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*Original Article*

# Ensuring QoS for NOMA Using GA Based Power Allocation Scheme with a Variant of Greedy Heuristic Pairing Algorithm

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**Abstract -** *Non-Orthogonal Multiple Access (NOMA) is emerging as a pivotal enabling mechanism for next-generation wireless communication systems. Due to its advanced integration capabilities, NOMA is a foundational and transformative access technology, which is key in addressing the evolving demands of upcoming network architecture. By effectively optimizing system parameters, NOMA can significantly contribute to green communication by reducing energy consumption and enhancing resource utilization efficiency. This article proposes an effective Multi-Objective Genetic Algorithm (MOGA)-based power allocation strategy integrated with a variant of the Greedy Heuristic Pairing Algorithm for Single-Carrier Non-Orthogonal Multiple Access (SC-NOMA) downlink systems, aiming to ensure user-oriented Quality of Service (QoS). To address this, the proposed scheme optimizes power allocation by exploiting MOGA, which simultaneously enhances the overall system sum rate and ensures fairness among users. User pairing is conducted through a Greedy Heuristic Algorithm, which strategically clusters users based on maximum differences in channel gains, thereby effectively exploiting the advantages of power-domain multiplexing. Extensive analytical and Monte Carlo simulation results confirm the effectiveness of the proposed methodology, demonstrating substantial improvements in outage performance and QoS guarantees for both cell-edge and cell-centred users. It is also revealed that when optimized via MOGA, three-user clustering provides better outage performance even at lower Signal-to-Noise Ratios (SNRs) compared to conventional two-user pairing schemes. This research paves the way for future exploration of advanced multi-objective evolutionary algorithms to enhance the NOMA system's efficiency and reliability.*

**Keywords -** *5G, MOGA, Outage analysis, QoS, Decent work and economic growth.*

## 1. Introduction

With the thrust of advanced multimedia applications, such as UHD Live feed, large-scale data traffic, sustainability of mobile communication services, and device access on the Internet of Things (IoT), wireless capacity requirements are rapidly escalating. Addressing next-generation challenges requires [1] an innovative technique capable of providing sustainable solutions beyond outmoded constraints.

Traditional radio access technologies rely on classical multiple access schemes such as Frequency-, Time-, and Code-Division Multiple Access (FDMA, TDMA, and CDMA), where standardized frequency bands, time slots, or spreading codes are assigned to a constrained number of users. Given the dramatic and unprecedented 500-fold rise in mobile data traffic observed over recent years [2], there is an urgent need to explore and adopt advanced radio access technologies to meet future demands. Cutting-edge paradigms now being explored include Massive MIMO architectures, ultra-dense network topologies, millimetre-wave links, and Non-Orthogonal Multiple Access (NOMA) have been proposed to effectively address these requirements by significantly enhancing both spectral efficiency and data throughput [3]Among these, NOMA has emerged as particularly promising, offering substantial advantages in terms of massive connectivity, reduced transmission latency, and improved spectral efficiency, enabled by its capability to accommodate multiple users at once within the single radio resource block.

Previously, NOMA was recognized as Multiuser Superposition Transmission (MUST) [4], involving superimposing signals from multiple users onto the same frequency band to enable simultaneous transmissions. User signals are superimposed into a composite signal at the transmitter, enabling simultaneous multiuser transmissions. At the receiver end, sophisticated decoding methods, including Successive Interference Cancellation (SIC) and Multiuser Detection (MUD), are utilized to decode and separate these multiplexed signals effectively.

NOMA has appeared as a highly promising applicant technology for upcoming wireless communication networks, including LTE-Advanced, 5G, and beyond-5G systems. It has the potential for effective integration into current multiple access standards. Nonetheless, certain critical challenges must be addressed, including interference management, power control, and complexity in receiver design, especially in highly dynamic or noisy environments. Addressing these challenges [5], fully realizing the potential of NOMA in next-generation wireless networks is important.

In Power-Based Non-Orthogonal Multiple Access (PD-NOMA), superposition coding consciously transmits multiple users' symbols at unequal power levels on the same time-frequency resource, so the receiver can apply Successive-Interference Cancellation (SIC). To guarantee that SIC is both feasible and efficient, two tightly coupled design stages are indispensable. First, a user-pairing (or clustering) algorithm selects combinations of users whose effective channel gains differ sufficiently typically by at least an order of magnitude, ensuring that the “strong” user can decode and remove the “weak” user’s signal with low error propagation. Second, an adaptive power-allocation mechanism assigns transmit power inversely to those channel gains while satisfying per-user Quality-of-Service (QoS) conditions and the base-station power budget.

Without deliberate pairing, channel gains within a cluster often converge, causing SIC failure and degrading spectral efficiency below that of Orthogonal Multiple Access (OMA); without dynamic power allocation, even well-paired users may violate minimum-rate or fairness requirements, which eventually nullify NOMA’s theoretical throughput advantage. Empirical studies [6, 7] show that the joint optimization of pairing and power allocation can deliver a 30–70 % higher sum rate, orders-of-magnitude lower outage probability, and significantly improved energy efficiency compared with ingenious or random configurations, underscoring that both mechanisms are essential [8] for real-world NOMA deployments.

In this article, the focus is on optimizing the performance of the system and ensuring the QoS of the users based on the optimization of the allocated power to the users with user pairing algorithms. Extensive performance analysis has been carried out for the Single Carrier Multi-objective Genetic Algorithm-based power distribution for the NOMA system. The pairs of users are created using the Variant of the Greedy Heuristic Pairing Algorithm, where a pair matrix is created based on the maximum channel gain discrepancy amongst the users. The model is utilized here for the user pair and power distribution. The optimal power is assigned to the NOMA pair users with a set of two users and a set of three users in a single RB. The Pareto-optimal power allocation coefficient is allotted to the users corresponding to their instantaneous channel gain condition using a Multi-Objective Genetic Algorithm (MOGA). The in-depth analysis of the SC MOGA-NOMA system model in terms of outage floor has been carried out. The key contribution to the article is as follows:

- Extensive outage probability analysis in Single-Carrier NOMA (SC-NOMA) systems is achieved by utilizing a QoS-aware power allocation scheme with an efficient user pairing algorithm for the upcoming wireless communication systems.
- Mathematical Abstraction of the system model in relation to the outage probability has been derived for two-user and three-user sets for the instantaneous CSI-based ordering scheme.
- The Multi-objective Genetic Algorithm (MOGA) is employed to address the non-convex optimization problem, simultaneously considering power allocation factors, Quality-of-Service (QoS) thresholds, and individual users' sum-rate requirements.
- Examining the outage and setting up the threshold for the detection of an achievable data rate of the individual users is carried out with the help of Outage floor analysis.
- Analyzing the outage floor of the SC MOGA-NOMA system along with the user pairing scheme to check the system's robustness and reliability for an acceptable level of service.

The rest of this article is structured as follows. Section 2 represents the work related to the Multi-objective optimization algorithms, user sorting and pairing schemes, and their relation to the NOMA. Section 3 represents the basic NOMA system model, the System model for the Variant of the Greedy Heuristic pairing Algorithm for a set of two/ three user pairs, and assumptions related to the SC NOMA system. Section 4 describes the problem formulation of optimization of the system through the Pareto optimal set of power allocation factors and related algorithms. Section 5 describes the mathematical Abstraction of the outage analysis for the MOGA-based SC NOMA system. An extensive analysis with achievable data rate is discussed with simulation results in Section 6. Section 7: Finally, conclude the article.

## 2. Related Work

A broad analysis of power distribution strategies for NOMA users has been conducted over recent years [9, 10]. To attain the determined sum rate of the users, the powers should be carefully allotted based on the users’ channel conditions, QoS requirements, and receiver capability.

In [11], EL-Sayed et al. propose “two power allocation strategies in which one is based on the channel state information from NOMA users and another based on the user's QoS needs." Which is called "CSI-based power allocation and QoS-based power allocation". The results show a 30% increment in the spectral efficiency of NOMA associated with OMA. Luo et al. [12] proposed a low-complexity algorithm. Complexity analysis was done using power allocation algorithms. This has been proved by applying the PLWF algorithm to allocate power among subcarriers and the FTPA algorithm to allocate power among overlapping users. It has been proved that the proposed method can reduce the high complexity of the OIWF and FIWF algorithms.

In [13], "A dynamic power allocation scheme based on hybrid NOMA (DH-NOMA)" is proposed, and closed-form terminologies for outage probabilities, along with their asymptotic estimates at high SNR, are derived. A key characteristic of DH-NOMA is its adaptive nature. If the channel gain of the stronger user falls below a certain edge determined by the weaker user's target data rate, the system switches to standard Orthogonal Multiple Access (OMA). Otherwise, NOMA is utilized to exploit the benefits of power-domain multiplexing. In [14], "The authors comparatively evaluate three power allocation strategies: Fixed Power Allocation (FPA), Fractional Transmit Power Allocation (FTPA), and Full Search Power Allocation (FSPA)." Among these, the complexity associated with the full search method is notably higher than that of the other strategies. Fractional transmit power allocation, however, provides a suboptimal yet computationally efficient solution. Different user pairing approaches, including "random user pairing and channel-state-based sorting", are examined. Performance evaluations are conducted concerning energy efficiency, spectral efficiency, and sum rate.

Combined user and power distribution is introduced in [15] based on the Grey Wolf Optimizer and particle swarm optimization. Evolutionary algorithms inspired by nature have been used to solve the problem. In the context of the NOMA network, it appears that the Grey Wolf Optimization (GWO) algorithm yields superior performance compared to Particle Swarm Optimization (PSO), especially regarding convergence speed. The complexity of solving the optimization problem increases as more users join the network due to the greater demand for network resources.

Das et al. [16] explored "power allocation within an Orthogonal Multiple Access (OMA)-supported NOMA system utilizing a Difference of Convex (DC) programming method. Under conditions of complete Channel State Information (CSI) availability at the base station, the researchers developed an optimization approach structured into three primary phases: "selection of co-channel user sets, distribution of power among multiplexed users in each sub-band, and allocation of power across multiple sub-bands". The collective goal of these phases was to enhance the weighted sum rate of the network." Given the non-convex and combinatorial complexity of the formulated optimization challenge, a two-phase heuristic solution was employed. Initially, each sub-band independently underwent a greedy user-selection approach paired with an iterative, suboptimal DC-based power allocation algorithm. Subsequently, the second phase utilized the same iterative DC-based technique for distributing power across the various sub-bands, capitalizing on the DC formulation of the revised optimization framework.

Multi-objective optimization seems to be a realistic model to solve the complex engineering optimization problem. In [17], a deep description of the multi-objective Genetic Algorithm is explained and investigated with the traditional Genetic Algorithm approach. It promotes specialization in fitness function as well as providing solution diversity. Different multi-objective GAs have been compared in terms of fitness assignment, Diversity mechanism, and Elitism. Minimizing the construction cost and maximizing the network throughput seems difficult with conventional multi-objective optimization [18]. The author has used a Multi-objective Evolutionary optimization technique to improve network performance and minimize the construction cost. Here, NSGA-II is utilized, and encoding-decoding methods are designed to optimize the problem.

In [19], A Multi-objective Genetic Algorithm (MOGA) is presented for optimizing power allocation in a NOMA-based 6G-empowered IoT network. The algorithm effectively addresses the fundamental non-convex optimization problem by simultaneously considering users' Quality-of-Service (QoS) requirements, Successive Interference Cancellation (SIC), and transmission power constraints. Applying this optimization technique demonstrates substantial enhancements in energy consumption and overall energy efficiency.

Due to "Computational complexity, non-elitist approach, and the need to specify the sharing parameter, there is a need to propose an improvement in NSGA [20]. " Deb et al. proposed NSGA-II for the same and provided the solution to these critical issues.

Choi et al. [21] proposed a Proportional Fairness Scheduling (PFS) scheme for downlink NOMA systems, which is capable of simultaneously serving several users with positive transmission rates. In [22], Xiao et al. addressed a convex optimization problem aimed at maximizing Energy Efficiency (EE) and Spectral Efficiency (SE) through an enhanced Particle Swarm Optimization (PSO) technique. They introduced a cyclic rotation strategy within the particle velocity updates, resulting in faster convergence than the conventional PSO algorithm.

Additionally, a different optimization approach, "examining the balance between Spectral Efficiency (SE) and

Energy Efficiency (EE) in downlink NOMA systems utilized, utilising Multi-objective Evolutionary Algorithms (MOEAs) [23]." "In this research, the effectiveness of algorithms such as Non-dominated Sorting Genetic Algorithm-II (NSGA-II), Strength Pareto Evolutionary Algorithm-II (SPEA-II), and Multi-objective Particle Swarm Optimization (MOPSO) was assessed." According to their comparative findings, SPEA-II emerged as the most effective algorithm for optimizing the SE–EE relationship within downlink NOMA networks.

Multi-objective evolutionary algorithms offer significant advantages in handling high-dimensional, nonlinear, and complex optimization tasks. By maintaining a diverse solution set, avoiding reliance on gradient information, and facilitating a direct search for Pareto-optimal trade-offs, MOEAs have become a powerful alternative to traditional multi-objective optimization methods in both academic research and industrial applications. It offers several key advantages such as Flexibility in scalability, a Pareto-Optimal set in a run, suitability in highly complex and nonlinear problems, better in avoiding local optima, no requirement for Gradient search, and it allows robustness to the uncertainties against noise and dynamic changes in objective functions.

Although a substantial body of work has examined NOMA performance at the system level, rigorous outage-probability analysis remains conspicuously sparse for the fundamental two-user and three-user clustering cases. This gap limits our ability to establish benchmark designs or validate power-allocation heuristics against closed-form reliability targets.

In this article, Multi-Objective Genetic Algorithm (MOGA) is practised to address the power allocation challenge of the SC NOMA system to optimize the system operation, ensuring the QoS of users, which is modelled as user-specific rate thresholds over realistic SNR ranges, and limiting outage. The Variant of the Greedy Heuristic User Pairing approach is also considered. Extensive outage floor analysis has been carried out with an achievable data rate to ensure the users' QoS requests.

## 3. System Model

The proposed Variant of a greedy-based heuristic user pairing scheme for a set of two users and three users is used here for the analysis perspective. The algorithm is greedy in terms of the requirement of selecting the pair of users who hold maximum channel gain difference between them, and Heuristic in terms of following the set of rules rather than following the complex optimization problem.

### *3.1. Assumptions*

This study analyses a downlink Single-Carrier Non-Orthogonal Multiple Access (SC-NOMA) system, wherein a single Base Station (BS) communicates with $k$ users, each equipped with a single antenna. The wireless links between the BS and each user $U_i, i \in 1,2,\cdots,k$ are represented by slow Rayleigh fading channels. It is supposed that perfect Channel State Information (CSI) is accessible at the receiver.

The Rayleigh fading channels are described by their Probability Density Functions (PDFs), with channel coefficients. $g_i$, capturing both small-scale fading phenomena and large-scale path loss influenced by the distance between the BS and the user $U_i$ . The channel gain for the user $U_i$ Is given by:

$$f_{|G_i|^2}(|g_i{}^2|) = \frac{1}{\beta_i^2} e^{\frac{-|g_i{}^2|}{\beta_i^2}} \tag{1}$$

Where $\beta_i$ represents the average channel gain modelled as $\beta_i^2 = \lambda_i d_i^{-\gamma}$. Here, $\lambda_i$ denotes the small-scale fading coefficient magnitude squared, following a Rayleigh fading distribution, with expectation $E[\lambda_i^2] = 1$.

The parameter $\gamma$, representing the path-loss exponent, is treated as a constant owing to the system's static configuration, while $d_i$ Denotes the distance between the base station and the $i-th$ user. Users are ordered according to their distances from the base station. $d_1 > d_2 > \cdots > d_i$In meters.

At the receiver side, signals are decoded using Successive Interference Cancellation (SIC), guided by the order of instantaneous channel gains. It is assumed that interference is perfectly eliminated during this process. Consequently, the SIC decoding sequence is determined solely by the sorted channel gain values, as referenced in [24].

In this study, we consider the availability of instantaneous Channel State Information (CSI) for the SC NOMA scenario. The users are arranged according to their average channel gains from the base station, represented as $\beta_1 \leq \beta_2 \leq \cdots \leq \beta_k$, where each $\beta_i$ denotes the expectation $\beta_i = E[|g_i|^2]$. Accordingly, the base station transmits a linearly combined superposed signal of all users' data symbols, allocating power to each user in decreasing order. $\alpha_1 \geq \alpha_2 \geq \cdots \geq \alpha_k$.

### *3.2. A Variant of the Greedy Heuristic Pairing Algorithm for a Set of Two Users*

Greedy Heuristic Pairing algorithms [25] are commonly used for pairing NOMA users, where users are paired based on a locally optimal or immediate criterion, rather than considering all possible pairings comprehensively. The idea is to make a quick, "greedy" choice at each step to achieve a broader optimization goal. It is a heuristic in nature as well as an efficient and simple pairing algorithm. In this article, a variant of the Greedy Heuristic is considered to make the set of two or three users in a single RB.

Two Users are paired if they hold maximum channel gain difference, and a matrix is formed $A(i,j)$ Having rows and columns for a number of users. Each element of the matrix is the maximum channel gain difference between respective users, diagonal elements are set to zero as the same users cannot be paired, as well as the user pair $P(U_i, U_j)$ is the same as $P(U_j, U_i)$. The matrix $A(i)$ It is shown below, with rows and columns representing the number of users. $\Delta_{i-j}$ Indicates the channel gain difference of the i-th and j-th user, where $1 \le i \le k$ $and$ $1 \le j \le k$.

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

Where,

$$\Delta_{i-j} = 0 \qquad i = j$$
$$\Delta_{i-j} = \Delta_{j-1} \qquad i \ne j$$
$$\Delta_{i-j} = abs\left(|g_i|^2, |g_j|^2\right)$$

Channel gain difference between users.

In the considered system, users are paired using a variant of the Greedy Heuristic Pairing Algorithm, forming NOMA user pairs based on their channel gain ordering. $|g_i|^2 \le |g_j|^2$. At the receiver end, Successive Interference Cancellation (SIC) is utilized to extract individual user signals from the aggregated received signal $y_N$ (where $(N = i,j)$). The Signal-to-Interference-plus-Noise Ratio (SINR) corresponding to the user $U_i$, and the Signal-to-Noise Ratio (SNR) for the user $U_j$ , are expressed as follows:

$$\begin{cases} SINR_i = \dfrac{\hat{h}_i \alpha_i \rho_s}{1 + \hat{h}_i \alpha_i \rho_s} & 1 \le i \le k/2, \; k/2 + 1 \le j \le k \\ SNR_j = \hat{h}_j \alpha_j \rho_s & k/2 + 1 \le j \le k \end{cases} \quad (3)$$

Here, $\rho_s = \frac{P_S}{\sigma^2}$ Signifies the total transmit SNR, and the channel gains are defined as $\hat{h}_i = min\left(|g_i|^2, |g_j|^2\right)$ and $\hat{h}_j = max\left(|g_i|^2, |g_j|^2\right)$. The power allocation coefficients for users $U_i$ and $U_j$ are $\alpha_i$ and $\alpha_j$, respectively, satisfying the constraints $\alpha_i + \alpha_j = 1$ and $\alpha_i > \alpha_j$. Given the specified instantaneous Channel State Information (CSI), the achievable data rates for each user pair can be formulated as follows:

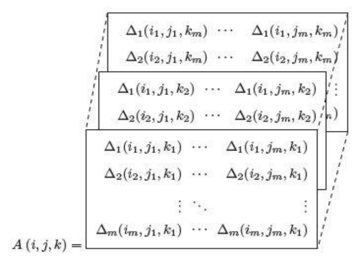
$$\begin{cases} R_i = log_2(1 + SINR_i) & 1 \le i \le k/2, \; k/2 + 1 \le j \le k \\ R_j = log_2(1 + SNR_j) & k/2 + 1 \le j \le k \end{cases} \quad (4)$$

Where $R_i$ and $R_j$ achievable individual data rates. The total sum rate is expressed as the summation of all paired users' achievable rates as below:

$$R_{TOTAL} = \sum_{i=1}^{k/2} \sum_{j=k/2+1}^{k} (R_i + R_j) \quad (5)$$

### *3.3. A variant of the Greedy Heuristic Pairing Algorithm for a Set of Three Users*

Similarly, the algorithm originally designed for a set of two users is extended to accommodate a set of three users. The same principle is applied, wherein users are clustered based on their maximum channel gain difference. For this purpose, a three-dimensional matrix $A(i,j,k)$ It is constructed so that the dimensions (rows, columns, and depth) match the number of users. Each element of the matrix represents the combined channel gain difference among the respective user triplets. As expected, diagonal elements are set to zero, since a user cannot be clustered with itself. Additionally, due to symmetry, the triplet $P(U_i, Uj, U_k)$ is considered equivalent to $P(U_j, Ui, U_k)$, $P(U_k, Ui, U_j)$And other permutations of the same user set. The 3-D matrix $A(i,j,k)$ It is shown below, with rows, columns, and pages as a number of users. $\Delta_{i-j-k}$ Indicates the channel gain difference of the i-th, j-th, and k-th user where $1 \le i \le k; 1 \le j \le k$ and $1 \le k \le k$. Finally, the output of the $P\left(k/3 \times 3\right)$ is generated with all users optimally paired.



(6)

$$\Delta_{i-j-k} = 0 \qquad for, i = j = k$$
$$\Delta_{i-j-k} = \Delta_{j-i-k} = \Delta_{j-k-i} \qquad for, i \ne j \ne k$$
$$\Delta_{i-j-k} = abs\left(|g_i|^2 - |g_j|^2 - |g_k|^2\right)$$

Channel gain difference between users.

In this system, users are organized into clusters of three using a modified Greedy Heuristic Pairing Algorithm, with their channel gains arranged in ascending order as $|g_i|^2 \le |g_j|^2 \le |g_k|^2$. As a result, the user $U_k$ experiences the best channel conditions, whereas users $U_j$ and $U_i$ Face relatively weaker links. To retrieve individual user signals from the combined received signal. $y_N$, where $N = i,j,k$, Successive Interference Cancellation (SIC) is employed at the receiver.

The corresponding SINRs and SNR for the three-user cluster ($U_i, Uj$, and $U_k$) are given as follows:

$$\begin{aligned} SINR_i &= \frac{\hat{h}_i\alpha_i\rho_s}{1+\hat{h}_i\alpha_j\rho_s+\hat{h}_i\alpha_k\rho_s} && 1 \le i \le {}^{k}/_{3} \\ SINR_j &= \frac{\hat{h}_j\alpha_j\rho_s}{1+\hat{h}_j\alpha_k\rho_s} && {}^{k}/_{3}+1 \le j \le {}^{2k}/_{3} \\ && & {}^{2k}/_{3}+1 \le k \le k \\ SNR_k &= \hat{h}_k\alpha_k\rho_s \end{aligned} \quad (7)$$

Where $\rho_s = \frac{P_s}{\sigma^2}$ Represents the total transmit SNR, and the channel is ordered as $|g_i|^2 \le |g_j|^2 \le |g_k|^2$. $\alpha_i, \alpha_j$, and $\alpha_k$ Are the allocated power coefficients for users $U_i$, Uj, and $U_k$, respectively. These power coefficients satisfy the constraints. $\alpha_i + \alpha_j + \alpha_k = 1$ and $\alpha_i > \alpha_j > \alpha_k$.

Based on the instantaneous CSI and the SINR/SNR definitions provided above, the achievable data rates for each user can be expressed as follows:

$$\begin{aligned} R_i &= log_2(1+SINR_i) && 1 \le i \le {}^{k}/_{3} \\ R_j &= log_2(1+SINR_j) && {}^{k}/_{3}+1 \le j \le {}^{2k}/_{3} \\ R_k &= log_2(1+SNR_k) && {}^{2k}/_{3}+1 \le j \le k \end{aligned} \quad (8)$$

Here, $R_i$, $R_j$, and $R_k$ Represent the achievable data rates for users. $U_i$, Uj, and $U_k$, respectively, based on instantaneous CSI-based user ordering. The overall sum rate is calculated by aggregating the achievable rates of all user pairs, as expressed below:

$$R_{TOTAL} = \sum_{i=1}^{k/_3} \sum_{j={}^{k}/_{3}+1}^{2k/_3} \sum_{k={}^{2k}/_{3}+1}^{k} (R_i + R_j + R_k) \quad (9)$$

## 4. Multi-Objective Genetic Algorithm-Based Optimal Power Allocation

Power allotment is crucial in NOMA systems, as it influences overall system performance. Effective power assignment not only enhances system capacity but also ensures that individual users' Quality of Service (QoS) requirements are met while maintaining fairness across all users in the network.

### *4.1. Problem Formulation for the Set of Two Users*

To find the Pareto-optimal set of power coefficients for the set of users that are combined using the mentioned user pairing scheme, below is the problem statement for two user pairings.

The problem is the Mixed Integer Nonlinear Programming function, which is solved using the *gamultiobj* function of MATLAB. It utilizes a variant of the NSGA-II algorithm to identify the Pareto-optimal front, thereby determining the optimal power distribution factors for the given set of paired users.

$$obj.fun = f(R_i, R_j): \underset{\{\alpha_i,\alpha_j\}}{max} \sum_{i=1}^{k/_2} \sum_{j={}^{k}/_{2}+1}^{k} (R_i + R_j)$$

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$$\begin{aligned} &C1: && (R_i + R_j) \ge (R_i^* + R_j^*) \\ &C2: && \alpha_i > \alpha_j \;;\; 1 \le i,j \le k \\ &C3: && \sum_{i=1}^{k/_2} \sum_{j={}^{k}/_{2}+1}^{k} (\alpha_i + \alpha_j) = 1 \\ &C4: && 0 < \alpha_i, \alpha_j < 1 \\ &\mathbf{C5}: && 0 \le i,j \le k \end{aligned}$$

The formulated problem's primary objective is to exploit the total achievable sum rate by optimally allocating power to the paired users. $U_i$ and $U_j$.

Constraint C1 ensures that the least achievable rate of each user in the pair is larger than or equivalent to the total system's essential sum-rate threshold, thereby maintaining the desired Quality of Service (QoS).

User pairings are performed based on a variant of the Greedy Heuristic Pairing algorithm, where users are sorted by their channel gains. $|g_i|^2 \le |g_j|^2$. This ordering ensures that the power allocation follows the condition $\alpha_i > \alpha_j$, where $\alpha_i$, and $\alpha_j$The power coefficients allocated to users.

$U_i$ and $U_j$, respectively. According to this scheme, the cell-edge user (with weaker channel gain $|g_i|^2$) is assigned additional power related to the cell-centre user (with stronger channel gain $|g_j|^2$), as formalized in Constraint C2.

To preserve the total transmit power budget, Constraint C3 enforces that the sum of the power allocation coefficients must be equal to one, satisfying the equality constraint of power conservation. Furthermore, Constraint C4 restricts each power coefficient $\alpha_i, \alpha_j$ to lie within the normalized range

$0 < \alpha_i, \alpha_j < 1$. Lastly, Constraint C5 mandates that the total number of users must be even, ensuring valid pairing without leftover users. The fitness function, which is derived from the objective function, is defined as follows:

$$fitnessfun = -f(R_i + R_j) + \sum_{i=1}^{k/_2} U_i\alpha_i(R_i) + \sum_{j={}^{k}/_{2}+1}^{k} U_j\alpha_j(R_j)$$

Translation of mathematical formulation of problems to the computational procedure is defined algorithmically as below: the optimization problem is solved using a variant of NSGA-II via MATLAB's built-in function *gamultiobj*, the process includes

Algorithm 1 MOGA for a set of Two Users

Input: Initial power allocation factors $\alpha_i$, $\alpha_j$ and corresponding user pairs $U_i$, $U_j$

Output: Optimized power allocation pairs $\alpha_i^*, \alpha_j^*$ for each user pair

Step:1 Define the objective function to be optimized.

$$obj.func = \sum_{i=1}^{k/2} U_i\,\alpha_i(R_i) + \sum_{j=1}^{k/2} U_j\,\alpha_j(R_j)$$

Step:2 Initialize the genetic algorithm by generating a finite set of candidate power allocation vectors as the initial population. Set the generation counter to zero $t = 0;\ t_{max} = 400$;

Step:3 For each generation, perform the following steps:

a. Calculate the fitness of each power allocation pair using the defined objective function.

b. Identify and retain the best-performing solution (Elitism) to pass on to the next generation.

c. Utilize selection, crossover, and mutation operations to create the latest candidate solutions.

d. If an optimal or sufficiently good solution has not yet been found, continue the evolutionary process.

Step:4 Increment the generation counter $(t = t + 1)$ and repeat Step 3 until a termination condition $t_{max} = 400$ is met (e.g., the maximum number of generations or convergence threshold).

Step: 5 Repeat Steps 1 to 4 iteratively for all user pairs until the user matrix is reduced to the final pair.

Step 6: End the loop when all optimal power pairs are computed for each user pair.

Step 7: Return the best individual power pairs $\alpha_i, \alpha_j$ for each corresponding user pair $U_i$, $U_j$, which ensures the user's QoS and lowers the outage probability.

### *4.2. Problem Formulation of a Set of Three Users*

Similarly, the formulation of the problem is extended to the set of three users. $U_i, Uj, and\ U_k$, and to find the optimal Pareto front as a power allocation coefficient as $\alpha_i, \alpha_j, and\ \alpha_k$ Respectively. The problem statement is formulated as follows.

$$obj.fun = f(R_i, R_j, R_k): \max_{\{\alpha_i, \alpha_j, \alpha_k\}} \sum_{i=1}^{k/3} \sum_{j=k/3+1}^{2k/3} \sum_{k=2k/3+1}^{k} (R_i + R_j + R_k)$$

S. T

$C1$: $\quad (R_i + R_j + R_k) \geq (R_i^* + R_j^* + R_k^*)$

$C2$: $\quad \alpha_i > \alpha_j > \alpha_k$

$C3$: $\quad \alpha_i > \alpha_j; \alpha_i > \alpha_k; \alpha_j > \alpha_k$

$C4$: $\quad \sum_{i=1}^{k/3} \sum_{j=k/3+1}^{2k/3} \sum_{k=2k/3+1}^{k} (\alpha_i + \alpha_j + \alpha_k) = 1$

$\boldsymbol{C5}$: $\quad 0 \leq \alpha_i, \alpha_j, \alpha_k \leq 1$

Constraint C1 ensures that the minimum achievable rate of each user in the triplet must be superior to or equivalent to the target total system sum rate, thereby maintaining reliable service across all clustered users. The users are clustered into sets of three based on the Variant of the Greedy Heuristic User Pairing method, where the channel gains are ordered as $|g_i|^2 < |g_j|^2 < |g_k|^2$. This ordering determines the corresponding power allocation such that $\alpha_i > \alpha_j > \alpha_k$ , with the user having the weakest channel state (typically the cell-edge user, $|g_k|^2$ )receiving the highest power share, and the cell-centred user $|g_i|^2$receiving the least.

To maintain the total, transmit power constraint, Constraint C4 ensures that the sum of the power allocation fractions $\alpha_i + \alpha_j + \alpha_k = 1$, satisfying the equality condition. Constraint C5 enforces that each fractional power value must lie within the normalized bounds $0 \leq \alpha_i, \alpha_j, \alpha_k \leq 1$. Furthermore, to allow proper three-user clustering without remainder, Constraint C6 specifies that the total number of users must be a multiple of three. The fitness function, which is derived from the objective function, is defined as follows:

$$fitnessfunction = -f(R_i + R_j + R_k) + \sum_{i=1}^{k/3} U_i\alpha_i(R_i) + \sum_{j=k/3+1}^{2k/3} U_j\alpha_j(R_j) + \sum_{k=2k/3+1}^{k} U_k\alpha_k(R_k)$$

The translation of the mathematical formulation into a computational procedure is systematically presented in the form of the subsequent algorithm.

Input: Initial power allocation factors $\alpha_i$, $\alpha_j, \alpha_k$ and corresponding user pairs $U_i$, $U_j$, and $U_k$

Output: Optimized power allocation pairs $\alpha_i^*, \alpha_j^*, \alpha_k^*$ for each user pair

Step:1 Define the objective function to be optimized

$$obj.func = \sum_{i=1}^{k/3} U_i\,\alpha_i(R_i) + \sum_{j=k/3+1}^{2k/3} U_j\,\alpha_j(R_j) + \sum_{k=2k/3}^{k} U_k\,\alpha_k(R_k)$$

Step:2 Initialize the genetic algorithm by generating a finite set of candidate power allocation vectors as the initial population. Set the generation counter to zero $t = 0;\ t_{max} = 400$;

Step:3 For each generation, perform the following steps:

a. Evaluate the fitness of each power allocation pair using the defined objective function.

b. Identify and retain the best-performing solution (Elitism) to pass on to the next generation.

c. Utilize selection, crossover, and mutation operations to create the latest candidate solutions.

d. If an optimal or sufficiently good solution has not yet been found, continue the evolutionary process.

Step:4 Increment the generation counter $(t = t + 1)$ and repeat Step 3 until a termination condition $t_{max} = 400$ is met (e.g., the maximum number of generations or convergence threshold).

Step: 5 Repeat Steps 1 to 4 iteratively for all user pairs until the user matrix is reduced to the final pair.

Step 6: End the loop when all optimal power pairs are computed for each user pair.

Step 7: Return the best individual power pairs $\alpha_i, \alpha_j, \alpha_k$ for each corresponding user pair $U_i$, $Uj, U_k$ This ensures the user's QoS and lowers the outage probability.

## 5. Outage Floor Analysis

This section evaluates the single-carrier NOMA system when users are ordered by their instantaneous CSI, under the ideal assumption of flawless successive interference cancellation at the receiver. Each user channel is modelled as an i.i.d. Rayleigh fading link, characterised by the probability density function in Equation (1). The analysis centres on instantaneous CSI–driven ordering strategies and derives the achievable data rates for each user in a two-user pairing configuration, as outlined below:

$$\widehat{R_\iota} = log_2\left(1 + \frac{\hat{h}_i\widehat{\alpha_j}\widehat{\rho_s}}{1 + \hat{h}_j\widehat{\rho_s}\sum_{k=j+1}^{K}\widehat{\alpha_k}}\right), i \le K, j < K$$

$$\widehat{R_J} = log_2\left(1 + \hat{h}_K\widehat{\alpha_K}\widehat{\rho_s}\right), i = j = K \tag{10}$$

For a set of three users,

$$\widehat{R_\iota} = log_2\left(1 + \frac{\hat{h}_i\widehat{\alpha}\widehat{\rho_s}}{1 + \hat{h}_j\widehat{\rho_s}\sum_{j=i+1}^{k}\widehat{\alpha_j} + \hat{h}_k\widehat{\rho_s}\sum_{k=j+1}^{K}\widehat{\alpha_k}}\right), 1 \le i \le K, \mathrm{i} + 1 \le j < K, k < K$$

$$\widehat{R_J} = log_2\left(1 + \frac{\hat{h}_j\widehat{\alpha_j}\widehat{\rho_s}}{1 + \hat{h}_k\widehat{\rho_s}\sum_{k=j+1}^{K}\widehat{\alpha_k}}\right), j \le K, k \le K$$

$$\widehat{R_k} = log_2\left(1 + \hat{h}_K\widehat{\alpha_K}\widehat{\rho_s}\right), i = j = K \tag{11}$$

The terms $\widehat{R_\iota}$, $\widehat{R_{J,}}$ and $\widehat{R_k}$ Correspond to the achievable data rates of users. $U_i$, $U_j$, and $U_k$, respectively, as computed based on user ordering derived from instantaneous Channel State Information (CSI).

### *5.1. Two User*

The outage probability for the user $U_k$, denoted $\widehat{P_{OUT}}^k$ Is the likelihood that the user cannot meet its required data rate under the prevailing channel and system conditions. Let $\widehat{R_\iota}$ Be the target rate, $g_i$ the Rayleigh fading coefficient, and $\hat{h}_i = \left|g_i\right|^2$ The instantaneous channel power gain for user i. When channel-state information is known at both the base station and the users, decoding proceeds in ascending order of channel gains:

$$\left|\widehat{h_1}\right| \le \left|\widehat{h_2}\right| \le \cdots \le \left|\widehat{h_\mathrm{K}}\right|$$

$$\text{Where } \left|\widehat{h_1}\right| = min(|\mathrm{g}_1|^2, |\mathrm{g}_2|^2, \dots, |\mathrm{g}_K|^2);$$

$$\left|\widehat{h_\mathrm{K}}\right| = max(|\mathrm{g}_1|^2, |\mathrm{g}_2|^2, \dots, |\mathrm{g}_K|^2).$$

Under this order, an outage for $\mathrm{U_k}$ occurs whenever the user's achievable rate falls below its threshold $\widehat{\mathrm{R_k}}$ A closed-form expression for this outage probability can be derived from the instantaneous CSI and the specified ordering. It assesses overall system performance for users with different QoS targets. The analysis also considers the impact on overall system throughput, thereby enabling a comprehensive understanding of performance trade-offs in NOMA systems.

In a similar manner to the derivation of $P_{OUT}^{K}$. The outage probability for a NOMA system employing instantaneous CSI-based user ordering can be determined by analyzing the Cumulative Distribution Function (CDF) of the weaker user's channel gain, specifically for $U_i$, where $1 \le i \le K$. The focus is placed on $\widehat{h_\iota}$, which represents the channel power gain of the user with the lowest gain in the group $i \le j \le K$. Given that the channel follows a Rayleigh fading model, as described by the Probability Density Function (PDF) in Equation (1), the corresponding CDF for $\widehat{U_\iota}$Can be expressed as:

$$F_{\widehat{h_\iota}}(\widehat{H_\iota}) = P(\widehat{H_\iota} \le \widehat{h_\iota})$$
$$= 1 - P(min\{|g_1|^2, |g_2|^2, \dots, |g_K|^2 > |\widehat{w_\iota}|^2\})$$
$$= 1 - \sum_{i=1}^{K}\sum_{k=1}^{i} P(\widehat{H_\mathrm{K}} > \widehat{h_\iota}) \tag{12}$$

The corresponding PDF can be derived by applying Equation (1), yielding:

$$F_{\widehat{h_\iota}}(\widehat{H_\iota}) = \sum_{k=1}^{i}\frac{1}{{\beta_k}^2}\sum_{k=1}^{i} e^{-(\widehat{h_\iota})\frac{1}{{\beta_k}^2}} \tag{13}$$

Similarly, the CDF of the user $\widehat{U_J}$ is

$$F_{\widehat{h_J}}(\widehat{H_\mathrm{J}}) = P(\widehat{H_\mathrm{J}} \le \widehat{h_\mathrm{J}})$$
$$= P\left(max\{|g_1|^2, |g_2|^2, \dots, |g_K|^2 \le \widehat{h_\mathrm{J}}\}\right)$$

$$= \sum_{j=1}^{K} \sum_{k=1}^{j} P\left(\widehat{H_K} \le \widehat{h_J}\right) \tag{14}$$

The corresponding PDF can be derived by applying Equation (1), yielding:

$$F_{\widehat{h_J}}\left(\widehat{H_J}\right) = \sum_{k=1}^{i}\left(1 - e^{-\left(\widehat{h_J}\right)\frac{1}{\beta_k{}^2}}\right) \tag{15}$$

The outage condition for the user $\widehat{U_\iota}$ It can be stated as follows:

$$\widehat{A_\iota} \equiv \begin{array}{c}\left\{log_2\left(1 + \frac{\widehat{h_1}\widehat{\alpha_J}\widehat{\rho_s}}{1 + \widehat{h_1}\widehat{\rho_s}\sum_{k=j+1}^{K}\widehat{\alpha_k}}\right) < \widehat{R_\iota}\right\} \\ P\left\{\widehat{h_\iota} < \frac{\widehat{X_\iota}}{\left(\widehat{\alpha_\iota} - \left(\sum_{k=j+1}^{K}\widehat{\alpha_k}\,\widehat{X_\iota}\right)\widehat{\rho_s}\right)}\right\}\end{array} \tag{16}$$

Where $\widehat{X_\iota} = 2^{\widehat{R_\iota}} - 1$, satisfying the constraint $\widehat{X_\iota} < \frac{\widehat{\alpha_J}}{\sum_{k=j+1}^{K}\widehat{\alpha_k}}$. Here, $\widehat{h_1}$ and $\widehat{h_J}$ Denote the Rayleigh-faded channel gains for users. $U_i$ and $U_j$, respectively, with $E\{|g_i|^2\} = \beta_i{}^2$, and their CDF is given in Equation (16).

Let $\widehat{A_\iota}$ Represent the outage condition for the user. $U_i$. An outage is said to occur when the intended transmission rate surpasses the maximum rate at which $U_i$ can reliably decode the signal intended for the user $U_j$, while being subjected to interference from users $U_{j+1}, \ldots, U_K$. This maximum achievable rate must meet or exceed the target QoS requirement, denoted by ($\widehat{R_\iota}\frac{bps}{Hz}$). Similarly, an equivalent outage condition can be formulated for the (jth) user.

$$\widehat{A_J} = \begin{cases} log_2\left(1 + \frac{\widehat{h_J}\widehat{\alpha_\iota}\widehat{\rho_s}}{1 + \widehat{h_J}\widehat{\rho_s}\sum_{k=j+1}^{K}\widehat{\alpha_k}}\right) < \widehat{R_\iota} & j < K \\ log_2\left(1 + \widehat{h_J}\widehat{\rho_s}\sum_{k=j+1}^{K}\widehat{\alpha_k}\right) < \widehat{R_J} & j = k \end{cases} \tag{17}$$

The outage probability corresponding to the $jth$ user is expressed as:

$$P\left\{\widehat{w_J} < max\left\{\frac{\widehat{X_\iota}}{\left(\widehat{\alpha_\iota} - \widehat{X_J}\sum_{k=j+1}^{K}\widehat{\alpha_k}\right)\rho_s}, \frac{\widehat{X_J}}{\widehat{\alpha_J}\widehat{\rho_s}}\right\}\right\} \tag{18}$$

Here, $\widehat{X_J} = 2^{\widehat{R_J}} - 1$. Based on this, the outage expressions for users $U_i$ and $U_j$ Can be formulated as follows:

$$\hat{P}_{OUT}^{U_i} = \int_0^{\frac{\widehat{X_\iota}}{\left(\widehat{\alpha_\iota} - \left(\sum_{k=j+1}^{K}\widehat{\alpha_k}\widehat{X_\iota}\right)\widehat{\rho_s}\right)}} F_{\widehat{h_1}}\left(\widehat{H_1}\right)\, d\left(\widehat{H_1}\right) \tag{19}$$

$$\hat{P}_{OUT}^{U_j} = \int_0^{max\left\{\frac{\widehat{X_\iota}}{\left(\widehat{\alpha_\iota} - \widehat{X_J}\sum_{k=j+1}^{K}\widehat{\alpha_k}\right)\rho_s}, \frac{\widehat{X_J}}{\widehat{\alpha_J}\widehat{\rho_s}}\right\}} F_{\widehat{h_J}}\left(\widehat{H_J}\right)\, d\left(\widehat{H_J}\right) \tag{20}$$

Equations (19) and (20) provide the individual outage probability analysis for the SC MOGA-NOMA system.

### *5.2. Three User*

The outage probability for the user $U_k$, denoted $\widehat{P_{OUT}}^k$ Quantifies the likelihood that $U_k$ cannot achieve its required rate $\widehat{R_k}$ Under the prevailing channel conditions. Each link is characterized by a Rayleigh fading coefficient. $g_i$ and an instantaneous power gain $\widehat{h_1} = |g_i|^2$. With perfect, instantaneous CSI known at both the base station and all users, decoding proceeds in ascending order of channel gains, in order $\widehat{h_1} \le \widehat{h_2} \le \cdots \le \widehat{h_J} \le \cdots \le \widehat{h_K}$, where

$$\widehat{h_1} = min(|g_1|^2, |g_2|^2, \ldots, |g_K|^2), \widehat{h_J} = min\left(|g_{i+1}|^2, |g_{i+2}|^2, \ldots, |g_j|^2\right); \quad and\ \widehat{h_K} = max(|g_1|^2, |g_2|^2, \ldots, |g_K|^2).$$

Using the resulting closed-form outage expressions, we assess how different user QoS targets impact overall system throughput and performance. Similarly to the derivation of $P_{OUT}^K$One can use the channel gain's CDF to compute the outage probability for the user. $\widehat{U_\iota}$,$1 \le i \le K$ in an instantaneous CSI-based NOMA downlink system. Specifically, this involves evaluating the CDF of the weaker user's channel gain, denoted as $\widehat{h_1}$ for $i \le j \le K$. The channel follows a Rayleigh fading model with its probability density function specified in Equation (1). Accordingly, the CDF for $U_i$ Is given by:

$$\begin{aligned} F_{\widehat{h_1}}\left(\widehat{H_1}\right) &= P\left(\widehat{H_1} \le \widehat{h_1}\right) \\ &= 1 - P\left(min\left\{|g_1|^2, |g_2|^2, \ldots, |g_K|^2 > \widehat{h_1}\right\}\right) \\ &= 1 - \sum_{i=1}^{K}\sum_{k=1}^{i} P\left(\widehat{H_K} > \widehat{h_1}\right) \end{aligned} \tag{21}$$

The corresponding PDF can be derived by applying Equation (1), yielding:

$$F_{\widehat{h_1}}\left(\widehat{H_1}^2\right) = \sum_{k=1}^{i}\frac{1}{\beta_k{}^2}\sum_{k=1}^{i} e^{-\left(\widehat{h_1}\right)\frac{1}{\beta_k{}^2}} \tag{22}$$

Similarly, the CDF of the user $U_j$ is

$$\begin{aligned} F_{\widehat{h_J}}\left(\widehat{H_J}\right) &= P\left(\widehat{H_J} \le \widehat{h_J}\right) \\ &= P\left(min\left\{|g_{i+1}|^2, |g_{i+2}|^2, \ldots, |g_j|^2 > \widehat{h_J}\right\}\right) \\ &= 1 - \sum_{j=1}^{K}\sum_{J=i+1}^{j} P\left(\widehat{H_J} > \widehat{h_J}\right) \end{aligned} \tag{23}$$

The corresponding PDF can be derived by applying Equation (1), yielding:

$$F_{\widehat{h_J}}\left(\widehat{H_J}\right) = \sum_{k=i+1}^{j}\frac{1}{\beta_k{}^2}\sum_{k=i+1}^{j} e^{-\left(\widehat{h_J}\right)\frac{1}{\beta_k{}^2}} \tag{24}$$

Similarly, the CDF of the user $U_K$ is

$$F_{\widehat{h_K}}\left(\widehat{H_K}\right) = P\left(\widehat{H_K} \leq \widehat{h_K}\right)$$
$$= P\left(min\{|g_1|^2, |g_2|^2, \dots, |g_K|^2 \leq \widehat{h_K}\}\right)$$
$$= \sum_{k=1}^{K} \sum_{k=1}^{j} P\left(\widehat{H_K} \leq \widehat{h_K}\right) \quad (25)$$

The corresponding PDF can be derived by applying Equation (1), yielding:

$$F_{\widehat{h_K}}\left(\widehat{H_K}\right) = \sum_{k=1}^{K} \left(1 - e^{-\left(\widehat{h_J}\right)\frac{1}{\beta_k{}^2}}\right) \quad (26)$$

The outage condition for the user $\widehat{U_\imath}$ It can be stated as follows:

$$\widehat{A_\imath} \equiv \begin{cases} log_2\left(1 + \frac{\widehat{h_1}\widehat{\alpha_J}\widehat{\rho_S}}{1 + \widehat{h_1}\widehat{\rho_S}\sum_{k=i+1}^{j}\widehat{\alpha_J} + \widehat{h_1}\widehat{\rho_S}\widehat{\sum_{k=J+1}^{K}}\widehat{\alpha_k}}\right) < \widehat{R_\imath} \\ P\left\{\widehat{h_1} < \frac{\widehat{X_\imath}}{\left(\widehat{\alpha_\imath} - \left(\sum_{k=i+1}^{j}\widehat{\alpha_J}\widehat{X_\imath}\right)\widehat{\rho_S} - \left(\sum_{k=j+1}^{K}\widehat{\alpha_k}\widehat{X_\imath}\right)\widehat{\rho_S}\right)}\right\} \end{cases}$$

(27)

Let $\widehat{X_J} = 2^{\widehat{R_J}} - 1$. This quantity must satisfy $\widehat{X_J} < \frac{\widehat{\alpha_J}}{\sum_{k=j+1}^{K}\widehat{\alpha_k}}$.

The symbols $\widehat{h_\imath}, \widehat{h_\jmath}$, $\widehat{h_K}$ Denote the Rayleigh-fading channel gains for users. $\widehat{U_\imath}$, $\widehat{U_J}$, and $\widehat{U_K}$ respectively, where $E\{|g_i|^2\} = \beta_i{}^2$. Their Cumulative Distribution Function (CDF) is provided in Equation (21). Define the outage event for the user $U_i$ by $\widehat{A_\imath}$ An outage occurs when the attempted transmission rate exceeds the highest rate at which $U_i$ can successively decode the messages of $U_j$ and $U_k$ while still experiencing interference from the remaining users $U_{i+1}, \dots, U_j, U_{j+1}, \dots, U_K$. This maximum decodable rate must reach at least the target Quality-Of-Service (QOS)$\widehat{R_\imath}\frac{bps}{Hz}$). A corresponding outage condition is defined analogously for the j − th user.

$$= \begin{cases} log_2\left(1 + \frac{\widehat{h_\jmath}\widehat{\alpha_\imath}\widehat{\rho_s}}{1 + \widehat{h_\jmath}\widehat{\rho_s}\sum_{j=i+1}^{j}\widehat{\alpha_J} + \widehat{h_\jmath}\widehat{\rho_s}\sum_{k=j+1}^{K}\widehat{\alpha_k}}\right) < \widehat{R_\imath};\ i < j < K \\ log_2\left(1 + \frac{\widehat{h_\jmath}\widehat{\alpha_\imath}\widehat{\rho_s}}{1 + \widehat{h_\jmath}\widehat{\rho_s}\sum_{k=j+1}^{K}\widehat{\alpha_k}}\right) < \widehat{R_J} \qquad j < K \\ log_2\left(1 + \widehat{h_\jmath}\widehat{\rho_s}\sum_{k=j+1}^{K}\widehat{\alpha_k}\right) < \widehat{R_k} \qquad j = k \end{cases}$$

$$P\left\{\widehat{h_\imath} < \frac{\widehat{X_J}}{\left(\widehat{\alpha_J} - \left(\sum_{k=j+1}^{K}\widehat{\alpha_k}\widehat{X_J}\right)\widehat{\rho_S}\right)}\right\}$$

Where $\widehat{X_J} = 2^{\widehat{R_J}} - 1$ satisfies $\widehat{X_J} < \frac{\widehat{\alpha_J}}{\sum_{k=j+1}^{K}\widehat{\alpha_k}}$, and $\widehat{h_\jmath}$ and $\widehat{h_K}$ Are the Rayleigh-faded channel gains for users $U_j$ and $U_k$, respectively, with $E\{|g_i|^2\} = \beta_i{}^2$. The CDF of these channel gains is provided in Equation (21). Define $\widehat{A_J}$ as the outage condition for the user $U_j$, . An outage arises when the requested transmission rate exceeds the largest rate at which $U_j$ can successively decode the signal intended for $U_k$, while treating the residual interference from users $U_{j+1}, \dots, U_K$ As noise, this service limit must at least equal the QoS target. $\widehat{R_J}\frac{bps}{Hz}$. A parallel definition applies to the user k − th.

$$\widehat{A_k} = \begin{cases} log_2\left(1 + \frac{\widehat{h_k}\widehat{\alpha_\imath}\widehat{\rho_s}}{1 + \widehat{h_k}\widehat{\rho_s}\sum_{k=j+1}^{K}\widehat{\alpha_k}}\right) < \widehat{R_J} \qquad j < K \\ log_2\left(1 + \widehat{h_k}\widehat{\rho_s}\sum_{k=j+1}^{K}\widehat{\alpha_k}\right) < \widehat{R_k} \qquad j = k \end{cases} \quad (28)$$

The outage probability corresponding to the $kth$ user is expressed as:

$$P\left\{\widehat{h_k} < max\left\{\frac{\widehat{X_\imath}}{\left(\widehat{\alpha_\imath} - \widehat{X_J}\sum_{j=i+1}^{j}\widehat{\alpha_J} - \widehat{X_k}\sum_{k=j+1}^{K}\widehat{\alpha_k}\right)\rho_S}, \frac{\widehat{X_J}}{\left(\widehat{\alpha_\imath} - \widehat{X_k}\sum_{k=j+1}^{K}\widehat{\alpha_k}\right)\rho_S}, \frac{\widehat{X_k}}{\widehat{\alpha_k}\widehat{\rho_S}}\right\}\right\}$$

Here, $\widehat{X_k} = 2^{\widehat{R_k}} - 1$. Based on this, the outage expressions for users $U_i$ , $U_j$ , and $U_k$ Can be formulated as follows:

$$\hat{P}_{OUT}^{U_i} = \int_0^{\frac{\widehat{X_\imath}}{\left(\widehat{\alpha_\imath} - \left(\sum_{j=i+1}^{j}\widehat{\alpha_J}\widehat{X_\imath}\right)\widehat{\rho_S} - \left(\sum_{k=j+1}^{K}\widehat{\alpha_k}\widehat{X_\imath}\right)\widehat{\rho_S}\right)}} F_{\widehat{h_1}}\left(\hat{H}_\imath\right)\, d\left(\hat{H}_\imath\right) \quad (29)$$

$$\hat{P}_{OUT}^{U_j} = \int_0^{\frac{\widehat{X_J}}{\left(\widehat{\alpha_J} - \left(\sum_{k=j+1}^{K}\widehat{\alpha_k}\widehat{X_J}\right)\widehat{\rho_S}\right)}} F_{\widehat{h_\jmath}}\left(\widehat{h_\jmath}\right)\, d\left(\hat{H}_\jmath\right) \quad (30)$$

$$\hat{P}_{OUT}^{U_i} = \int_0^{\frac{\widehat{X_\imath}}{\left(\widehat{\alpha_\imath} - \left(\sum_{j=i+1}^{j}\widehat{\alpha_J}\widehat{X_\imath}\right)\widehat{\rho_S} - \left(\sum_{k=j+1}^{K}\widehat{\alpha_k}\widehat{X_\imath}\right)\widehat{\rho_S}\right)}} F_{\widehat{h_1}}\left(\hat{H}_\imath\right)\, d\left(\hat{H}_\imath\right) \quad (31)$$

Equations (29), (30), and (31) provide the individual outage probability analysis for the SC MOGA-NOMA system.

## 6. Simulation Results and Discussion

Simulation results are provided to evaluate the outage performance of the NOMA system utilizing MOGA-based power allocation. User pairing is carried out using a modified version of the Greedy Heuristic Pairing Algorithm, and the corresponding outage characteristics are examined. The primary metric considered is the outage probability, which is assessed under varying Signal-to-Noise Ratio (SNR) conditions and across different target data rate requirements. Both theoretical analysis and Monte Carlo simulations are conducted for two-user and three-user NOMA clusters under an MOGA-based optimization framework implemented in MATLAB. These simulations highlight each user's performance within the SC MOGA-NOMA system, specifically focusing on outage behaviour. In this section, we present several outage vs.

SNR results under instantaneous CSI while examining the influence of diverse QoS requirements on individual user performance. Unless otherwise specified, the simulation parameters are set as follows.

The number of users is k=6 for a set of two users grouped and making three groups, and k=9 for three users making three groups according to the stated user pairing algorithm. Considering $U_1$ as a cell-centred user and $U_2$ As a cell-edge user, the allocated power is inversely proportional to the value assigned and optimized with MOGA. The threshold rates of individual users' QoS have been set to $\hat{R}_1 = \hat{R}_2 = 1\frac{bps}{Hz}, 0.5\ \frac{bps}{Hz}$.

Figures 1 and 2 illustrate the outage performance for a two-user subset selected from a three-user cluster within an SC MOGA-NOMA framework. The threshold data rates for both users are set to $\hat{R}_1 = \hat{R}_2 = 1\frac{bps}{Hz}$ In one scenario and $\hat{R}_1 = \hat{R}_2 = 0.5$ in the other. A comparison of the two figures indicates that the user $U_2$ is likely decoded before $U_1$, as it demonstrates a consistently lower outage probability within the group. In a lower SNR region, as mentioned $U_2$ has a higher probability than $U_1$ As power is allocated to the $U_2$ It is less likely to decode its signal, and as power increases, the detection becomes more efficient without any interference from the other signals. If the threshold of QoS is reduced by half, the outage lowers further.

Next, analysis is done on the performance in terms of varied threshold QoS for each user, in which $U_1$ The strongest user has given the threshold data rate, which is half of that. $of\ U_2$ And we have also analyzed the result for the vice versa case. Figures 3 and 4 have that analysis for the same. Where in the first, the rate is $\hat{R}_1 = 0.5$, $\widehat{R}_2 = 1\frac{bps}{Hz}$, while in the second $\hat{R}_1 = 1$, $\widehat{R}_2 = 0.5\frac{bps}{Hz}$. In both cases, the outage monotonically decreases; however, reducing the detection rate can assure system performance with lowered outage.

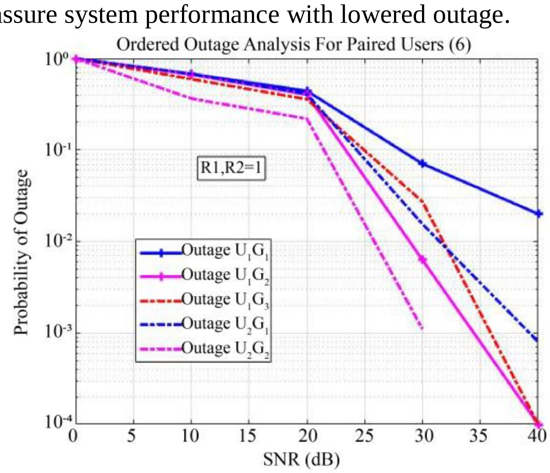


**Fig. 1 Outage analysis of SC MOGA-NOMA system for a set of two users with achievable data rates as $\widehat{R_1} = \widehat{R_2} = 1\ {bps}/_{Hz}$.**

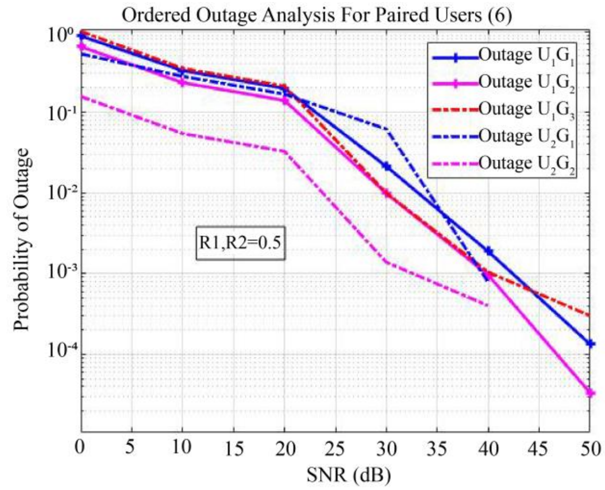


**Fig. 2 Outage analysis of SC MOGA-NOMA system for a set of two users with achievable data rates as $\widehat{R_1} = \widehat{R_2} = 0.5\ {bps}/_{Hz}$.**

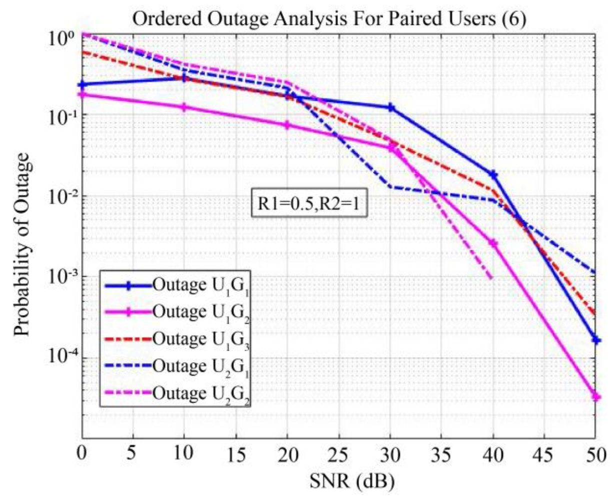


**Fig. 3 Outage analysis of SC MOGA-NOMA system for a set of two users with achievable data rates as $\widehat{R_1} = 0.5$, $\widehat{R_2} = 1\ {bps}/_{Hz}$.**

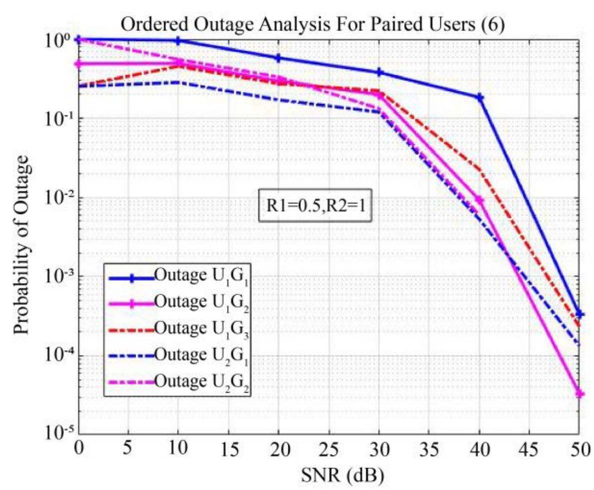


**Fig. 4 Outage analysis of SC MOGA-NOMA system for a set of two users with achievable data rates as $\widehat{R_1} = 1$, $\widehat{R_2} = 0.5\ {bps}/_{Hz}$.**

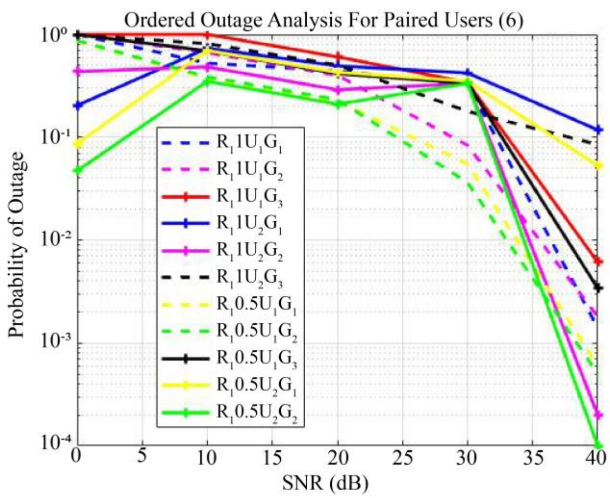


**Fig. 5 Comparative outage analysis of SC MOGA-NOMA system for a set of two users with achievable data rates as** $\widehat{R_1}$, $\widehat{R_2} = 1\, {}^{bps}/_{Hz}$, $\widehat{R_1}$, $\widehat{R_2} = 0.5\, {}^{bps}/_{Hz}$.

In Figure 5 & Figure 6 Simulation has been done for 3 groups of two users each, and the threshold for data rates has been taken as One in which both for $U_1$, $U_2$The data rates are the same, i.e. $\widehat{R_1}$, $\widehat{R_2} = 1\, {}^{bps}/_{Hz}$One in which both for $U_1$, $U_2$ The data rates are the same, i.e. $\widehat{R_1}$, $\widehat{R_2} = 0.5\, {}^{bps}/_{Hz}$.

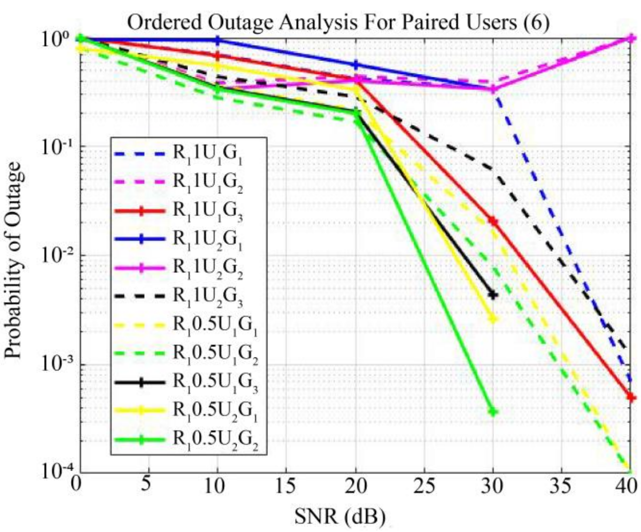


**Fig. 6 Comparative outage analysis of SC MOGA-NOMA system for a set of two users with achievable data rates as** $\widehat{R_1}$, $\widehat{R_2} = 1\, {}^{bps}/_{Hz}$, $\widehat{R_1} = 0.5$, $\widehat{R_2}$=1

Similarly, for the 3 groups of two users each, the threshold for data rate has been taken as one in which both. $U_1$ and $U_2$ have the same data rates, i.e. $\widehat{R_1}$, $\widehat{R_2} = 1\, {}^{bps}/_{Hz}$, while in other $\widehat{R_1} = 0.5\, {}^{bps}/_{Hz}$ and $\widehat{R_2} = 1\, {}^{bps}/_{Hz}$. One can observe that the other half of the data rate achieves a lower outage compared to the one with higher detection, but also at a higher value of SNR, its performance achieves a further lower outage. There should be a trade-off for the system requirement; the threshold can be determined and set.

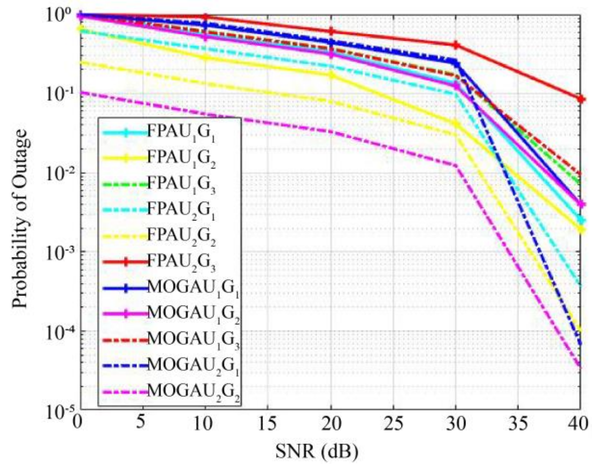


**Fig. 7 Comparative outage analysis of FPA & MOGA based NOMA system for two user pairings with** $\widehat{R_1}$, $\widehat{R_2} = 1\, {}^{bps}/_{Hz}$.

A comparison with the conventional FPA is made with the MOGA-NOMA System. The six users are paired in a group of three, and the achievable data rate is considered. $\widehat{R_1}$, $\widehat{R_2} = 1\, {}^{bps}/_{Hz}$. The power allocation coefficients for FPA are given as $\alpha_1 = 0.8$; $\alpha_2 = 1 - \alpha_1$, while for comparative analysis, optimized power is allocated from the MOGA-based allocation. If we focus on the $U_2$, which experiences a lower data rate and achieves a better outage than the FPA. The performance of the distant user is better with the MOGA-based NOMA system.

Figure 8 Depicts the performance of outage vs threshold of QoS rate performance, varied threshold rate detection from $0.4 - 2.8$ has been taken as a performance metric, one can observe that for low to moderate values, outage of $U_2$, significantly increasing the performance of the system.

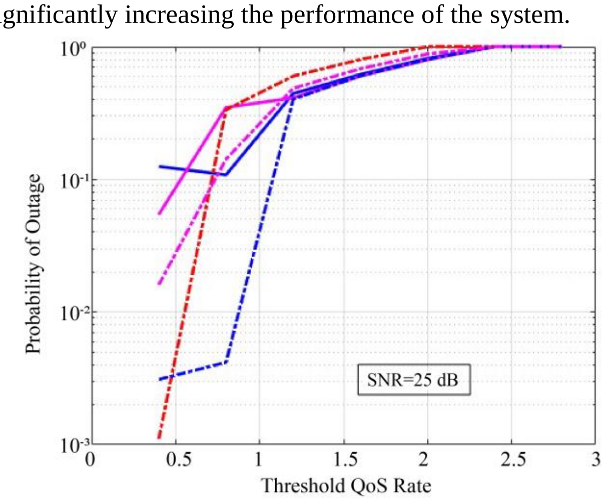


**Fig. 8 Outage analysis with varied threshold QoS rate of SC MOGA-NOMA system for a set of two users with fixed SNR of** $25dB$

In a typical NOMA setup, users are broadly divided into two QoS categories: cell-centre users, who are close to the base station and target higher data rates, and cell-edge users, located farther away and requiring a lower, predetermined rate. To maintain reliable service for the weaker link, the cell-edge user is allocated a larger share of the transmit power, and its SINR (or rate) threshold is set lower than that of the nearby user. The optimal power levels are determined with a Multi-Objective Genetic Algorithm (MOGA), and the choice of system parameters obtained through this optimization strongly influences overall performance. Further, the outage of three users has been analyzed. The users are clustered in a group of three, with $k = 9$ users, and 3 groups are made. The targeted data rate for the users $U_1, U_{2,}$ and $U_3$ is 1 bps/Hz and 0.5 bps/Hz. Outage analysis is shown below in Figure 9 and in Figure 10. It is observed in Figure 9 that the sudden shoot of $U_3$, is that at higher SNR regions, there is a failure to decode its symbol and propagate the SIC detection error.

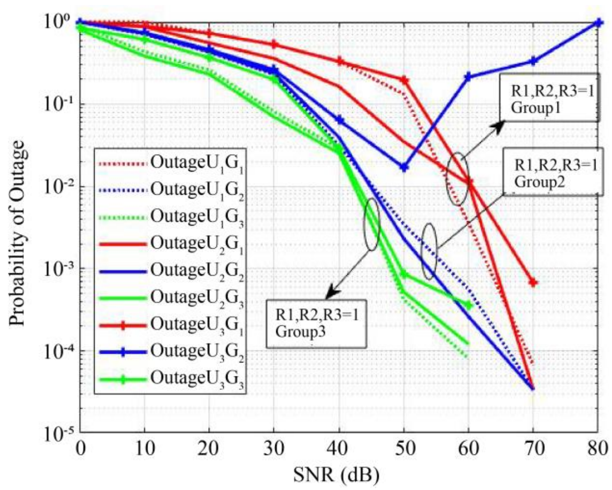


**Fig. 9 Outage analysis of SC MOGA-NOMA system for a set of three users with achievable data rate as $\widehat{R_1} = \widehat{R_2} = \widehat{R_3} = 1\ {bps}/{Hz}$.**

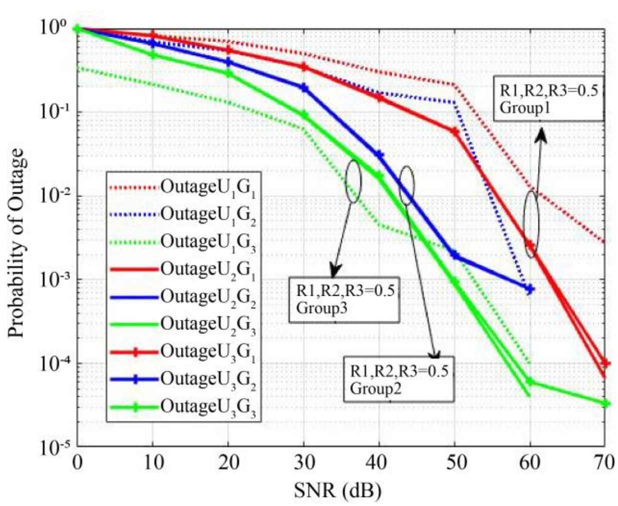


**Fig. 10 Outage analysis of SC MOGA-NOMA system for a set of three users with an achievable data rate as $\widehat{R_1} = \widehat{R_2} = \widehat{R_3} = 0.5\ {bps}/{Hz}$**

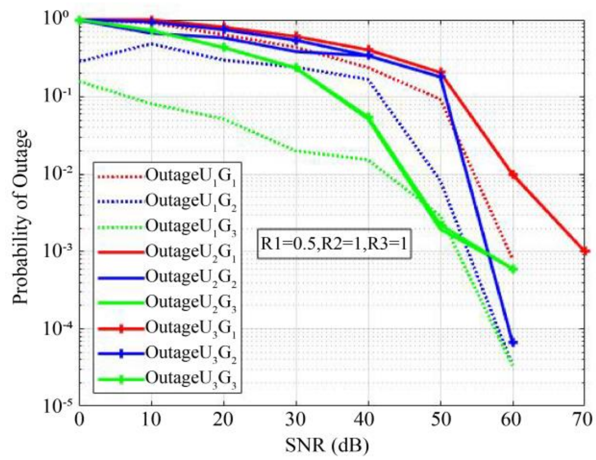


**Fig. 11 Outage analysis of SC MOGA-NOMA system for a set of three users with an achievable data rate as $\widehat{R_1} = 0.5\ \widehat{R_2} = 1,\ \widehat{R_3} = 1\ {bps}/{Hz}$.**

The probability further lowers if the threshold of detection is half in the three-user scenario, while keeping it. $U_{2,}$ and $U_3$ at 1 ${bps}/{Hz}$. The crossover of the user $U_{2,}$ and $U_{3,}$ occurred at higher SNR, depicting that the outage probability of U1 is dominated by the outage of $U_{2,}$ and $U_3$. As the symbol detection of $s_2$ dominates the net outage of $U_2$.

## 7. Conclusion

This work has conducted an analysis to ensure that users' minimum data rate thresholds are satisfied, aiming to optimize overall system performance through detailed outage analysis. Recognizing that user pairing and power allocation critically impact NOMA system performance, this study employs a variant of the Greedy Heuristic Algorithm for user pairing, coupled with a Multi-objective Genetic Algorithm for optimal power allocation. The performance of the resulting SC MOGA-NOMA system has been evaluated analytically and validated through MATLAB simulations, focusing specifically on individual user outage probabilities under various Quality of Service (QoS) threshold rates.Simulation results demonstrate that cell-edge users exhibit significantly improved outage performance compared to cell-centred users in high-SNR regions. Additionally, reducing the target detection rate by half further enhances reliability, ensuring robust system performance while meeting network QoS requirements. Furthermore, extending from the conventional two-user NOMA pairing, the proposed three-user clustering achieves notably superior outage performance, even at lower SNR values, if power allocation coefficients are carefully optimized. Future research may build on these results by investigating and assessing alternative advanced Multi-Objective Evolutionary Algorithms (MOEAs) to achieve further performance improvements in NOMA systems.

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