Adapted Wild Horse Optimization for Sub-Carrier Selection and Power Allocation in Downlink non-orthogonal frequency division multiplexing System

M. Saranya Nair

Senior Assistant Professor
School of Electronics Engineering, VIT University,
Chennai Campus, Tamil Nadu 600127, India.
saranyaratheesh87@gmail.com

Abstract: The non-orthogonal multiple access (NOMA) is one of the enhanced multiple access scheme aids the users to share similar resources with the allocated power levels. However, the number of users gets increased and reduces the SE performance due to complex allocation of resources in the NOMA system. To overcome this issue, several optimization technique have been introduced to allocate the subcarriers (SC) and powers to all the available NOMA users effectively. However, the existing optimizers consumes high iterations and fails to produce global optimal solutions for processing the recent NOMA system. Hence this study introduces a novel adapted wild horse optimization (AWHO) technique for joint subcarriers and power allocation in the downlink NOMA system. The proposed method is processed and analyzed via MATLAB platform and several performance measures like spectral efficiency, energy efficiency, sum rate, throughput and fairness indexes are analyzed and compared with existing techniques. The proposed method obtains the SE of 15.76bps/Hz, EE of 20.95bps/Hz, throughput of 51.03, sum rate of 498.36bps/Hz, and FI of 0.955.

Keywords: Joint Subcarrier and Power Allocation, Downlink Non-Orthogonal Multiple Access System, Adapted Wild Horse Optimization, Spectral Efficiency Maximization, Fairness Index, User Pairing

1. Introduction

Due to the emergence of cloud based and IoT (Internet of Things) applications, wireless communication need a transition to support large data, latency and large scale connectivity. In 5G wireless network, the Non-Orthogonal Multiple Access (NOMA) is considered as the effective promising technology that allows various intermediate transmission via allocating same frequency channel to different users [1]. NOMA provides various features such as better performance, better affinity, better user fairness, better mobile states and better spectral efficiency (SE) [2].

There are two stages in NOMA models; they are power domain based NOMA and code domain based NOMA. In power domain based NOMA, the transmission of different users are carried out simultaneously by creating the gain of channel variation between the multiplexed users. Then, the code domain based NOMA achieves multiplexing in code domain and the power domain based NOMA achieves multiplexing in power domain [3-5].

The power domain based NOMA is the capacity achieving multiple accessing model on the basis of SIC (successive interference cancellation) and the major aim is to improve the SE [6]. In NOMA, every subcarrier (SC) is allocated to many users and multi-users with high power levels are aided in the same resource block. The rapid advancement in energy constrained wireless devices demanding for high data rates to the further transmission models [7-9]. In traditional multicarrier system, the radio frequency band is split into multi-SCs and every SC is allocated for avoiding multi-user interference. The low transmission power is provided to the user with more channel gain and high transmission power is provided to the user with less channel gain [10].

Various research works are conducted for joint SC and power allocation and it aims to maximize the sum-rates, max-min fairness and proportional fairness. FTPC (Fractional transmit power control) is generally utilized for sum rate maximization and provides fraction of the total power to every user on the basis of the condition of the channel [11]. Further, sub optimal power allocation and greedy user allocation model on the basis of difference of convex programming for maximizing the weighted sum rate. When compared to the conventional OMA (orthogonal multiple access), NOMA model achieve high SE and high throughput by providing SIC at the receiving side [12].

In NOMA, the power allocation is considered as major challenge in 5G communication models. In NOMA, the resource allocation involves SC assignment of user, and power allocation are major to attain better performance. Most of the existing works are carried out for single cell NOMA model [13]. With the perfect CSI (channel state information), some SC and power allocation models are used for maximizing sum-rate for the downlink MIMO model. The dynamic power models are used for enhancing the WSR (weighted sum-rate) and sum-rate in multicarrier NOMA systems [14]. In the case of cellular downlink model, the NOMA achieves enhanced ergodic sum-rate when compared to OMA. The energy efficiency (EE) is considered as the major for 5G and it is essential to verify EE for NOMA system [15]. Further, near optimal user cluster model is developed for maximizing the sum-rate and for every cluster the optimal power allocation is provided [16].

Nowadays, the NOMA system have gained much attention due to its increased accessibility of multiple users with a similar resources thereby enhancing the spectral efficiency effectively. In NOMA system, the users are multiplexed with the same resources leads to high interferences at the receiver side. To overcome this issue, several techniques have been introduced by the researchers and it highly depend upon the number of users and utilized SCs. In addition to this, some other complexities like varying channel condition due to paired users reduces the efficiency of the NOMA system. Several researchers pointed out the CCI and SIC in the receiver side to decode the interference during data transmission. These kinds of major drawbacks motivated us to develop an optimal joint power and subcarrier allocation in downlink NOMA system. Recently, many optimization techniques are used for optimizing the transmit power for every sub-channel. Hence, this work presents a SC selection and power allocation strategy for the downlink NOMA system using en adaptive optimization technique. The major contributions of the proposed work are depicted below:

- To present a novel optimization (AWHO) technique to maximize the sum-rate, throughput, spectral efficiency and energy efficiency of the downlink NOMA system.
- To propose an adapted wild horse optimization (AWHO) for optimal subcarrier and power allocation by considering the spectral and energy efficiency as the fitness function.
- To introduce a novel dynamic weight approach (DWA) is into the adaptive optimizer to obtain global optimal solution for the downlink NOMA system.
- To implement the proposed method in MATLAB platform and compare the performance of the proposed optimal power allocation with other schemes for verifying its effectiveness.

The rest of the sections are organized in the upcoming section: Section 2 presents the literature survey of recently published paper. Section 3 demonstrates the detailed description of the developed methodology. Section 4 evaluates the results and discussion. Section 5 explains about the conclusion of the proposed work.

2. Related Works

Alhusseini et al. [17] put up a joint SC and power allocation challenge for the PD-NOMA-based MISO multi-spot-beam satellite network architecture. Under the restrictions of SC and transmit power, the issue under consideration reduces the overall signal strength. An alternating approach was taken to resolve this issue. The transmission power levels were modified using the SCA method and the SC allocation was modified by using INLP method. Additionally, the Monotonic Optimization approach was used to resolve the problem in order to determine the best answer. While taking into account both receiver and transmitter power consumption, it is not possible to use joint uplink and downlink communication.

Ardakani et al. [18] looked into a method for MC-NOMA backscatter. By concurrently optimizing the reflection coefficients and SC allocation, a challenge for maximizing aggregate data rate is defined. The presented issue displays hidden monotonicity structure and is not convex. Discrete monotonic optimization was used to create an ideal plan. The introduction of a suboptimal method with polynomial time complexity and sequential convex estimate as its foundation. However, this approach is difficult to compute.

Abrardo et al. [19] has looked into the power and channel allocation issue for multicarrier non-orthogonal multiple access (NOMA) full duplex (FD) networks. Two algorithms based on the breakdown of the basic allocation scheme into lower-complexity sub-problems solvable in the Lagrangian dual domain with a considerable reduction in the computing burden were introduced after the block coordinated descent (BCD) method.

Cejudo et al. [20] examined the issue of resource allocation in multi - carrier NOMA with BER and transmission power limits. For realistic QAM levels, precise values of the ideal channel gain ratios among two NOMA clients were calculated, as well as the numerical limits of the channel gain ratios that satisfy BER restrictions. Depending on these discoveries, an IRA-DRS technique for data rate and continuous power allocation was developed, along with a user pairing algorithm with quasi-linear complexity. And yet, it is necessary to enhance the latency and security of this method.

In mmWave heterogeneous environment, Hadi et al. [21] looked into a new allocation of resources, 3D beam shaping, and cross-tier interference mitigation challenge. The introduction of an OMA-NOMA based cross-tier interference mitigation method saw the division of the overall bandwidth into OMA-based and NOMA-based sub-carriers. By maximizing the sub-channel allocation, beam formation vector, and BS tilt angle, an optimization problem with goal of maximizing the sum data rate of an OMA-NOMA based method under network instability was established. Techniques like the ASM approach, SCA technique, and linear programming tools are employed to tackle the MINLP problem that has been introduced.

A global optimal method was put forth by Banerjee et al. [22] for the joint power and sub-carrier allocation in multicell NOMA systems. Because it now meets the essential and sufficient conditions for a workable SIC, its complexity has been decreased. The approach could be adjusted to account for additional parameters in order to serve as a benchmark solution or to offer an appropriate solution for the multi-cell, multi-carrier NOMA resource allocation problem. However, as the number of users grows, so does the system's latency.

Wang et al. [23] included several real-world practical restrictions in the VLC system and the added QoS while also proposing a novel SC and power allocation approach for OFDM-NOMA VLC. The method takes user fairness into account as well as being relevant in situations when the overall number of multiplexed clients and the amount of multiplexing clients per SC really aren't equal. However, this system finds it challenging to save energy.

Table 1: Brief details of state of art techniques

Reference number	models	Benefit	Drawback	Performance evaluation
Alhusseini et al. [17]	MISO multi-spot-beam satellite system	better coverage, low complexity and low cost for the satellite systems	High energy consumption while performing transmission and receiving.	Total transmit power and computational time
Ardakani et al. [18]	multicarrier NOMA (MC-NOMA) backscatter communication system	higher aggregate data rate	Computation difficulty	Average aggregate data rate
Abrardo et al. [19]	block coordinate descent (BCD) algorithm	better the performance of the algorithm because of the larger amount of diversity	Complex structure	Utility and complexity
Cejudo et al. [20]	quadrature amplitude modulation (QAM) schemes	Better sum-rate close to the performance of exhaustive search	Poor Latency and security	BER, IRA-DRS average channel gain ratio and sum rate
Hadi et al. [21]	auxiliary variables, alternate search method (ASM) and successive convex approximation (SCA) technique	Better efficiency	The number of users is low, the performance will decrease	Sum data rate
Banerjee et al. [22]	global optimal algorithm	Improved effectiveness	This algorithm is time consuming	Sum data rate, Average running time and cumulative distribution function (CDF)
Wang et al. [23]	SC and power allocation method	exhibits the best fairness performance and lowest loss rate	Challenging to save energy.	Jain's fairness index, Total throughput and SC loss rate

Problem statement: NOMA is considered as the major solution for the future generation for supporting large connectivity and high throughput. For utilizing the advantage of the NOMA system, the major challenge is how to optimally distribute the resources like channel and power to the user's for maximizing the performance of the system. During the last two decades, the multicarrier approaches are mainly utilized in broadband wireless communication because of their robust in resource allocation and sub-carrier allocation. The combination of NOMA in present wireless communication network makes various problems because of the intra cell interference, low signal strength and multipath transmission. Moreover, the exploitation of overall bandwidth by every users may be restrictive on the basis of the complexity. NOMA is integrated with OMA models for designing wireless communication models. The multi-carrier NOMA (MC-NOMA) makes the simultaneous exploitation of the sub-set of SCs from the sub-set of the users. Furthermore, it is essential to consider the effective power allocation model which can attain low complexity, coherent connectivity, and high transmission rate. Hence, this work presents an optimal subcarrier selection and power allocation model for maximizing the sum-rate in downlink NOMA system.

3. System Model

Let us assume the downlink NOMA system with a bandwidth (BW) B is transmitted over the base station (BS) into the subcarrier (SC) sets $s = \{1,...., S\}$ where S represents the total number of SCs. Consider the BS contains all the data about the channel state information (CSI). Based on the CSI of SC, the BS allocates the low complex SCs to all the users $u = \{1,...., U\}$ where U manipulates the total users utilized by the BS. The BS in the NOMA system allocates varying power levels to all the user based on NOMA principles. Here, the single subcarrier is allocated to different users and the data received to the user contains multiple subcarriers. While accessing with multiple users, high interferences are obtained due to the presence of user's subcarriers. To overcome this issue, each subcarriers are assigned to the dual users only and the number of users is considered as double of subcarriers $(U = 2S)$. Figure 1 represents the system model of the downlink NOMA system.

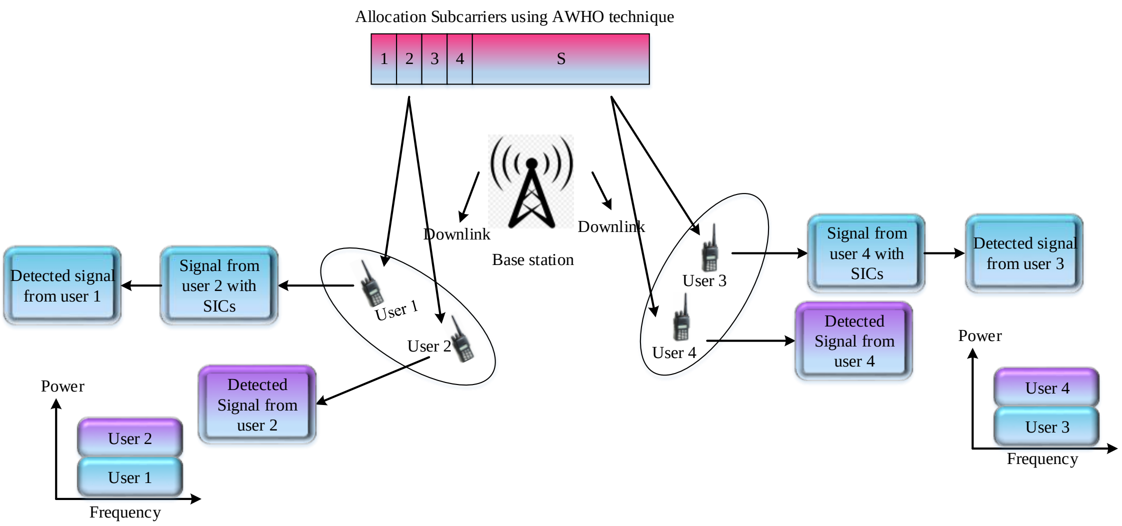


Figure 1. System model of the downlink NOMA system

With the subcarrier u, the signal is transmitted to the BS to all the paired users $x, y \in \{1,...., U\}$ and the transmitted signal can be mathematically represented as,

$$T_s = \sqrt{P_{s,x}}\, m_{s,x} + \sqrt{P_{s,y}}\, m_{s,y} \tag{1}$$

Here, $P_{s,x}$ and $P_{s,y}$ manipulates the allocated powers to users x and y that are combined on the similar subcarrier s. In addition to this, $m_{s,x}$ and $m_{s,y}$ signifies the data signal transmitted to users x and y on subcarrier s.

The user x with the obtained signal with the subcarrier s can be represented as,

$$k_{s,x} = H_{s,x} T_s + g_{s,x} \tag{2}$$

Here, $H_{s,x}$ contemplates the x^{th} user's channel gain from BS on subcarrier s , $g_{s,x}$ denotes the additive white Gaussian noise for the x^{th} user having zero mean and variance $\sigma^2 = n_0 \frac{B}{S}$ where n_0 signifies the spectral density of noise power, and B manipulates the BW.

In the receiver part, the decoding of self-interference cancellation (SIC) is computed with the use of channel gains. However, this decoding process can be done by arranging the channel gains in descending order with the help of noises present in the subcarriers. In subcarrier s , the channel gains are standardized using noise for user y which is lesser than the user x and it can be represented as, $\frac{|H_{s,x}|}{\sigma^2} > \frac{|H_{s,y}|}{\sigma^2}$. Finally, the signal from the y^{th} user $m_{s,y}$ are decoded using x^{th} user and then deduct $m_{s,y}$ from the received signal $m_{s,x}$ without receiving noises from the y^{th} user. However, the user y decodes the signal $m_{s,y}$ without cancelling the interference and proceed with the x^{th} user signal as the interference. For enhancing the NOMA performance, the paired users with lower channel gains are given high powers and for high channel gains low powers are allocated on the basis of $P_{s,x} < P_{s,y}$.

Assuming the transmitted BW per subcarrier to 1Hz, the energy efficiency (EE) of the downlink NOMA system can be mathematically formulated as,

$$EE_n = \frac{S_{R,u,s}}{P_t + P_c} \tag{3}$$

Here, $S_{R,u,s}$ manipulates the total sum rate and it can be represented as, $S_{R,s,u} = \sum_{s=1}^{S}\sum_{u=1}^{U} B \log_2 (1 + g_{s,u} P_{s,u})$ whereas, $g_{s,u}$ denotes the AWGN for the u^{th} user having zero and $P_{s,u}$ signifies transmitted power on SC s for user u . Also, P_t manipulates the transmitted power and it can be formulated as, $P_t = \sum_{s=1}^{S}\sum_{u=1}^{U_s} P_{s,u}$ and P_c contemplates user's circuit power consumption. The total system's EE can be formulated as, $EE = \sum_{n=1}^{N} EE_n$. The spectral efficiency (SE) is defined as the measure of usage of the entire resources and it can be formulated as,

$$SE_n = \frac{S_{R,s,u}}{B} = \frac{1}{B}\sum_{s=1}^{S}\sum_{u=1}^{U} \log_2 (1 + g_{s,u} P_{s,u}) \tag{4}$$

3.1 Problem Statement

Assume $(S \times U)$ as the SC allocation matrix to define the pairing relationship between SCs and users in the matrix Z where the binary element $z_{s,u}$ computes whether the SC s is assigned to user u and it can be mathematically formulated as,

$$Z = \begin{bmatrix} z_{1,1} & \ldots\ldots & z_{1,u} \\ \ldots\ldots & \ldots\ldots & \ldots\ldots \\ z_{s,1} & \ldots\ldots & z_{s,u} \end{bmatrix} \tag{5}$$

$$z_{s,u} = \begin{Bmatrix} 1, & whether\ u\ is\ allocated\ to\ s^{th}\ SC \\ 0, & none \end{Bmatrix} \tag{6}$$

In NOMA system, only paired users can split its SCs simultaneously and each user can receive the information from any one of the SC. Hence, the number of users will be double the number of SC to reduce the decoding of SIC at the receiver.

Normally, several constraints are considered as the optimization problem for effective SC and power allocation in the NOMA system. In this work, energy efficiency is considered as the objective function between the NOMA users per SCs to reduce the SICs under many constraints and it is stated below:

$$Q_1 = \max_{P_{s,u}, P_t} \sum_{n=1}^{N} EE_n \tag{7}$$

$$\begin{aligned} C_1 &= S_{R,u,s} \geq S_{R,u,s}^{\min}, s \in \{1,..., S\}, u \in \{1,...., U\} \\ C_2 &= \sum_{s=1}^{S} \sum_{u=1}^{U} P_{s,u} \leq 1 \\ C_3 &= P_{s,y} \leq P_{s,x}, y \leq x, y, x \in \{1,..., U\} \\ C_4 &= P_u \leq 0, P_{s,u} \in [0,1], \forall s, u \end{aligned} \tag{8}$$

Here, C_1 manipulates the minimum data rate requirement, C_2 depicts the transmission power constraints in the NOMA system, C_3 represents the user having poor channel and failure may arises while allocating power to the user, C_4 structural constraints for P_u , $P_{s,u}$.

Based on the objective function of maximum SE, the joint optimization problem can be represented as,

$$\max_{SE_n} = \frac{1}{B} \sum_{s=1}^{S} \sum_{u=1}^{U} \log_2 \left(1 + g_{s,u} P_{s,u}\right) \tag{9}$$

The constraints for the SE are given below:

$$\begin{aligned} C_1 &= \sum_{s=1}^{S} \sum_{u=1}^{U} H_{s,u} \leq P_{\max} \forall s, u \\ C_2 &= \sum_{s=1}^{S} \sum_{u=1}^{U} H_{s,u} \geq 0 \ \forall s, u \\ C_3 &= \sum_{s=1}^{S} \sum_{u=1}^{U} H_{s,u} \leq 1 \forall s, u \\ C_4 &= \sum_{s=1}^{S} \sum_{u=1}^{U} H_{s,u} \in [0,1] \end{aligned} \tag{10}$$

Here, C_1 indicates the maximum power allocation for every user, C_2 represents the power constraint for the BS in each channel, C_3 manipulates the data rate for every user, C_4 indicates the time taken by each channel for each user, C_5 represents the limit as [0,1].

4. Proposed Methodology

Non-Orthogonal Multiple Access (NOMA) is considered as one of the major multiple access for the 5G communication system and has the potential to enhance the system. The major aim of the work is to develop and design an energy efficient subcarrier and power allocation in NOMA model in an efficient way. The conventional subcarrier and power allocation model ensures better computational efficiency; but lacks in optimized power to the system.

This work focused on designing a joint energy and spectral efficient optimized multi-objective subcarrier and power allocation scheme (JESEOM-SPAC) in NOMA model. In this research, we have considered multi-objective functions such as throughput, sum rate, energy efficiency, and spectral efficiency for the subcarrier allocation scheme. There are many possible schemes for paired users to be allocated to different subcarriers, but the system performance is different in all schemes. For better sub carrier selection and power allocation, in this research the intelligent optimization model is proposed and it is named as adapted wild horse optimization (AWHO). In the experimental scenario, the performance measures of energy efficiency, spectral efficiency, outage probability, achievable sum rate and throughput are analyzed and compared with existing OMA models to prove the efficacy of the proposed NOMA based subcarrier allocation scheme.

4.1 Joint optimal SC and power allocation using AWHO technique

For optimal SC and power allocation, a novel adapted wild horse optimization (AWHO) technique is proposed in this study. For SC allocation, the user pairing of NOMA system works by multiplexing high channel gain user with low channel gain user. The obtained EE and SE by the high channel gain user manipulates the total SE and EE obtained per subcarrier. Hence, when the channel gain of the users gets increases then the system capacity also gets maximized. However, to maximize the channel gain difference between the paired users the SIC performance needs to be maximized. This can be performed by pairing high channel gain user with the low channel gain user. In NOMA system, the allocated powers and channel gains of the user are inverse in nature. Thus the power allocated to the high channel gain user gets reduced when the channel gain of the weak user gets reduced. Finally, the SE and EE of the strong user gets reduced and the system capacity also gets reduced. Based on the allocated power, the efficiency of the weak user gets maximized and this will not affect the strong user to reduce its capacity.

It is proved that the pairing of weak user with the strong user increases the SE, EE and system capacity. However, the interference within the paired users gets increased when the channel gain between the users gets reduced. Thus the computation complexity of the interference cancellation increased for each users at the receiver side. To overcome this issue, a novel AWHO technique is proposed to maximize the channel gain difference within the paired users so that the SE and EE performance gets increased.

The main objective of the proposed algorithm is to maximize SE and EE in which the total sum-rate gets maximized. The proposed AWHO algorithm separates the SC into two groups based on the standard deviation (SD) of the channel gains per SC. Normally, it is the measure of deviation among the channel gain of the users per SC. However, lower SD indicates that the user's channel gains are closer to the average of user's channel gain per SC and for greater SD, the user's channel gains remains separated all over the range. This proves that the value of SD must be higher to achieve maximum difference between the users channel gain. Thus, the subcarrier between the paired users remains efficient and capacity of the system gets improved.

The SCs are initially allocated to the users with lower SD in which the priority is given to the paired users with greater differences in the channel gains. Then, the SC are allocated with the users having greater SD values. In this stage, the SC are re-arranged to verify whether the selected first user shows higher channel gains. The steps involved in the proposed algorithm is depicted in detail below:

Initially, the SD is computed for each SC with respect to the user's channel gain and it can be mathematically formulated as,

$$SD_u = \sqrt{\frac{\sum_{u=1}^{U}\left(\left|H_{s,u}\right|^2 - \frac{\sum_{u=1}^{U}\left|H_{s,u}\right|^2}{U}\right)^2}{U-1}} \tag{11}$$

Then, calculate the threshold value which is similar to the average of SD for each SCs and it can be formulated as,

$$T = \frac{sum\ of\ SD\ for\ each\ SC}{number\ of\ SC} \tag{12}$$

After the calculation of threshold, separate the SC into two subsections. In the first section (F_1), the SC are allocated with SD less than or similar to the threshold value. In the second section (F_2), the SC are allocated based on SD values greater than the threshold value. The allocation of SC for the initial section have undergone four different stages.

Initially, the best channel gain for each SCs are calculated and then arrange the SCs based on greater best channel gain value to the lower best channel gain value. After arranging the SCs, user's channel gain are ordered in descending manner. Finally, the users with higher channel gain are paired with second lower channel gain user by eliminating paired selected users from the SC allocation process. This process is repeated till all the SC in the first group choose their paired users. The same operation is performed for the next group to allocate the SCs to all the selected paired users.

After allocating SCs to all the paired users, the BS transmits the power per SC to the paired users by splitting the SCs with the use of AHWO algorithm. In the AHWO technique, the power per SC s is determined for paired users with the use of channel gains. Initially, the number of users are optimally selected with the use of AWHO technique in which the users are allocated on the available SCs based on the power to achieve increased EE and SE. The effective SC are allocated with the maximum power to enable maximum SE and EE in the NOMA system. Assume U as the number of users that varies from $1\ to\ y$.

4.1.1 Fitness Evaluation

In the NOMA system, the allocation of power per SC to all the paired users are considered as the main fitness function for maximizing the EE and SE effectively. Here, solving the optimization problem and finding the global solution is more critical. To overcome this issue, the dependency of user and the power based on channel gain P_a are included in the fitness evaluation of the NOMA system. Then the EE term in equation (7) can be reformulated as,

$$EE_n = \frac{S_{R,u,s}}{P_t + P_c + P_a} \tag{13}$$

Here, P_a contemplates the dependency of user and the power based on channel gain. The parameter P_t can be mathematically represented as,

$$P_t = P_{\max} \sum_{s=1}^{S} \sum_{u=1}^{U_s} \alpha_{(s,u)q} \tag{14}$$

Here, $\alpha_{(s,u)q}$ manipulates the signal q and allocated power coefficient for user u on SC s. The relation between the powers allocated to the paired users can be mathematically formulated as,

$$P_a = \beta \left(\frac{q_{1,y} + q_{2,D}}{q_{1,1} + q_{2,1}} \right) P_{a,y} + (1-\beta) \left(\frac{q_{1,1} + q_{2,1} - q_{1,y} - q_{2,D}}{q_{1,1} + q_{2,1}} \right) P_{a,y} \tag{15}$$

Here, β manipulates the correlation factor, and D represents the data rate. In the adaptive algorithm, the power per SC s is given to the two paired users finally based on the channel gains hence $P_{s,x} = \beta_s . P_x$ and $P_{s,y} = (1-\beta_s).P_y$ where, β_s is between $(0 < \beta_s < 0.5)$ and it can be formulated as,

$$\beta_s = \frac{\left(|H_{s,x}|^2\right)^{-\lambda}}{\left(|H_{s,x}|^2\right)^{-\lambda} + \left(|H_{s,y}|^2\right)^{-\lambda}} \tag{16}$$

Here, λ is between $(0 < \lambda < 1)$ and it is the power decay distribution factor of AWHO algorithm. If $\lambda = 0$ then it is considered as equal powers are allocated to the paired users. When λ is increased, then the value of β_s, SE, EE and sum rate will be decreased. For users with lower channel gain are provided high powers by increasing λ and the SCs are kept constant for analyzing the performance of the proposed method. For simulation process λ is set to 0.2 to maximize the SE and EE by providing high and low powers to the low and high channel gain users respectively.

4.2 Algorithmic Procedure for proposed AWHO Technique

The adapted wild horse optimization (AWHO) algorithm comprises of three diverse vital stages namely initialization, exploration and exploitation. The proposed meta-heuristic algorithm avoids earlier convergence and reduces the number of iteration. Here, the initialization phase is given to both stallions and foals. Then dynamic weight approach is introduced to balance both exploitation and exploration thus the waterhole mechanism gets improved effectively.

4.2.1 Initialization

Initially, the wild horses are highly interested in chasing and running each other. With the use of this strategy, the random positions $Y_{G,j}^{i}$ of both foals and stallions are mathematically interpreted as,

$$Y_{G,j}^{i} = LB + (UB - LB) \times r \tag{17}$$

Here, LB contemplates the lower limit, UB manipulates the upper limit, r manipulates the random numbers and its value is less than 0.1.

4.2.2 Exploration phase (Dynamic weight approach (DWA))

Most of the foal's life is disbursed grazing near to its group and to simulate grazing phase, the stallion position is assumed in the center of grazing area. The below given formulation is utilized to enable other individuals to migrate.

$$\upsilon = \begin{cases} w_{\min} + (w_{\max} - w_{\min}) \times \dfrac{F_i(t) - F_{\min}(t)}{F_{avg}(t) - F_{\min}(t)}, if\ F_i(t) \le F_{avg}(t) \\ w_{\max} \qquad if\ F_i(t) > F_{avg}(t) \end{cases} \tag{18}$$

$$Y_{G,j}^{i} = 2M \cos(2\pi NM) \times \left(X - Y_{G,j}^{i}\right) + w \times X \tag{19}$$

From the above expression, $Y_{G,j}^{i}$ specifies the position of i^{th} group member and j^{th} horse, M represents an adaptive parameter and the random distribution is signified as N that ranges from -2 to 2. Also, $w_{\max}$ and $w_{\min}$ manipulates the maximum and minimum boundary values, $F_i(t)$ manipulates the fitness of the present horse at t^{th} iteration, $F_{avg}(t)$ manipulates the average fitness of horses and $F_{\min}(t)$ manipulates the minimum fitness of the population. The linearly decreasing parameter L_p can be mathematically formulated as,

$$L_p = 1 - \frac{t}{T} \tag{20}$$

Here, t represents the current iterations, and T contemplates the maximum iterations. One of the special horse behaviour on comparison with other animals is foal separation from their group over their mating. To simulate the mating behaviour of horses, the following expression is utilized.

$$\begin{gathered} Y_{G,q}^{p} = Crossover\left(Y_{G,j}^{s}, Y_{G,i}^{f}\right), i \ne j \ne q, s = f = end \\ Crossover = mean \end{gathered} \tag{21}$$

From the above expression, $Y_{G,q}^{p}$ denotes the horse position of p from group q that are generated by the horse positions q in group i and horse f in group j. In this algorithm, the crossover probability is assumed to constant and it is termed as CP

4.2.3 Exploitation phase (Competition for waterholes (COWH))

In this stage, the powers are found by two paired users simultaneously. Then there arises a competition between the NOMA users for the power and it can be mathematically formulated as,

$$Y_{G,j}^{i} = \upsilon - M \times \left(Y_{G,j}^{i} \times r_1 - Y_{G,j}^{i} \times r_2\right) \tag{22}$$

Here, r_1 and r_2 manipulates the random numbers between -1 to 1. With the use of COWH and DWA approach, the position gets again updated and it can be mathematically formulated as,

$$Y_{G,j}^{i} = \begin{cases} 2M \cos(2\pi NM) \times \left(\upsilon - Y_{G,j}^{i}\right) + \upsilon \times w \quad if\ r_3 > 0.5 \\ (\upsilon - M) \times \left(Y_{G,i}^{j} \times r_1 - Y_{G,j}^{i} \times r_2\right) \quad if\ r_3 \le 0.5 \end{cases} \tag{23}$$

Here, the water hole position is denoted as υ, r_1, r_2 and r_3 contemplates the random number, $Y_{G,i}^{j}$ manipulates the position of j^{th} group member and i^{th} horse. Thus, the equation (23) is used to maximize the SE and EE of the NOMA system that highly depends upon position of horses, crossover probability (CP), horse proportions (HP), upper-lower boundary values, and running probability (RRP). Algorithm 1 represents the pseudocode of the proposed Allocation process.

Algorithm 1: Pseudocode of the proposed Allocation process

Procedure of subcarrier allocation using AWHO algorithm

Start

Initialize the channel gain matrix $C = |H_{s,u}|^2 \; \forall s \in S$ SCs and $u \in U$ users

For $s = 1$ to S **do**

Calculate $SD_u = \sqrt{\dfrac{\sum_{u=1}^{U}\left(|H_{s,u}|^2 - \dfrac{\sum_{u=1}^{U}|H_{s,u}|^2}{U}\right)^2}{U-1}}$

Calculate $T = \dfrac{sum\ of\ SD\ for\ each\ SC}{number\ of\ SC}$

End for

Separate S SCs into two subsections

F_1 = SCs having $(SD \le T)$

F_2 = SCs having $(SD > T)$

Considering the SCs in F_1

For $s_1 = 1$ to S_1 i.e., $F_1 < S$ **do**

Choose the maximum channel gain for each s_1 SC: i.e., $C_{s1}^{\max} = |H_{s,u}|_{\max}^2$;

Arrange s_1 SC in descending order based on $C_{s1}^{\max}$;

End for

For arranged F_1 subcarrier **do**

Arrange users in descending order based on $|H_{s,u}|_{\max}^2$;

Group (Pair) the users of $|H_{s,u}|_{\max}^2$ with the second user i.e., $|H_{s,u}|_{\min}^2$ by removing two paired users from the allocation process;

Analyse the selected two paired users with the use of SCs s_1 from F_1 for not allocating SCs to that users.

End for

Perform subcarriers in F_2 **do**

For $s_2 = 1$ to F_2 i.e., $F_2 < S$ **do**

Choose the maximum channel gain for each s_2 SC: i.e., $C_{s2}^{\max} = |H_{s,u}|_{\max}^2$;

Arrange s_2 SC in descending order based on $C_{s2}^{\max}$;

End for

For arranged F_2 subcarrier do

Arrange the remaining unselected users in descending order based on $|H_{s,u}|_{\max}^2$

Group (Pair) the users of $\left|H_{s,u}\right|_{\max}^{2}$ with the second user i.e., $\left|H_{s,u}\right|_{\min}^{2}$ by removing two paired users from the allocation process

Analyse the selected two paired users with the use of SCs s_2 from F_2 for not allocating SCs to that users.

End for

Procedure of power allocation using AWHO technique

Start

Initialize the number of paired users x and y along with its subcarrier s, other parameters like PC, HP, upper-lower boundary values, and random initializations present in the optimizer

Set the maximum iteration T;

For paired users

Select powers to be allocated;

While $(t \le T)$

Evaluate L_p using equation (19);

End for

For the number of paired users

For the powers to be allocated to the users

If $r > RRP$

If $r > 0.5$

Update the position of the horse using equation (21);

Else

Obtain the horse position using equation (18);

End if

Else

Obtain the horse position using equation (16);

End if

If the SE and EE is maximized with the allocated power

Replace the location of horse using equation (18);

End if

End for

$t = t + 1$

End while

Return the best outcome obtained by AWHO

End

5. Results and Discussion

The proposed method is implemented in MATLAB platform and different measures like SE, EE, fairness index, outage probability, sum-rate and throughput by varying SNR are analyzed. Also, some of the existing techniques like orthogonal multiple access (OMA), random pairing (RP), traditional far-near pairing (TFNP), and user pairing (UP) [24] are compared and analyzed with the proposed study. The work is processed with Intel® core ™ i5-4570S CPU with 2.90GHz processor. The RAM is about 8GB with a 64-bit operating system and for displaying, no pen or paper is utilized. Table 1 contemplates the system and algorithmic parameters of the proposed method.

Table 1. System and algorithmic parameters of the proposed method

System parameters	Value
Bandwidth	10MHz
Total NOMA users	128
Number of subcarriers	64
Carrier frequency	120GHz
SNR	30dB
Modulation order	2
Algorithmic parameters	

Total populations	100
Horse probability	0.2
Crossover probability	0.13
Random running probability	0.1
Maximum iteration	100

5.1 Performance Metrics

The spectral efficiency (SE) can be defined as the ratio of total sum rate to the total amount of BW consumed for signal transmission and it can be derived as,

$$SE = \frac{Total\ \ sum - rate}{BW\ \ consumed} \tag{24}$$

The energy efficiency (EE) is defined as the ratio of total sum rate of the system to the total power consumed by the system and it can be represented as,

$$EE = \frac{Total\ \ sum - rate}{total\ \ power\ \ consumed} \tag{25}$$

Sum rate is used to analyze the SIC performance for the downlink NOMA systems and it can be formulated as,

$$S_{R,s,u} = \sum_{s=1}^{S} \sum_{u=1}^{U} B \log_2 \left(1 + g_{s,u} P_{s,u}\right) \tag{26}$$

Here, $g_{s,u}$ denotes the AWGN for the u^{th} user and $P_{s,u}$ signifies transmitted power on SC s for user u .

Throughput is defined as the total SCs and power allocated within the specific time period. It is expressed as,

$$Throughput = \frac{Total\ \ SCs\ \ and\ \ power\ \ allocated\ \ to\ \ the\ \ NOMA\ \ users}{Time\ \ period} \tag{27}$$

Fairness index (FI) is a metric works with the use of Jain's fairness index and it can be mathematically formulated as,

$$FI = \frac{\left(\sum_{u=1}^{U} R_u\right)^2}{U \sum_{u=1}^{U} \left(R_u\right)^2} \tag{28}$$

Here, R_u indicates the sum-rate of the user u .

5.2 Performance analysis of the proposed over the existing studies

In this section, the performance obtained by the proposed study is analyzed via graphical illustration. Some of the metrics like sum rate, throughput, SE, and EE are analyzed by varying SNR under varying subcarriers and users. Also, some of the existing studies have been undertaken to prove the efficiency of the proposed method.

Figure 2 contemplates the SE, EE and fairness index of the proposed method by varying number of SCs and users. By analyzing the SE, EE and FI performance, totally 128 users and 64 subcarriers are considered by varying the SNR values respectively. In Figure (2a), the SE performance is analyzed for the proposed method by varying the number of SCs and users. For SNR=30dB, the proposed method obtains the SE of 14.16bps/Hz on 16 SCs and 32 users respectively. For 32 SCs and 64 users, the proposed method obtains the SE of 15.23bps/Hz. For 64 SCs and 128 users, the proposed method obtains the value of 15.76bps/Hz. In Figure (2b), the EE analysis is performed for the proposed method by varying the number of users and SCs. For SNR=30dB, the proposed method obtains the EE of 14.16bps/Hz on 16 SCs and 32 users respectively. For 32 SCs and 64 users, the proposed method obtains the EE of 15.30bps/Hz. For 64 SCs and 128 users, the proposed method obtains the EE of 20.95bps/Hz. In Figure (2c), the FI analysis is performed for the proposed method by varying the number of users and SCs. For SNR=30dB, the proposed method obtains the FI of 0.93 on 16 SCs and 32 users respectively. For 32 SCs and 64 users, the proposed method obtains FI of 0.94. For 64 SCs and 128 users, the proposed method obtains the FI of 0.955.

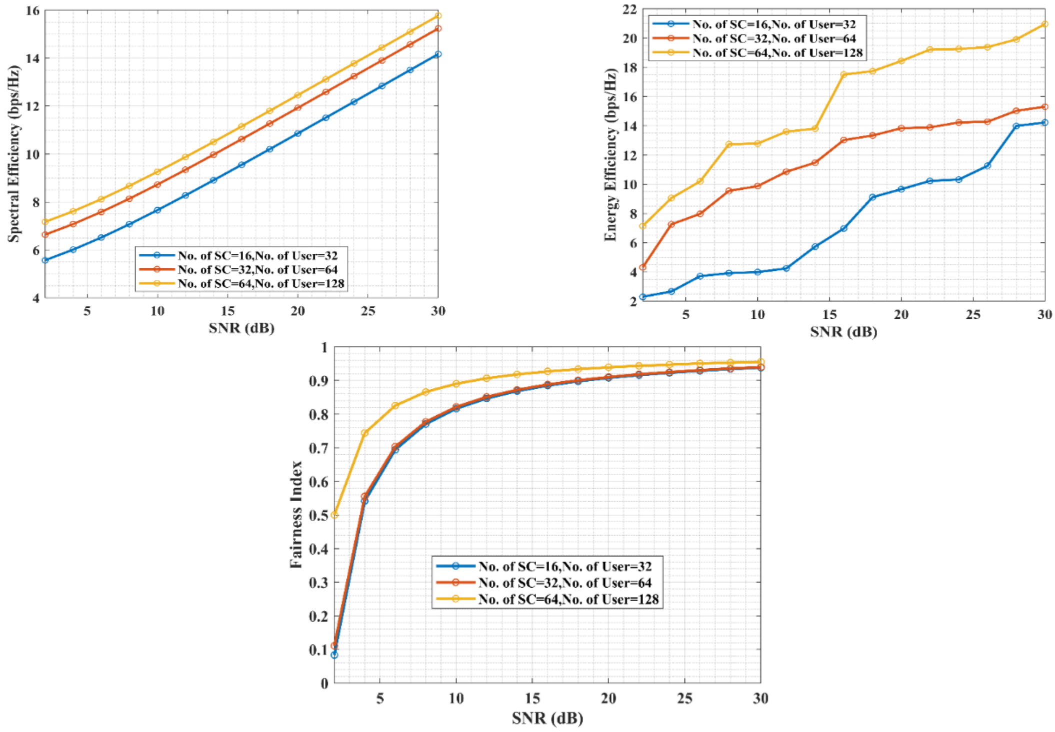
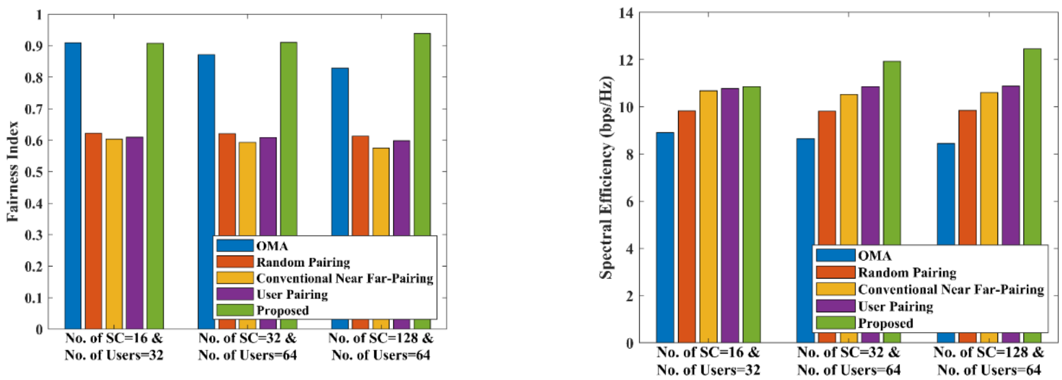


Figure 2. SE, EE and FI of the proposed method by varying number of SCs and users, (a) SE analysis, (b) EE analysis, and (c) FI analysis



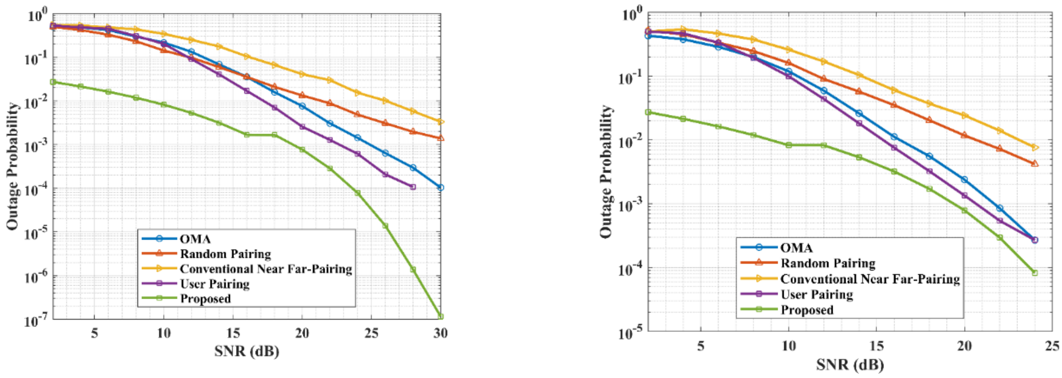
(a) (b)

Figure 3. Fairness index (FI) and SE of the proposed method over existing techniques, (a) FI for SNR=20dB, and (b) SE for SNR=20dB

Figure 3 illustrates the FI and SE of the proposed method over existing techniques. Figure (3a) and (3b) illustrates the FI for SNR=20dB, and SE for SNR=20dB respectively. In Figure (3a), it is noted that the FI performance gets increased more than the existing techniques. In the existing RP technique the SCs are allocated to all the users randomly without any user preferences. This may causes failure in SIC decoding and interference within the channel gets increased. The proposed method considers the SC allocation for the paired users based on strong user channel gain with the low channel gain user. The proposed NOMA system accurately allocates the power to the available BW per SC uniformly between the paired users and utilizes total power of the SC. For SNR=20db, the existing OMA, RP, TFNP, UP and proposed NOMA obtains the FI of 0.9, 0.62, 0.60, 0.61 and 0.90 on 16 SCs and 32 users respectively. For SNR=20db, the existing OMA, RP, TFNP, UP and proposed NOMA obtains the FI of 0.87, 0.62, 0.59, 0.60 and 0.91 on 32 SCs and 64 users respectively. For SNR=20db, the existing

OMA, RP, TFNP, UP and proposed NOMA obtains the FI of 0.82, 0.61, 0.57, 0.59 and 0.93 on 128 SCs and 64 users respectively.

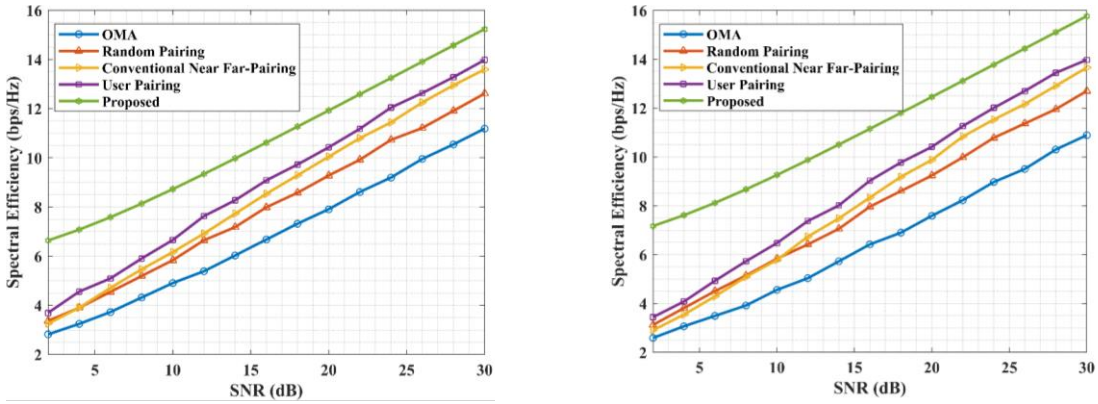
From the figure (3b), it is clear the proposed method obtains higher SE compared to traditional techniques. The performance measures are taken by varying SCs and users. In addition to this, the SE gets reduced with increase in SCs for all the techniques due to high competition over the users. For SNR=20db, the existing OMA, RP, TFNP, UP and proposed NOMA obtains the SE of 8.9bps/Hz, 9.82bps/Hz, 10.68bps/Hz, 10.78bps/Hz and 10.85bps/Hz on 16 SCs and 32 users respectively. For SNR=20db, the existing OMA, RP, TFNP, UP and proposed NOMA obtains the SE of 8.6bps/Hz, 9.8bps/Hz, 10.52bps/Hz, 10.88bps/Hz and 11.85bps/Hz on 32 SCs and 64 users respectively. For SNR=20db, the existing OMA, RP, TFNP, UP and proposed NOMA obtains the SE of 8.45bps/Hz, 9.8bps/Hz, 10.6bps/Hz, 10.87bps/Hz and 12.45bps/Hz on 128 SCs and 64 users respectively.



(a) (b)

Figure 4. Outage probability (OP) of the proposed method over existing techniques, (a) OP for 64 subcarriers and 32 users, (b) OP for 32 subcarriers and 16 users.

Figure 4 contemplates the OP of the proposed method over existing techniques. Figure (4a), and (4b) OP for 64 subcarriers and 32 users and for 32 subcarriers and 16 users respectively. The OP is determined as the probability of the user's data transmission rate must be less than the considered data rate of 1bps/Hz. The proposed method is better when the OP is lower and it is efficient compared to existing techniques. The data rate can be enhanced by pairing the strong channel gain user with the second lowest channel gain user or any random paired users. For SNR=24dB, the existing OMA, RP, TFNP, UP and proposed NOMA obtains the OP of 0.0003, 0.0041, 0.007, 0.0002 and 8.29E-5 for 32 SCs and 16 users respectively. For SNR=30dB, the existing OMA, RP, TFNP, UP and proposed NOMA obtains the OP of 0.00014, 0.0014, 0.003, 0, 0E-0 for 64 SCs and 32 users respectively.



(a) (b)

Figure 5. SE of the proposed method over existing techniques, (a) SE for 32 subcarriers and 64 users, (b) SE for 64 subcarriers and 128 users.

Figure 5 represents the SE of the proposed method over existing techniques. Figure (5a), and (5b) represents the SE for 32 subcarriers and 64 users and SE for 64 subcarriers and 128 users. Form the graphical illustration, it is clear that the proposed method increases its SE with increase in SNR compared to the existing techniques. The proposed algorithms gives greater priority to the SCs that having maximum channel gain than the lower channel gain. Moreover, it is paired with users having strong channel gain and the users having second lowest channel gain. However, the proposed system does not consider the paring of user with lowest channel gain that reduces the sum rate performance. For SNR=30dB, the existing OMA, RP, TFNP, UP and proposed NOMA obtains the SE of 11.18bps/Hz, 12.61bps/Hz, 13.59bps/Hz, 13.9bps/Hz and 15.23bps/Hz for 32 SCs and 64 users respectively. For SNR=30dB, the existing OMA, RP, TFNP, UP and proposed NOMA obtains the SE of 10.89bps/Hz, 12.7bps/Hz, 13.65bps/Hz, 13.97bps/Hz and 15.76bps/Hz for 64 SCs and 128 users respectively.

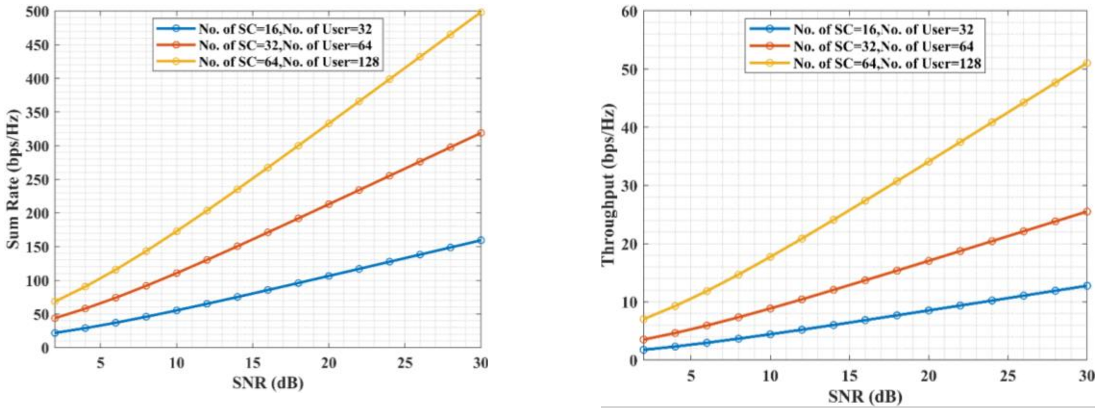


Figure 6. Sum rate and throughput of the proposed method by varying number of SCs and users, (a) Sum rate analysis, (b) Throughput analysis

Figure manipulates the sum rate and throughput of the proposed method by varying number of SCs and users. The sum rate and throughput performances are analyzed for the proposed method under varying users and SCs. It is noted that the sum rate and throughput for 64 SCs and 128 users are increased more compared other considered users in the graphical illustration. For SNR=30db, the proposed technique obtains the sum rate of 159.475bps/Hz on 16 SCs and 32 users. By considering the throughput analysis, proposed technique obtains the sum rate of 12.75 on 16 SCs and 32 users. For SNR=30db, the proposed technique obtains the sum rate of 318.95bps/Hz on 32 SCs and 64 users. By considering the throughput analysis, proposed technique obtains the value of 25.51 on 32 SCs and 64 users. For SNR=30db, the proposed technique obtains the sum rate of 498.36bps/Hz on 64 SCs and 128 users. By considering the throughput analysis, proposed technique obtains the value of 51.03 on 64 SCs and 128 users.

6. Conclusion

The proposed study introduced a novel optimization technique for performing joint SC and power allocation in downlink NOMA system. In this research, a novel AWHO based optimization technique is proposed to allocate subcarriers and powers to all the available users in the NOMA system. With the use of this algorithm, the SE and EE of the system gets maximized and proved effective performance in allocation process. The proposed method is implemented in python platform and different metrics like SE, EE, sum rate, throughput and fairness index are analyzed and compared with existing studies. The proposed method obtains the SE of 15.76bps/Hz, EE of 20.95bps/Hz, throughput of 51.03, sum rate of 498.36bps/Hz, and FI of 0.955. The proposed method have multiple advantages like maximizing the fairness among the NOMA users and shows enhanced SE performance capable of supporting 5G networks effectively. Despite this, the proposed system processed with only subcarrier and power allocation in the NOMA system. In future, the study will be extended further for allocating several resources for enhancing the EE and SE performance in the NOMA system.

Reference

[1] He C, Hu Y, Chen Y and Zeng B (2019) Joint power allocation and channel assignment for NOMA with deep reinforcement learning. IEEE Journal on Selected Areas in Communications vol. 37, no.10, pp.2200-2210.
[2] Salaün L, Chen CS and Coupechoux M (2018) Optimal joint subcarrier and power allocation in NOMA is strongly NP-hard. In 2018 IEEE International Conference on Communications (ICC) pp. 1-7. IEEE.
[3] Kanaga Suba Raja S and Bamila Virgin Louis A (2021) Optimal resource allocation in 5G system using modified lion algorithm. IET Communications, vol. 15, no. 1, pp.126-141.
[4] Khan WU, Yu Z, Yu S, Sidhu GAS and Liu J (2019) Efficient power allocation in downlink multi-cell multi-user NOMA networks. IET Communications vol. 13, no. 4, pp.396-402.

[5] Islam SR, Avazov N, Dobre OA and Kwak KS (2016) Power-domain non-orthogonal multiple access (NOMA) in 5G systems: Potentials and challenges. IEEE Communications Surveys & Tutorials, vol. 19, no. 2, pp.721-742.
[6] Cai W, Chen C, Bai L, Jin Y and Choi J (2017) Subcarrier and power allocation scheme for downlink OFDM-NOMA systems. IET Signal Processing vol. 11, no. 1, pp.51-58.
[7] Khan WU, Liu J, Jameel F, Sharma V, Jäntti R and Han Z (2020) Spectral efficiency optimization for next generation NOMA-enabled IoT networks. IEEE Transactions on Vehicular Technology, vol. 69, no. 12, pp.15284-15297.
[8] Song X, Dong L, Wang J, Qin L and Han X (2019) Energy efficient power allocation for downlink NOMA heterogeneous networks with imperfect CSI. IEEE Access, vol. 7, pp.39329-39340.
[9] Long K, Wang P, Li W and Chen D (2019) Spectrum resource and power allocation with adaptive proportional fair user pairing for NOMA systems. IEEE Access, vol. 7, pp.80043-80057.
[10] Timotheou S and Krikidis I (2015) Fairness for non-orthogonal multiple access in 5G systems. IEEE signal processing letters vol. 22, no. 10, pp. 1647-1651.
[11] Zhang H, Yang N, Long K, Pan M, Karagiannidis GK and Leung VC (2018) Secure communications in NOMA system: Subcarrier assignment and power allocation. IEEE Journal on Selected Areas in Communications, vol .36, no. 7, pp.1441-1452.
[12] Salaün L, Coupechoux M and Chen CS (2020) Joint subcarrier and power allocation in NOMA: Optimal and approximate algorithms. IEEE Transactions on Signal Processing vol. 68, pp.2215-2230.
[13] Wang G, Shao Y, Chen LK and Zhao J (2021) Subcarrier and power allocation in OFDM-NOMA VLC systems. IEEE Photonics Technology Letters, vol. 33, no. 4, pp.189-192.
[14] Wang Q and Zhao F (2019) Joint spectrum and power allocation for NOMA enhanced relaying networks. IEEE Access, vol. 7, pp.27008-27016.
[15] Xu W, Li X, Lee CH, Pan M and Feng Z (2017) Joint sensing duration adaptation, user matching, and power allocation for cognitive OFDM-NOMA systems. IEEE Transactions on Wireless Communications, vol. 17, no. 2, pp.1269-1282.
[16] Ali MS, Tabassum H, and Hossain E (2016) Dynamic user clustering and power allocation for uplink and downlink non-orthogonal multiple access (NOMA) systems. IEEE access vol. 4, pp.6325-6343.
[17] Alhusseini M, Azmi P, Mokari N (2019) Optimal joint subcarrier and power allocation for MISO-NOMA satellite networks. Physical Communication vol. 32, pp. 50-61.
[18] Ardakani FD, Wong VW. Joint reflection coefficient selection and subcarrier allocation for backscatter systems with NOMA. In2020 IEEE Wireless Communications and Networking Conference (WCNC) 2020 May 25 (pp. 1-6). IEEE.
[19] Abrardo A, Moretti M, Saggese F (2020) Power and subcarrier allocation in 5G NOMA-FD systems. IEEE Transactions on Wireless Communications vol. 19, no. 12, pp. 8246-60.
[20] Cejudo EC, Zhu H, Wang J (2021) Resource allocation in multicarrier NOMA systems based on optimal channel gain ratios. IEEE Transactions on Wireless Communications vol. 21, no. 1, pp. 635-50.
[21] Hadi M, Ghazizadeh R (2021) Joint sub-carrier allocation and 3D beamforming design in OMA-NOMA based mmWave heterogeneous networks under channel uncertainties. AEU-International Journal of Electronics and Communications vol. 137, pp. 153809.
[22] Banerjee S, Chen CS, Coupechoux M, Sinha A (2022) Joint power and subcarrier allocation in multi-cell multi-carrier NOMA. In2022 Thirteenth International Conference on Ubiquitous and Future Networks (ICUFN) pp. 180-185. IEEE.
[23] Wang G, Shao Y, Chen LK, Zhao J (2021) Subcarrier and power allocation in OFDM-NOMA VLC systems. IEEE Photonics Technology Letters vol. 33(4), pp. 189-92.
[24] Abd-Elnaby M, Sedhom GG, Messiha NW, Elwekeil M (2021) Efficient user pairing algorithm for enhancement of spectral efficiency and interference cancelation in downlink NOMA system. Wireless Networks vol. 27, pp. 1035-47.

Authors Profile

Dr.M.Saranya Nair, Assistant Professor Senior Grade in the School of Electronics Engineering, VIT University Chennai Campus has 12 years of teaching experience including research experience in Wireless Sensor Networks, Cellular Networks, Underwater Networks, and IoT in Healthcare. She has completed B.E. in Electronics and Communication Engineering from Anna University in 2008, M.E in Communication and Networking from Anna University, Chennai in 2010 and Ph.D. in Electronics Engineering from VIT - Chennai in 2020. During Ph.D., she has proposed an efficient time synchronization algorithm for underwater acoustic wireless sensor networks. Her areas of specialization are Wireless Sensor Networks – Applications & Protocol Design, Underwater Acoustic Wireless Sensor Networks, IoT in Healthcare & Industry 4.0, Cellular Networks – Energy Optimization in 5G and Beyond, Energy Harvesting and Management. She has published more than 15 research publications in reputed journals and contributed for more than 5 books in Springer, Elsevier and Wiley, etc.