FACTA UNIVERSITATIS
Series: **Automatic Control and Robotics** Vol. 22, Nº 1, 2023, pp. 29 - 38
https://doi.org/10.22190/FUACR230324003P

Regular Paper

PERFORMANCE OF UPLINK-NOMA WITH USER PAIRING AND DATA RATE-BASED POWER SCHEME

UDC ((519+004.451.5):621.395.38)

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Abstract. *This paper analyzes a performance of uplink power-domain non-orthogonal multiple access (NOMA) system with 2K users in which a resource allocation is taken into consideration. Since the power allocation and user pairing are tightly intertwined, they are considered as a hybrid issue. Accordingly, High-High/High-Low user pairing process precedes date rate-based power allocation. Derived closed-form expressions for the outage probabilities and the sum data rate for uplink power-domain NOMA system over a composite Fisher-Snedecor (F) fading channel are used for an extensive performance evaluation. The impact of different fading/shadowing channel conditions, various users' positions and their number on the performance metrics is examined. Presented results have high level of generality since the F fading model provides accurate characterization of the multipath/shadowing conditions in numerous communication scenarios of interest.*

Key words: *Composite fading channels, non-orthogonal multiple access, sum data rate, outage probability, uplink communication*

Received March 24, 2023 / Accepted May 08, 2023
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1. INTRODUCTION

Recent studies demonstrate that the non-orthogonal multiple access (NOMA) has the potential to be applied in various fifth generation (5G) communication scenarios, including Machine-to-Machine (M2M) communications and the Internet-of-Things (IoT). Moreover, there are some of performance improvement when NOMA is integrated with various effective wireless communications techniques, such as cooperative communications, multiple-input multiple-output (MIMO), beamforming, space–time coding, network coding, full-duplex, etc. [1]-[3]. In addition, besides artificial intelligence (AI)/machine learning (ML), quantum communication/quantum machine learning (QML), blockchain, terahertz and mmWave communications, tactile internet, small cell communication, fog/edge computing, NOMA is also seen as one of key technologies to achieve beyond 5G (B5G) and 6G communications [4].

NOMA schemes can be generally grouped into two types: code-domain and power-domain NOMA. The power-domain NOMA can serve multiple users in the same time slot, OFDMA subcarrier, or spreading code and multiple access is realized by allocating different power levels to users [5]. In the code-domain NOMA, each user is assigned a unique codebook which is complex-valued and multidimensional [6]. The code-domain NOMA can enhance the spectral efficiency, but it requires a high transmission bandwidth and it is not easily applicable in the current systems. On the other hand, the employment of the power-domain NOMA does not require hefty structural changes in the existing networks and, moreover, improves the spectral efficiency without using the additional bandwidth [7].

In order to exploit benefits that the power-domain NOMA offers, it is necessary to tackle user pairing and power allocation issues. The importance of user pairing, assigning two users to a single resource block, is investigated in [8]. It is shown that pairing users, whose channels are significant different, results in the high performance gain over OMA using fixed power allocation technique. In a real scenario where large number of users is located in the cell, the differences in channel gains between matched users decrease resulting in overall capacity degradation [9]. Therefore, the clustering – the process of selecting which users form a particular cluster (in two-user NOMA this is often referred to as 'pairing') should be addressed. In [10], the proposed pairing scheme provides uniform gap gain for all pairs avoiding or minimizing the mid users pairing problem. Authors in [9] presente distributed NOMA (D-NOMA) which exploits the intergroup gap and facilitates a controlled data throughput distribution of NOMA weak pairs more precisely. In [11], the developed vertical pair concept does not affect the bandwidth occupied by the users and all users use all available spectrum. The pairing scheme adequate to be used in NOMA applicable for visible light communication is presented in [12]. Further, the pairing schemes grouping two and three users in each cluster and at the same time appropriate for MIMO-NOMA are described in [13,14]. Power allocation inherently intersects with user pairing. Fixed power allocation and dynamic power allocation algorithms can be distinguished. Fixed power allocation model assigns the same power levels to users, while in the case of the dynamic power allocation model the power level for each user can be adjusted depending on the instantaneous channel gain. The dynamic power allocation algorithms characterized with low complexity are proposed in [15,16]. Unfortunately, they cannot provide high-capacity requirements of future mobile communication systems. The algorithm presented in [17] could achieve the optimal total throughput performance, but their complexity makes it difficult for the practical systems for multiuser scenario. To solve the problem of computational complexity, providing at the same time the performance close to the optimum in terms of sum capacity, machine learning and deep learning based methods for downlink NOMA are proposed in [18].

Fading and shadowing are fundamental characteristics of wireless channels. Therefore, their characterization in the propagation wireless channel is important for improving the system performance. Widely used fading models are Rayleigh, Rice, Nakagami-m, and Hoyt, while shadowing is usually statistically modelled by the lognormal distribution. So therefore, the composite fading channel is usually modelled as Rayleigh-lognormal, Rice-lognormal and Nakagami-lognormal. The main drawback of the lognormal distribution is its analytical intractability. The gamma distribution is proposed as an alternative to the lognormal distribution. It is more mathematical tractable and leads to new composite fading models (K model, generalized K model) [19]. The Fisher-Snedecor, F, distribution is alternative to the composite generalized K distribution, and also it is proposed as better fit for the experimental data [20]. In [21], it can be found a comprehensive summary of analyzed performance metrics of uplink NOMA systems over different fading channels.

In light of the importance and actuality of the F fading model for characterization of a wireless channel, we analyze the outage performance of the uplink power-domain NOMA system over the composite F fading channel in [22]. Based on the analytical expressions for outage probabilities of users operating in the two-user NOMA system derived in [22], the new power allocation algorithm is proposed in [23]. Since the proposed algorithm is designed for two-user NOMA system, to apply it in a realistic scenario, it is necessary to couple it with an adequate user pairing scheme. In this paper we apply High-High and High-Low pairing schemes [24].

2. System and Channel Model

In the considered system, $2K$ users are uniformly-distributed within a cell and grouped in a cluster composed of two users. The grouping of a large number of users in NOMA cluster is not recommended because of the performance degradation caused by a residual interference, increased complexity and power consumption. Each group consists of a cell-center, i.e. near user, U_{C-C}, and a cell-edge, i.e. far user, U_{C-E}, which represent the user pair. Base station (BS) is located at the center of the cell. Both users simultaneously transmit their information symbols, s_i (i = 1 for U_{C-C} and i = 2 for U_{C-E}) to the BS over a same resource. It is supposed that one resource block (RB) is allocated to every pair and all users are equipped with a single antenna (Fig. 1).

In uplink two-user NOMA system, the signal received at the BS is expressed as the linear combinations of two transmitted signals

$$y = \sum_{i=1}^{2} \sqrt{g_i P_i} h_i s_i + n, \tag{1}$$

where h_i is the channel coefficient and P_i is the transmit power of i-th user in the cluster, with P representing the total power per RB. A distance-based path gain between the BS and the i-th user in the cluster is defined as $g_i = g_0 / [H^2 + (x_i^2 + y_i^2)]^{\beta/2}$ [21], where g_0 is the reference gain at the reference distance, β is the path-loss exponent, x_i and y_i are coordinates that define the position of the i-th user of the cluster in the cell, and H is BS antenna height. It is satisfied that $E\{|s_i|^2\} = 1$, while n denotes additive white Gaussian noise (AWGN) with zero-mean and variance σ^2.

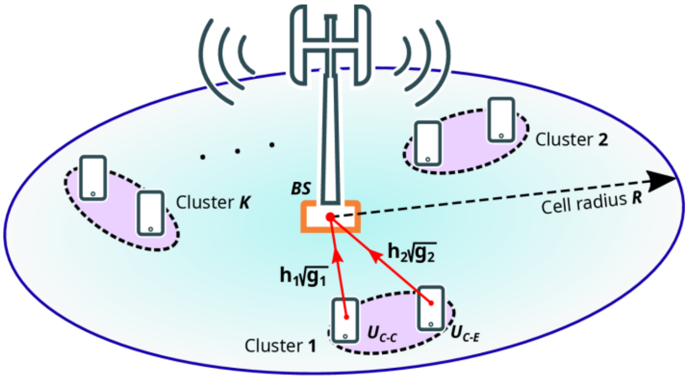

Fig. 1 System model [22]

In downlink power-domain NOMA, multiple users share the same resource domains, but different power levels are allocated to each of them at the BS/transmitter. Detection of the transmitted signals should be done at receivers appling the successive interference cancelation (SIC). In uplink power-domain NOMA, users also share the same resources, but simulatneously transmit signals to common receiver/BS. Thus, the received signal is the superposed signal comprising of signals transmitted from all users. Now, the SIC is employed at BS to decode the information transmitted from multiple users.

In uplink NOMA, users are ordered in a way that their indexes follow the order of decreasing channel gains. Therefore, a stronger channel user is decoded at the BS experiencing interference from all other users in the cluster/pair with weaker channels. For the considered system we can write $g_1|h_1|^2 > g_2|h_2|^2$. Therefore, after decoding the signal sent by the first user, in our case by the cell-center user, s_1, the BS substracts $\sqrt{g_1 P_1} h_1 s_1$ from the received signal y. Then the signal corresponding to the second user, s_2, is decoded. The received signal-to-interference-noise ratio (SINR) associated with the signal transmitted by the i-th user can be evaluated as [22]

$$\gamma_{i,NOMA} = \begin{cases} \dfrac{g_1 P_1 |h_1|^2}{g_2 P_2 |h_2|^2 + \sigma^2}, & i = 1 \\ \dfrac{g_2 P_2 |h_2|^2}{\sigma^2}, & i = 2 \end{cases}. \tag{2}$$

The transmit power allocated to near and far users, in each cluster, are P_1 and P_2, respectively. These powers can be defined as $P_1 = a_1 P$, $P_2 = a_2 P$, with $0 < a_1 < 1$, $a_1 > a_2$ and $a_1 + a_2 = 1$.

The outage performance of uplink two-user NOMA system is analyzed in [22]. The outage probabilities of cell-center, $U_{C\text{-}C}$, and cell-edge, $U_{C\text{-}E}$, users are derived respectively as

$$\begin{aligned} P_{out,1}(\gamma_{th,1}) = & \frac{1}{\Gamma(m_1)\Gamma(k_1)\Gamma(m_2)\Gamma(k_2)} \sum_{r=0}^{+\infty} \frac{(-1)^r g_1^r k_1^r \overline{\gamma}_1^{\,r}}{m_1^r \gamma_{th,1}^r r!} \\ & \times G_{4,4}^{3,3}\left(\frac{m_2 g_1 k_1 \overline{\gamma}_1}{m_1 g_2 k_2 \overline{\gamma}_2 \gamma_{th,1}} \middle| \begin{matrix} 1, 1-k_2, r-m_1+1, r+1 \\ m_2, r+k_1, r, r+1 \end{matrix} \right) \end{aligned} \tag{3}$$

$$P_{out,2}(\gamma_{th,2}) = 1-[1-P_{out,1}(\gamma_{th,1})]\left[1-G_{2,2}^{1,2}\left(\frac{m_2\gamma_{th,2}}{g_2 k_2 \overline{\gamma_2}}\middle|\begin{matrix}1-k_2,1\\ m_2,0\end{matrix}\right)\right], \tag{4}$$

where $\gamma_{th,i}$ is the threshold rate, $R_{c,i}$ ($\gamma_{th,i} = 2^{R_{c,i}} - 1$) is the target rate, m_i is the fading severity parameter, k_i is the shadowing shaping factor and $\overline{\gamma_i}$ is the average SNR corresponding to the i-th user in the cluster/pair. The $G_{p,q}^{m,n}\left(z\middle|\begin{matrix}-\\-\end{matrix}\right)$ is the Meijer's G function and $\Gamma(\cdot)$ is the Gamma function.

3. USER PAIRING IN UPLINK NOMA

As we have already supposed, $2K$ NOMA users are spatially located in the cell. High capacity gain can be achieved if users in cluster have a significant disparity in the channel gains. Therefore, it cannot be achieved with a large number of users in a cluster [25]. So, that indicates the necessity of using some pairing scheme. In this paper we implement High-High/High-Low pairing schemes. This two schemes are described through the following steps [24]:

1. Divide all users into two groups: High channel gain users and Low channel gain users.
2. Arrange users in each group in descending channel gain order.
3. Form a cluster of two users by pairing users from each group forming a K user pairs as: Paring the first user of the high channel gain user group with the first user of low channel gain user group, and so on $\{\{h_1, h_{K+1}\}, \{h_2, h_{K+2}\},...\}$ – High-High scheme; Paring the first user of the high channel gain user group with the last user of low channel gain user group, and so on $\{\{h_1, h_{2K}\}, \{h_2, h_{2K-2}\},...\}$ – High-Low.

4. POWER ALLOCATION ALGORITHM

Some of performance metrics that can be taken into consideration in the design of power allocation algorithms are sum rate, fairness, energy efficiency, number of admissible users, etc. A retrospective of some well-known power allocation algorithms can be found in [26].

In [23], the power allocation algorithm based on achievable sum data rate of uplink two-user NOMA trasmission is proposed. Namelly, the power levels allocated to two users, in the previously determined cluster/pair, are obtained to maximize the sum data rate, as

$$\begin{aligned}\max R_{sum} &= \max\left\{R_{c,1}[1-P_{out,1}(P_1)] + R_{c,2}[1-P_{out,2}(P_2)]\right\},\\ P_1 + P_2 &= P.\end{aligned} \tag{5}$$

5. NUMERICAL RESULTS

In this section, we investigate the outage and capacity performance of the uplink NOMA system in which High-High/High-Low schemes are used for the clustering process, while the dynamic power algorithm based on the sum data rate is applied to assign different power levels to clustered users. In the simulation setup, it is assumed that users are uniformly distributed within a circle with radius of 200 m. BS is located in the center of the circle, mounted at the height of 100 m. So, using notation (x, y, H), the position of BS can be marked as (0, 0, 100).. Consequently, the position of cell-center and cell-edge users in the cluster can be marked as (x_1, y_1, 0) and (x_2, y_2, 0), respectively. The additional simulation parameters are $g_0 = 50$dB and $\beta = 3$. The different wireless channel conditions are perceived through different values of fading parameters k_i and m_i.

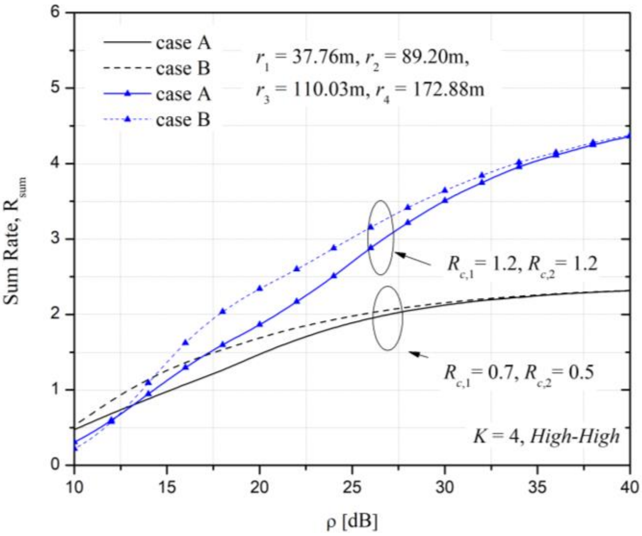

Fig. 2 Sum data rate versus ρ (K = 4, position 1)

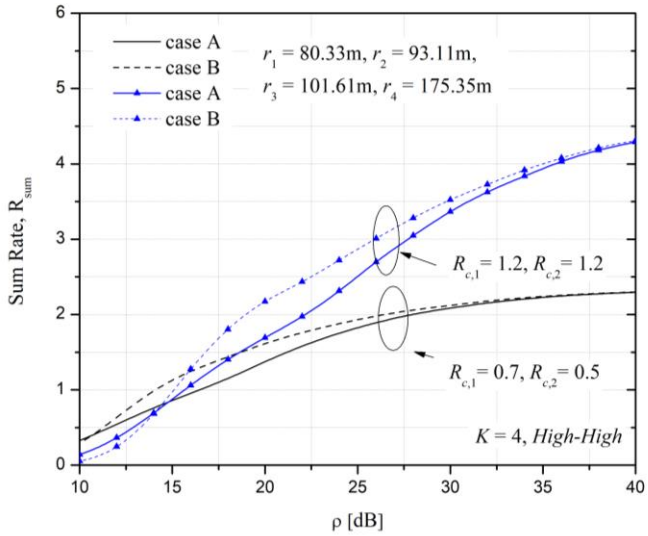

Fig. 3 Sum data rate versus ρ (K = 4, position 2)

Figure 2 and 3 plots the achievable sum data rate as a function of the signal-to-noise ratio (SNR), $\rho = P/\sigma^2$, for the scenario of four users differently positioned in the cell (position1 and position 2). In addition, two different channel conditions are set as case A and case B.

Case A	$m_1 = 1, m_2 = 1, k_1 = 12, k_2 = 3$
Case B	$m_1 = 3, m_2 = 1, k_1 = 10, k_2 = 1$

Also, two different target rate distributions between users in the cluster are defined.

Let us analyze the presented results. Increase in the transmit power leads to growth in data sum rate that achieves its saturation, determined by target data rates $R_{sum\max} = K(R_{c,1} + R_{c,2})$, for high SNR. The explanation for that can be found in the applied power allocation algorithm which determines power coefficients, a_1 and a_2, to realize the maximum possible sum data rate for any SNR value. It is well known that in the composite *F* fading model, the parameter *k* defines the sharpness of the shadowing phenomenon, while the parameter *m* defines the fading severity. Better channel conditions, i.e. higher values of parameters *k* and *m* (light shadowing and less severe fading conditions) ensure that the system can offer a higher data rate to users for small and moderate SNR values. For high SNR values, the influence of channel conditions is neglected, since the applied power allocation algorithm provides that NOMA system offers maximum data rate to users. It is noticable that the influence of a wireless environment on the capacity performance of NOMA system is more intensive for higher target rates. If we compare Figs. 2 and 3, we can find that more uniformly distributed users in the cell lead to higher difference in channel gain between users, that is preserved with applied High-High user pairing scheme, which provides higher achievable sum data rate.

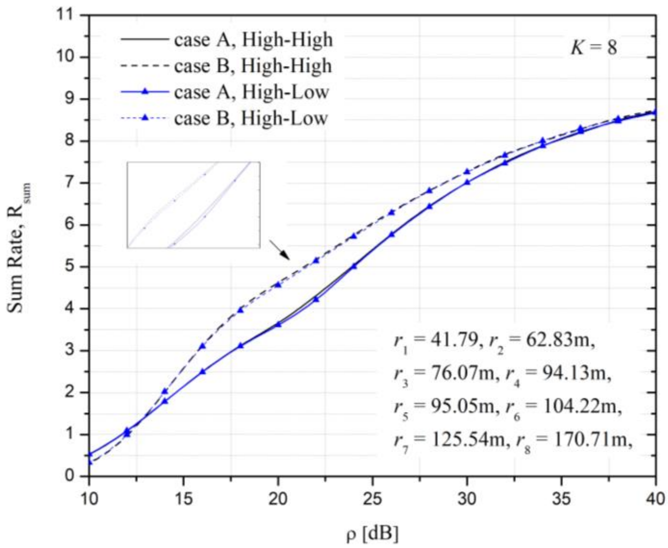

Fig. 4 Sum data rate versus ρ (K = 8)

Results presented in previous two figures refer to the High-High user pairing scheme. Intending to compare High-High with High-Low new results are depicted in Fig. 4. Difference between these two schemes is diminutive, but still in favour of High-High. Even it is not presented in the figure, same behaviour of curves exists also for the number of users larger than eight. The advantage of the first scheme can be explained with a constant difference in channel gain between all paired users. In contrast to that, in the High-Low scheme there are pairs with significant difference in channel gain (for example the first pair – the strongest and the weakest user), as well as the pair with the almost negligible difference. The latter case is not recommended for NOMA due to a strong influence of interference during the decoding process (for example last pair – the users quite close to each other). Probably, the applied power allocation algorithm does not allow a higher difference between these two pairing schemes from the sum data rate point of view.

In Figs. 5 and 6, the outage probabilites of cell-center user, U_{C-C}, and cell-edge user, U_{C-E}, as a function of the average SNR are depicted. It is supposed that twenty users operates in the cell and wireless channel conditions are discribed as case B. Outage probabilities of the paired

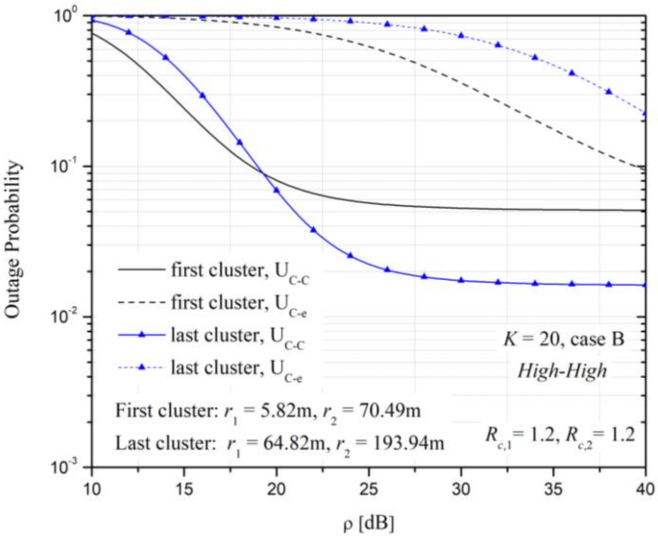

Fig. 5 Outage probability versus ρ (K = 20, High-High)

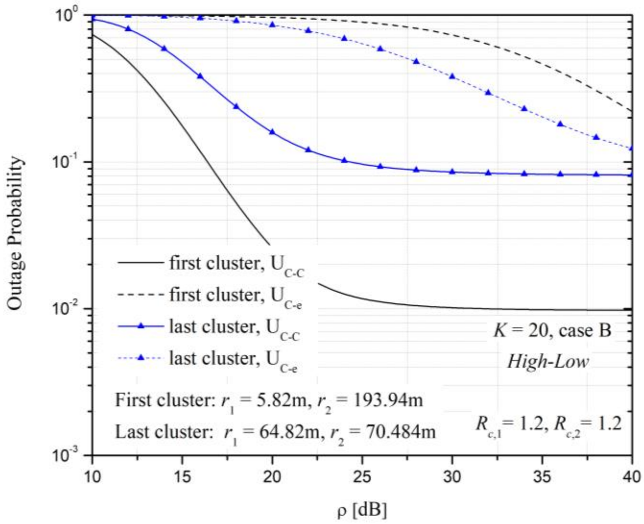

Fig. 6 Outage probability versus ρ (K = 20, High-Low)

users in two clusters are presented, the first and the last one, for both considered pairing schemes. It is confirmed once again that greater difference in channel gain between paired users provides better system performance. Therefore, the outage performance of NOMA user pair grouped by High-Low algorithm is a sligthly worse, especially for the last pair. In order to improve outage performance of that user pair, actually the user pair with small difference in channel gain between users, D-NLUPA algorithm can be applied [27].

6. CONCLUSION

In this paper, the study of the performance of an uplink two-user NOMA system has been conducted for the wireless environment that has been modeled as the Fisher-Snedecor fading. To avoid the complexity in the SIC when more users exist in the cell, two different pairing schemes have been applied. The process has been followed by the power allocation algorithm designed to maximize the sum data rate of the NOMA system. For one such system, sum data rate realized in NOMA and outage probabilities of individual users have been analyzed. General conclusions are: the influence of fading parameters on the sum data rate is evident in the small and moderate SNR region; sum data rate curves saturate for large SNR; both pairing schemes provide almost the same sum data rate; from the outage probability point of view the priority is on the side of High-High scheme utilization.

Based on the derived conclusion, future extensions to our work could be directed to the application of D-NLUPA algorithm in order to improve the system performance of the considered NOMA system.

Acknowledgement: *This work has been supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia.*

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