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A Novel User Grouping Algorithm for Downlink NOMA

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Research Article

Keywords: 5G, Non-orthogonal multiple access (NOMA), Downlink, User grouping

Posted Date: April 22nd, 2021

DOI: https://doi.org/10.21203/rs.3.rs-413432/v1

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Wireless Personal Communications manuscript No.
(will be inserted by the editor)

A Novel User Grouping Algorithm for Downlink NOMA

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Received: date / Accepted: date

Abstract Non-orthogonal multiple access (NOMA) is one of the promising radio access techniques for resource allocation improvement in the 5^{th} generation of cellular networks. Compared to orthogonal multiple access techniques (OMA), NOMA offers extra benefits, including greater spectrum efficiency which is provided through multiplexing users in the transmission power domain while using the same spectrum resources non-orthogonally. Even though NOMA uses Successive Interference Cancellation (SIC) to repeal the interference among users, user grouping has shown to have a substantial impact on its performance. This prformance improvement can appear in different parameters such as system capacity, rate, or the power consumption. In this paper, we propose a novel user grouping scheme for sum-rate maximization which increases the sum-rate up to 25 percent in comparison with two authenticated recent works. In addition to being matrix-based and having a polynomial time complexity, the proposed method is also able to cope with users experiencing different channel gains and powers in different sub-bands.

Keywords 5G · Non-orthogonal multiple access (NOMA) · Downlink · User grouping

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1 Introduction

Non-orthogonal multiple access (NOMA) has been considered as a promising technique for 5G radio networks [1]. Considering spectral-power efficiency, NOMA techniques, especially in fading environments, are superior to orthogonal ones (OMA) [2]. This superiority is the result of exploiting the frequency channel by more than one user simultaneously and in the same cell [3]. There are different types of NOMA techniques including Power-Domain NOMA in which users are multiplexing in the power domain [4]. Since more than one user is using the same time, frequency, and code resources in NOMA, users experience co-channel interferences. In fact, NOMA cannot prevent inter-cell interferences due to using all the capacity of sub-bands. As a result, it is not practical to have all the users in the system performing NOMA jointly, even though it uses Successive Interference Cancellation (SIC) at the receiver side to repeal the interferences [2, 3]. In many recent research works, it has been shown that user grouping can hugely improve NOMA performance compared to OMA. In [5], it has been shown that the throughput and sum-throughput increase in both uplink and downlink NOMA if users are grouped. In the proposed scheme in [6], users are paired using NOMA and all pairs are allocated with conventional OMA. The maximum sum-rate of this scheme is better than OMA. An exhaustive search is used in [7] for user grouping, but the result is the same. In [8] it has been shown that user grouping increases the sum-rate of NOMA in multi-cell networks. Finally, the positive effects of user grouping on fairness, rate, and sum-rate have been studied in [9]. Putting OMA aside, other related researches study different user grouping strategies and try to make its performance even better by following different goals including minimizing the power consumption, decreasing the outage probability, and bit error rate. There are two recent works that try to maximize the sum-rate. In [10] a machine learning algorithm has been used in mm-Wave NOMA. The result tends to a better sum-rate than the exhaustive search and the matching algorithms. The optimal algorithm proposed in [11] is not practical due to computational complexity for a big number of users. But the suboptimal algorithm increases the sum-rate in comparison with the random user grouping algorithm. In this paper, we propose a novel matrix-based user grouping algorithm with polynomial time complexity. In addition to being optimal and practical, the proposed algorithm takes different user gains and user powers in different sub-bands into account. In order to do that, in section 2 the System Model and Problem Formulation are presented. Section 3 introduces the new Optimal User Grouping Algorithm. In section 4 Numerical Results, Performance Comparison, and Computational Complexity are provided, and finally Section 5 presents the Conclusion.

2 System Model and Problem Formulation

2.1 System Model

Having Shannon Theory in mind, consider a downlink, one-cell network in which there is a base-station with just one antenna supporting n users. The base station sends the data to all the users simultaneously and has limited power. In this network, signals experience Additive White Gaussian Noise (AWGN) with zero mean and variance σ_n^2. If h_i denotes the i^{th} user's channel gain, it is assumed that it is sorted in ascending order as $h_1 \geq h_2 \geq \cdots \geq h_n$, so that the first user always uses the strongest channel. In a NOMA channel, sending data to all users in that channel at the same time by using the whole bandwidth is manageable through performing Superposition Coding (SC) at the sender side and Successive Interference Cancellation (SIC) at the receiver side. In fact, the base-station sends a linear superposed code of n users' data by allocating a fraction of the total power to each user e.g. allocates P_i to U_i. At the receiver side, user U_i decodes the data from all the weaker users i.e. U_m such that $m < i$. Then these signals are subtracted from the received signal and while considering stronger signals (U_m such that $m > i$) as interference, U_i is decoded. The signal received by U_i is given by:

$$y_i = h_i x + w_i \tag{1}$$

in which $x = \Sigma_{i=1}^{n} \sqrt{P_i} S_i$ is the superposed signal transmitted from the base-station, with S_i being the signal for user U_i, h_i is the channel gain, and w_i shows the AWGN for the user i.

2.2 Problem Formulation

If Superposition Coding at the sender side and Successive Interference Cancellation at the receiver side are conducted correctly, the data rate is equal to:

$$R_i = B \log_2 (1 + \frac{P_i \gamma_i}{\Sigma_{j=1}^{i-1} P_j \gamma_i + 1}) \tag{2}$$

where $\gamma_i = \frac{h_i}{w_i}$ is the normalized channel gain, and B is the channel bandwidth. Thus, to improve the sum data rate we need to follow:

$$\max \Sigma_{i=1}^{n} R_i \tag{3}$$

while considering the total transmission power constraint as below:

$$P_1 + P_2 + \cdots + P_n \leq P_T \tag{4}$$

This means that, we have a mixed integer non-linear programming problem.

3 New Optimal User Grouping Algorithm

In [12] Hungarian Algorithm has been considered to be an optimal solution for the Assignment Problem. Then, in [13] the Alternate Algorithm has been driven from the Hungarian Algorithm which is less complex. Our proposed scheme uses the Alternate Algorithm to find an optimal solution for our specific user grouping problem.
Steps of the proposed scheme:

- Create the matrix of users' channel gains, in which users are placed in rows and sub-bands are placed in columns (the ij^{th} entry shows the i^{th} user's channel gain in j^{th} sub-band).
- While the number of users is bigger than the number of sub-bands:
  - ☐ for the number of sub-bands:
    - Find the maximum entry in each row. Create a table of rows and columns of maximum entries (users and the sub-band in which they have the maximum gain). If for more than one user, one sub-band was chosen, find the second maximum entry in those rows. Calculate the difference between the first and the second maximum entry. Choose the biggest difference.
      Note: If gain differences were equal, choose the user with the smaller power.
      Note: If chosen user's power was bigger than chosen sub-band's power, consider the next option.
    - Subtract the chosen user's power from the chosen sub-band's power.
    - Delete chosen entry's row and column from the matrix.
  - ☐ Recreate the matrix but without deleted rows.
- If the number of users is smaller than the number of sub-bands:
  - ☐ For each user list the sub-bands with bigger powers.
  - ☐ Choose the sub-band in which the user has the biggest gain.
- If there are users left ungrouped, user grouping is not possible.

Algorithm 1 shows the proposed scheme in more details.

Algorithm 1: The Proposed Algorithm

```
Result: Grouped users or fail message
Input1: UserNumber
Input2: Sub − bandNumber
Input3: UserPowers = [1, 2, . . . , i]
Input4: Sub − bandPowers = [1, 2, . . . , j]
Input5: Gains = [γ11 ··· γ1m; ⋮ ⋱ ⋮; γn1 ··· γnm]
while UserNumber > Sub − bandNumber do
    next try:
    foreach user in Gains do
        sub − band(user) ← FindMax Gains(user) ;
        foreach user in sub − band do
            if sub − band(user i) == sub − band(user j) then
                nextOption(user) ← FindNextMax in Gains(user i)
                 ;
                difference(user) ← sub − band(user) −
                 nextOption(user) ;
                if difference(user i) == difference(user j) then
                    choose ← user(FindMin powers(user)) ;
                else
                    choose ← FindMax difference(user) ;
                end
                if Powers(sub − band) > powers(user) then
                    result+ = (choose, sub − band) ;
                    Powers(sub − band)− = powers(user) ;
                    Delete Gains(user, sub − band) ;
                else
                    Omit user ;
                    Goto next try ;
                end
            else
                if Powers(sub − band) > powers(user) then
                    result+ = (user, sub − band) ;
                    Powers(sub − band)− = powers(user) ;
                    Delete Gains(user, sub − band) ;
                else
                    Omit user ;
                    Goto next try ;
                end
            end
        end
    end
end
foreach user in Gains do
    if Powers(sub − band) > powers(user) then
        remainSub − bands ← sub − band(user) ;
    else
end
foreach user in remainSub − bands do
    choose ← FindMax (user) ;
    result+ = (user, sub − band) ;
    Powers(sub − band)− = powers(user) ;
    Delete Gains(user, sub − band) ;
end
if Gains! = [0] then
    Return " no optimal solution!" ;
else
    Return result;
end
```

4 Numerical Results, Performance Comparison, and Computational Complexity

4.1 Numerical Results

In this section, simulation results are presented. These results have been generated by MATLAB. The major simulation parameters are being shown in Table 1.

Table 1 Simulation Parameters

Parameter	Value
Carrier Frequency	$20MHz$
Bandwidth	$180KHz$
Antenna's height	$30m$
Antenna gain	$60dBi$

The results confirm that the proposed algorithm has no limit on the number of users and sub-bands. If the sum of users' powers is bigger than the total transmission power, some of the users remain ungrouped and the fail message declares that there is no optimal solution. Figure 1 shows how 200 users are grouped in 6 sub-bands. In this part, the noise figure is 7 dB. Figure 1a shows ungrouped users in a 1000 m cell and in Figure 1b users are grouped in 6 groups.

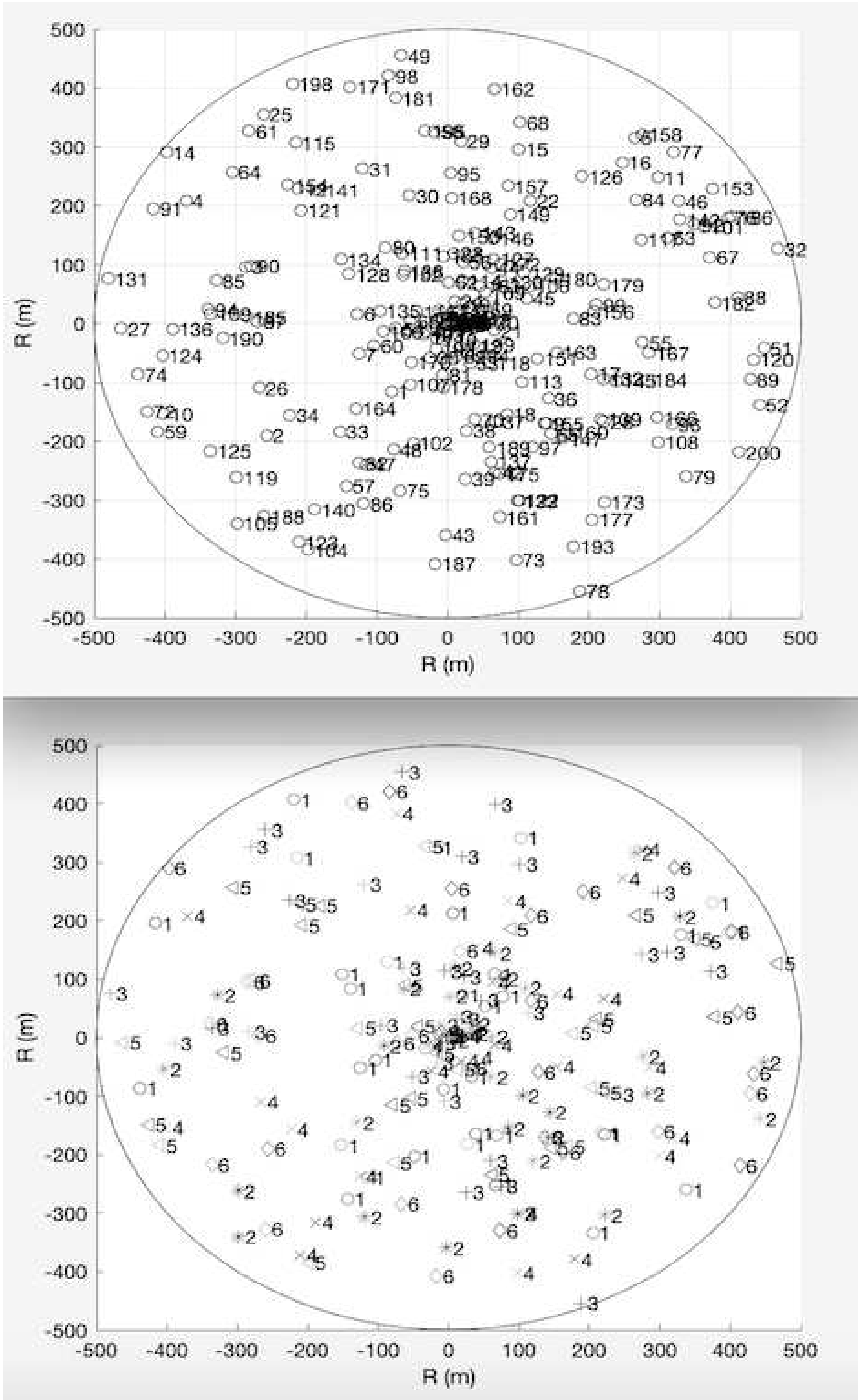

Fig. 1 Functionality of the Proposed Algorithm
a 200 ungrouped users
b 200 users grouped in 6 sub-bands

4.2 Performance Comparisons

In this section, we compare the proposed algorithm with OMA, NOMA without any user grouping, random user grouping, algorithm in [5], and algorithm in [11]. First of all, we compare the proposed algorithm with OMA and NOMA in a situation in which there is no user grouping. In this part, the cell radius is 500 m and noise figure is 7 dB. Users are grouped into 2, 5, 10, 25, 50, and 100 groups; and the simulation is repeated for 20, 50, 100, and 200 users. The results show that OMA outperforms NOMA without user grouping due to inter-cell interference, but the Proposed Algorithm improves NOMA sum-rate especially when the number of groups increases. According to figures 2 to 5, the biggest gap between OMA and NOMA with the Proposed Algorithm happens when there are 200 users in the system.

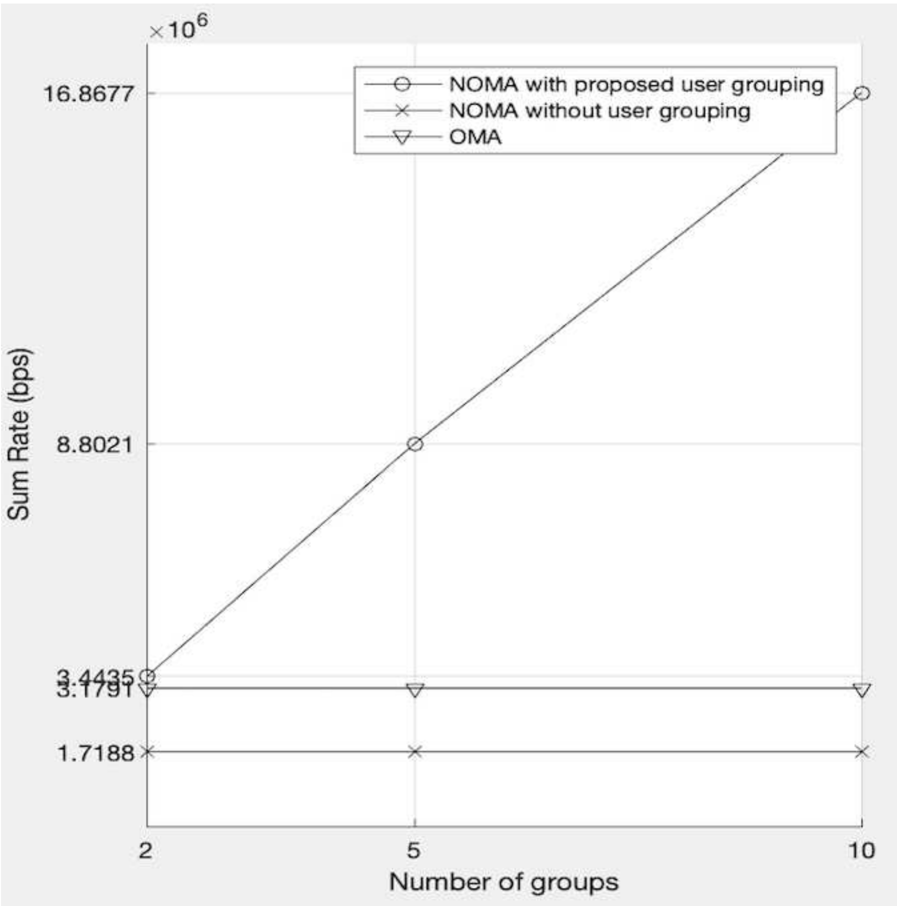

Fig. 2 Comparison of the Proposed Algorithm with OMA and NOMA without user grouping with 20 users

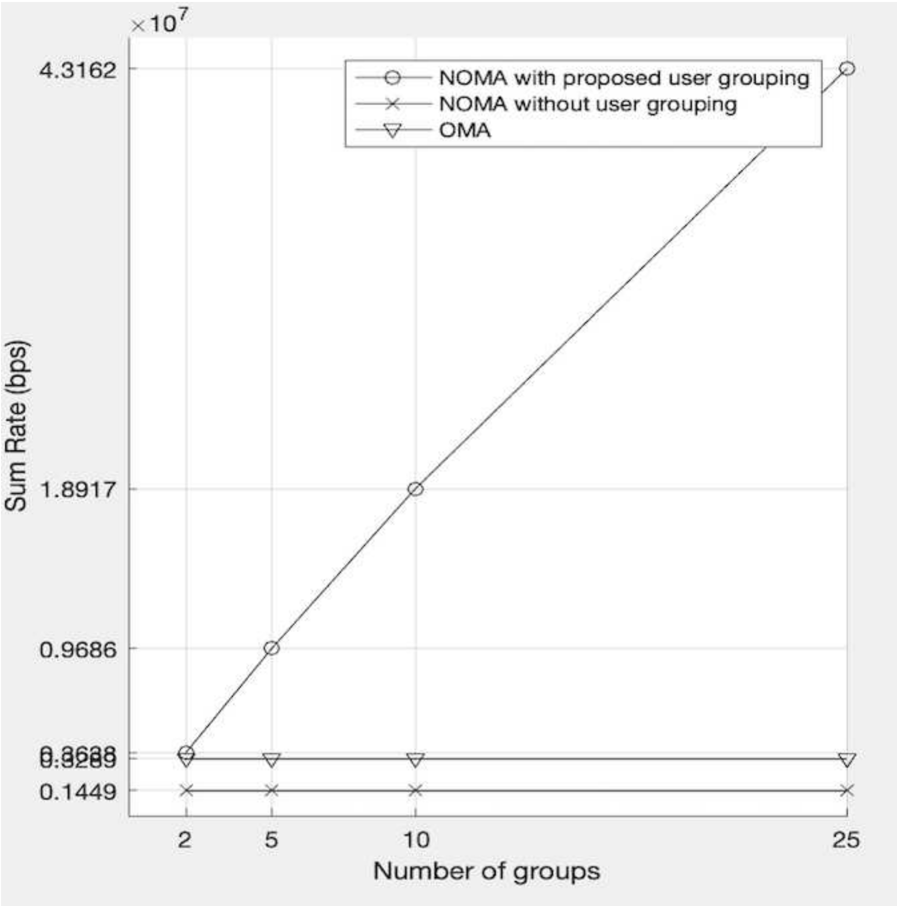

Fig. 3 Comparison of the Proposed Algorithm with OMA and NOMA without user grouping with 50 users

Figures 6 and 7 show the situation in which the noise figure changes from 3 to 9 dB. The cell size is 500 m and there are 100 users in the system. Users are grouped into 20 and 50 groups. Numerical results confirm that NOMA without user grouping is interference-limited and cannot be used. Between OMA and the proposed algorithm, OMA is less sensitive to noise changes due to allocating just one user in each orthogonal sub-band. In NOMA with the Proposed Algorithm, the effect of noise is more considerable when the number of groups is smaller and thus there are more users in each group.

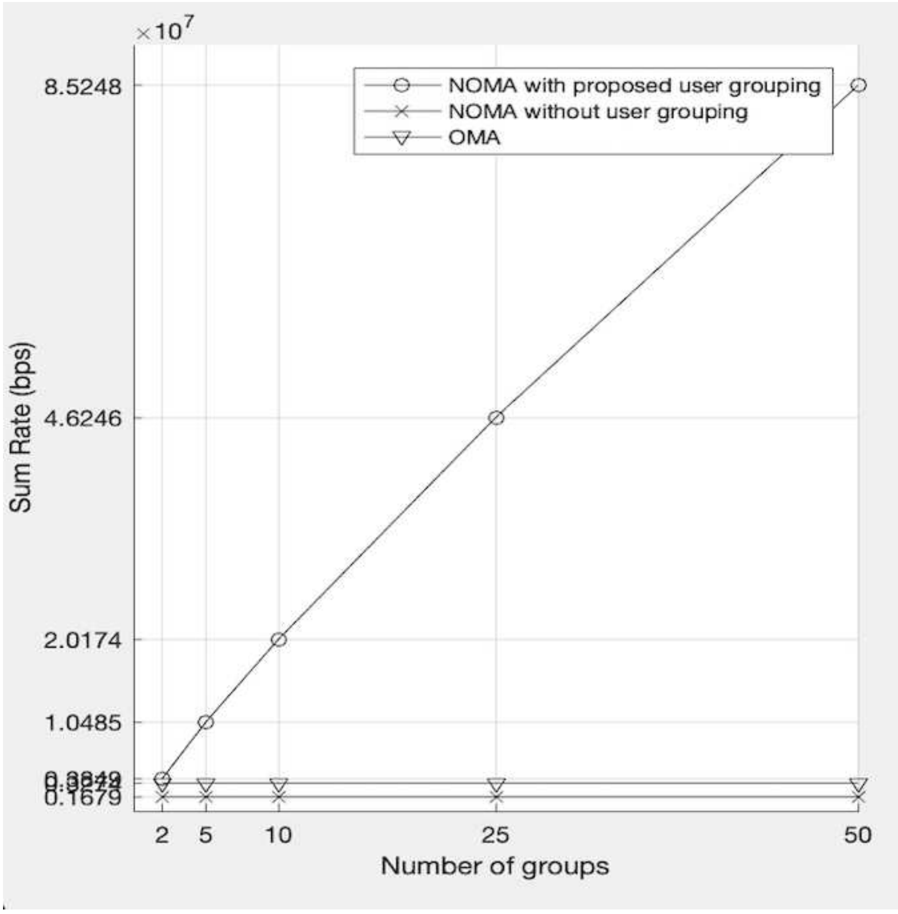

Fig. 4 Comparison of the Proposed Algorithm with OMA and NOMA without user grouping with 100 users

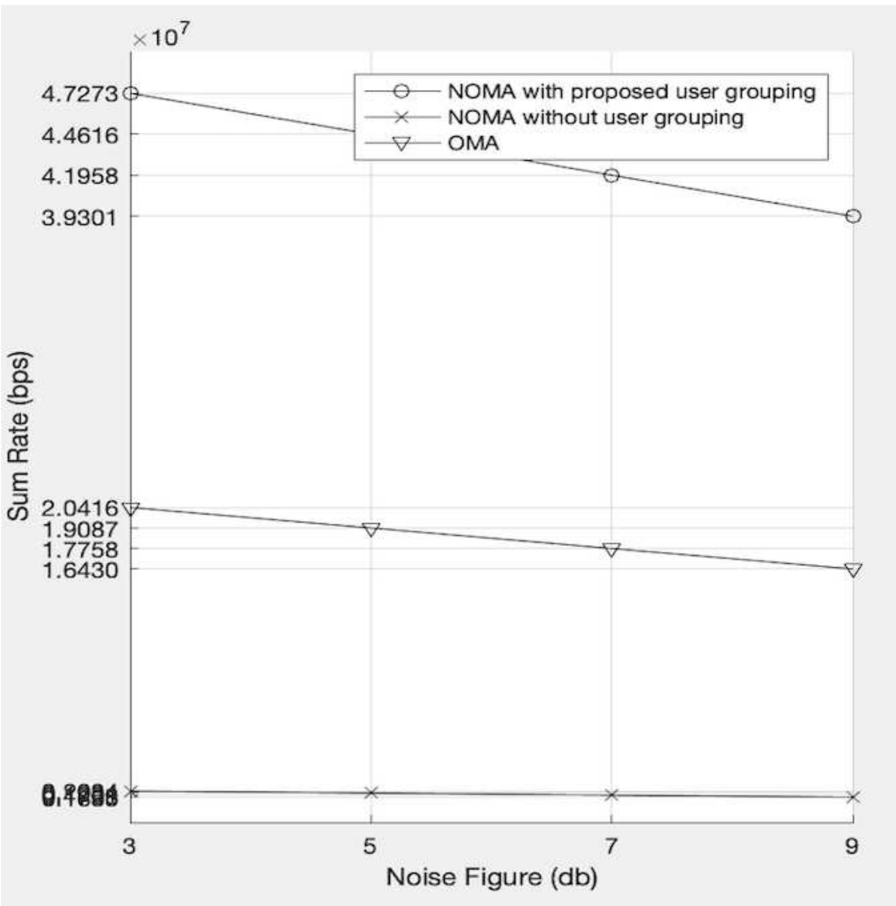

Fig. 6 Comparison of the Proposed Algorithm with OMA and NOMA without user grouping in 20 groups

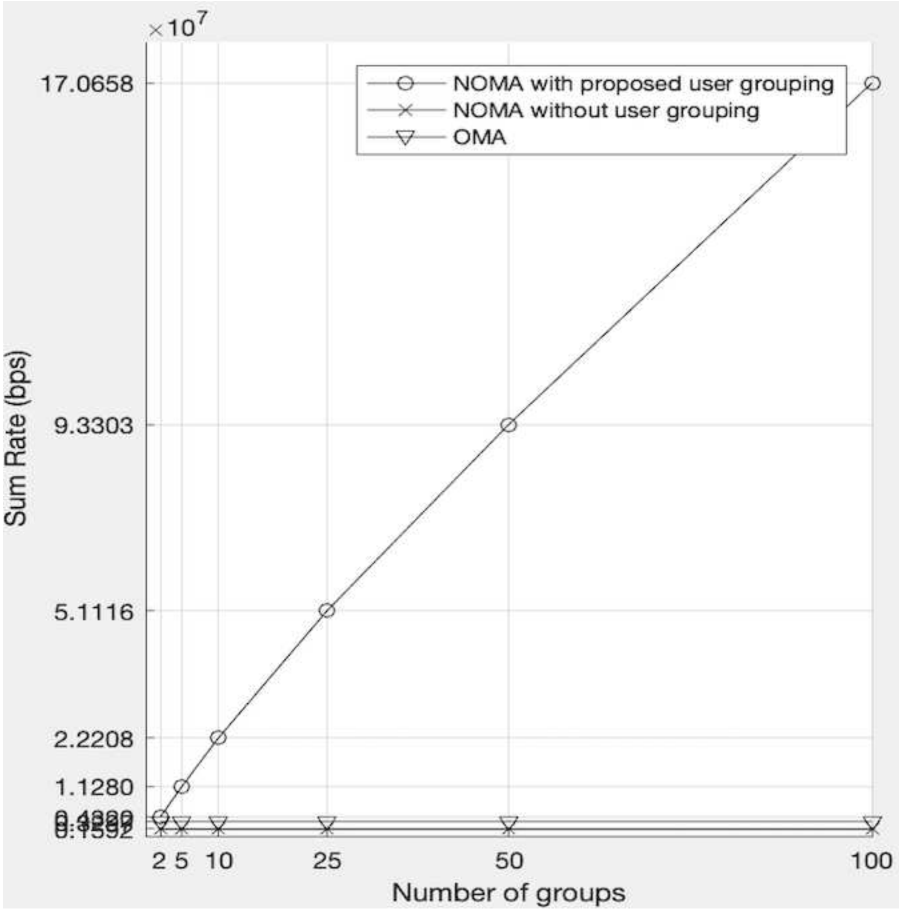

Fig. 5 Comparison of the Proposed Algorithm with OMA and NOMA without user grouping with 200 users

In Figures 8, 9, 10 and 11 the proposed algorithm has been compared to random user grouping, algorithm in [5] and algorithm in [11]. Cell radius and the noise figure are 500 m and 7 dB. Users are grouped into 2, 4, 8, 16, 32, 64, and 128 groups and the simulation has been repeated for 32, 64, 128, and 256 users. According to the results, when there are just 2 groups, the difference in sum-rate is not considerable. But as the number of groups increases, the Proposed Algorithm outperforms other algorithms. To be more specific, when users are paired, the Proposed Algorithm improves sum-rate from 22 to 25 percent.

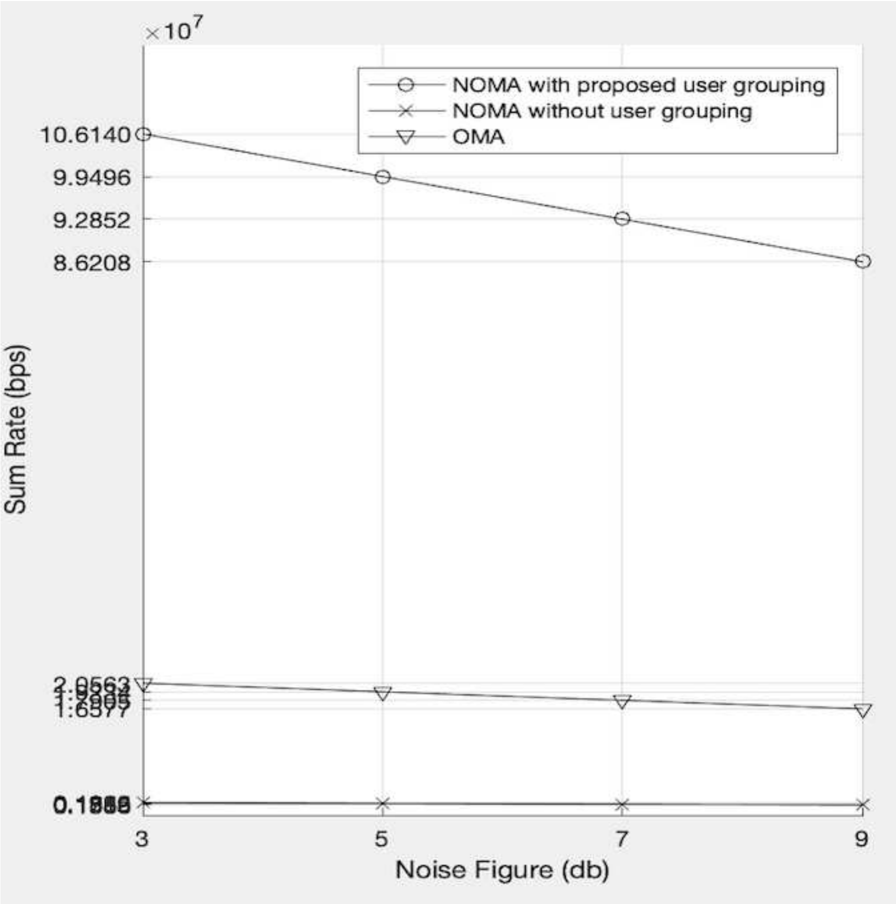

Fig. 7 Comparison of the Proposed Algorithm with OMA and NOMA without user grouping in 50 groups

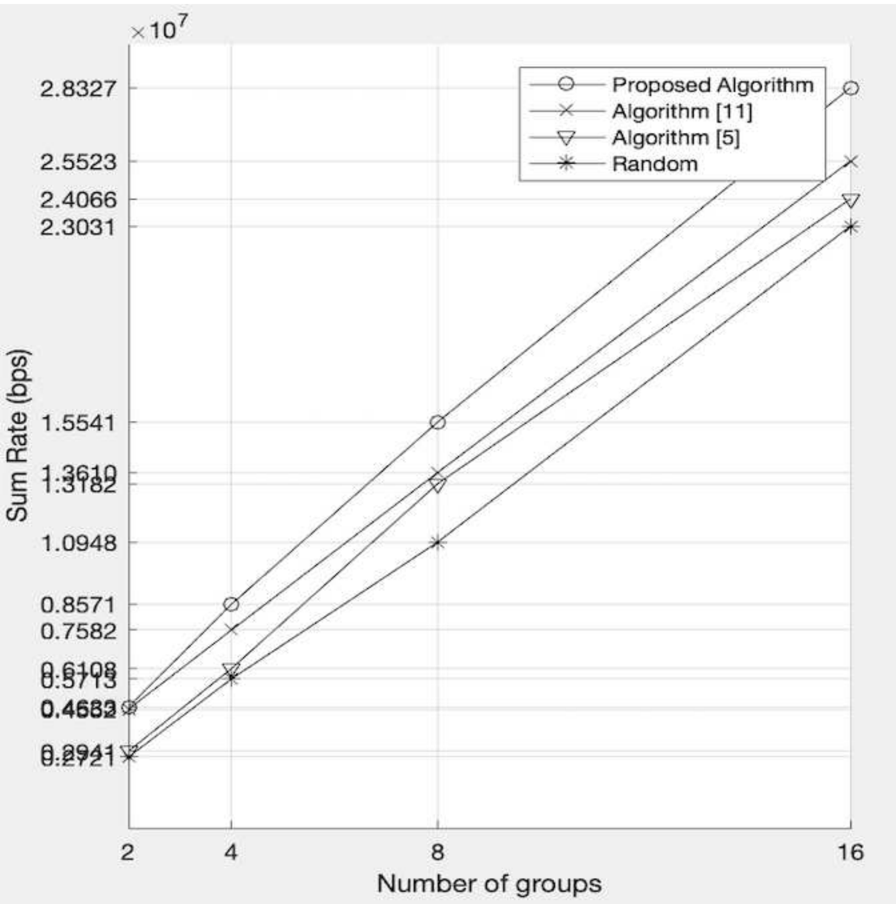

Fig. 8 Sum-rate comparison of the Proposed Algorithm with random user grouping, algorithm [5] and algorithm [11] with 32 users

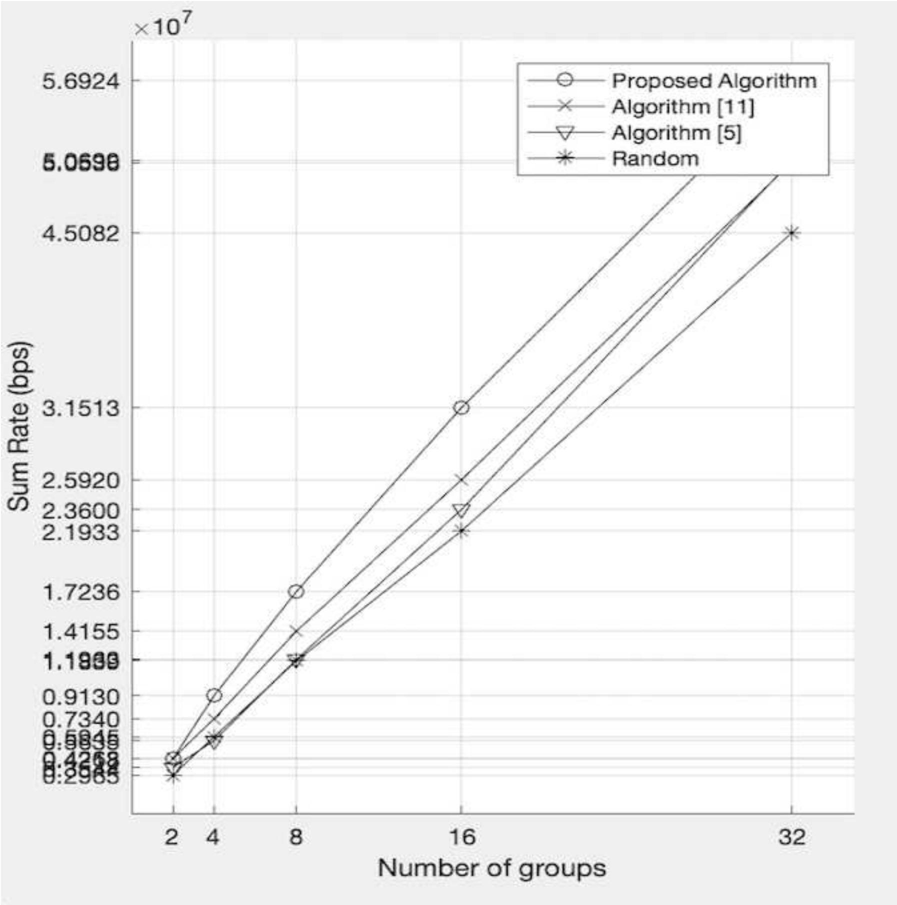

Fig. 9 Sum-rate comparison of the Proposed Algorithm with random user grouping, algorithm [5] and algorithm [11] with 64 users

Figure 12 compares the system capacity improvement made by the Proposed Algorithms with algorithms [5] and [11]. In this simulation cell radius is 500 m, the noise figure is 7 dB, the number of users is 80 and they are grouped in 2, 4, 5, 10, and 20 groups. Capacity Improvement is more considerable when the number of groups increases. Comparing to NOMA without user grouping, the Proposed Algorithm improves system capacity up to 2350 percent. Finally, Figure 13 shows the Proposed Algorithm performance in different cell sizes. Results show that when the cell is smaller, sum-rate increases more.

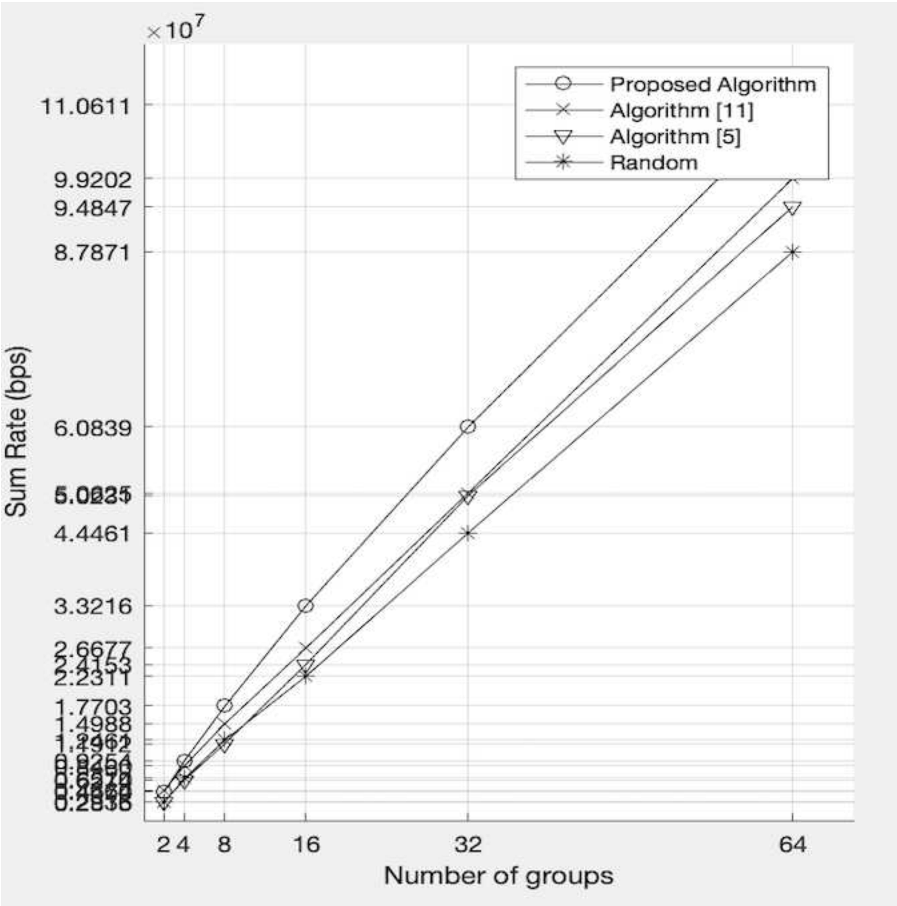

Fig. 10 Sum-rate comparison of the Proposed Algorithm with random user grouping, algorithm [5] and algorithm [11] with 128 users

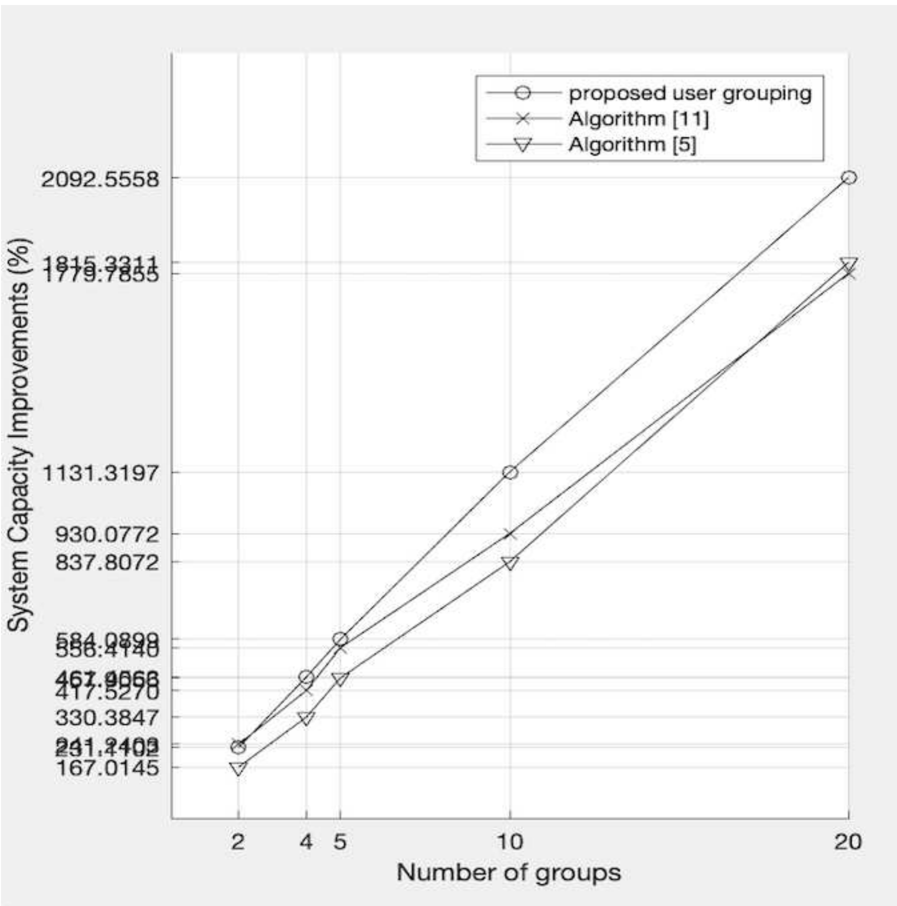

Fig. 12 Capacity improvement comparison of the Proposed Algorithm, algorithm [5] and algorithm [11] with 80 users

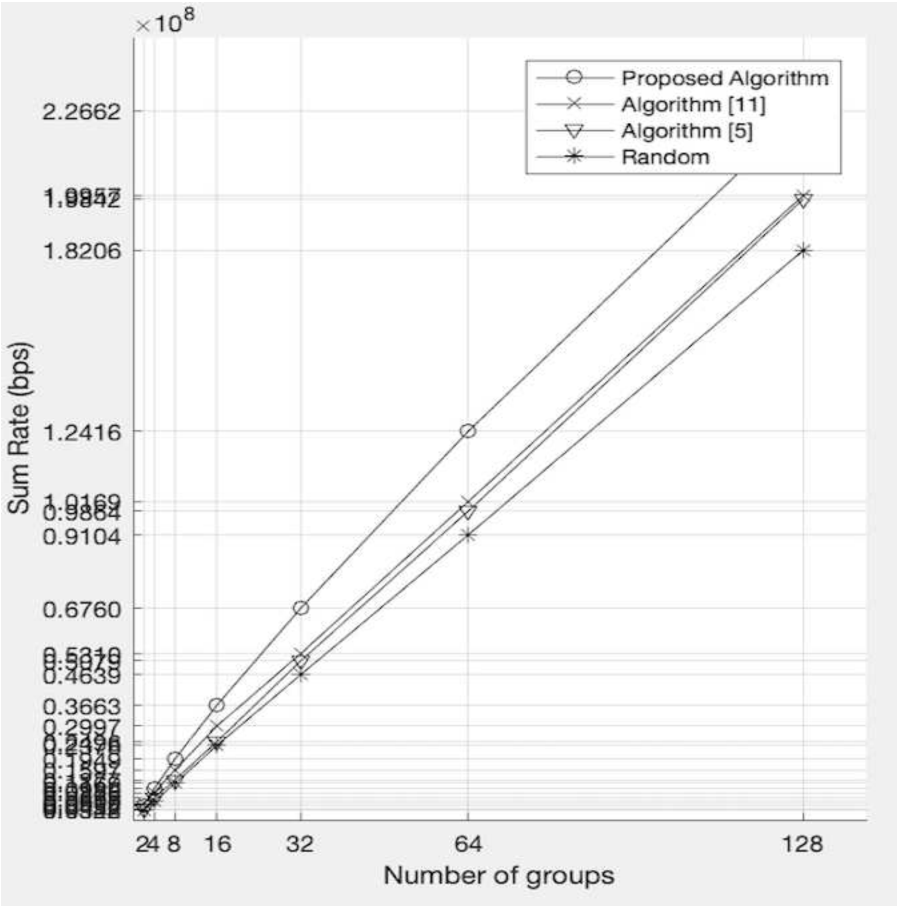

Fig. 11 Sum-rate comparison of the Proposed Algorithm with random user grouping, algorithm [5] and algorithm [11] with 256 users

4.3 Computational Complexity

The computational complexity of an algorithm is very important to its practicality. In this section, proves of the Proposed Algorithm having a polynomial time complexity have been provided. The proposed algorithm consists of three main loops. There are two inner loops. For n users, the first loop repeats n times. The second loop compares users, which in the worst case needs to be repeated for $n(n-1)$ times. Thus, the complexity of these two loops is given by:

$$[n(n-1)] + n = n^2 + n - n = n^2 \tag{5}$$

The outer loop, repeats $n - m$ times in which m shows the number of subbands. As a result, the computational complexity of the algorithm is equal

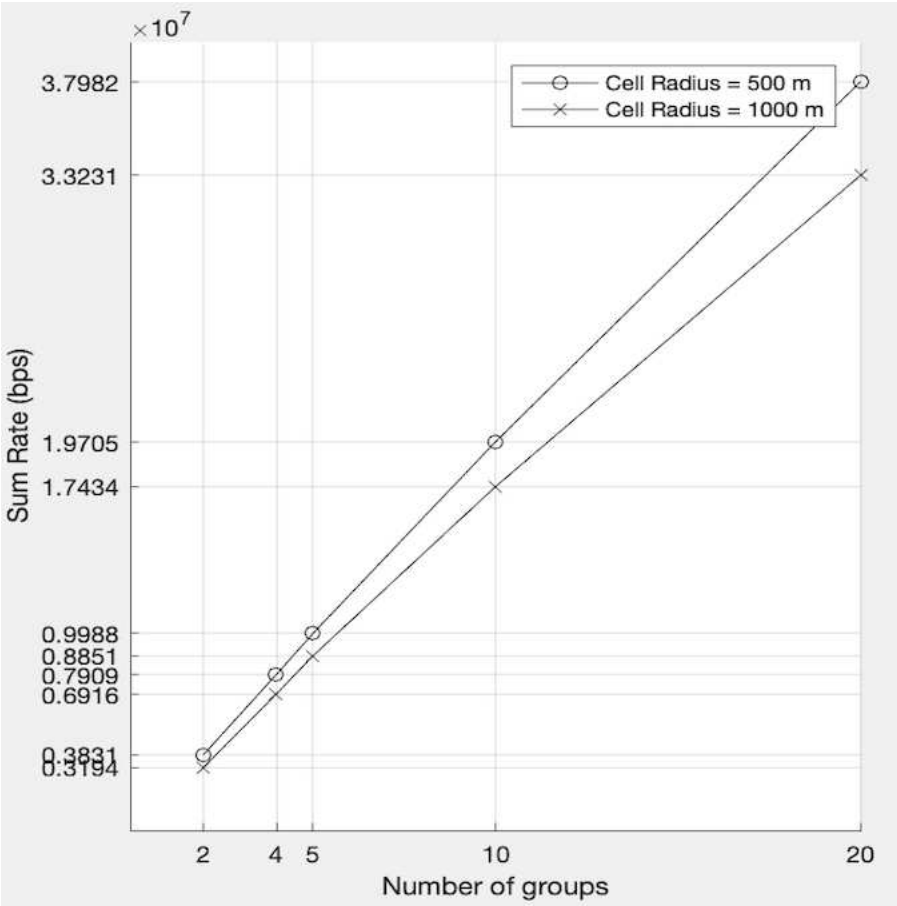

Fig. 13 Sum-rate comparison of the Proposed Algorithm in different cell radius

to:

$$n^2(n - m) = n^3 - (mn)^2 \tag{6}$$

where $m < n$. This shows that the complexity order of the Proposed Algorithm is $O(n^3)$.

5 Conclusion

A practical and optimal user grouping is necessary for using the maximum potential of NOMA. In this paper, we proposed a flexible user grouping algorithm for sum-rate maximization, which can be used for any given number of users and sub-bands. If the sum of users' powers is more than the total transmission power, some users remain ungrouped. In this algorithm, users' gains are different in each sub-band and this makes the algorithm more practical and realistic. The Proposed Algorithm increases sum-rate up to 25 percent compared to some previous algorithms and improves system capacity hugely. Considering the computational complexity of the algorithm, it runs in a polynomial time.

Declarations:

Funding: No funding was received for conducting this study.

Conflicts of interest/Competing interests: The authors have no relevant financial or non-financial interests to disclose.

Availability of data and material: Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

Code availability: Custom code in MATLAB has been used for simulation.

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Figures

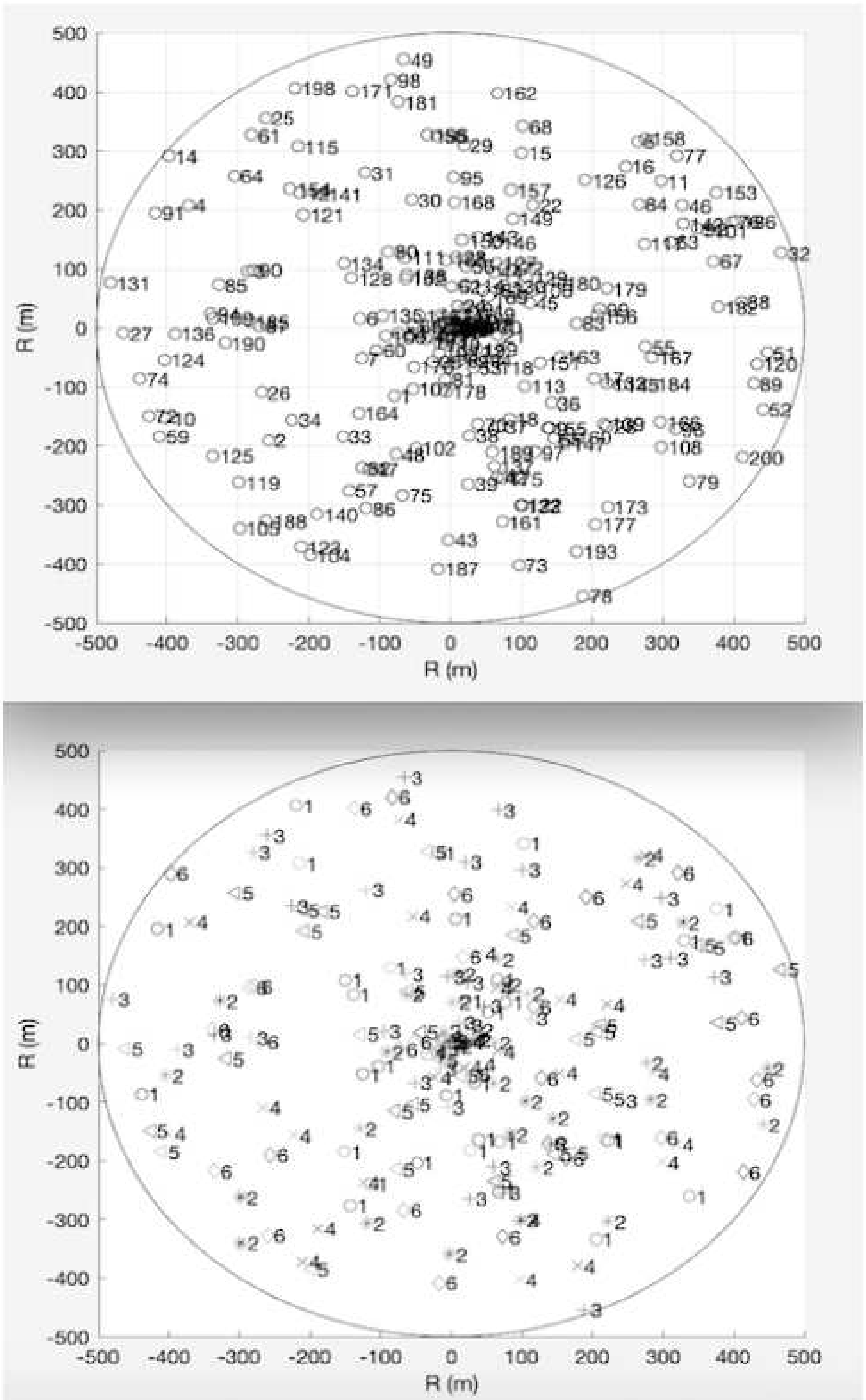

Figure 1

Functionality of the Proposed Algorithm a 200 ungrouped users b 200 users grouped in 6 sub-bands

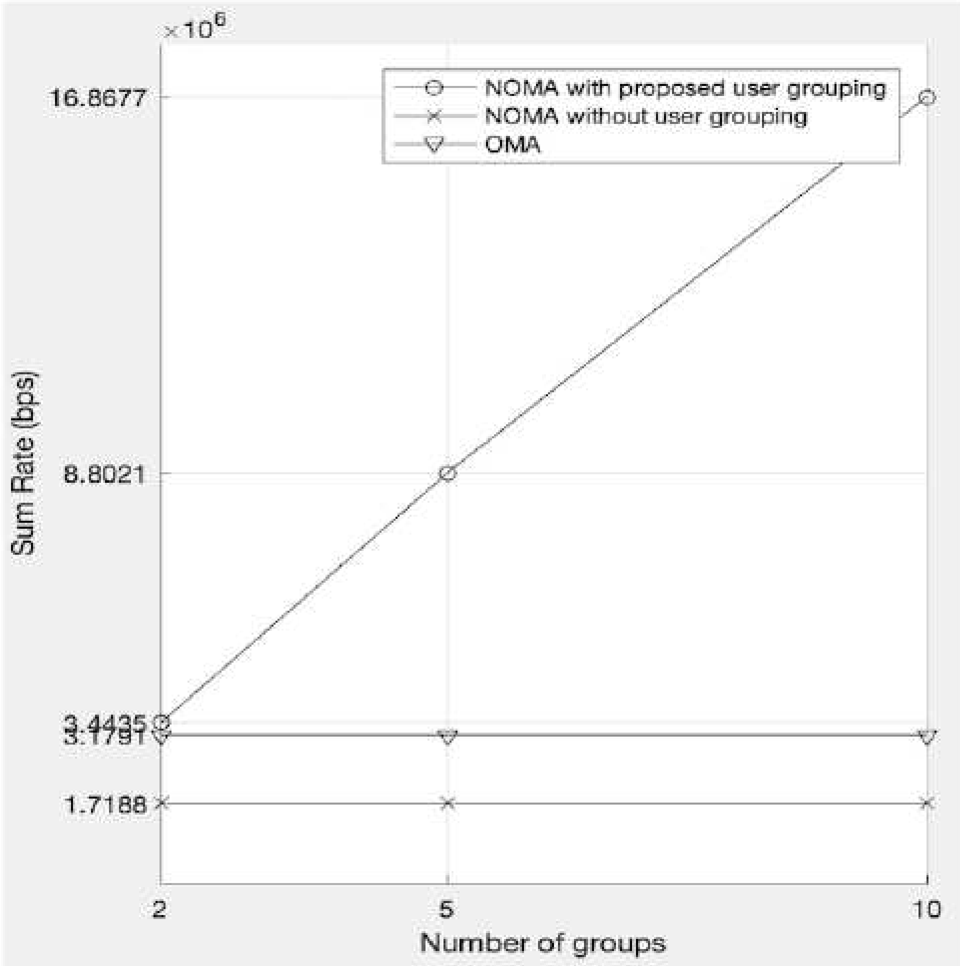

Figure 2

Comparison of the Proposed Algorithm with OMA and NOMA without user grouping with 20 users

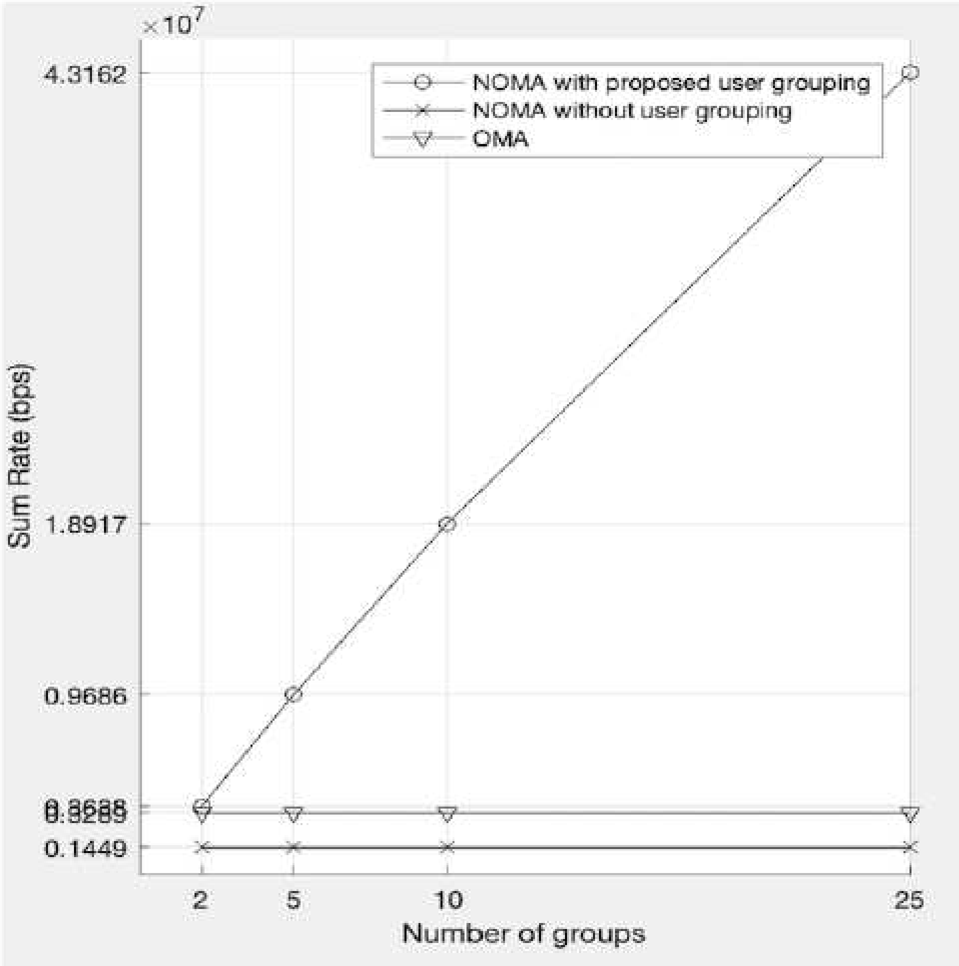

Figure 3

Comparison of the Proposed Algorithm with OMA and NOMA without user grouping with 50 users

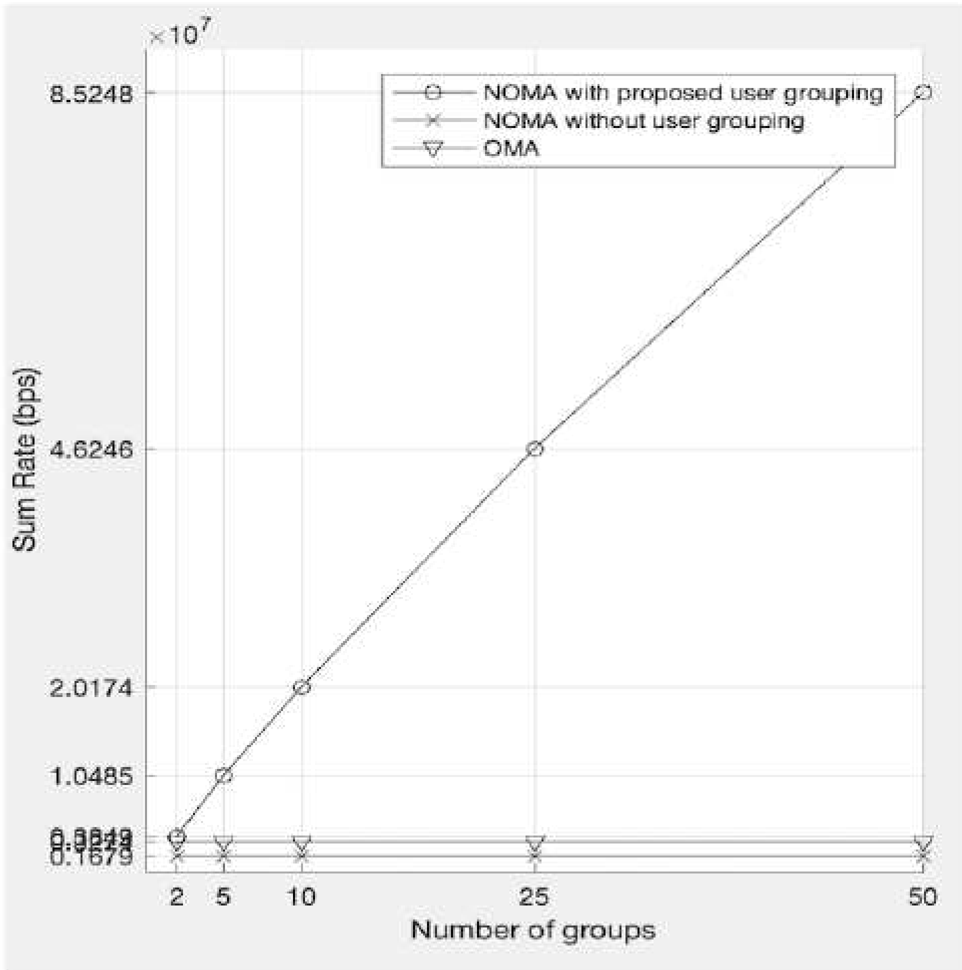

Figure 4

Comparison of the Proposed Algorithm with OMA and NOMA without user grouping with 100 users

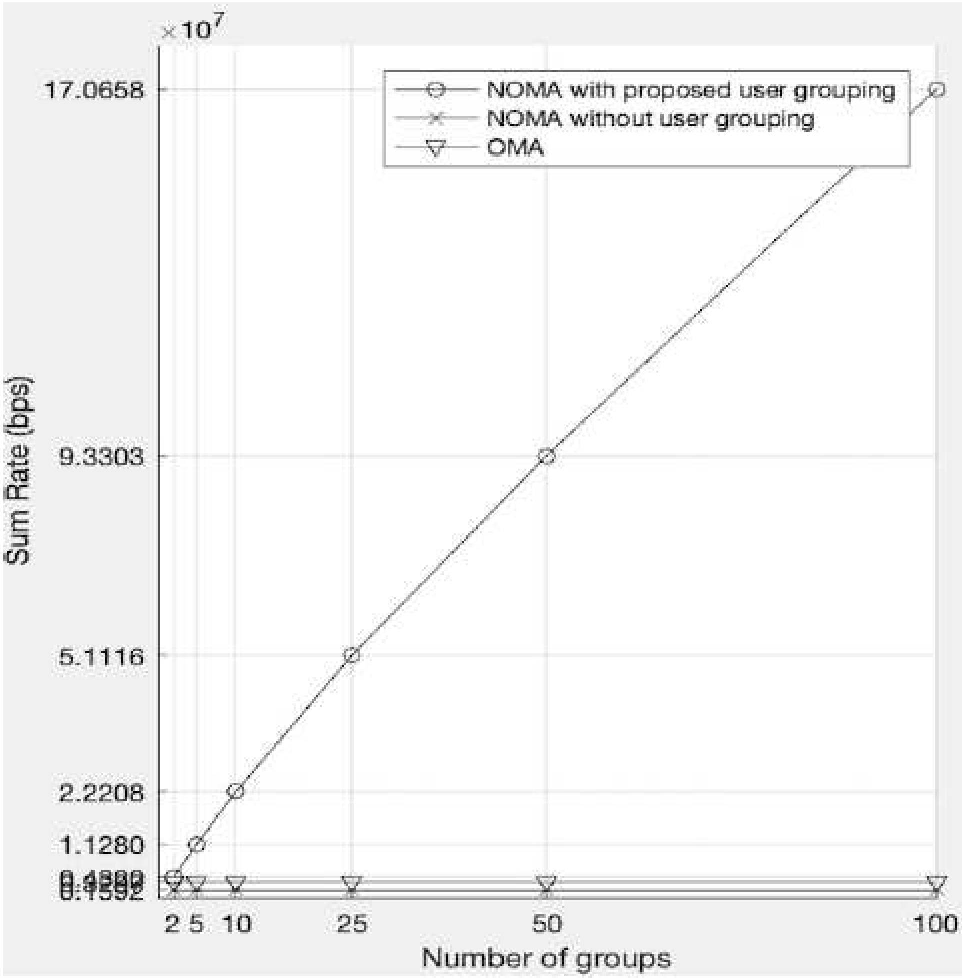

Figure 5

Comparison of the Proposed Algorithm with OMA and NOMA without user grouping with 200 users

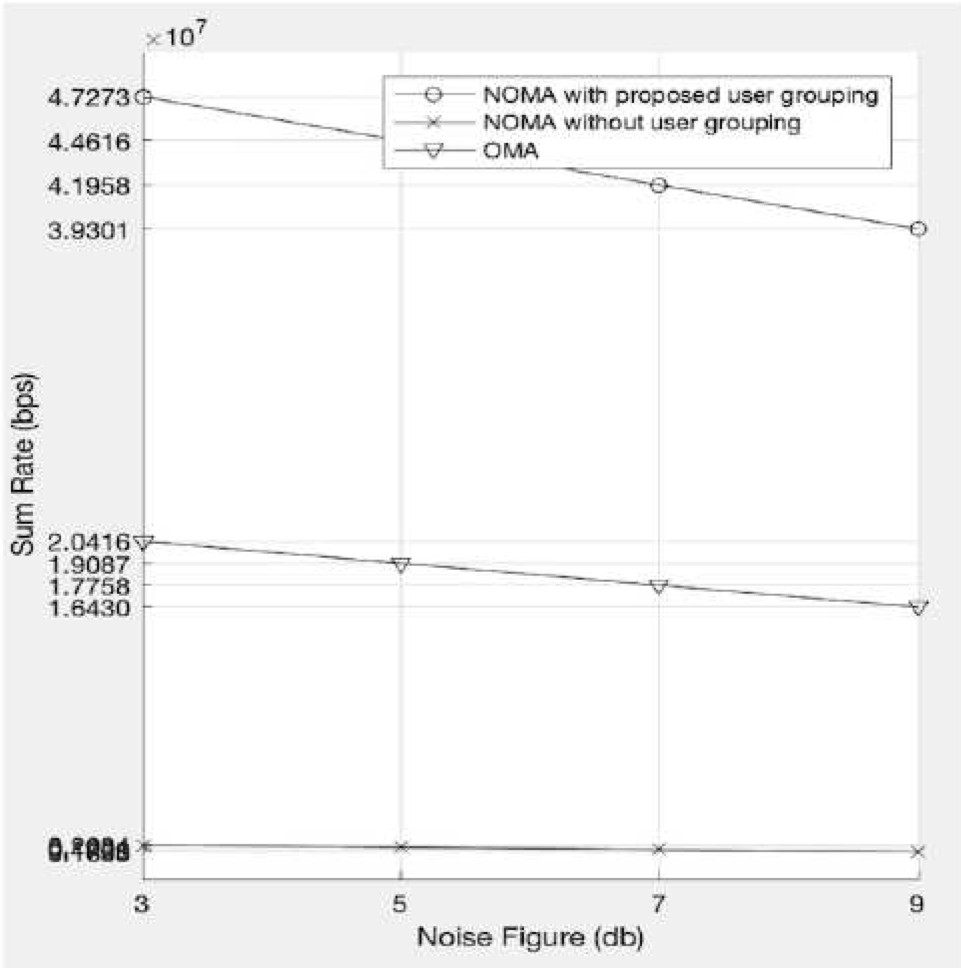

Figure 6

Comparison of the Proposed Algorithm with OMA and NOMA without user grouping in 20 groups

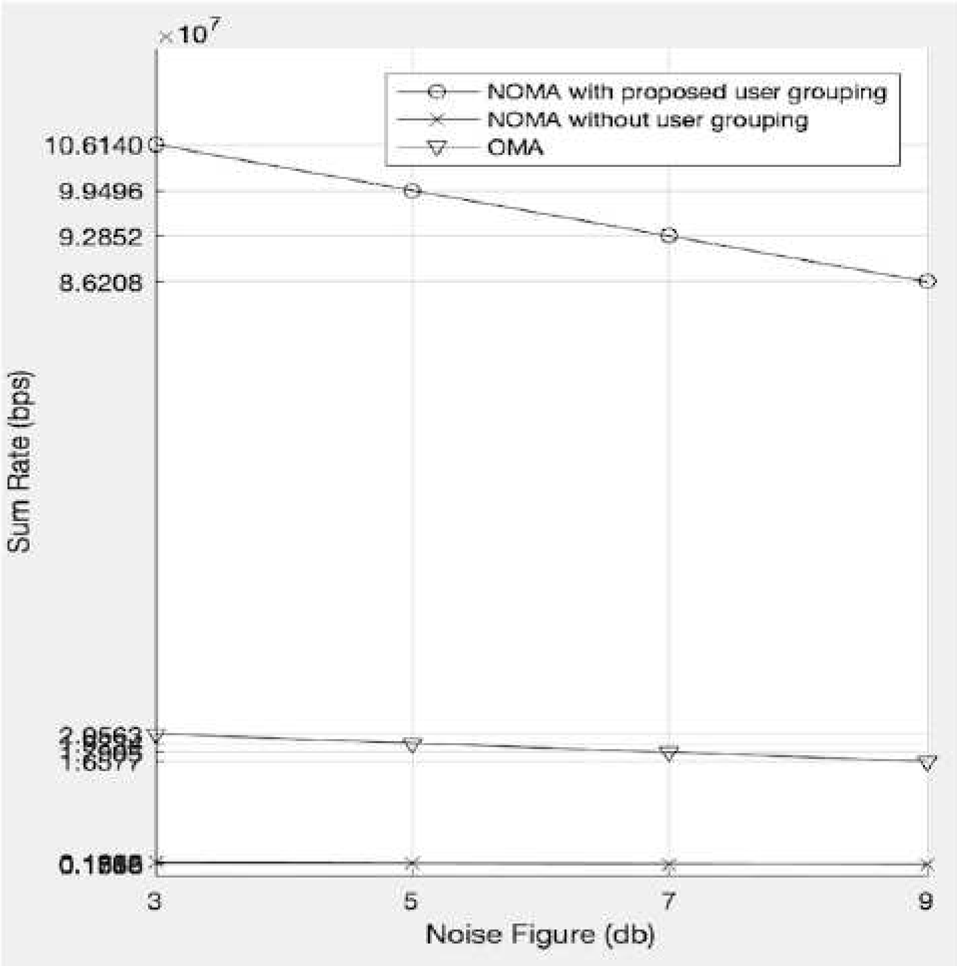

Figure 7

Comparison of the Proposed Algorithm with OMA and NOMA without user grouping in 50 groups

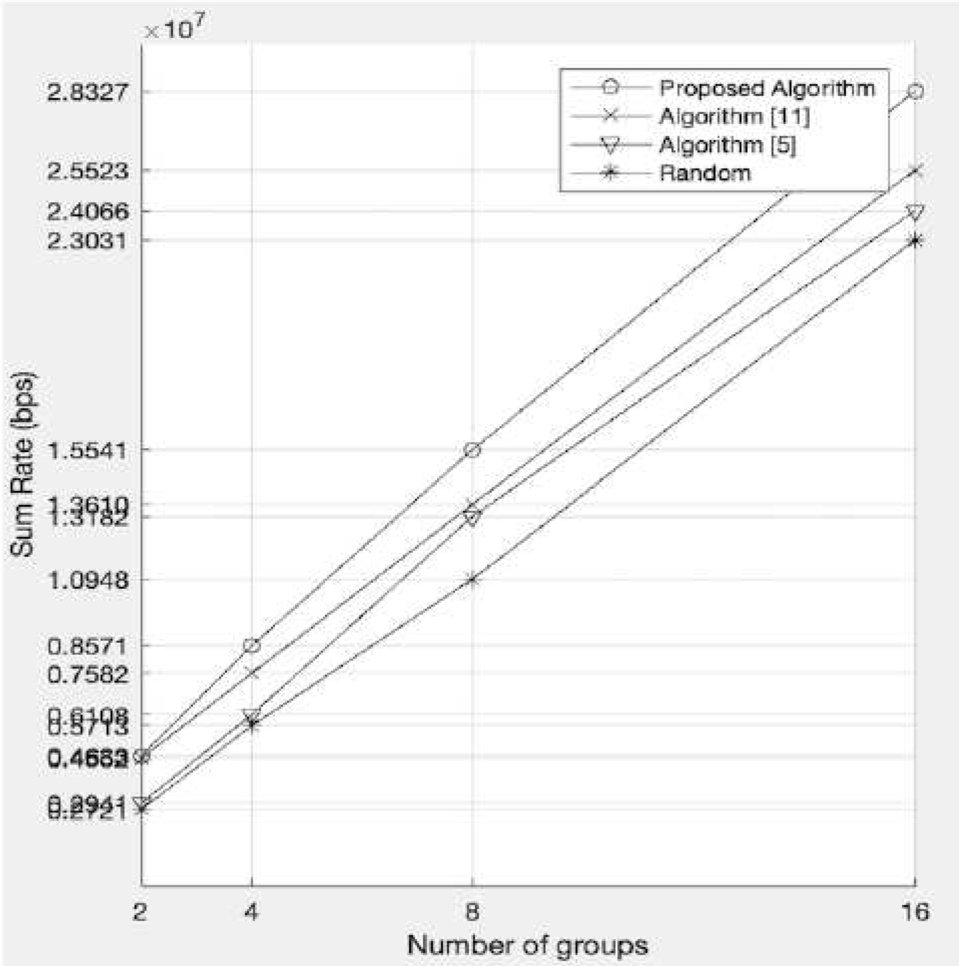

Figure 8

Sum-rate comparison of the Proposed Algorithm with random user grouping, algorithm [5] and algorithm [11] with 32 users

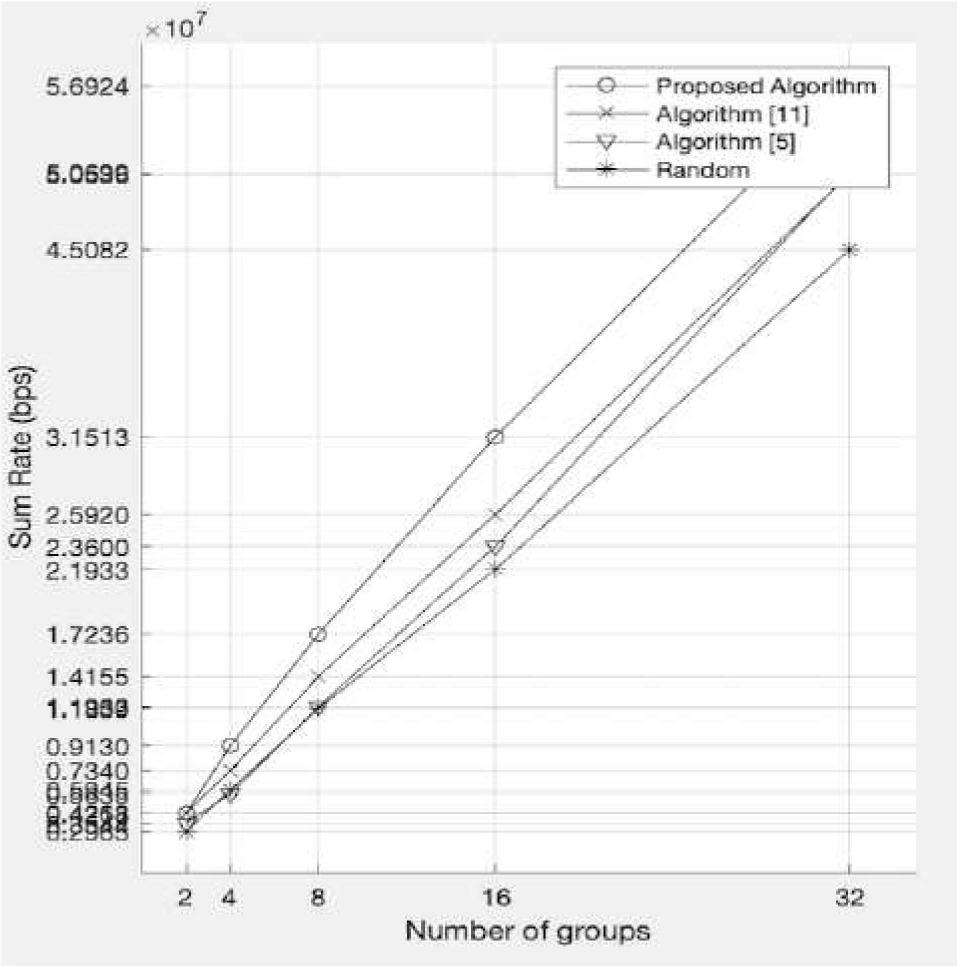

Figure 9

Sum-rate comparison of the Proposed Algorithm with random user grouping, algorithm [5] and algorithm [11] with 64 users

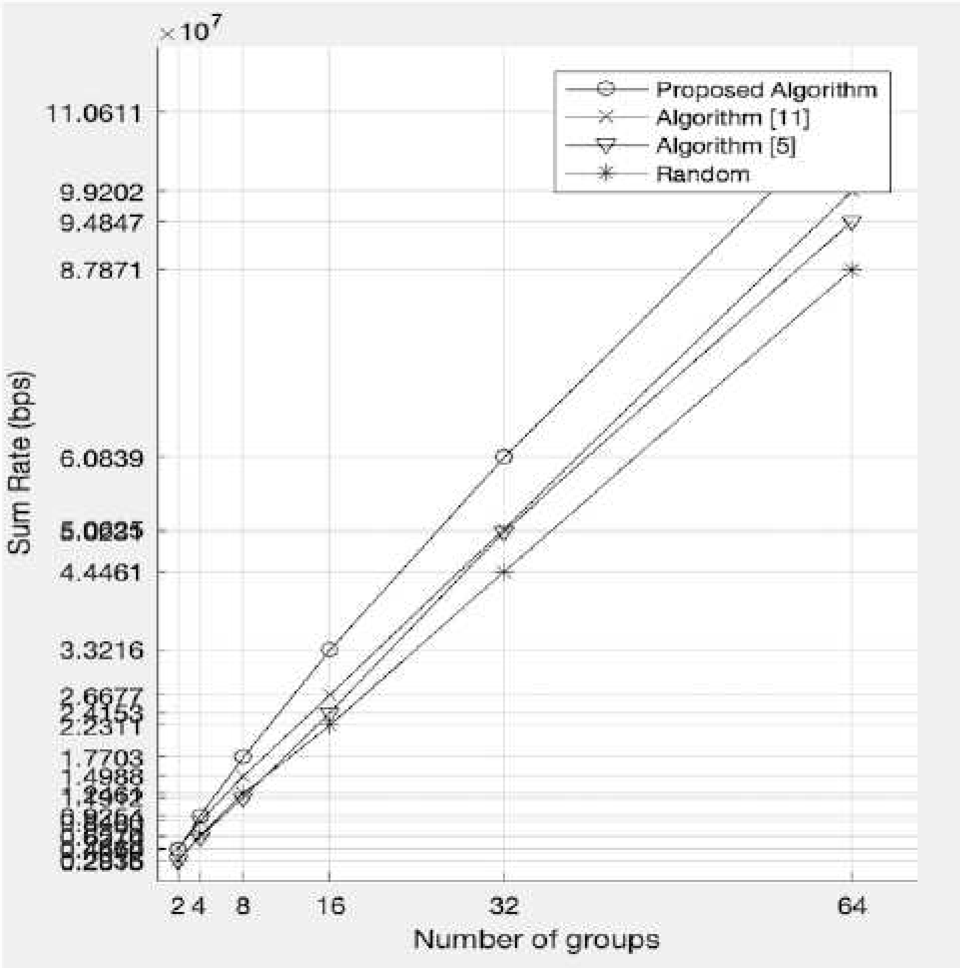

Figure 10

Sum-rate comparison of the Proposed Algorithm with random user grouping, algorithm [5] and algorithm [11] with 128 users

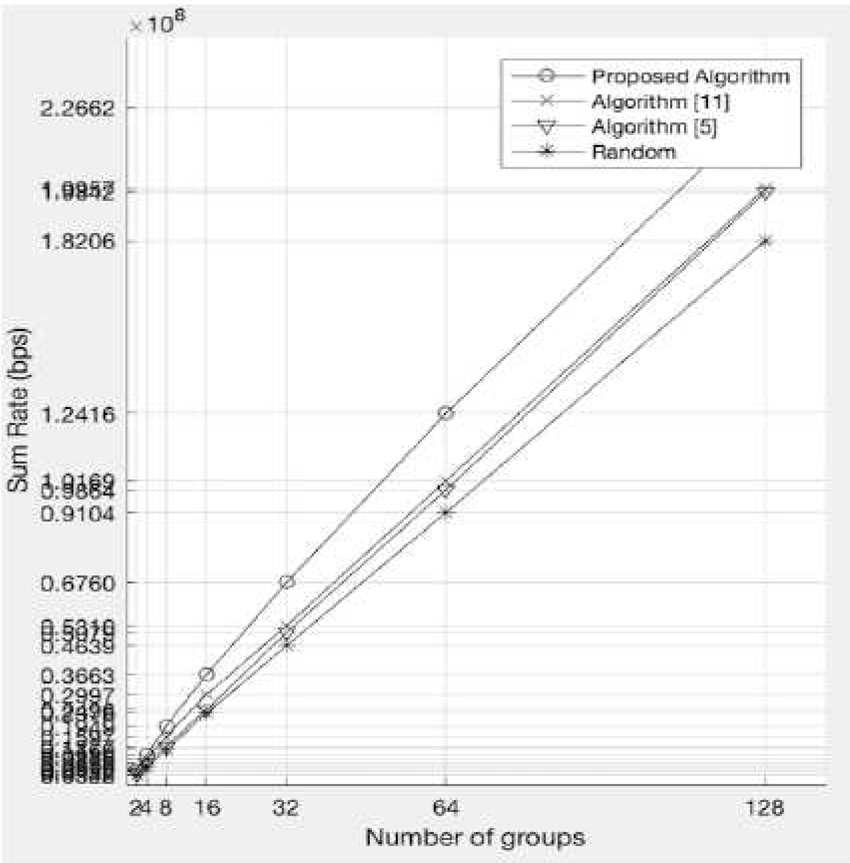

Figure 11

Sum-rate comparison of the Proposed Algorithm with random user grouping, algorithm [5] and algorithm [11] with 256 users

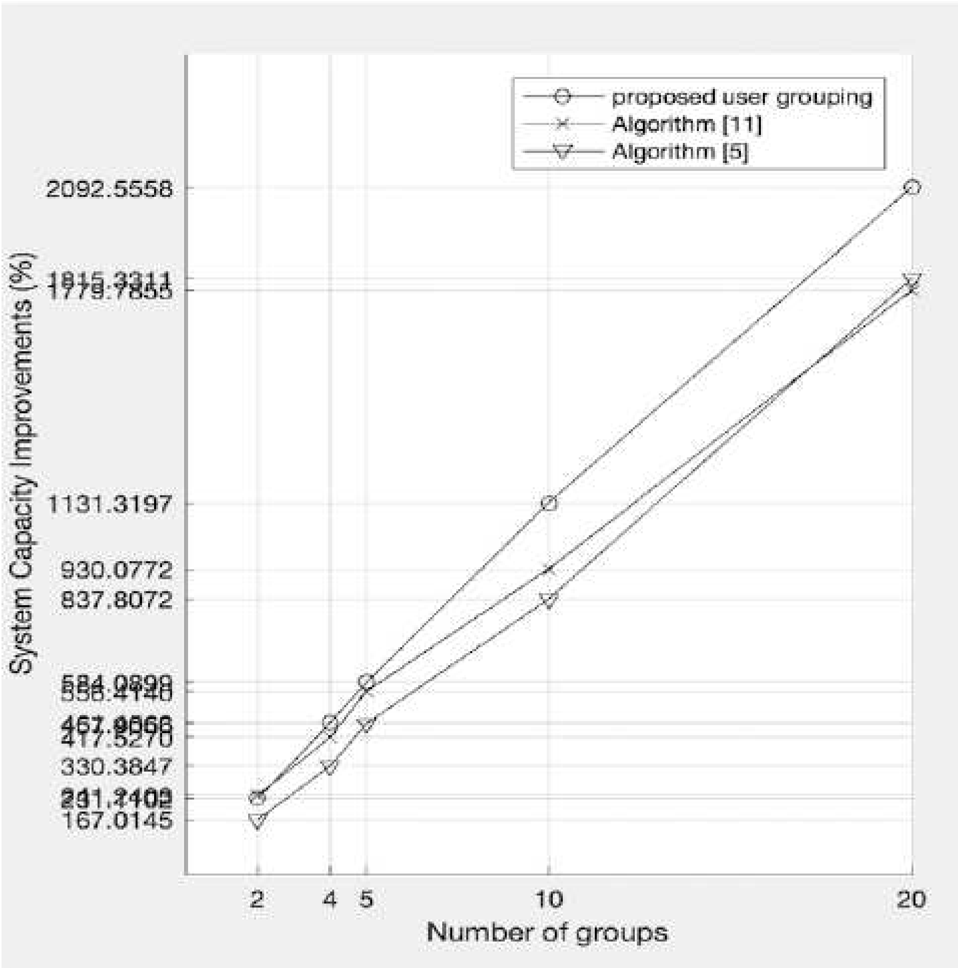

Figure 12

Capacity improvement comparison of the Proposed Algorithm, algorithm [5] and algorithm [11] with 80 users

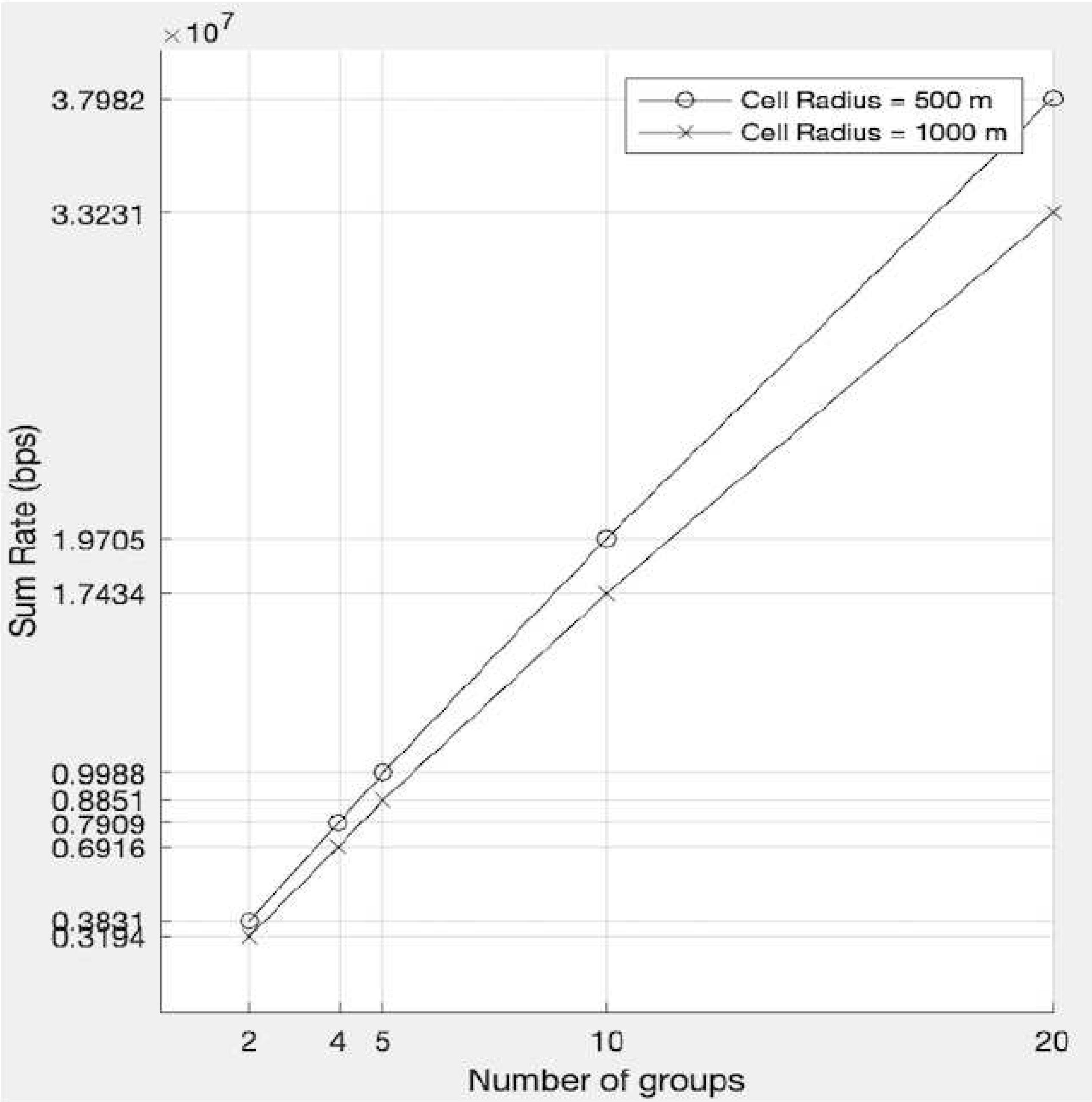

Figure 13

Sum-rate comparison of the Proposed Algorithm in different cell radius