TELKOMNIKA Telecommunication, Computing, Electronics and Control
Vol. 19, No. 6, December 2021, pp. 1803~1810
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v19i6.18580

5G NOMA user grouping using discrete particle swarm optimization approach

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Article Info

Article history:

Received Nov 15, 2020
Revised May 19, 2021
Accepted May 27, 2021

Keywords:

Discrete
Multiple access
Non-orthogonal
Particle swarm optimization
User grouping

ABSTRACT

Non-orthogonal multiple access (NOMA) technology meets the increasing demand for high-seed cellular networks such as 5G by offering more users to be accommodated at once in accessing the cellular and wireless network. Moreover, the current demand of cellular networks for enhanced user fairness, greater spectrum efficiency and improved sum capacity further increase the need for NOMA improvement. However, the incurred interference in implementing NOMA user grouping constitutes one of the major barriers in achieving high throughput in NOMA systems. Therefore, this paper presents a computationally lower user grouping approach based on discrete particle swarm intelligence in finding the best user-pairing for 5G NOMA networks and beyond. A discrete particle swarm optimization (DPSO) algorithm is designed and proposed as a promising scheme in performing the user-grouping mechanism. The performance of this proposed approach is measured and demonstrated to have comparable result against the existing state-of-the art approach.

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1. INTRODUCTION

Future 5G mobile networks are expected to have high radio demands in terms of connectivity, data rates, capacity and bandwidth. The non-orthogonal multiple access (NOMA) system [1]–[5], which is one of the promising candidates to further enhance the 5G network technology by allowing multiple users to share the same frequency subcarrier [6]. Recent studies [7], [8] in investigating and improving 5G NOMA systems have shown that NOMA is effective in utilizing the radio bandwidth more efficiently by allowing bandwidth sharing amongst the users. Not only does it improve the bandwidth efficiency, but this approach also increases the achievable sum capacity.

The computational complexity tends to level up in selecting and grouping the best users when the total number of users in the NOMA system increases since the demand for data connection keeps increasing nowadays. Therefore, the NOMA user-grouping model proposed in this paper is designed and implemented based on the swarm intelligence approach in order to lower the computational complexity as well as to improve the spectral efficiency and the achievable throughput after selecting and grouping the users. NOMA is one of the techniques that fulfil the future radio systems demand by allowing users to simultaneously access the same radio bandwidth and at the same time improving the sum capacity. NOMA has been demonstrated to increase the total number of user connections for massive machine type communication (mMTC) and ultra reliable and low latency communication (URLLC) [9] to five and nine times of respectively [10]. In NOMA, the spectral efficiency is also optimized because the users are assigned with the same frequency subcarrier to efficiently utilize the available bandwidth.

By permitting multiple users sharing the same bandwidth, NOMA systems will optimize the spectral efficiency as more users are accessing the wireless network at once. To reduce the interference that exists between the users sharing the same frequency subcarrier, the successive interference cancellation (SIC) approach is carried out in NOMA [11]–[15]. However, as the number of users accessing the cellular network [16]–[18] increases, the computational complexity of the NOMA system will increase especially when performing the user grouping. Choosing the users are essential to ensure that the sum capacity that can be offered to the users in the cellular network is maximized while maintaining or possibly improving the achievable throughput in NOMA.

Different from orthogonal multiple access (OMA) systems, where the users are separated orthogonally with different bandwidth, a user in NOMA will be allowed to share the same frequency subcarrier allowing a user with a relatively poorer channel condition to share the bandwidth with a user with a better channel condition. In OMA however, a user who possesses a good channel condition will be prioritized first while the user in a bad channel condition must wait to be served by the base station. As a result, the users in OMA will experience the fairness problem, causing higher latency for them to access the wireless network. On the other hand, these problems will be improved in NOMA, which will provide improved user fairness [19], as NOMA serves the users in pairs or groups.

The key design aspect of NOMA are power allocation and user pairing [20]. A study carried out in [20] has proposed a new user grouping scheme for NOMA. The proposed scheme, which is known as power fixed fairness allocation (PFFP) has been demonstrated to reduce the computational load by seven times lower than the exhaustive search (ES) scheme, which considers all possible options. This shows that user scheduling implemented in NOMA system is important in selecting the users to reduce the interference experienced by the sharing users. However, the total number of users considered is relatively small. As the demand for Internet and data connection keeps growing, the total number of users is expected to increase, rendering a larger computational load to perform the user grouping mechanism.

Therefore, in response to this problem, a novel user scheduling scheme is proposed in this paper to be implemented in a 5G NOMA system model by using the discrete particle swarm optimization (DPSO) [21], [22] approach. Swarm intelligence [23]–[27] is a well-established optimization scheme in a wide variety of applications including image and signal processing as well as wireless and cellular communication. However, most of the previous existing schemes in swarm intelligence implementation for cellular communication revolves around power allocation due to the continuous nature of swarm intelligence formulation. Since user grouping is discrete in nature, a DPSO algorithm is designed and implemented in this paper. A concise study is carried out by analysing and improving the performance of DPSO together with other existing schemes.

2. 5G NOMA NETWORK WITH DPSO USER GROUPING

Consider a high-speed cellular network adopted with NOMA, having one cell located at the central of the network consisting of three sectors, where each of the sectors is denoted as $S_{i,j}$ with i as the number of cells, $i \in [1, N_{sites}]$ and j as the sector number, $j \in [1, 3]$. Assuming that this single cell is utilized fully by all the users who have the similar amount of accessible bandwidth at all sectors and cells. The first sector, $S_{1,1}$ will be chosen to analyse the proposed approach. Then, under this first sector as the reference, a number of users, N_{ue} will be allocated in each of a total of N_g groups. Each of the users in this first sector will be grouped to be distributed with one of N_{r_b} resource blocks.

The average amount of power received P_{j,i,u,r_b} over resource block, r_b for user u at sector j and cell i is shown in (1). A resource block, r_b, is allocated to a user u with an average transmitted power, $P_u = \alpha_u P_t$ where α_u is the power ratio from a total power P_t. The path gain and the fading shadow between cell i and user u is represented as $G_{path}(i,u)$ and $c_{u,i}$ respectively. Another gain parameter, $G_{antenna}(j,i,u)$ represents the antenna gain [28] of user u at each sector, while f_{j,i,u,r_b} is the fast fading function in small scale correspondingly. Therefore, the average received power P_{j,i,u,r_b} can be written as;

$$P_{j,i,u,r_b} = P_u G_{path}(i,u) c_{u,i} G_{antenna}(j,i,u) f_{j,i,u,r_b} \quad (1)$$

3. THE RESEARCH METHOD

The research methodology applied in this paper can be divided into three major steps. The first step is to measure the signal to interference plus noise ratio (SINR) of each individual user before selecting the users to be grouped in each group. The second step is to formulate the user grouping mechanism based on the discrete particle swarm optimization approach. This is carried out based on the pre-measured SINR values in the first step for each user and the NOMA system model for 5G networks is considered. Finally, the last step is to perform the interference cancellation mechanism, by using the SIC approach, in each group to ensure that each user in each group can be detected, hence optimizing the achievable overall throughput and bandwidth efficiency.

The implementation of NOMA is primarily about pairing or grouping two users under the same resource block r_b. To achieve performance enhancement especially the throughput, SIC is exercised in NOMA to reduce the interference between the sharing users. In this case, SIC is performed by first measuring the SINR of the selected users, namely u_1 and u_2. In the next subsection, the first step which is the measurement of the SINR of each individual user will be presented.

3.1. SINR measurement of each individual user

In this beginning step, the SINR is measured independently without considering the interference caused the other user who is allocated with the same frequency subcarrier. This is similar to the ordinary orthogonal multiple access (OMA) approach, except that it is carried out to determine who is the first and the second user for optimizing the SIC operation and throughput improvement. By ignoring the noise expression, which is assumed to be much smaller than the total interference experienced by each user, the SINR $\gamma_{u_1,r_b}^{1,1}$ for a user u in cell 1 and sector 1, before NOMA user grouping and SIC operation, is expressed as follows:

$$\gamma_{u,r_b}^{1,1} = \frac{P_{1,1,u,r_b}}{\sum_{i=1}^{N\_sites}\sum_{j=2}^{3} P_{i,j,u,r_b}}. \tag{1}$$

In the next subsection, the NOMA user grouping mechanism based on the formulated discrete particle swarm optimization approach will be described.

3.2. NOMA user grouping based on DPSO approach

The main objective in this step is to group the users in each group based on the pre-measured SINR values in the previous step. Each group will be allocated with one resource block r_b which will be then shared by the users selected to be in the group. In this paper, the number of users per group is chosen to be two, which is the default number of users per group in NOMA.

The order of the two users is determined such that the independent or OMA SNIR values of both users are $\gamma_{u_2,r_b}^{1,1} > \gamma_{u_1,r_b}^{1,1}$, where $P_{u_1} = \alpha_1 P_t$ and $P_{u_2} = \alpha_2 P_t$ with $\alpha_1 + \alpha_2 = 1$. The SINR of the second user is chosen higher because it will be detected first before the first user, hence requiring a better SINR value to increase the probability of detecting the signal of the second user successfully. Once it is detected, SIC will be performed to remove the information of the second user, which is considered as the interference for the first user, before detecting the signal of the first user. Hence the SINR of the second user of a NOMA system can be expressed as follows;

$$\gamma_{u_2,r_b}^{1,1}(u_2) = \frac{P_{1,1,u_2,r_b}}{\sum_{i=1}^{N_{sites}}\sum_{j=2}^{3} P_{i,j,u_2,r_b}}, \tag{2}$$

and the SINR of the first user is represented in (4) as follows;

$$\gamma_{u_1,r_b}^{1,1}(u_1) = \frac{P_{1,1,u_1,r_b}}{\sum_{i=1}^{N\_sites}\sum_{j=2}^{3} P_{i,j,u_1,r_b} - P_{1,1,u_2,r_b}}. \tag{3}$$

In this paper, maximizing the attainable throughput

$$R_{T,s,c} = f(u_1, \cdots, u_{N_{ug}}), \tag{5}$$

in bits per second over a bandwith of $2W$ Hz for cell c and sector s will be configured as the objective or the fitness function, as follows;

$$f(u_1, \cdots, u_{N_{ug}}) = 2W \sum_{n=1}^{N_{ug}} \log_2 \gamma_{u_n,r_b}^{s,c}(u_n). \tag{6}$$

The proposed DPSO scheme is designed to determine the user grouping in a 5G NOMA network. To begin the algorithm, the swarm population is configured to represent all possible combinations of users in a 5G NOMA network. The size of the population is denoted as n and the number of particles in each population is m. To update the velocity and distance of each particle based on a particle swarm optimization approach, a number of parameters are initialized which include the inertia weight, w, and the acceleration factors, c_1, c_2.

However, as the main output of this algorithm is discrete in nature, a discrete particle swarm optimization algorithm or DPSO has to be designed such that the user grouping, which is indicated as user indices and hence in discrete form, can be produced as given below:

The proposed DPSO Algorithm

The input parameters:

- Number of particles, M
- Population size, S
- Inertia weight, w
- Acceleration factor, c_1, c_2
- Maximum number of iterations, N

The output parameters:

- The user indices (the global best) in each group, g_b
- The fitness function value, $f(g_b)$

The pseudocode:

```
Initialize the general best g_b
Initialize the maximum iteration, N
Initialize the population size, S, and the number of particles per population, M
Initialize the distances x_t(i,j) for ∀ i = 1,2,⋯,S and j = 1,2,⋯,M
for t = 1:N
   for i = 1:S
```

$$x_{d,t}(i,j) = \underset{j}{\text{sortindex}}\, x_t(i,j) \tag{7}$$

$$p_b = \arg\max_{x_t(i,j)} f\left(x_{d,t}(i,j)\right) \tag{8}$$

$$\text{if}\ f(p_b) > f(g_b) \tag{9}$$

$$g_b = p_b \tag{10}$$

```
      end
      for j = 1:M
```

$$v_t(i,j) = wv_{t-1}(i,j) + c_1 r_{1,t}\left(p_b - x_{t-1}(i,j)\right) + c_2 r_{2,t}\left(g_b - x_{t-1}(i,j)\right) \tag{11}$$

$$x_t(i,j) = x_{t-1}(i,j) + v_t(i,j) \tag{12}$$

```
      end
   end
end
```

As seen in the given pseudocode, the proposed DPSO algorithm begins with initializing a random swarm population, $x_t(i,j)$, and the global best user grouping, g_b, which is randomly configured. In addition, the maximum iteration, the population size and the number of particles are also initialized.

In (7), a function called sortindex is applied to sort the particles indices or positions based on the distance values which have been randomly initialized. This scheme will render integers $x_{d,t}(i,j)$ representing the particles' indices. Using these integer numbers as the input, the fitness function $f(x)$, as given in (6), is calculated to determine the fitness value. The set of particles having the maximum fitness value in population i will be chosen as the current best, p_b, as indicated in (8). Then the fitness value of the current best, $f(p_b)$, is compared against the fitness value of the global best, $f(g_b)$, as shown in (9). If the current best value is larger than the global best value, then the global best value will be updated according to have the current best value, as shown in (10).

The next step is to update the two particle swarm optimization equations, which are the velocity and the distance, as given in (11) and (12) respectively. Two random values, $r_{1,t}$ and $r_{2,t}$, are generated to calculate (11). The algorithm is then repeated for all iterations and particles in all populations until the stopping criterion or the maximum iteration is met. When the users for each group have been identified, the users will then be allocated with the corresponding resource block. Now, the NOMA system is ready to allow the signal transmission and reception for all users, provided that the SIC operation is in place, as will be further explained in the next subsection.

3.3. SIC operation

The SIC operation, although appears to be straightforward, is essential in ensuring that the throughput and bandwidth efficiency improvements are realized in the NOMA 5G networks which have been implemented with the user grouping mechanism based on the proposed DPSO approach. The SIC operation is implemented after the signal of the first user in the group, which has the better SINR value than the other user, is detected. Once the first user is successfully detected, SIC operation will be carried out to remove the signal contect which is associated to the first user before detecting the signal destined for the second user in the same group. By cancelling the interference, the effective SINR of the second user will be higher, hence increasing the probability of the received signal for the second user to be detected. In the next section, the proposed approach is implemented for grouping the users in NOMA and performance achievement is observed.

4. RESULTS AND ANALYSIS

Based on the configuration discussed in the previous section, a NOMA system is considered with 19 cells, each of which consists of three sectors. The input data values, including the channel gain values, are chosen based on the 3GPP standard values which are widely applied in literature, such as in [20], [26]. The objective of the simulation run in this section is to group the users based on the proposed DPSO scheme and other state-of-the-art schemes before the performance is measured in terms of the mean throughput and the average mean square error per user, which are formulated based on equations given in (1) to (7). Table 1 shows the parameter values applied in the simulation. The choice of the parameter values is mainly made based on [24] as well as the number of users considered in the radio cells.

Table 1. The parameter values for DPSO performance

Parameters	Ideal criteria
Inertia weight, w	$0.9 \leq w \leq 1.2$
Population size, S	$8 \leq n \leq 50$
Maximum iteration, N	$3 \leq N \leq 1000$
Acceleration coefficient c_1, c_2	2

The first simulation is started based on the given parameter values in Table 1, with the maximum number of iterations is set to nine and the size of the population is varied between 8 to 50, subject to the total number of users being grouped. In addition to the proposed DPSO scheme, user grouping is also performed using the PFFP scheme [20], which is a fast and efficient user grouping approach. As a reference, the exhaustive search (ES), which considers all possible solutions to find the user groupings, is also carried out.

In Figure 1, the mean throughput is measured when the number of available resource blocks is varied between 1 to 5. This range of resource block numbers is also chosen based on the data used in [20]. Each resource block will be shared by two users. By running the proposed scheme along with PFFP and ES, it can be observed that the mean throughput achieved by the proposed scheme performs better than PFFP. Moreover, the achieved mean throughput attained by the proposed DPSO is closed to the upper bound set by ES. The gap between the mean throughput achieved by the proposed DPSO and the existing scheme, ES, grows wider as the number of resource blocks increases.

In Figure 2, the average mean square error per user is measured, where the mean square error is measured as $MSE = 1/(1 + SINR)$, where SINR represents the signal to interference and noise ratio. As seen in the image, the lowest average mean square error is achieved by the ES, which constitutes the lower bound. As for the proposed DPSO scheme, it can be observed that the recorded average mean square error is lower than that of the existing scheme, PFFP. The mean square error should be reduced to improve the signal transmission in the radio network.

Figure 3 depicts the fitness function values achieved by the proposed DPSO algorithm. These fitness function values are recorded at every iteration for different numbers N_{rb} of resource blocks, ranging from $N_{rb} = 1$ to $N_{rb} = 5$. It can be observed that the proposed DPSO algorithm converges before the number of iterations reaches 10. As expected, the proposed scheme takes more iterations before it converges when the number of resource blocks increases. This is mainly because the number of input variables of the proposed DPSO is directly proportional to the number of resource blocks. Hence as the number of resource blocks increases, the number of input variable increases, yielding more iterations required before the convergence. This relatively small number of maximum iterations achieved by the proposed DPSO algorithm is important to reduce the required computational load especially when the number of users and the number of resource blocks increase.

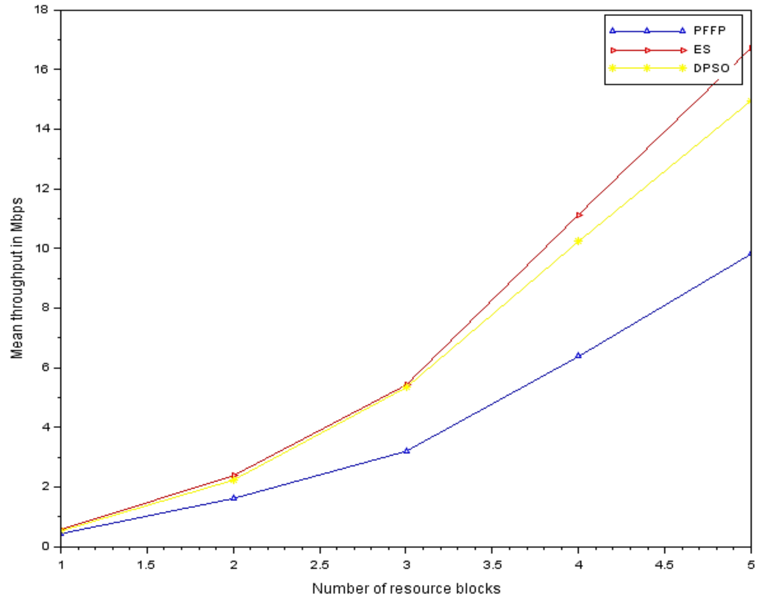

Figure 1. Mean throughput achieved by the user grouping schemes under consideration

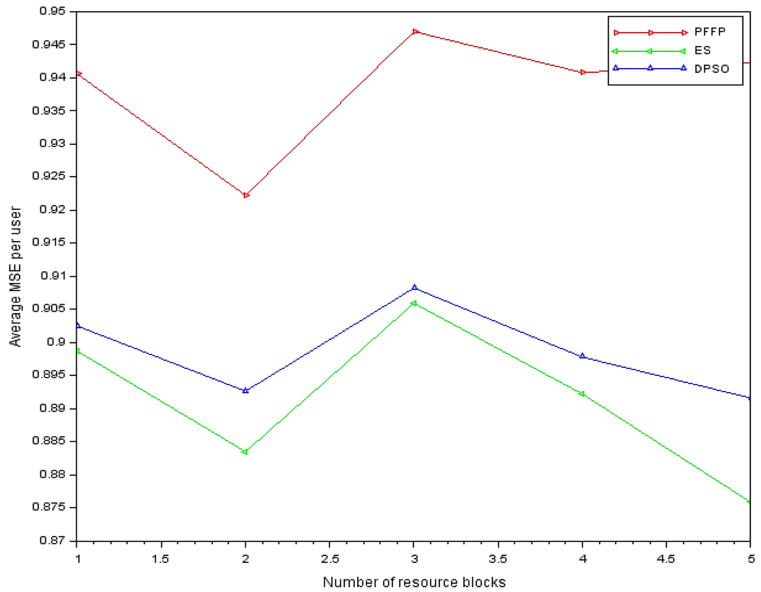

Figure 2. Average mean square error per user recorded for each user grouping approach

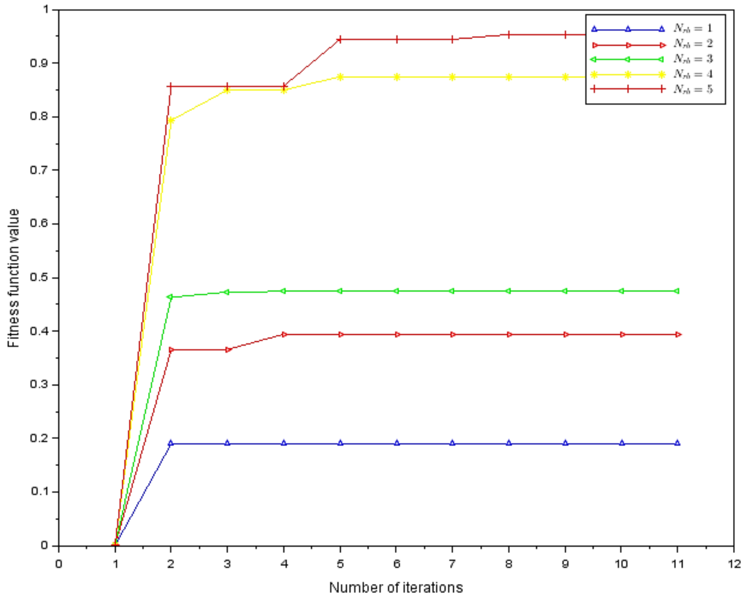

Figure 3. The fitness function values achieved at every iteration

5. CONCLUSION AND FUTURE WORK

The proposed discrete particle swarm optimization approach is implemented to find the user grouping in 5G NOMA systems. The existing methods, which apply the particle swarm optimization algorithm for power allocation in NOMA, focus only on power-domain problems in NOMA systems and not the user grouping and bandwidth allocation. Therefore, a new method is devised in this paper based on the discrete particle swarm optimization approach to perform user grouping, which needs the discrete version of particle swarm optimization. By finding and ordering the discrete values of the distances determined in the particle swarm optimization algorithm, the users can be grouped such that the fitness function, which measures the throughput value, is maximized. It has been demonstrated that this proposed DPSO scheme has produced satisfactory throughput values, on par with the values achieved by the existing user grouping technique. As the number of resource blocks is increased, the performance of the proposed DPSO is observed to be improved. In the future, the proposed DPSO scheme will be further improved and tested with more users and resource blocks especially with the increasing demand for data connections in cellular networks.

ACKNOWLEDGEMENTS

This paper is funded under UMK-Fund Grant (R/FUND/A0100/01860A/001/2020/0082). The authors are immensely grateful to all colleagues from Universiti Malaysia Kelantan for their advices and insights to the authors in completing this paper.

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