is made ($|h_s| \geq 0.2$) for each subcarrier.

The time complexity involved in comparison for single subcarrier with N users is

$$N - 1 \text{ operations}$$

Since there are M subcarriers. Hence, the total number of operations are

$$M(N - 1)\text{Operations} \tag{15}$$

Adding Equations (11)+(12)+(14)+(15)

$$M(N-1) + 2M\ln M + M\left(\frac{N-1}{2}\right) + M(N-1) \tag{16}$$

$$M(N-1) + 2M\ln M + M\left(\frac{N-1}{2}\right) + M(N-1)$$
$$= MN - M + 2M\ln M + \left(\frac{MN}{2}\right) - \frac{M}{2} + MN - M$$
$$= 2\text{MN} - 2\text{M} + \frac{\text{MN}}{2} - \frac{\text{M}}{2} + 2\text{M}\ln\text{M} \tag{17}$$

The computational complexity of the proposed LGSF-TBAUGA is calculated with N = 8 users for M = 4 subcarriers, is (Table 1)

$$2MN - 2M + \frac{MN}{2} - \frac{M}{2} + 2M\ln M$$
$$= 2*4*8 - 2*4 + \frac{4*8}{2} - \frac{4}{2} + 2*4\ln 4$$
$$= 81 \text{ Operations.}$$

In Figure 2 represents the computational complexity operations of proposed and existing algorithms. The number of operations are increased when the number of users are increased. It depends upon the different subcarrier user nomination techniques. The performance of proposed and existing algorithms values are listed in the Table 2, and the corresponding simulated values are shown in Figure 2.

Table 1. Computational complexity of varies methods.

Algorithm	No. of operations
RP	N
CUP	$M(N-1)$
WCUFSA	$2N\ln N + 2N(M-1)$
WSF-SUAA	$2M\ln M + 2M(N-1)$
Proposed LGSF-TBAUGA	$= 2MN - 2M + \frac{MN}{2} - \frac{M}{2} + 2M\ln M$

6. Simulation results

This simulation results cover the discussion with the proposed LGSF-TBAUGA method, which is compared

Table 2. Operations performed by the various SUAs.

Number of Users	No. of Operations of the Different SUA				
	RP	CUP	WCUFSA	WSF-SUAA	Proposed LGSF-TBAUGA
N = 4	4	6	19	14	18
N = 8	8	28	81	61	81
N = 16	16	120	312	273	333
N = 32	32	496	1181	1080	1329
N = 40	40	780	1815	1679	2070

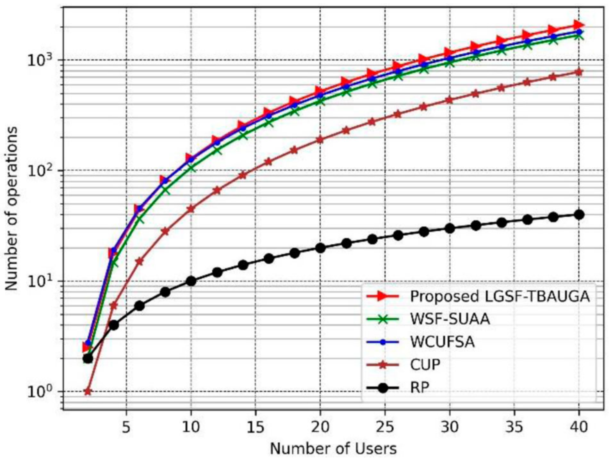

Figure 2. Computational complexity (operations) of proposed and existing algorithms.

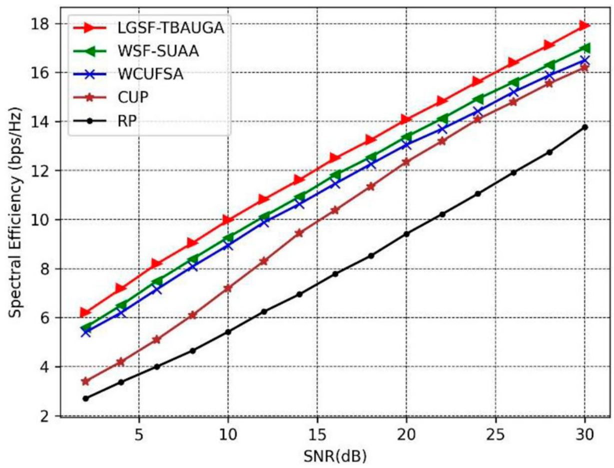

Figure 3. Performance of spectral efficiency between proposed and existing algorithms.

with some existing methods, like CUP, RP, WCUFSA and WSF-SUAA. Our downlink NOMA simulations use the channel model. A Rayleigh-distributed random variable is used as the fading parameter in a multipath frequency selective fading channel model. Normalized bandwidth for each subcarrier is reduced to 1 Hz. The BS evenly distributes transmit power to all subcarriers. The notation of $\alpha_s + \alpha_w = 1$, it determines how much power is assigned between the grouped users, and the fixed power allocation method is implemented between the grouped users.

The simulation results focus primarily on the SNR, here, the number of users is considered as $N = 32$ users and per subcarrier, two users are assigned, so 16 subcarriers are considered $M = 16$. The process of calculating SE [33] is carried out by examining the signal transmitting from the BS to the m_n users are grouped with the subcarrier of n is shown in Equation (18)

$$SE = \frac{Overall\ system\ achieved\ sum\ rate}{Total\ BW\ used} \tag{18}$$

In Figure 3 The performance of spectral efficiency of the proposed algorithm with other existing methods is simulated. In this, the proposed algorithm performed at a larger spectral efficiency compared with other algorithms because of grouping the users between the subcarriers. The strongest user and the next strong user are grouped; because of this, the sum rate of grouped users is increased. The sufficient channel gain difference is maintained through the proposed algorithm, so it avoids imperfection in the SIC process. The LGSF-TBAUGA that has been proposed is capable of handling significantly higher spectral efficiencies.

The proposed algorithm produced high SE; evidence for that is shown in Figure 4, which exhibits the performance of SE for a range of user densities at SNR = 20dB. In this, initially, the SE of the proposed approach and the other two methods (WSF-SUAA and WCUFSA) are similar when the quantity of users is minimal. When the user count increases, the SE of the suggested approach produces a higher performance. Before user grouping, the least channel gain user subcarriers are sorted in ascending order, and the sum rate of each subcarrier is improved according to the threshold-based user grouping, since the proposed approach has enhance the SE at SNR is 20dB is greater than 3.4%, 4.5%, 12.2% and 20.7% of WSF-SUAA, WCUFSA, CUP and RP respectively.

In Figure 5 displays the Fairness Index (FI) of the proposed LGSF-TBAUGA, WSF-SUAA, WCUFSA, CUP and RP algorithms. The FI of NOMA schemes by [34]. In Figure 5, the FI values are shown against the signal-to-noise ratios.

$$Fairness\ Index = \frac{\left(\sum_{n=1}^{N} DR_n\right)^2}{N\sum_{n=1}^{N}(DR_n)^2} \tag{19}$$

The FI is a quantitative measure of how well users are treated based on data rate. Analysis of the *FI* of $m = 16$

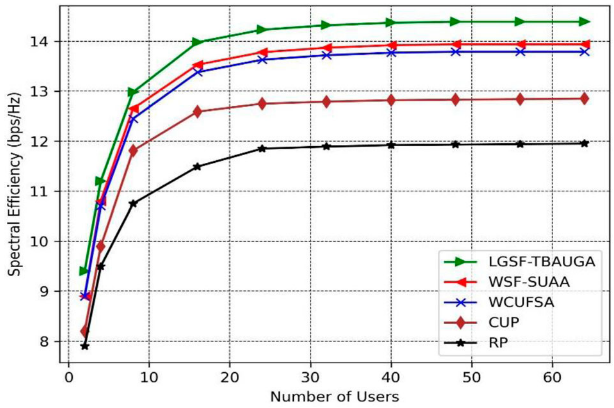

Figure 4. Spectral efficiency for a range of user densities at SNR = 20dB.

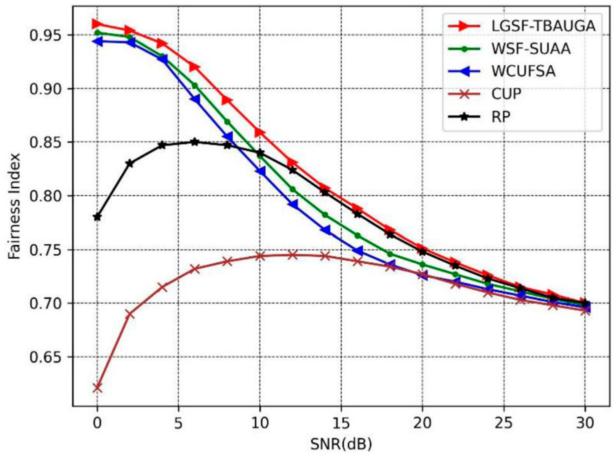

Figure 5. Obtained LGSF-TBAUGA fairness index and other methods.

subcarriers and $n = 32$ users. The objective of the fairness index seeks to provide evidence of the degree to which the system distributes its available resources in a fair manner. As long as SNR is below 10 dB, it seems that LGSF-TBAUGA has an increased FI than CUP and RP. When SNR increases above 10 dB, the RP, WSF-SUAA, and proposed LGSF-TBAUGA perform similarly. The WCUFSA performance is different because it produces the same average data rate of the least gain user. In higher SNR values, the FI of all methods is performing nearly similarly.

As the SNR rises, the LGSF-TBAUGA system becomes more efficient at using its available bandwidth, but this comes at the expense of user fairness. The FI decreases as SNR increases, indicating that the efficiency gains have been at the cost of fairness. Once the system reaches a saturation point, it becomes less efficient at handling additional users. The arrangement implies that, up until a specific point in the operational settings, LGSF-TBAUGA maintains a balance between efficient resource allocation and fair distribution, with the former taking precedence in better signal conditions.

From these simulation results, we infer that LGSF-TBAUGA trades off user fairness for improved spectral efficiency, especially as signal conditions get better (higher SNR), and manages to maintain efficiency across a growing user base up to a saturation point. The system's design likely balances efficiency and fairness, prioritizing the former in favourable conditions while attempting to maintain a degree of the latter.

7. Conclusion

The selection of subcarrier and the user nomination technique for the Downlink NOMA system are investigated in this paper. For that, LGSF-TBAUGA is proposed. Then, the performance of the proposed algorithm is compared with existing algorithms, like CUP, RP, WCUFSA and WSF-SUAA. In the proposed user grouped method, the selection of the strongest channel gain user and next strong channel gain user (not the least channel gain user or weak user) increases the Individual user data rate, so the grouped user subcarrier sum rate is increased. Here, the next strong user is selected based on the threshold value. So, the sufficient channel gain difference is maintained, and it helps to avoid imperfection in the SIC process. The computational complexity of the proposed method is calculated, and it's slightly higher when compared with existing algorithms. The simulation results show that the proposed algorithm increases the Individual user data rate, increasing the overall sum rate. This is reflected in SE at SNR is 20dB is greater than 3.4%, 4.5%, 12.2% and 20.7% of WSF-SUAA, WCUFSA, CUP and RP respectively, and the user FI of the proposed LGSF-TBAUGA is better than the existing algorithms. Future research in subcarrier user nomination should explore dynamic subcarrier allocation algorithms considering real-time network conditions and investigate machine learning-based approaches for predicting user demands and optimizing subcarrier assignments, aiming to enhance spectral efficiency and overall system performance. Incorporating an adequate power allocation system into the proposed LGSF-TBAUGA will be necessary.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

Data may be provided based on request

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