Diyala Journal of Engineering Sciences

Journal homepage: https://djes.info/index.php/djes

ISSN: 1999-8716 (Print); 2616-6909 (Online)

# The Impact of User-Pairing on the Performance of Non-Orthogonal Multiple Access (NOMA) System

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**ARTICLE INFO**

***Article history:***
Received November 3, 2021
Accepted February 15, 2022

***Keywords:***
Non-orthogonal multiple access (NOMA)
User pairing
Sum rate
Energy efficiency

**ABSTRACT**

Non-orthogonal multiple access (NOMA) is being considered as a candidate to meet the expected traffic demand growth in 5G and beyond 5G (5GB) networks. Due to the complexity of applying multiuser detection at the NOMA receiver, a number of works have suggested applying user-pairing to simplify dealing with all users as a whole. This paper addresses the effect of applying user-pairing on the performance of NOMA assisted system in general proposes three different user pairing approaches to examine which one is best for boosting the performance of multiuser NOMA system and making it reaches its potential. This paper evaluates the performance of NOMA system with organized (uniform), random, and distance-based user pairing schemes. Simulation results show that the organized pairing assisted NOMA scheme offers the best performance as compared to its pairing peer techniques in terms of the overall sum rate and the energy efficiency.

## 1. Introduction

Non-orthogonal multiple access (NOMA) has emerged as a candidate air-interface technology in order to provide robust network connectivity, meet high traffic demand, maintain high spectral efficiency and capacity, for the fifth-generation (5G) and beyond (5GB) cellular networks. NOMA provide power domain multiplexing among the communicating users through superposition coding and allows them to share the whole radio spectrum to amplify the overall spectral efficiency [1-3]. Sharing the whole bandwidth is the main difference between NOMA and its orthogonal counterparts that allocates each user with part of the available radio subcarriers [4]. The users are classified and assigned their transmission power according to the received channel powers. Then each user decodes its intended data signal based on its channel rank among its peer, where the weak user treats the stronger user as noise while decoding its own signal. On the other hand, the user with high-channel power decodes the signals of its weaker peers before decoding its intended data, and this mechanism is known as successive interference cancellation (SIC). Applying SIC as well as transmission power assignment to a multiuser NOMA system is still practically under consideration due to complexity issues. Hence, the concept of pairing and clustering forms a measure to reduce this complexity and simplifies dealing with a large number of users.

There are already a considerable number of literatures works about NOMA in which it showed its potential in meeting the expected

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DOI: 10.24237/djes.2022.15108

challenges to be faced in 5G and beyond 5G systems and those works have already proved that NOMA offers good fairness among its users than its predecessors. Many works have addressed NOMA combination with several technologies to boost their performance for future applications; such as multiple-input, multiple output-based NOMA (MIMO-NOMA) systems to boost the multiuser diversity gain as well as improving the spectral efficiency [2], NOMA based Het. Net [5], in which a multipoint-to-point communication is achieved using NOMA concept.

NOMA was also presented as a delivery approach for multicast systems [6], NOMA-based cloud-radio access networks (CRAN) [7], etc., most of those works have showed that expressing a multiuser NOMA system is not simple and requires a complex approach specially to design the SIC decoding process. Therefore, some researchers investigated user pairing and user clustering as a mean to handle this problem. For instance, the work in [1] presented a divide and allocate power allocation technique that depends on pairing the active users in hierarchical manner. This work is different from our considered pairing categories by the fact that the authors of [1] proposed equal power allocation per each user pair before allocating the power individually between the paired users. The authors of [8] considered the downlink of NOMA based millimetre wave (mmWave) networks. They studied user pairing as a means to simplify applying NOMA as underly to mmWave networks. This work focuses on analysing the overall performance through the derivation of the coverage probability expression for the considered system.

This work also pairs the users depending on the predetermined value that is related to the distances from the users to the BSs. The authors in [9] considered user pairing in the uplink to assess the session that the users establish while communicate with the BS to send feedback about the channel state. However, the proposed pairing categories could be assessed for uplink application in future works. However, this work focuses on the uplink of NOMA system while our intention in this paper is to investigate the downlink performance. In addition, the authors in [10] considered optimizing the performance of NOMA based wireless networks. This work differs from our approach in the sense that the authors adopted the assumption of in-band full duplex BS in the applied NOMA system which is very different from our work as it suits half duplex and full duplex scenarios which are out of the scope of our article. Moreover, a downlink NOMA-MIMO system is considered in [11], in which the authors studied users clustering rather than user pairing. The authors investigated the number of users to be clustered and they applied 3-users per cluster as a measure to boost the connectivity and the channel capacity.

However, not many have examined the impact of the nature of user pairing on the overall performance of NOMA based systems. In other words, this paper addresses the effect of user pairing upon the overall behavior of NOMA based wireless systems and not solely from power allocation perspective. This paper also makes benefit from the conclusions obtained by previous works in terms of user pairing importance in simplifying the design of SIC receiver and in reducing the required steps to apply superposition coding in power domain. For example, the authors of [12] presented a hierarchical user pairing based NOMA model to simplify dealing with the complexity of multi user scenario. In [13], the authors presented a scheme that depends on selecting the best-user for full duplex cooperative D2D-NOMA system. Based on which, the cellular spectrum is shared by choosing the D2D source that offers the highest achievable SINR. In addition, the optimization NOMA based CRAN is investigated by [7] in terms of the achievable energy efficiency. The authors proposed a number of power allocation assignments and addressed the effectiveness of NOMA-CRAN combination in a multi-tier network. Nevertheless, the authors in [14] studied pairing in NOMA system to support its fairness, however, they stated that the considered approach has a considerable complexity and they formulated an optimization problem which has a nonconvex nature and requires mixed integer optimization programming to be solved.

On the other hand, in this paper, all the considered pairing categories have simple procedures to be applied. Lately, new techniques are being investigated to improve the overall performance of NOMA based systems, such as intelligent reflective surface (IRS) [15-17] that consist of adding a plane of reflective surface that contains array of reflective elements into the coverage area to strengthen the received signals by user-pairs. Cell free massive MIMO [18, 19] is also being proposed to be combined with NOMA to increase the spatial diversity gain.

## 2. The proposed user pairing methodologies

Figure 1 illustrates a simple scenario of four active users trying to communicate in pairs within a coverage area that is obstacle with buildings. This an example of pairing the active users into two pairs, namely, pair A and B. to be more practical, Table 1 displays the parameters adopted in this paper's simulation along with this scenario and those parameters were chosen based on LTE standards. The mechanisms behind pairing the users will be explained next and a comparison among user pairing techniques will be investigated to identify the best approach and to examine their effect on the overall NOMA system performance. Three user pairing categories will be proposed and compared in this paper to examine which approach is better for NOMA system performance.

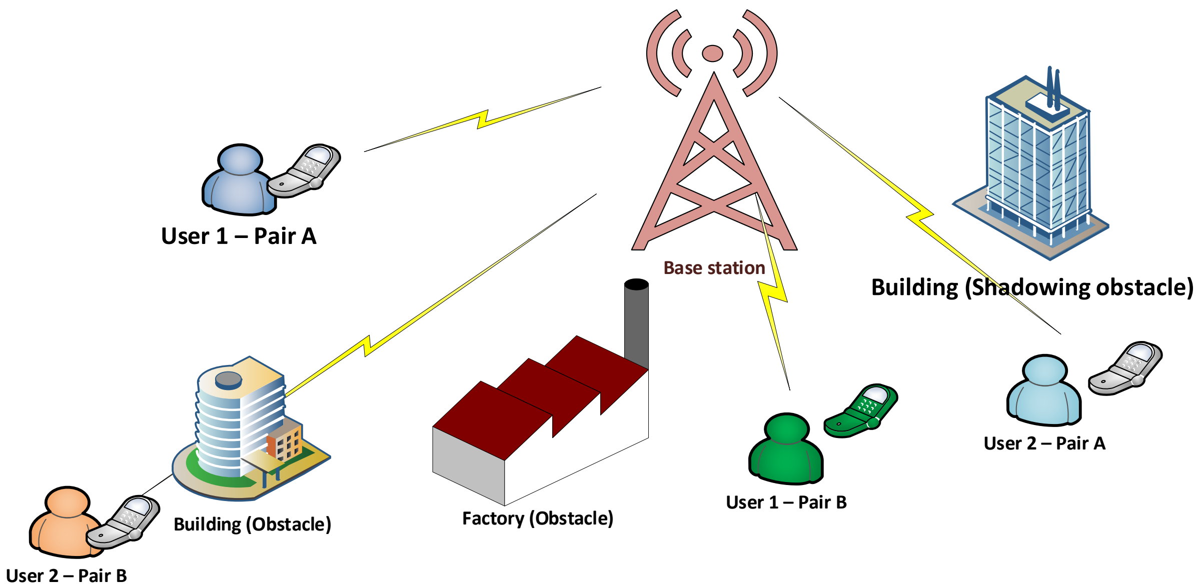


**Figure 1.** Active user pairs communicating through the base station

**Table 1**: Parameters used in simulation set up

| Parameter | Value | Parameter | Value | Parameter | Value |
|---|---|---|---|---|---|
| No. of active users (M) | 8 | No. of radio resources (N) | 50 | Resource bandwidth ($B_n$) | 200kHz |
| Total transmission Power ($P^T$) | 40dBm | Path loss exponent ($\alpha$) | 3.76 | Diameter of the coverage area (D) | 0.5km |
| Overall bandwidth (B) | 10 MHz | Noise power spectral density ($N_0$) | 174 dBm/Hz | Lognormal shadowing standard deviation ($\beta$) | 8dB |

### *2.1 Category I: Organized user pairing*

An organized user pairing scheme will be compared against a random pairing, where in the former pairing scheme the users are organized in a queue ascendingly or in descending order according to their received channel gains as described in Algorithm 1. Then each user is paired to its next neighbor user.

Algorithm 1: Organized pairing

- **(go through all channel gains)**

***for*** z = 1: length [channel_gains]

- **(save a specific channel gain)**

element_z = channel_gains[z]
i = z – 1

- **(as there is still unconsidered channel gains and indices, continue sorting)**

***while*** i > 0 && channel_gains[i] < element_z ***do***
channel_gains[i+1] = channel_gains[i]
i = i - 1
channel_gains[i+1] = element_z
***end while***
***end for***

In this case, the strongest pair will cancel the signals of all other pairs with lower channel gains using SIC and after that decodes its data signal. On the other hand, the pair with the lowest channel gains will treat the stronger pairs as noise and then decodes its intended data signal.

### *2.2 Category II: Random user pairing*

The concept behind random pairing is simpler than the organized pairing counterpart as it does not require the users to be arranged in queue. Random pairing simply works in such that the base station will count the number of active users and pair every two users regardless of them having the highest and/or the lowest channel powers. SIC will be applied as stated earlier with the exception in here is that the channel gain summation of the paired users will determine whether they consider others as noise or cancel them with SIC before detecting their own data signals. It is worth mentioning that both pairing approaches require the knowledge of the channel state information (CSI) at the base station.

### *2.3 Category III: Distance based user pairing*

In this pairing category, the users are paired based on their distance to the serving base station. This distance plays a major role in deciding the large scale fading experienced by the users, in particular, the cell edge users. In this pairing category, each user is simply paired with its closest peer. Considering the distance as a pairing criterion is mainly to check if it plays a vital role in the overall system behaviour.

## 3. System model

To assess the proposed pairing categories, a downlink NOMA system is simulated with a base station at the center of a coverage area with diameter *D*=0.5km. In which there are *M* active users who are being served by that base station using NOMA by sharing the whole radio bandwidth (*B*). For such set up, the total achievable sum rate according to (downlink) NOMA principle is given as

$$S_{Total} = B \sum_{m=1}^{M} \sum_{n=1}^{N} \log_2(1 + \Gamma_{m,n}) \ \left(\frac{bit}{\sec}\right) \qquad \dots (1)$$

where $\Gamma_{m,n} = \frac{P_{m,n} G_{m,n}}{N_0 + \mathrm{I}}$ stands for the *m*-th user SINR over the *n*-th radio resource and $\mathrm{I} = \sum_{j=m+1}^{M} P_{j,n} G_{m,n}$. Where $P_{m,n}$ is the transmission power assigned to the m-th user over the *n*-th resource, and the variable $G_{m,n}$ denotes the channel gain received by the *m*-th user over the *n*-th resource, and it hold the effect of the small scale, selective fading channel as well as the large scale fading channel and it is evaluated as $G_{m,n} = \left|h_{m,n}\right|^2 d_{m\ m}^{-\alpha} \eta_m$, with $d_m, \alpha$ and $\eta_m$ refer to the distance between the *m*-th user and the serving base station, the path loss exponent, and the lognormal shadowing factor, respectively.

For the decoding purposes at the NOMA receiver, the users are considered to be in an ascending order. It is worth mentioning that $\mathrm{I} = 0$ for the user with the highest $G_{m,n}$ as it will apply SIC to cancel all other users signals before extracting its own. Another performance benchmark examined in this paper is the energy efficiency. Examining the overall system energy efficiency is necessary to limit the power consumption which is an important resource. The energy efficiency represents the ratio of the sum rate to the total available power and it could be given as [20]

$$\text{Energy effciency} = \frac{\mathrm{S_{Total}}}{\sum_{\mathrm{m=1}}^{\mathrm{M}} \sum_{\mathrm{n=1}}^{\mathrm{N}} \mathrm{P_{m,n}}} \left(\frac{\text{bit}}{\text{joule}}\right) \quad \dots (2)$$

### *3.1 Per-User power allocation*

To maintain a fair comparison among the proposed pairing categories. The power is assumed to be allocated equally among the formed user pairs, i.e., the power of each pair is determined by $pair\ power\ (P_e) = P^T/(M/2)$, where $P^T$ refers to the total available transmission power at the base station. After deciding the total pair power, then the power allocated within each pair is performed by allocating the user with the high channel gain $0.7P_e$ while the user with the low channel gain is given $0.3P_e$, keeping in mind the power allocated among all the users maintain the constraint $\sum_{m=1}^{M}\sum_{n=1}^{N} P_{m,n} \leq P^T$.

## 3. Results and discussion

This section presents simulation results to evaluate the performance of the proposed user pairing categories. The applied simulations were obtained through MATLAB through Monte-Carlo iterations, and the simulation set up was based on the parameters listed in Table 1. It should be noted that those parameters were chosen according to 5G and 3GPP-LTE standards to emulate practical situations.

Figure 2 displays the behaviour of the user pairing categories in terms of the achieved sum rate against various numbers of active users. This figure shows that in general, all the categories' trends are declining as the numbers of users increase, this is due to the increased competition over the available resources. A detailed examination of Figure 2 shows that category I (i.e., organized user pairing) offers the best performance as compared to the other categories, whilst category III (i.e., the distance-based user pairing) offers the worst performance trends. This is evidence that user arrangement before pairing application is very necessary as it affects the power allocation and the detection process at each user pair.

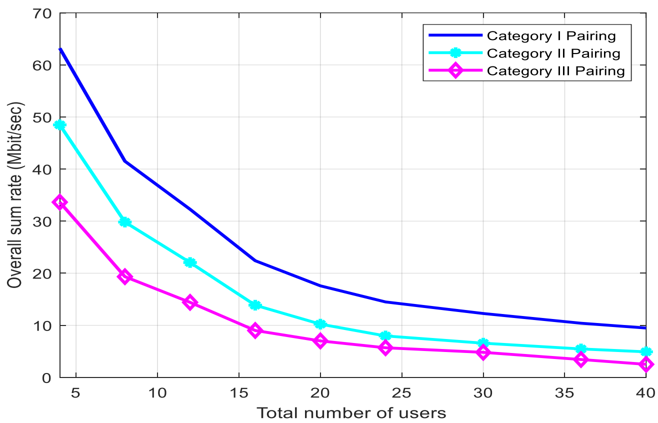


**Figure 2.** Evaluating the overall system sum rate in terms of the total number of users

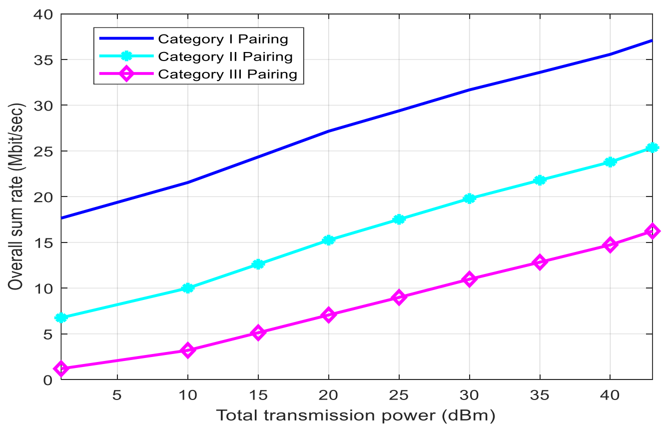


**Figure 3.** Evaluating the overall system sum rate for several levels of transmission power

Figures 4 and 5 illustrate the performance of the compared pairing categories against increasing numbers of users and transmission power levels, respectively. Assessing the energy efficiency behavior is necessary to check how well each pairing category affects the consumed power. From Figure 4, it is obvious that the energy efficiency of all the compared categories increases slightly as a result of multiuser diversity gain. This figure also proves that category I pairing is the best among its counterparts.

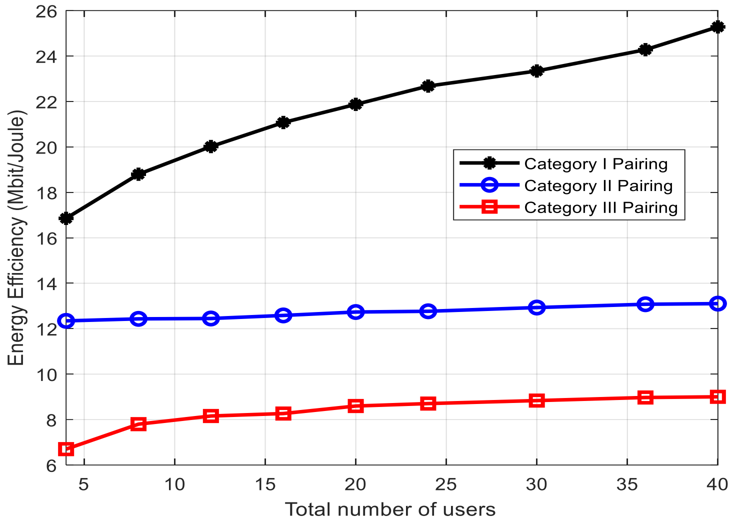


**Figure 4.** A comparison among the studied pairing categories in terms of the energy efficiency against increasing numbers of active users

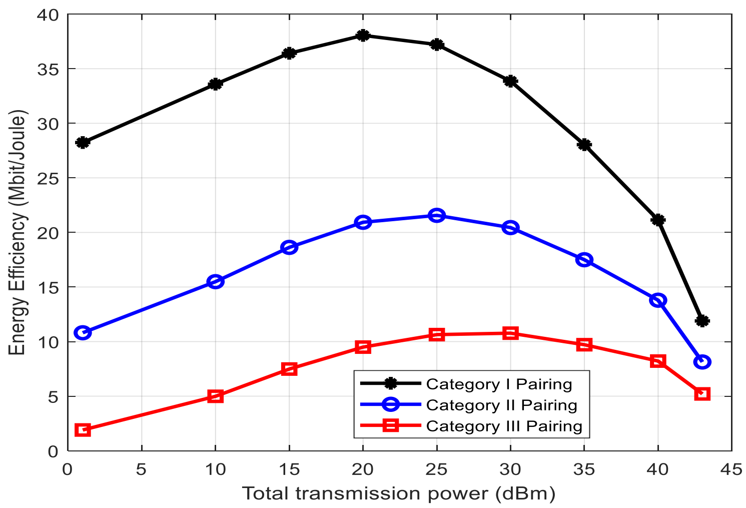


**Figure 5.** Energy efficiency evaluation for the three user pairing categories against various levels of transmission power

Figure 5 confirms the superiority of category I pairing as compared to categories II and III. In addition, it also indicates that the NOMA-energy efficiency is a convex function of the transmission power. This because, as the transmission power increases it helps NOMA users' pairs to comfortably maintain a stable performance and reach a good quality of service level. After that, the energy efficiency starts to increase then, at a certain level, drops down which reflects the fact that the extra available power becomes wasted and the system becomes energy inefficient.

## 4. Conclusions

This paper presented a downlink NOMA system with multiuser scenario. Three user pairing categories were proposed to investigate the best pairing approach that could serve NOMA to reach its potential and meet the expected challenges in 5G and 5GB networks. Namely, organized, random, and distance-based user pairing was considered and the obtained results showed that adopting organized user pairing depending on the overall user-channel gain offers the best version of NOMA system. On the other hand, the random user pairing approach offered less gain than its predecessor despite its simplicity, whilst the distance based user pairing approach offered the least performance gain which reflects the fact that the distance does not provide a comprehensive view of the user channel conditions.

To be specific, at a transmission power level of 15dBm, category I pairing achieves a sum rate and energy efficiency of 24 Mbit per second, and 36 Mbit per joule, respectively, which is about the double outcome of the levels reached by category II pairing at the same level of transmission power. On the other hand, at 15 dBm of transmission power, category III pairing achieves a sum rate of 5 Mbit per second and energy efficiency of around 8 Mbit per joule. Moreover, in terms of increasing numbers of users against the energy efficiency, category I pairing expresses noticeable proportional performance in accordance with the numbers of users where, as depicted in figure 4, the energy efficiency varies from 17 to 25 Mbit per joule as the users increases from about 2 to 40 users. However, under the same circumstances, category II pairing shows almost a flat behaviour, and so is the case with category III pairing except the period where the users varies from 2 to 5.

For future research direction, it is possible to consider clustering in addition applying radio subbands based user pairing. Another future direction could include user pairing assisted D2D-NOMA communication system. It is also interesting to apply high data rate evaluation techniques that were used in [21] on NOMA to test its response as it offers high data rates. Moreover, it is interesting to consider image-reformation techniques such as wavelet transform [22] and framelet transform [4] in designing the SIC structure.

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