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Original Article

Novel User Pairing and Optimal Power Allocation for Single Carrier NOMA System

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Abstract *- Non-Orthogonal Multiple Access (NOMA) appears to be a favorable technique for meeting the requirements of the next generation of wireless communication networks. This paper addresses the challenge of an abundant number of users and their power allocation, which is solved using a Genetic Algorithm (GA). Users are paired in groups of two and clusters of three in a single radio resource block using the proposed Novel User Pairing Algorithm (NUPA). The main goal is to maximize the capacity of the system under minimum rate constraints. The proposed NUPA NOMA system model is tested with different power allocation schemes. It is observed that the NUPA with GA system outperforms other conventional user pairing approaches and power allocation schemes such as fixed power allocation, fractional transmit power allocation, and orthogonal multiple access technique power allocation in terms of maximization of the capacity. Simulation results show that the NOMA system with a Novel User Pairing Algorithm and Genetic Algorithm-based power allocation obtains better results in terms of capacity.*

Keywords *- 5G, GA, Instantaneous CSI, Power allocation, User pairing.*

1. Introduction

With 5G and beyond 5G networks, there is a sudden increase in the requirements of spectral efficiency, data rates, number of users, and multimedia traffic. Non-Orthogonal Multiple Access (NOMA) seems suitable for multiple access techniques to fulfil such requirements [1-2]. NOMA involves Superposition Coding (SC) at the transmitter and Successive Interference Cancellation (SIC) at the receiver [2]. Power-Domain (PD-NOMA) and Code-Domain (CD-NOMA) are the two primary types of NOMA techniques. In the former, users are multiplexed with different power levels in the same frequency and time domain, while in the latter case, diverse codes are used to differentiate between users [3]. In the PD-NOMA technique, power allocation plays a key role in the performance of the NOMA system [4]. Due to this, NOMA can serve more users in the same bandwidth, and thereby increase the spectrum efficiency. In this work, the PD-NOMA technique with a Single Carrier Downlink (SC-DL) system has been considered.

Due to the orthogonal resources, Orthogonal Multiple Access (OMA) technology seems to be highly advantageous in terms of interference cancellation, in which frequency-time follows a principle of orthogonality. At the same time, in NOMA, all users are incorporated into the same frequency and time resources with different power levels, which can cause interference. This interference can further be mitigated by using successive interference cancellation SIC at the receiver. As users are differentiated with different power levels, the user at a far distance from the base station has more power than the user near the base station. At the receiver, the user with a higher signal level is detected first and removed; later, the signal with successive higher levels is detected and removed. In [5] hybrid MA system is proposed in which the problem of interference with several users and the principle of orthogonality has been addressed. A significant focus should be placed on mitigating interference at the receiver, minimizing decoding complexity, shortening the delay at the receiver, and improving system capacity.

NOMA can effectively work and produce more improvements than conventional OMA systems in terms of capacity and spectrum sharing by carefully choosing the power levels for each user. Again, NOMA pairs to be carefully made which can effectively increase the system capacity[5]. If two users are paired and total power is divided between two rather than dividing the whole in many numbers of users, a significant improvement in the sum rate is achieved [6].

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The performance of the system depends on choosing the users for the NOMA pair and assigning the power to them, which is the primary focus of the paper. Again, power assignment falls into two categories: fixed power allocation and dynamic power allocation [7]. In the former one, the fixed amount of power is divided between the NOMA pair, while later, depending on the channel condition, a different power is assigned. There is also evidence that the performance of the system may be adversely affected if the number of users to be used as a NOMA pair is not carefully chosen [8].

Again, it is crucial to focus on which users can be grouped as NOMA users in a single Resource Block (RB). As user pairing directly affects the capacity of the system. It is shown in [5] that NOMA is significantly more efficient than OMA on paired user channels if the channel conditions are distinct, which is the primary focus of this article. For example, two usersi, j are re paired if they hold distinct channel conditions. The maximum channel difference (i-j) between users qualifies for a NOMA pair.

The main focus of the article is optimum pairing and optimal power allocation to paired users using Genetic Algorithm (GA). The pairing is achieved by the Novel User Pairing Algorithm, which in turn maximizes the sum rate. The simulation results are obtained to reflect the superiority of the proposed system to the existing one in terms of capacity.

The proposed work has been extended to three user clustering and optimal power assigning to achieve the improvement in the sum rate. The major contribution of the work is as follows:

- Proposed NUPA scheme to address the pairing of the two users depending on the maximum channel gain difference between them.
- Extended NUPA for three-user clustering again, this depends on their distinctive channel condition.
- Defining optimum power allocation problem for downlink single carrier NOMA and solved using GA.
- Evaluate the performance of the system with different power allocation strategies such as Fixed Power Allocation (FPA), Fractional Transmit Power Allocation (FTPA), and conventional methods such as OMA.

The rest of the paper is organized as follows. Section 2 represents a literature survey on PD-NOMA and user pairing mechanisms. Section 3 presents the system model and assumptions for the proposed single-carrier NOMA system. Section 4 discusses the proposed NUPA scheme for two-user pairing and three-user clustering. The solution to the proposed system in terms of optimized power is obtained with GA, as in Section 5. Simulation results and discussion are evaluated for the proposed system in Section 6, and Section 7 concludes the paper.

2. Related Work

Power allocations to the users play an important part in the NOMA system. The users are differentiated with their allocated power at the receiver utilizing successive interference cancellation, while superposition coding is used at the transmitter. Apart from 2G, 3G, and 4G systems where they utilize time-frequency as a multi-access technique, NOMA utilizes multi-user access techniques for spectral efficiency and massive connectivity in 5G and beyond [9].

In PD-NOMA, the signal has the power level difference by which it can be separated at the receiver; the signal with higher energy is detected and extracted first, which may cause interference to the lower energy signal, and successively all signals are detected [10].

There are different power allocation strategies have been proposed in [11-14]. The low complexity power allocation algorithms than high complexity traditional water filling algorithms have been addressed in [15], where the author has proposed the FSPA Full Search Power Allocation Algorithm in comparison to the fixed power and fractional transmit power allocation algorithm, where the search of all power combination is based on minimum power search granularity which maximizes the transmission rate of the NOMA at maximum.

However, its complexity increases with more number of users. In this article, the issue of accommodating more users is addressed by grouping the users in a pair of two and a cluster of three after which the optimal power is assigned with the help of the GA tool.

There are numerous studies in which the selection of users to use as NOMA pair has been done [16, 17]. In [8], the Genetic Algorithm (GA) is used to make a pair of users for OFDM based NOMA DL system where the search space of GA should be small to provide better solutions, while in [16], To find optimal user pairs, the author obtained a globally optimal solution with a minimum rate constraint. The two pairs of users and four pairs of users were analyzed using different case statements.

Fast optimal and suboptimal schemes for user grouping have been addressed in [18], where computational complexity is considered. The system’s sum rate is maximized using the proposed algorithm. However, the suggested optimal solution can only be chosen if the number of users is less (i.e.$m \leq 11$); if users are more than that, then a suboptimal solution should be used with a higher SNR range.

In [19] authors have proposed a scheme for NOMA user grouping/ clustering for the uplink and downlink system and derive the optimal power allocation to the NOMA cluster. In [20] a GA approach is used to solve the problem of user clustering to optimize system throughput with minimum rate constraints. In [21], Power allocation and user pairing for the CR-NOMA system are addressed with the distributed matching algorithm, and the proposed system is compared to the OMA system.

This article proposes an ideal NOMA system with a Novel Two-User Pairing Algorithm (NUPA) with an extension to three-user clustering. Based on this, the NOMA system model is created for a solution. Genetic Algorithm (GA) is used to allocate power between paired users, which optimizes the systems' capacity in terms of the total sum rate.

The proposed NUPA is based on the maximum channel gain difference between two/or three users and depends on which optimal power is allocated by the GA tool using the Matlab optimization toolbox. GA is used such that it optimizes the system performance than conventional power allocation schemes. The results are tested with different power allocation schemes with several users and/or SNR values also, Jains' fairness index is analyzed with different performance metrics.

3. System Model

A single-carrier non-orthogonal downlink system with one base station and m several users. All are equipped with one antenna, the channel is assumed to be slow fading, and CSI is perfectly available at the receiver.

A PDF of a Rayleigh fading channel contains the channel fading coefficient hi, with the components of small-scale fading and path loss based on the distance between the base station and the user $U_i, i \in \{1,2,\cdots,m\}$, which is given as,

$$f_{|H_i|^2}\left(|h_i|^2\right)=\frac{1}{\delta_i^2}e^{-\frac{|h_i|^2}{\delta_i^2}} \tag{1}$$

Here δ_i average channel gain modeled as $\delta_i^2=\chi_i dm_i^{-\gamma}, \chi_i$ denotes the squared magnitude of channel co-efficient, which indicates small-scale fading giving, $\mathrm{E}\left[\chi_i^2\right]=1$. γ is a path loss component dmi and is a distance of i-th users from the base station. The users' distances are $dm_1 > dm_2 > \ldots dm_m$ in meters.

On the Receiver-side, SIC is performed on the signals using channel gain information [2], and interference cancellation is assumed to be perfect. Initially, the strongest signal (the one with the more power) is decoded by treating all other signals as interference. The second strongest signal is decoded from the composite signal and canceled out, and so on.

The process is repeated until the weakest signal (the one with lesser power) is detected. This SIC detection order is also influenced by the ordered channel gain information [2]. Therefore, instantaneous CSI for Single Carrier NOMA systems is considered here. Within this system, the Fixed Power Allocation (FPA) scheme, GA-based Power Allocation, and Fractional Transmit Power Allocation (FTPA) are examined with a power allocation co-efficient, where all the co-efficient add up to one. Details on allocated power are given in the following subsections.

The NOMA system, in which the first two users are paired, while later the three users are clustered according to the proposed NUPA, is explained in the following sub-sections. The analysis has been carried out separately and performances are measured in terms of capacity.

A channel gain average, from the base station to the end-user m is ordered as $\delta_1 \le \delta_2 \le \cdots \le \delta_m$. Base station users have access only to instantaneous CSI information, knowing the perfect CSI δ_i is average channel gain, which is given by $\delta_i = \mathrm{E}\left[|h_i|^2\right]$.

Now, in NOMA, the base station linearly combines all users' symbols as superposed signals with differently allocated power $a_1 \ge a_2 \ge \cdots \ge a_m$. The Single Carrier NOMA system assigns greater power to the user who is farthest from the base station and lesser power to the nearest one.

The users are paired into N(I, j); N(I, j, k) two user pairs and three user clusters, respectively. These paired users transmit information in the same radio resource block. The summation of all power co-efficient which is assigned to user pairs is always one, i.e.

$$\sum_{i=1}^{m/2} a_i + \sum_{j=m/2+1}^{m} a_j = 1 \quad \sum_{i=1}^{m/3} a_i + \sum_{j=m/3+1}^{2m/3} a_j + \sum_{k=2m/3+1}^{m} a_k = 1$$

The superposed signal for each pair of users is given for two users and three users as Equations (2) and (3) as,

$$S=\sum_{i=1}^{m/2}\sqrt{a_i P}S_i + \sum_{j=m/2+1}^{m}\sqrt{a_j P}S_j \tag{2}$$

$$S=\sum_{i=1}^{m/3}\sqrt{a_i P}S_i + \sum_{j=m/3+1}^{2m/3}\sqrt{a_j P}S_j + \sum_{k=2m/3+1}^{m}\sqrt{a_k P}S_k \tag{3}$$

Which is transmitted by the base station to all users in the Single Carrier NOMA system over the same radio resource block and is received by each i-th, j-th, and k-th user as a,

$$\begin{cases} y_i = h_i S + n_i \\ y_j = h_j S + n_j \end{cases} \quad (4)$$

and

$$\begin{cases} y_i = h_i S + n_i \\ y_j = h_j S + n_j \\ y_k = h_k S + n_k \end{cases} \quad (5)$$

S is the superposed signal, which has S_i, S_j, S_k symbols of each user U_i, U_j and U_k, respectively, h_i, h_j, h_k follows Rayleigh faded distribution n_i, n_j, and n_k and represents i.i.d Additive White Gaussian Noise (AWGN), which belongs to CN(0,σ_2), which σ^2 denotes noise power and P is total transmitted power.

3.1. Achievable Rate for Two Users

In this system $|h_i|^2 \le |h_j|^2$, which means the channel gain of the user U_j is higher than the channel gain of U_i. The receiver performs SIC to extract the data signal from the received signals $y_N(N = i, j)$.

In two user cases, the signal U_j has coherent detection of its symbol S_j, which is also the strongest symbol, and subsequently removes S_i which is considered as interference. After which, it is followed by a re-modulation and cancellation of the decoded signal Y_j to have the signal at a particular user. Here, the Signal-to-Interference-Plus-Noise-Noise Ratio (SINR) and signal-to-noise ratio for U_i and U_j are as follows:

$$\begin{cases} SINR_i = \dfrac{w_i a_i \rho_s}{1 + w_i a_j \rho_s} & 1 \le i \le m/2, m/2 + 1 \le j \le m \\ SNR_j = w_j a_j \rho_s & m/2 + 1 \le j \le m \end{cases} \quad (6)$$

Here $\rho_s = \frac{P_S}{\sigma^2}$ is the total transmit SNR. $w_i = \min\left(|h_i|^2, |h_j|^2\right), w_j = \max\left(|h_i|^2, |h_j|^2\right), a_i\ a_j$ and are allocated power coefficients related to the user $U_i\ U_j$, respectively.

Let the two users $U_i, 1 \le i \le m/2$ and $U_j, m/2 + 1 \le j \le m$ their allocated powers are a_i, a_j respectively, where $a_i + a_j = 1$ and $a_i > a_j$, then the achievable rates of each user are expressed, based on Equation (6) as for instantaneous CSI is,

$$\begin{cases} R_i = \log_2(1 + SINR_i) & 1 \le i \le m/2, m/2 + 1 \le j \le m \\ R_j = \log_2(1 + SNR_j) & m/2 + 1 \le j \le m \end{cases} \quad (7)$$

Where, R_i and R_j are achievable data rates. The total sum rate is defined as the summation of all paired user's achievable rates as below:

$$R_{TOTAL} = \sum_{i=1}^{m/2} \sum_{j=m/2+1}^{m} \left(R_i + R_j\right) \quad (8)$$

3.2. Achievable Rate for Three Users

In this system $|h_i|^2 \le |h_j|^2 \le |h_k|^2$, which means the channel gain of the user U_k is higher than the channel gain of U_j and U_i. The receiver performs SIC to extract the data signal from the received signals Y_N (N=I, j, k). In three user cases, U_i, U_j and U_k are the users' SINRs and SNRs which has been calculated as;

$$\begin{cases} SINR_i = \dfrac{|h_i|^2 a_i \rho_s}{1 + |h_i|^2 a_j \rho_s + |h_i|^2 a_k \rho_s} & 1 \le i \le m/3 \\ SINR_j = \dfrac{|h_j|^2 a_j \rho_s}{1 + |h_j|^2 a_k \rho_s} & m/3 + 1 \le j \le 2m/3 \\ SNR_k = |h_k|^2 a_k \rho_s & 2m/3 + 1 \le k \le m \end{cases} \quad (9)$$

Here, $\rho_s = \frac{P_s}{\sigma^2}$ is the total transmit SNR $|h_i|^2 \le |h_j|^2 \le |h_k|^2$, a_i, a_j and a_k are allocated power coefficients related to the user U_i, U_j and U_k respectively.

Let the three users $U_i, \left(1 \le i \le m/3\right), U_j, \left(m/3 + 1 \le j \le 2m/3\right)$ and $U_k, \left(2m/3 + 1 \le k \le m\right)$. Their allocated powers are a_i, a_j and a_k respectively, where $a_i + a_j + a_k = 1$ and $a_i > a_j > a_k$, then the achievable data rates of each user are expressed, based on Equations (9), as for instantaneous CSI are,

$$\begin{aligned} R_i &= \log_2(1 + SINR_i) & 1 \le i \le m/3 \\ R_j &= \log_2(1 + SINR_j) & m/3 + 1 \le j \le 2m/3 \\ R_k &= \log_2(1 + SNR_k) & 2m/3 + 1 \le j \le m \end{aligned} \quad (10)$$

Where, R_i, R_j and R_k are instantaneous CSI-based user ordering achievable data rates. The total sum rate is defined as the summation of all paired users' achievable rates as below:

$$R_{TOTAL} = \sum_{i=1}^{m/3} \sum_{j=m/3+1}^{2m/3} \sum_{k=2m/3+1}^{m} \left(R_i + R_j + R_k\right) \quad (11)$$

4. Novel User Pairing Algorithm

A Novel User Pairing Algorithm (NUPA) is proposed based on the maximum channel gain difference between two/or three users. An iterative algorithm is used for pairing users based on their channel gain differences.

In this algorithm, the user pairs are updated at each iteration. Apart from others' work, which focuses on Distributed Matching Algorithm (DMA) [21] or joint user pairing and power allocation [16, 22], the unique solution is proposed based on the maximum channel gain difference between two/ three users for pairing of NOMA users.

4.1. Two Users Pairing

Two Users are paired if they hold maximum channel gain difference; a matrix is formed A(i, j) having rows and columns as number of users.

Each element of the matrix is the maximum channel gain difference between respective users, diagonal elements are obvious to zero as the same users cannot be paired as well as the user pair $P(U_i,U_j)$ is the same $P(U_j,U_i)$.

Algorithm 1 shows the pairing of two users, in which a pair matrix p is generated with size (m/2x2). A detailed description of the Novel User Pairing Algorithm is explained below. The work is extended to generating a cluster of three users in the same radio resource block which is presented in the next subsection.

Algorithm 1: Two User Pairing

Input : Number of Users U_i and U_j.

Output : User Pairs P_2.

Step 1 : Define m and, relate h_i, calculate $E\left(|h_i|^2\right)$.

Step 2 : Initially, start with a square matrix with rows and columns as m users. U_i and U_j where i=j.

Step 3 : for columns (number of users U_j)

- Generate A(i, j) a matrix with each matrix element as an absolute difference between the respective channel gains of users, as stated in Equation (12).
- Find a pair of users having maximum channel gain difference in the matrix A.
- Store those pair of users as their channel gain matrix p, and eliminate that pair of users from the respective row and column from the matrix A.
- Reproduce the matrix $A^*(j^*, j^*)$.
- Repeat the above steps and regenerate the matrix $A^*(j^*, j^*)$ at each iteration.
- Update the matrix p at each iteration until all pairs are made.

Step 5 : end for

Step 6 : end for

Step 7 : Store optimal user pair in the matrix p.

Step 8 : Repeat steps 1 to 7 until all pairs are made and left matrix A with only one user pair.

Step 9 : p matrix of size (m/2x2) has been generated with a user pair.

The matrix $A(i, j)$ is shown below, with rows and columns as number of users. Δ_{i-j} indicates the channel gain difference of the i-th and j-th user where $1 \le i \le m$ and $1 \le j \le m$. Finally, at output the $P\left(m/2 \times 2\right)$ is generated with all users optimally paired.

$$A(i,j) = \begin{array}{c|ccccc|} & U_1 & U_2 & \cdots & U_{m-1} & U_m \\ U_1 & 0 & \Delta_{1,2} & \cdots & \Delta_{1,m-1} & \Delta_{1,m} \\ U_2 & \Delta_{2,1} & 0 & \cdots & \Delta_{2,m-1} & \Delta_{2,m} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ U_{m-1} & \Delta_{m-1,1} & \Delta_{m-1,2} & \cdots & 0 & \Delta_{m-1,m} \\ U_m & \Delta_{m,1} & \Delta_{m,2} & \cdots & \Delta_{m,m-1} & 0 \end{array} \quad (12)$$

Where,

$$\begin{aligned} \Delta_{i-j} &= 0 & i = j \\ \Delta_{i-j} &= \Delta_{j-1} & i \ne j \\ \Delta_{i-j} &= abs\left(|h_i|^2, |h_j|^2\right) & \end{aligned} \quad (13)$$

Channel gain difference between users.

4.2. Three Users Clustering

Similarly, the algorithm that is used for the pairing of two users' are to be modified for the clustering of three users. The same concept is taken for the pairing of three users, where users are clustered if they hold maximum channel difference between them, and a 3D matrix is formed A(i, j, k) having rows, columns, and pages as several users.

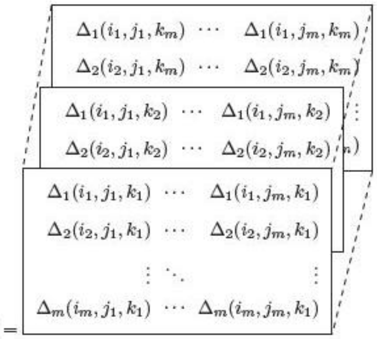
Each element of the matrix is the channel gain difference between respective users, diagonal elements are obvious to zero as the same users cannot be paired as well as the user pair

$P(U_i, U_j, U_k)$ is the same as $P(U_j, U_i, U_k)$ and $P(U_k, U_i, U_j)$. Algorithm 2 shows the clustering of three users, in which a matrix p is generated with size (m/3x3).

Algorithm 2: Three User Clustering

Input	:	Number of Users U_i, U_j and U_k.
Output	:	User pairs p_3.
Step 1	:	Define m and related channel gain coefficients and calculate the absolute value of channel gain for individual users.
Step 2	:	Initially, start with a 3D matrix with rows, columns, and pages as several users. U_i, U_j and U_k where $i = j = k$;
Step 3	:	for the page (number of users U_k)
Step 4	:	for rows (number of users U_i)
Step 5	:	for columns (number of users U_j) • Generate A(i, j, k) a matrix with each element as a difference between the respective channel gains of users based on Equation (15). • Find a pair of users form the matrix A having maximum channel gain difference and store it in the matrix p. • Store and eliminate that pair of users from the respective row, column, and page. • Reproduce the matrix $A^*(j^*, j^*)$. • Repeat the above steps and regenerate the matrix $A^*(j^*, j^*)$ at each iteration. • Update the matrix p at each iteration until all pairs are made. • Find a cluster of users having maximum channel gain difference.
Step 6	:	end for
Step 7	:	end for
Step 8	:	end for
Step 9	:	Store the optimal user pair in the matrix, p eliminate that user pair from A, and reproduce the matrix A^+.
Step10	:	Repeat steps 1 to 9 until all pairs are made and left matrix A with only one user pair.
Step11	:	P matrix of size (m/3x3) has been generated with a user pair.

The 3-D matrix $A(i, j, k)$ is shown below, with rows, columns, and pages as several users. Δ_{i-j-k} indicates the channel gain difference of the i-th, j-th, and k-th user where $1 \le i \le m; 1 \le j \le m$ and $1 \le k \le m$. Finally, at output the P(m/3x3) is generated with all users optimally paired.

$A(i, j, k) =$  (14)

$$\begin{aligned} &\Delta_{i-j-k} = 0 && for, i = j = k \\ &\Delta_{i-j-k} = \Delta_{j-i-k} = \Delta_{j-k-i} && for, i \ne j \ne k \\ &\Delta_{i-j-k} = abs\left(|h_i|^2 - |h_j|^2 - |h_k|^2\right) && \end{aligned} \quad (15)$$

Channel gain difference between users.

5. GA Objective Function and Optimization

In this section, the optimum power is found for the paired users based on the Genetic Algorithm. GA is known as a population-based meta-heuristic algorithm to explore large search spaces in complex optimization problems [23]. To solve the power requirements of paired users (2 or 3) in individual radio resource blocks and to increase the total sum rate of paired users' multi-objective is used. The paired users are again identified as a near user and far user according to which the power is optimized.

GA contains three rules: mutation, crossover, and selection [20], in which the selection rule selects the individuals, called parents, who contribute to the population of the next generation. The crossover rule combines the two parents to form children for the next generation, and later, one is used to apply random changes to individual parents to form children.

Moreover, in selection, tournament selection is used as a selection operator in the GA function which chooses each parent by choosing the size of players at random and then choosing the best individual out of that is set to be a parent. Here the value of size is several variables. For the crossover operation, a crossover intermediate is used where a child is created by taking a single weighted ratio of parents. The weights are created by taking the ratio, which, in our case, is several variables. The formula that is used to create a child is,

$$child = parent1 + rand * ratio * (parent2 - parent1)$$

In mutation, the mutation-adapt feasible function is used as a rule. This function is adaptive concerning the successful or unsuccessful generation. The direction and step length are chosen according to the bounds and linear constraints. The proposed *gamultiobj*-based algorithm will stop when it reaches the maximum number of iterations.

GA generates a population of points at each iteration, in which the best Pareto optimal point is an optimal solution. Here, the *gamultiobj*-based function from the optimization toolbox Matlab calculates the fitness function with linear and non-linear constraints as defined in the problem Equation (16) and Equation (21) to maximize capacity with optimal power pairs. The GA obtains the fitness function by linearly scaling the raw fitness *f(x)* and scale fitness F(x),

$$F(x) \equiv af(x) \pm b,$$

Which maximizes the total sum rate.

In this paper, the problem is defined as Equation (16) and (21), which is to maximize the power such that it maximizes the individual sum-rate of paired users, which eventually becomes a fitness function of the GA. It is known that the power at the base station is fixed so the power is allocated to the users according to their channel requirements. The far user is allocated maximum power while the near user has with lowest one. The users are paired according to the user pairing algorithm stated in Sections 3.1 and 3.2 and those paired users are used as input to the *gamultiobj* function to obtain optimized power for the individual users for maximization of individual sum rate and later capacity.

5.1. Genetic Algorithm for Two Users

Here, the main objective is to maximize the individual sum rate as well as the total sum rate in terms of optimizing the allocated fraction of power to each user pair U_iU_j. It is a multi-objective Mixed Integer Non-Linear Programming (MINLP) function for a single carrier NOMA system, with the problem defined as follows:

$$obj.fun = f(R_i, R_j) : \max_{\{a_i, a_j\}} \sum_{i=1}^{m/2} \sum_{j=m/2+1}^{m} (R_i + R_j) \quad (16)$$

S.T
C1: $(R_i + R_j) \geq (R_i^* + R_j^*)$
C2: $a_i > a_j \quad 1 \leq i, j \leq m$
C3: $\sum_{i=1}^{m/2} \sum_{j=m/2+1}^{m} (a_i + a_j) = 1$
C4: $0 < a_i, a_j < 1$
C5: $0 \leq i, j \leq 1$

In the above problem, the main objective is to maximize individual sum rate in terms of maximizing allotted power to the user pairs U_i U_j respectively. Constraint C1 ensures that the minimum achievable rate of each user should be greater than the individual sum rate of OMA users. The users are paired according to maximum channel gain differences stated in section 3.1, so the pair has been made as near user and far user, where the channel coefficients are taken as $|h_i|^2 \leq |h_j|^2$, which confirms $a_i > a_j$ the allocated power to the user pair. The far user $(|h_i|^2)$ receives more power, i.e. a_i, compared to near user $|h_j|^2$ s. C2 states the same.

While the total of power must remain constant, C3 shows that the summation of all fractional power must be the equality constraint. The fractional powers should be in range value between 0 to 1 which is imposed in C4. As well as for pairing user total number of users even, as stated in C5.

The fitness function, which is derived from the objective function, is defined below:

$$fitness.fun = -f(R_i + R_j) + \sum_{i=1}^{m/2} U_i a_i (R_i) + \sum_{j=m/2+1}^{m} U_j a_j (R_j) \quad (17)$$

The negative sign is added to the objective function to convert the minimization problem into the maximization problem.

Algorithm 3: Optimal Power Allocation using GA for two user pair

Input	:	Power allocation factors a_i and a_j
Output	:	Optimized power pairs a_i^* and a_j^*
Step 1	:	Define an objective function as $obj.fun = \sum_{i=1}^{m/2} U_i a_i (R_i) + \sum_{j=m/2+1}^{m} U_j a_j (R_j)$
Step 2	:	Generate the finite combination of power allocation vectors for initialization and set the generation counter. $t = 0; t_{max} = 400;$
Step 3	:	for $t < t_{max}$ • Calculate the fitness function value for each pair of users as optimum power; • Keep the best-allocated power pair to the next generation and perform the selection rule; • Perform crossover and mutation operations if the best-allocated power pair is not obtained;
Step 4	:	Increment the generation counter $t = t + 1$ till the termination condition is reached;
Step 5	:	Repeat steps 1 to 4 until all pairs are made and left matrix A with only one pair.
Step 6	:	end for;
Step 7	:	Interpret the best individual power pair a^*_i and a^*_j as the solution to maximize capacity with generated user pairs U_i and U_j respectively.

Algorithm 3 illustrates more on optimum power allocation by Genetic Algorithm. Initially, the random power allocation factors (a_i, a_j) are supplied as input and output are expected as the optimum pair of power allotted to the user pair (a^*_i, a^*_j). The fitness function is defined as the main objective function of the problem in which the equality and non-equality constraints are defined as C1, C2, C3, and C4. In the next step, initially, the finite combinations of power allocation vectors are generated with random combinations, and the timer is set to start. After which the fitness function is calculated as per defined problem statements and with constraints, the best and constant power pair is given to the next generation, and the selection rule is performed. After which, the two rules are performed, which are cross-over and mutation; in this process, the new set of power pairs is generated to replace the old pair if the calculated fitness function achieves maximization. The solution gives optimum power pairs based on the paired users. This optimization problem is solved by the GA tool in MATLAB.

The proposed work has been carried out for different power allocation schemes such as FPA, GA-based PA, and FTPA. The allocated fixed power vectors are calculated for FPA a_i, and a_j=1-a_i, in FTPA power is allocated dynamically as per the channel gains of paired users. The FTPA power equation is given as,

$$a_i = \frac{\sum_{i=1}^{m/2}\left(|h_i|^2\right)^{-g}}{\sum_{j=m/2+1}^{m}\left(|h_j|^2\right)^{-g}} \tag{18}$$

and,

$$a_i = \frac{\sum_{j=m/2+1}^{m}\left(|h_j|^2\right)^{-g}}{\sum_{i=1}^{m/2}\left(|h_i|^2\right)^{-g}} \tag{19}$$

Where, g is a decaying fractional quantity range from 0 to 1, for g =0 an equal power allocation is considered for the pair of users.

As well as, the simulation results are obtained for FPA, FTPA, and GA-based power allocation with fairness analysis. The fairness of allocated power to the user pairs is compared to Jain's Fairness Index, which is calculated based on Equation (20), which is given below,

$$JFI_{(R_i+R_j)} = \frac{\left(\sum_{i=1}^{m/2} a_i|h_i|\rho_s + \sum_{j=m/2+1}^{m} a_j|h_j|\rho_s\right)^2}{m\times\left(\sum_{i=1}^{m/2} a_i^2|h_i|^2\rho_s^2 + \sum_{j=m/2+1}^{m} a_j^2|h_j|^2\rho_s^2\right)} \tag{20}$$

The fairness analysis shows how fairly power is allocated to the users. The Jain's Fairness Index (JFI) measures the "Equality" of the power allocations to the users, which is measured in a bound between 0 and 1, and they are continuous.

5.2. Genetic Algorithm for Three Users

Similarly, for the three users' cluster U_i, U_j, and U_k, the main objective is to maximize the individual data rate in terms of optimizing the allocated power to each user. It is a multi-objective Mixed Integer Non-Linear Programming (MINLP) function for a single carrier NOMA system, with the problem defined as follows:

$$obj.fun = f(R_i, R_j, R_k): \max_{\{a_i, a_j, a_k\}} \sum_{i=1}^{m/3}\sum_{j=m/3+1}^{2m/3}\sum_{k=2m/3+1}^{m}(R_i+R_j+R_k) \tag{21}$$

S.T.
C1: $(R_i+R_j+R_k) \geq (R_i^*+R_j^*+R_k^*)$
C2: $a_i > a_j > a_k$
C3: $a_i > a_j; a_i > a_k; a_j > a_k$
C4: $\sum_{i=1}^{m/3}\sum_{j=m/3+1}^{2m/3}\sum_{k=2m/3+1}^{m}(a_i+a_j+a_k)=1$
C5: $0 < a_i, a_j, a_k < 1$
C6: $1 \leq i, j, k \leq m$

Constraint C1 ensures that the minimum achievable individual sum rate of each user should be greater than the individual sum rate of OMA users. The users are clustered according to channel differences as stated in Equation (15), where the channel coefficients are taken as $|h_i|^2 < |h_j|^2 < |h_k|^2$, which confirms $a_i > a_j > a_k$ the allocated power.

The far user $\left(|h_k|^2\right)$ receives more power, i.e. a_i compared to near user $\left(|h_i|^2\right)$s. While the total of power must remain constant, C4 shows that the summation of all fractional power must be the equality constraint. The fractional powers should be in range value between 0 and 1 which is imposed in C5. As well as for pairing user total number of users in multiple of 3, as stated in C6.

The fitness function, which is derived from the objective function, is defined below:

$$fitnessfunction = -f(R_i+R_j+R_k) + \sum_{i=1}^{m/3}U_iP_i(R_i) + \sum_{j=m/3+1}^{2m/3}U_jP_j(R_j) + \sum_{k=2m/3+1}^{m}U_kP_k(R_k) \tag{22}$$

Algorithm 4: Optimal Power Allocation Using GA for Three User Cluster

Input : Power allocation factors a_i, a_j and a_k.

Output : Optimized power pairs a_i^*, a_j^* and a_k^*.

Step 1 : Define an objective function as

$$obj.fun = \sum_{i=1}^{m/3} U_i P_i(R_i) + \sum_{j=m/3+1}^{2m/3} U_j P_j(R_j) + \sum_{k=2m/3+1}^{m} U_k P_k(R_k)$$

Step 2 : Generate the finite combination of power allocation vectors for initialization and set the generation counter $t = 0; t_{\max} = 400;$

Step 3 : for $t < t_{\max}$

- Calculate the fitness function value for each pair of users as optimum power;
- Keep the best allocated power pair to the next generation and perform the selection rule;
- Perform crossover and mutation operations;

Step 4 : Increment the generation counter $t = t + 1$ till the termination condition is reached;

Step 5 : Repeat steps 1 to 4 until all pairs are made and left matrix A with only one user pair.

Step 6 : end for;

Step 7 : Interpret the best individual power pair a_i^*, a_j^* and a_k^* as the solution to the maximizing sum-rate problem with generated user pairs U_i, U_j and U_k respectively.

Algorithm 4 explains optimum power allocation by Genetic Algorithm. Initially, the random power allocation factors (a_i, a_j, a_k) are supplied as input and output are expected as the optimum pair of power allotted to the user pair (a^*_i, a^*_j, a^*_k). The fitness function is defined as the main objective function of the problem in which the equality and non-equality constraints are defined as C1, C2, C3, C4, and C5.

Further, the finite combinations of power allocation vectors are created with random combinations. After which the fitness function is calculated as per defined problem statements and with constraints, the best and steady-state power pair is given to the next generation, and the selection rule is performed. A negative sign is added to the fitness function to convert the problem into minimization.

The proposed work has been carried out for different power allocation schemes such as FPA, GA-based PA, and FTPA. The allocated fixed power vectors are calculated for FPA as $a_i\ a_j = \frac{2}{3}(1 - a_i); a_k = \frac{2}{3}(1 - (a_i + a_j))$, and in FTPA, power is allocated dynamically as per the channel gains of paired users. The FTPA power equation is given as,

$$a_i = \frac{\sum_{i=1}^{m/3} \left(|h_i|^2\right)^{-g}}{\sum_{j=m/3+1}^{2m/3} \left(|h_j|^2\right)^{-g} + \sum_{k=2m/3+1}^{m} \left(|h_k|^2\right)^{-g}}$$
$$a_j = \frac{\sum_{j=m/3+1}^{2m/3} \left(|h_j|^2\right)^{-g}}{\sum_{i=1}^{m/3} \left(|h_i|^2\right)^{-g} + \sum_{k=2m/3+1}^{m} \left(|h_k|^2\right)^{-g}}$$
$$a_k = \frac{\sum_{k=2m/3+1}^{m} \left(|h_k|^2\right)^{-g}}{\sum_{i=1}^{m/3} \left(|h_i|^2\right)^{-g} + \sum_{j=m/3+1}^{2m/3} \left(|h_j|^2\right)^{-g}} \quad (23)$$

Where, g is a decaying fractional quantity range from 0 to 1, for g=0 an equal power allocation is considered for the pair of users.

As well as, the simulation results are obtained for FPA, FTPA, and GA-based power allocation with fairness analysis. The fairness of allocated power to the user pairs is compared to Jain's Fairness Index, which is calculated based on Equation (24), which is given below,

$$JFI_{(R_i+R_j+R_k)} = \frac{\left(\sum_{i=1}^{m/3} a_i|h_i|\rho_s + \sum_{j=m/3+1}^{2m/3} a_j|h_j|\rho_s + \sum_{k=2m/3+1}^{m} a_k|h_k|\rho_s\right)^2}{m \times \left(\sum_{i=1}^{m/3} a_i^2|h_i|^2\rho_s^2 + \sum_{j=m/3+1}^{2m/3} a_j^2|h_j|^2\rho_s^2 + \sum_{k=2m/3+1}^{m} a_k^2|h_k|^2\rho_s^2\right)} \quad (24)$$

6. Simulation Results and Discussion

Simulation results are provided to show the superiority of the proposed system based on NUPA with conventional power allocation algorithms and GA-based power allocation. The pairing and clustering of users are carried out by the NUPA scheme and, in terms of capacity have been maximized. The capacity has been taken as a performance metric with SNR and Number of users. Jains' fairness index is also calculated and shown with different PA schemes and SNR/number of users.

The theoretical calculation, as well as the Monte-Carlo simulation, is done for two user pairs and three user clusters with a GA-based optimization tool in MATLAB with FPA and FTPA. Jain's Fairness Index is also observed to see the fairness of the allocation of power to the paired users. The simulation parameters and their values are defined in Table 1. In the simulation, Rayleigh flat fading is used to model the channel, and noise is considered as Additive White Gaussian Noise (AWGN) with noise density as -174dBm/Hz and carrier frequency as 1GHz. The coverage of BS in a circular radius is 500m; the number of users (m) is taken in multiple of two, for two users' pairing, and in multiple of three for three user clustering. In a RB NOMA users are paired with a maximum of two and three. Other parameters are described in the related result figure.

Table 1. Simulation parameters

Parameters	Values
Carrier Frequency (f)	1 GHz
BS maximum transmit power (P)	46 dBm
Coverage of BS	With radii of 500m
Number of users (m)	For a user pair {6,8,10,….,60} For a user cluster {6,9,12,……,60}
Maximum users as NOMA pair in one RB	{2, 3}
Path loss component (λ)	2.3
AWGN power density	-174dBm/Hz
Channel model	Rayleigh flat fading
Initial population size (GA)	10

The user pairs are further classified as far user and near user and accordingly, power has been assigned to increase the capacity of the users. In which the transmit signal power of the user (m-1) is α dB stronger than user m. The sensitivity factors that have been taken into account are channel gain, power allocation co-efficient and capacity and SIC ordering.

In Figure 1, capacity analysis has been done with varied SNR values, with channel gain as calculated as of Equation (1), which is taken as $E\{|h|^2\} = \delta^2 = 5$, fixed power allocation coefficients $a_i = 0.6$, and $a_j = 1 - a_i$; FTPA is calculated as per Equations (18) and (19) in sub-section 4.1 with the value of g as 0.2.

The number of users m= 12 is, with U_i, U_j= 6. It is seen that GA outperforms other power allocation schemes such as FPA, FTPA, and OMA-based power allocation. The capacity is greater when there is an optimized value of power allocated. The users are paired according to the maximum channel gain difference between them. Those users are further classified as near users and far users and accordingly allocated with optimized power.

In Figure 2 capacity analysis has been compared with the number of users with different power allocation factors; here, the number of users' ranges from 5 to 35 with fixed SNR of 40dB.

We have also calculated Jain's fairness index for two users' pair according to the mentioned Equation (20) in subsection 4.1 to have an analysis of the proposed user pairing algorithm with optimized GA-based power allocation, FPA, and FTPA, which can be seen in Figures 3 and 4 for varied SNR values and varied number of users respectively.

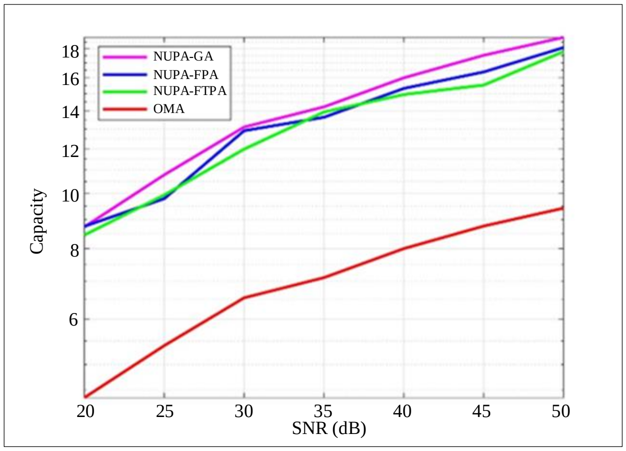


Fig. 1 Two user pairing total capacity analysis for GA, FPA, and FTPA-based power allocation with OMA

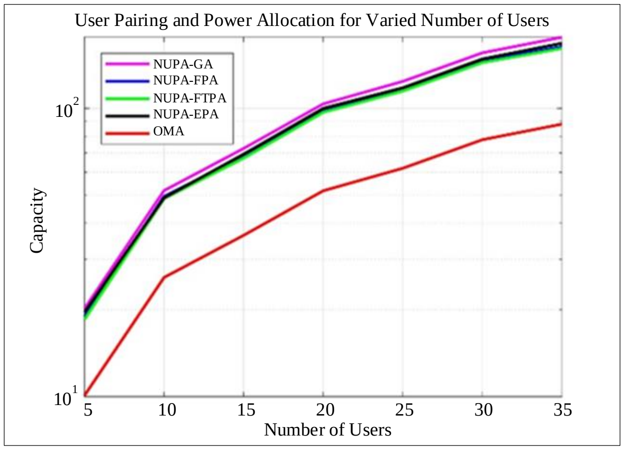


Fig. 2 Two user pairing total capacity analysis with a varied number of users for GA, FPA, and FTPA-based power allocation with OMA

Figure 3 indicates the range of SNR over which the fairness of allocated power is calculated. At around 40dB, the system is fair to the power allocation, keeping that as a parameter analyzed in Figure 4, in which for fixed SNR, 40 dB and varied users are calculated for fairness analysis. NUPA-GA performs well in fairness for more number of users. The expansion of the pairing algorithm to the three-pair user is briefly discussed in section 3.2. The number of users must be in multiples of three to have a cluster of three user pairs. Again, those three users are paired according to the definition of the pairing algorithm. Later on the group of three users, the power is allocated and compared with different PA schemes.

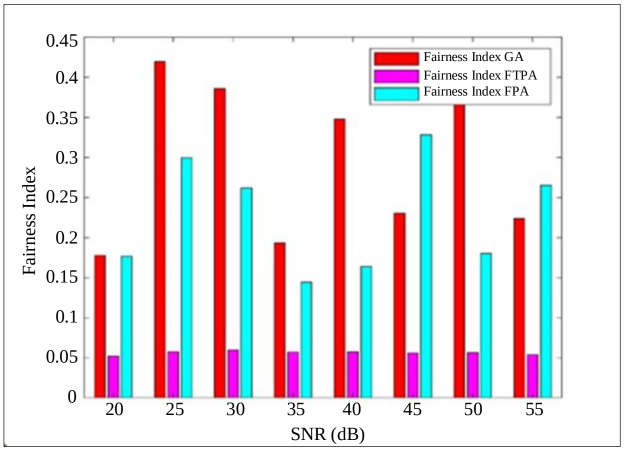


Fig. 3 Two user pairing fairness index analysis with varied SNRs for GA, FPA, and FTPA-based power allocation

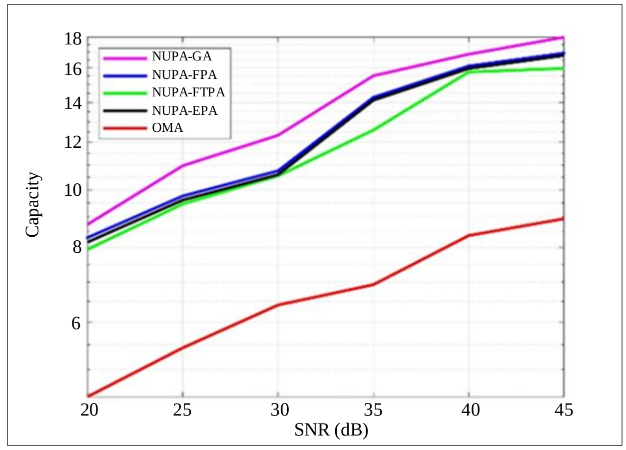


Fig. 5 Three user pairing capacity analysis for GA, FPA, and FTPA-based power allocation with OMA

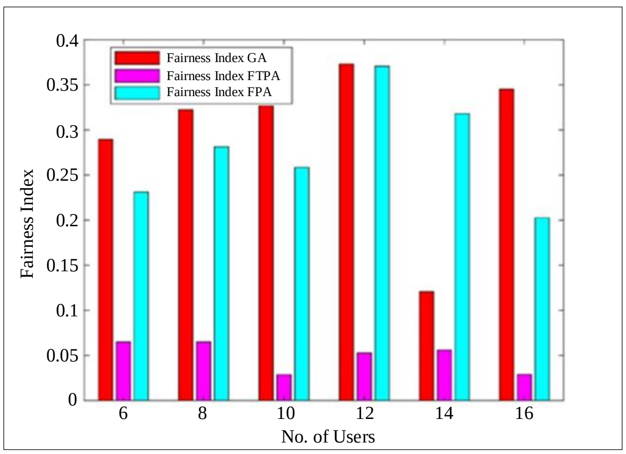


Fig 4 Two user pairing fairness index analysis with varied numbers of users for GA, FPA, and FTPA-based power allocation

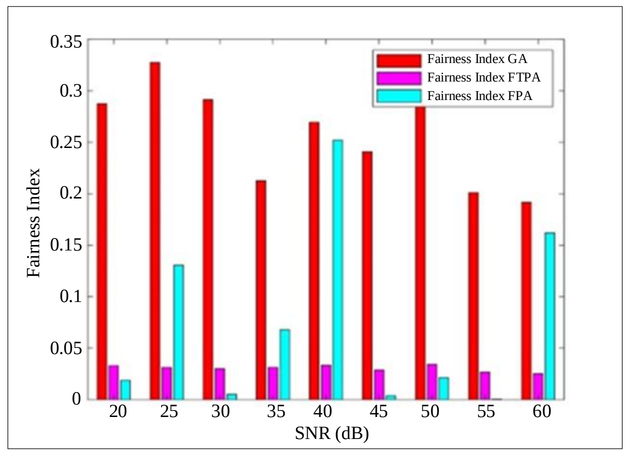


Fig. 6 Three user clustering fairness index analysis with varied SNRs for GA, FPA, and FTPA-based power allocation

Figure 5 shows the same capacity achievement for three users' pairing with varied SNR values, GA based PA is used to allocate power to the user pairs, with $E\{|h|^2\} = \delta = 5$ channel gain, fixed power allocated coefficients as $a_i = 0.6$; $a_j = 2/3(1 - a_i)$; and $a_k = 2/3(1 - (a_i + a_j))$; FTPA is calculated as per mentioned Equation (23) in sub-section 4.2 with $g = 0.2$.

The number of users m=12 is, with $U_i, U_j, U_k = 4$. It is observed that our proposed PA scheme, along with the novel user pairing algorithm, outperforms other schemes in terms of capacity.

Similarly, Jain's fairness index for three users' pair according to Equation (24) in subsection 4.2 has been analyzed on proposed NUPA with optimized GA-based power allocation, FPA, and FTPA, which can be seen in Figures 6 and 7 for varied SNR values and varied number of users respectively.

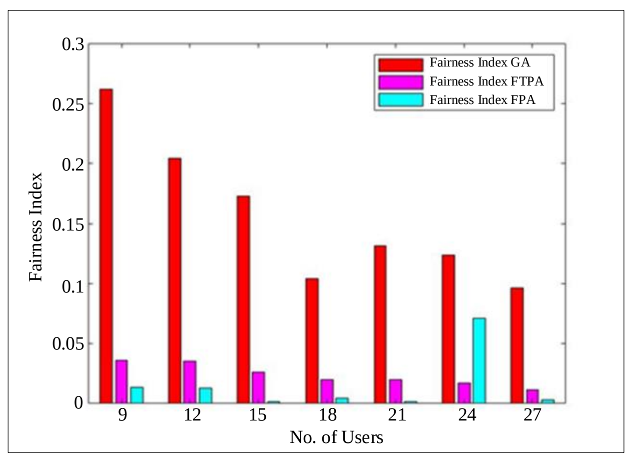


Fig. 7 Three user clustering fairness index analysis with varied numbers of users for GA, FPA, and FTPA-based power allocation

It is observed that in a cluster of three, the power is fairly allocated at different SNR ranges, as shown in Figure 6, and for varied numbers of users, as shown in Figure 7. The system performs fairly in the range of 25dB to 50dB for power allocation. The system is fairer in pairing two users for the proposed NUPA-GA-based system than a cluster of three. Pairing users in pairs of two or three with the proposed algorithm increases the system performance in terms of capacity; a paired user with optimized power allocation boosts the system performance in terms of capacity. From the figure, it is seen that at 40 dB.

7. Conclusion

The proposed work focuses on capacity maximization with ordered SIC decoding at the receiver, using the proposed NUPA user pairing scheme and GA-based optimal power allocation in single-carrier NOMA DL systems. Based on channel gain differences, the system pairs up two users and three users, and GA-based power is assigned to them. As can be seen, when users are paired in two and clustered in threes and assigned optimized power, capacity increases in comparison to conventional power allocation such as FPA, FTPA, and EPA.

The results are carried out with different performance metrics such as JFI analysis, SNR analysis, and varied numbers of users as performance metrics. They are compared with GA-based PA, FPA, FTPA, and OMA-based PA. The results clearly show proposed NUPA, along with optimized power (GA-based), performs best and achieves higher capacity than the conventional PA methods.

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