Sum Rate Analysis of Downlink NOMA over α-$\mathcal{F}$ Fading Channels

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Abstract. *In this paper, our focus is towards resource allocation in a multiuser downlink non-orthogonal multiple access (NOMA) system. In the power-domain NOMA, where multiple access is realized by assigning different power levels to the clustered users, a certain degree of advantage of NOMA depends on clustering of users and power levels allocated to them. This study proposes a new power allocation algorithm, based on sum rate as performance criterion, which is applied for the clusters defined by High-High/High-Low pairing scheme. The proposed algorithm takes into account fairness between clustered users from the acquired users' rate point of view. It provides better sum rate performance of NOMA compared to OMA, but also a low gap between the individual rates of paired users. The detailed numerical and independent simulation results for the downlink NOMA over general* α-$\mathcal{F}$ *fading channels are shown.*

Keywords

Non-orthogonal Multiple Access (NOMA), composite α-$\mathcal{F}$ fading, user pairing, resource power allocation, downlink NOMA, rate fairness

1. Introduction

One of the society needs that should be ensured in near future is an instantaneous unlimited wireless connectivity request. Therefore, 6G is expected to enable links 100 to 1000 times faster than 5G, in orders of Tbps. In addition, 6G will be able to efficiently realize hundred-fold larger number of connections than 5G. For Industrial Internet of Things (IoT) and latency-sensitive applications (augmented reality, autonomous vehicles, factory automation control, etc.), the latency time of 1 ms guaranteed in 5G is too long. Prediction for 6G is latency less than 1 ms, i.e. around 0.1 ms. Moreover, 6G technologies are expected to be more energy efficient. The last, but not the least, the trend in 6G is reliability of 99.99999% [1]. As a prominent member of the next generation multiple access family, non-orthogonal multiple access (NOMA) has been recognized as a promising multiple access candidate for the 6G networks.

The potentials of NOMA by overcoming OMA in terms of capacity and user-fairness are revealed in [2]. Unlike OMA, NOMA can allow all users to access the same frequency resource at the same time, which can be achieved in two general ways defining type of NOMA: power-domain NOMA and code-domain NOMA. The power-domain NOMA enables simultaneous multiuser access, assigning different levels of power to the users, according to the channel conditions. Code-domain is fundamentally evolved on the concept of allocating different spreading codes to the users that enable signals separation at the receiver. In addition, the code-domain NOMA can remarkably enhance spectral efficiency, at the cost of the transmission bandwidth and substantial modification of the existing systems. On the contrary, the power-domain NOMA neither requires a major upgrade to the present network design nor a wider transmission bandwidth [3]. However, in power-domain NOMA in order to segregate the user's information from the superimposed signal, successive interference cancelation (SIC) should be inserted at the receiver side which causes increased receiver complexity.

A detailed retrospective of different modifications of the power-domain and the code-domain NOMA is given in [4], while some of hybrid models can be found in [5], [6]. Novel alternative approaches, based on NOMA technology, are also proposed. The effective way to expand the coverage of NOMA transmission is to apply cooperative technique into NOMA system. The cooperative NOMA networks can be classified into two categories: the first in which dedicated relays assist communication between base

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station (BS) and NOMA user; and the second one in which users with favorable channel's conditions are classified as relays among BS and users with unfavorable channel conditions [7].

The multiple-input multiple-output (MIMO) is popular technique to increase the spectral efficiency by exploiting resources in the spatial domain. Therefore, the MIMO-NOMA systems can take advantage of the extent in both the space and power domains, thus enhancing system spectrum efficiency even more [8]. The superiority of MIMO-NOMA over MIMO-OMA in terms of both the sum channel capacity and ergodic sum capacity is confirmed in [9]. Moreover, power-domain NOMA can be also combination with heterogeneous networks [10], visible light communication [11], unmanned aerial vehicles (UAVs) [12], etc.

The NOMA has ability to serve multiple users simultaneously on the same frequency/time resources which nominees it as suitable for scenarios with a large number of users. In order to satisfy Quality of Service (QoS), and concurrently, provide better fairness among users, ensuring that all users receive their fairly shared part of the resources, power allocation and user clustering represent important issues. Efficiently managed resources allow the BS to control flexibly the general data rate, the cell edge data rate, user fairness, and other performance indicators. The optimal solution leading to the best possible utilization of NOMA potentials should be built up on an exhaustive search of user grouping in the clusters and allocation of particular power levels. Unfortunately, it is impractical in computational terms. Therefore, investigations are focused on the design of various practical sub-optimal algorithms.

The most common user pairing algorithms are conventional ones, in which grouping of users in one cluster is based on the channel gain differences among them [13–16]. The model taking into account signal-to-noise ratio (SNR) levels in user clustering process is proposed in [17]. Authors in [18], [19], nominate algorithms that adjust adaptively the clusters to the dynamics of the communication systems. In order to reach the performance approaching a theoretical upper-bound, an artificial neural network is applied for the users' pairing in [20, 21], with less complexity than exhaustive search method. User clustering and power allocation are tightly related to each other. Power allocation in power-domain NOMA enables multiuser access, so research into power allocation domain is of crucial importance. Commonly, the power allocation algorithms are able to ensure QoS and maximize the sum rate (total/per cluster) [16, 17, 22]. The artificial intelligence approach showed to be a hundred-fold faster than exhaustive search [23]. In addition, the system performance approaching optimal, for the downlink power allocation, can be found.

The wireless communication channels may suffer the multipath fading and shadowing, simultaneously. Indisputable advantages of NOMA are shown through system performance analysis over various fading channels. For example, the outage performance for NOMA with fixed power allocation over Nakagami-m fading channels is investigated in [24], while the outage performance of NOMA over Rayleigh/Rician fading channels is proposed in [25]. Furthermore, the error performance of NOMA system over generalized α-η-μ fading is presented in [26]. Important performance metrics for NOMA system, servicing multiple users, over α-μ fading channels are investigated in [27], and over composite G_K fading channels in [28]. The channel capacity, outage probability and error performance of clustered NOMA over k-μ fading channel, is analyzed in [29]. The G_K distribution is shown as suitable for describing UAV [30] and vehicle-to-vehicle communication links [31], and also attractive for channel modelling in NOMA.

The composite α-$\mathcal{F}$ fading model, that jointly encompasses the multipath fading, shadowing and nonlinearity of communication media, yields a better fit to the empirical data of device-to-device wireless communication [32], in comparison to previously mentioned fading models. This model also shows to be an accurate model for describing channels in mobile communication, cellular networks, wearable communications, and vehicular wireless networks. Therefore, it is seen as good candidate for link description in the future B5G [33]. In [34], the ergodic capacity and outage probability of two-user NOMA system over α-$\mathcal{F}$ fading channel in which the fixed power levels are allocated to users that are randomly selected to form a cluster are analyzed. In this paper, the system in [34] is upgraded by introducing the sub-optimal user pairing strategy known as High-High/High-Low, and proposing a novel power allocation algorithm. The benefits of our work can be summarized as:

1. The power levels of users are determined to maximize sum-rate, as more realistic performance criterion than ergodic capacity, relying on the obtained expressions for the outage probability of grouped users in [34].
2. The fairness between the grouped users, from the individual user rate point of view, is achieved by introducing a certain tolerance coefficient.
3. The proposed resource allocation method for the downlink power-domain NOMA can be applied over various fading channels.

The remainder of this paper is organized as follows. Section 2 presents the system model, while a novel resource allocation method is proposed in Sec. 3. The outage performance analysis of two-user NOMA over α-$\mathcal{F}$ fading channels from [34], which is indispensable for sum rate analysis carried out in this paper, is shown in Sec. 4. Numerical results are given in Sec. 5, and the paper is concluded in Sec. 6.

2. System Model

We assume that a single transmitter, i.e. BS, non-orthogonally transmits signals to the intended users over the same radio resources. In addition, $2K$ users are uniformly

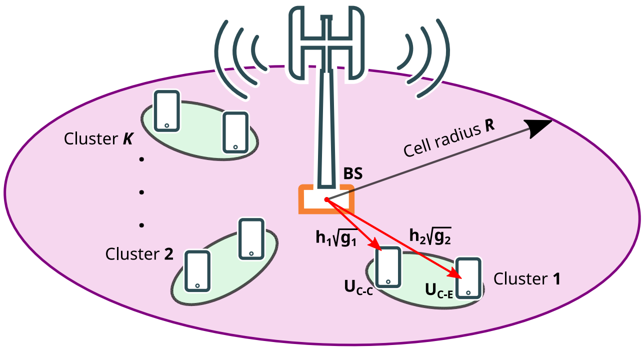


Fig. 1. The considered system model of downlink NOMA.

distributed within a cell. In practice, when a large number of NOMA users share the same time/frequency resources (resource block (RB)), the performance degradation due to the residual interference, increased complexity, the channel state information (CSI) feedback overhead and computing power is inevitable [35], [36]. The concept of downlink power-domain NOMA refers to the power allocation in accordance with the specific channel conditions, in an inverse proportional manner. Significant channel gain differences among users are required to enhance network performance, which cannot be achieved with a large number of users served by BS over the same RB [37].

Therefore, in this work, users are clustered into K groups of two users, a cell-center, $U_{\text{C-C}}$, and a cell-edge user, $U_{\text{C-E}}$, which share the same resources. As shown in Fig. 1, BS is located at the center of the cell. The $U_{\text{C-C}}$ user is spatially closer to the BS, experiencing more favorable channel conditions than the $U_{\text{C-E}}$ user, which is far from the BS. The $U_{\text{C-C}}$ or $U_{\text{C-E}}$ user receives the superimposed signal broadcasted by BS:

$$Y_i = \sqrt{g_i} h_i \sum_{l=1}^{2} \sqrt{a_l P} X_l + n_i, \ \ i = 1,2 \tag{1}$$

where P is the total power per RB and h_i is the channel coefficient from BS to i-th user ($i = 1$ for $U_{\text{C-C}}$, and $i = 2$ for $U_{\text{C-E}}$). A distance-based path gain between BS and the i-th user can be expressed as [35]

$$g_i = g_0 \Big/ \left[H^2 + \left(x_i^2 + y_i^2 \right) \right]^{\beta/2} \tag{2}$$

where g_0 represents the reference distance. The position of the i-th user is defined with x_i and y_i coordinates, and H and β are the BS antenna height and the path loss exponent, respectively. The power allocation factor a_l ($0 < a_l < 1$, $l = 1, 2$) refers to the power level assigned to the user. In a downlink scenario, condition $|h_1|^2 > |h_2|^2$ yields to $a_1 < a_2$ with $a_1 + a_2 = 1$. Finally, X_i represents the data symbol intended to convey to the i-th user with unitary energy $\mathrm{E}\{|X_i|^2\} = 1$, and n_i is notation for the complex additive white Gaussian noise (AWGN).

The baseline idea of the downlink power-domain NOMA system is that user who receives higher power can detect its information and treats signals itended to the other users from the cluster as interference. Further, users receiving lower power have to employ SIC to decode their respective information. Consequently, in the described system, $U_{\text{C-C}}$ at first decodes the message of $U_{\text{C-E}}$, and then employs SIC to decode its own information. The $U_{\text{C-E}}$ does not apply SIC and decodes its own information treating the signal of $U_{\text{C-C}}$ as interference. Therefore, the received signal-to-interference-and-noise ratios (SINRs), γ_i ($i = 1, 2$), are defined as:

$$\gamma_1 = \rho a_1 g_1 |h_1|^2, \quad \gamma_2 = \frac{\rho a_2 g_2 |h_2|^2}{\rho a_1 g_2 |h_2|^2 + 1} \tag{3}$$

where $\rho = P/N_0$ is SNR with N_0 representing the variance of AWGN.

3. Resource Allocation Algorithm

Resource allocation is identified as a critical approach in NOMA to facilitate performance gain over OMA, and it attracts tremendous attention. Depending on the targeted performance, wireless environment conditions, and admissible complexity of implementation, there are numerous algorithms for user clustering. Frequently, clustering algorithms are compatible with power allocation strategies in terms to achieve higher performance gain with lower computational complexity and to provide user fairness at the same time.

The greater the channel gain difference between the multiplexed users is, the greater improvement of performance of NOMA in comparison to OMA is noticeable. Based on the user's instantaneous CSI obtained by the BS, the channel gains of all users can be sorted in descending order. The most of clustering strategies support pairing the near user (with high channel gain) with the far user (with low channel gain), to preserve the channel gain difference between the users, which are served in the same RB.

In this paper, we use the High-High/High-Low pairing schemes. These two schemes can be described by the following steps [13], [15]:

1. Divide all users into two groups: High channel gain users and Low channel gain users.
2. Arrange them in each group in descending channel gain order.
3. Generate a two-user clusters, in total number of K, pairing users from each group:
   a. Paring the first user of the High channel gain user group with the first user of the Low channel gain user group and so on, i.e. $\{\{h_1,h_{K+1}\}, \{h_2,h_{K+2}\},..., \{h_K,h_{2K}\}\}$ – High-High scheme;
   b. Paring the first user of the High channel gain user group with the last user of the Low channel gain user group and so on, i.e. $\{\{h_1,h_{2K}\}, \{h_2,h_{2K-1}\},..., \{h_K,h_{K+1}\}\}$ – High-Low scheme.

The High-High and High-Low schemes are shown, graphically, in Fig. 2, for $2K = 8$. Numerous published re-

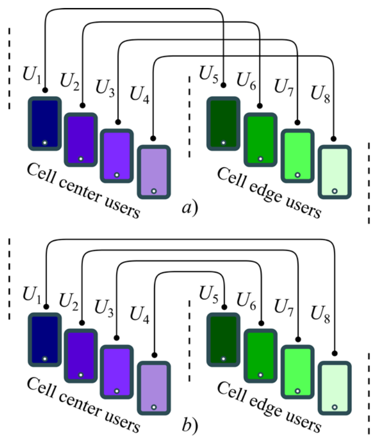


Fig. 2. The user pairing scheme: a) High-High; b) High-Low (example of $2K = 8$).

searches confirm that the High-Low scheme provides satisfactory system performance. However, in order to avoid possible zero gain difference between clustered users, which can appear in that scheme, its modifications is also proposed [15, 38, 39].

In the previously published researches, the most of proposed power allocation algorithms are based on maximizing the sum ergodic capacity, while the user fairness criterion is determined through additional requirements. For example in [40], the ergodic capacities of individual NOMA users in the cluster are required to be greater than the ergodic capacities of OMA users under the same conditions. Further, authors in [17], [41–43] define a minimum rate requirement for each user.

In this work, we deal with the user pairing, as well as the power allocation problem. In [34], the fixed-power allocation algorithm is applied in two-user NOMA system model. The obtained results (Fig. 6 in [34]) show that from the ergodic sum capacity point of view, NOMA outperforms OMA in all SNR region. In addition, we have noticed that the cell-edge user in OMA can achieve significantly higher ergodic capacity than in NOMA, in the range of higher SNR regime. Since the ergodic capacity is by the theory maximum data rate, the algorithm proposed in this paper is based on the achievable rate, which is associated with a realistic scenario. The proposed algorithm, TPSR (Tolerance-Power-Sum-Rate), is formulated in the following way:

$$\max R_{\mathrm{sum}} = \max\left\{R_{\mathrm{c},1}\left[1-P^{(1)}_{\mathrm{out}_{\mathrm{NOMA}}}\left(a_1P\right)\right]+R_{\mathrm{c},2}\left[1-P^{(2)}_{\mathrm{out}_{\mathrm{NOMA}}}\left(a_2P\right)\right]\right\} \tag{4}$$

with the fairness constraint determined as:

$$\begin{aligned} C_{\mathrm{tol}}R_{\mathrm{c},1}\left[1-P^{(1)}_{\mathrm{out}_{\mathrm{OMA}}}\left(P\right)\right] &< R_{\mathrm{c},1}\left[1-P^{(1)}_{\mathrm{out}_{\mathrm{NOMA}}}\left(a_1P\right)\right],\\ C_{\mathrm{tol}}R_{\mathrm{c},2}\left[1-P^{(2)}_{\mathrm{out}_{\mathrm{OMA}}}\left(P\right)\right] &< R_{\mathrm{c},2}\left[1-P^{(2)}_{\mathrm{out}_{\mathrm{NOMA}}}\left(a_2P\right)\right] \end{aligned} \tag{5}$$

where the parameter C_{tol}, tolerance coefficient, defines degree of fairness, while $R_{\mathrm{c},i}$ represents the target rate of the i-th user, and $R_{\mathrm{c},i}\left[1-P^{(i)}_{\mathrm{out}_{\mathrm{NOMA}}}\left(a_iP\right)\right]$ is individual user rate of the i-th NOMA user, while $R_{\mathrm{c},i}\left[1-P^{(i)}_{\mathrm{out}_{\mathrm{OMA}}}\left(P\right)\right]$ is individual user rate of the i-th OMA user. The algorithm aims to maximize the total sum rate under the constraint that will not allow a huge difference in the achieved rate of users in NOMA and OMA regime, which was recognized as a problem in [34]. The power allocation algorithm that would be used in comparison purpose, MPSR (Maximal-Power-Sum-Rate), is described by (4). It is noticeable that its basic aim is to maximize total sum rate, without taking into account achieved individual rate of users and their mutual ratio.

4. Sum Rate Analysis over α-$\mathcal{F}$ fading Channels

In order to convey the sum rate analysis of downlink NOMA over general α-$\mathcal{F}$ fading channels this section provides the required mathematical background.

In wireless transmission, the SINR level serves to track the occurrence of radio link failures and/or determine the maximum achievable data rate. The probability density functions (PDFs) of SINRs of $U_{\text{C-C}}$ and $U_{\text{C-E}}$ users, over the channels subjected to α-$\mathcal{F}$ fading, are derived in [34] as:

$$p_{\gamma_1}(\omega)=\frac{\alpha_1\theta_1^{m_1}}{2B\left(\mu_1,m_1\right)}\frac{\omega^{\frac{\alpha_1}{2}\mu_1-1}}{\left(\omega^{\frac{\alpha_1}{2}}+\theta_1\right)^{m_1+\mu_1}} \tag{6}$$

where $\theta_1=\frac{\left(\rho g_1a_1\right)^{\alpha_1/2}\left(m_1-1\right)\Omega_1}{\mu_1}$, and

$$p_{\gamma_2}(\omega)=\frac{\alpha_2\theta_2^{m_2}}{2B\left(\mu_2,m_2\right)}\frac{W_{\mathrm{th}}}{\left(W_{\mathrm{th}}-\omega\right)^2}\frac{\left(\frac{\omega}{W_{\mathrm{th}}-\omega}\right)^{\frac{\alpha_2}{2}\mu_2-1}}{\left(\left(\frac{\omega}{W_{\mathrm{th}}-\omega}\right)^{\frac{\alpha_2}{2}}+\theta_2\right)^{m_2+\mu_2}} \tag{7}$$

where $\theta_2=\frac{\left(\rho g_2a_1\right)^{\alpha_2/2}\left(m_2-1\right)\Omega_2}{\mu_2}$ and $W_{\mathrm{th}}=\frac{a_2}{a_1}$.

The m_i ($m_i > 1$) is the shape shadowing parameter of user's channels, α_i ($\alpha_i > 0$) is the non-linearity of the propagation medium, Ω_i is the mean signal power and μ_i is the number of multipath clusters defining fading and $B(\cdot,\cdot)$ is Beta function.

In [34], the exact expressions for the outage probabilities, $P^{(1)}_{\mathrm{out}_{\mathrm{NOMA}}}$ and $P^{(2)}_{\mathrm{out}_{\mathrm{NOMA}}}$, are determined in the following way

$$P^{(1)}_{\mathrm{out}_{\mathrm{NOMA}}}=\frac{1}{\Gamma\left(m_1\right)\Gamma\left(\mu_1\right)}G^{1,2}_{2,2}\left(\mu_1\frac{\left(\frac{\gamma^{\mathrm{NOMA}}_{\mathrm{th},1}}{\rho a_1g_1}\right)^{\alpha_1/2}}{\left(m_1-1\right)\Omega_1}\middle|\begin{matrix}1-m_1,1\\ \mu_1,0\end{matrix}\right), \tag{8}$$

and
$$P^{(2)}_{\mathrm{out}_{\mathrm{NOMA}}} = \begin{cases} \Upsilon, & \gamma_2 < \gamma^{\mathrm{NOMA}}_{\mathrm{th},2} \\ 0, & \text{otherwise} \end{cases}, \tag{9}$$

with
$$\Upsilon = \frac{1}{\Gamma(m_2)\Gamma(\mu_2)} \times G^{1,2}_{2,2}\left(\frac{\mu_2}{\Omega_2(m_2-1)} \left(\frac{\gamma^{\mathrm{NOMA}}_{\mathrm{th},2}}{\rho a_1 g_2 \left(W_{\mathrm{th}} - \gamma^{\mathrm{NOMA}}_{\mathrm{th},2}\right)} \right)^{\alpha_2/2} \middle| \begin{matrix} 1-m_2, 1 \\ \mu_2, 0 \end{matrix} \right) \tag{10}$$

where $\gamma^{\mathrm{NOMA}}_{\mathrm{th},i} = 2^{\frac{R_{c,i}}{\mathrm{BW}}} - 1$ are the threshold rates with BW being the bandwidth and $G^{m,n}_{p,q}\left(z \middle| \begin{matrix} - \\ - \end{matrix}\right)$ denotes univariate Meijer's G function.

Following the similar procedure as for NOMA and acknowledging that in OMA regime there is no mutual interference among the users, the outage probability of OMA users in the cluster can be expressed as [34]

$$P^{(i)}_{\mathrm{out}_{\mathrm{OMA}}} = \frac{1}{\Gamma(m_i)\Gamma(\mu_i)} G^{1,2}_{2,2}\left(\mu_i \frac{\left(\frac{\gamma^{\mathrm{OMA}}_{\mathrm{th},i}}{\rho g_i} \right)^{\alpha_i/2}}{(m_i-1)\Omega_i} \middle| \begin{matrix} 1-m_i, 1 \\ \mu_i, 0 \end{matrix} \right) \tag{11}$$

where $\gamma^{\mathrm{OMA}}_{\mathrm{th},i} = 2^{\frac{2R_{c,i}}{\mathrm{BW}}} - 1$ since the pre-log factor is 1/2 in OMA user rate, with TDMA scheme, relying to the fact that each user transmits only half of time [42].

The individual rates of NOMA users can be evaluated by substituting (8), (9) and (10) in $R_{c,1}\left[1 - P^{(1)}_{\mathrm{out}_{\mathrm{NOMA}}}(a_1 P)\right]$ and $R_{c,2}\left[1 - P^{(2)}_{\mathrm{out}_{\mathrm{NOMA}}}(a_2 P)\right]$. Further, the rate of same users treated as OMA can be obtained by substituting (11) in $R_{c,i}\left[1 - P^{(i)}_{\mathrm{out}_{\mathrm{OMA}}}(P)\right], i = 1,2$.

The computational complexity of the proposed algorithm can be significantly reduced by using asymptotic expressions for outage probabilities derived in [34] instead of the exact formulas (8–11).

5. Numerical Results

In this section, we investigate the sum rate performance of downlink NOMA system in which High-High/High-Low schemes are used for clustering process, while dynamic power allocation algorithm based on the sum data rate is applied. In such a way, different power levels are assigned to clustered users, whereby certain fairness is set as the constraint for achieved rates of individual users.

In the simulation setup, it is assumed that users are uniformly distributed within a circle with radius of R. The BS is located in the center of the circle, mounted at height of H. The additional simulation parameters are $g_0 = 50$ and $\beta = 3$, without loss of generality. The different wireless channel condi-

ES_j	α	m	μ	R and H
ES_1	$\alpha_1 = 1$ $\alpha_2 = 1$	$m_1 = 7$ $m_2 = 7$	$\mu_1 = 5$ $\mu_2 = 5$	$R = 200$ m $H = 100$ m
ES_2	$\alpha_1 = 2$ $\alpha_2 = 1$	$m_1 = 7$ $m_2 = 3$	$\mu_1 = 5$ $\mu_2 = 4$	$R = 200$ m $H = 100$ m
ES_3	$\alpha_1 = 1$ $\alpha_2 = 1$	$m_1 = 7$ $m_2 = 7$	$\mu_1 = 5$ $\mu_2 = 5$	$R = 300$ m $H = 50$ m

Tab. 1. Environment scenarios' description.

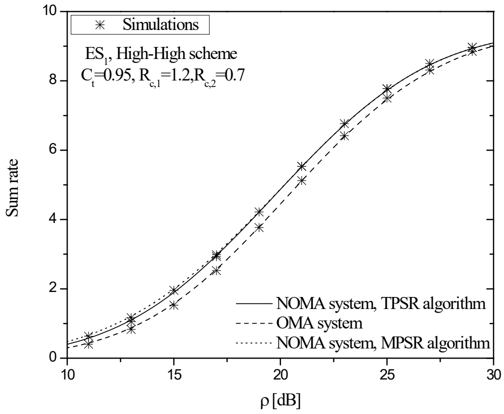
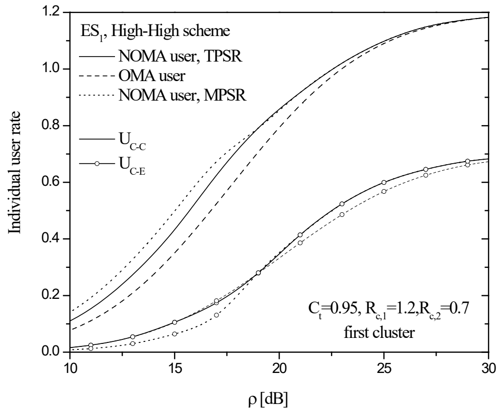
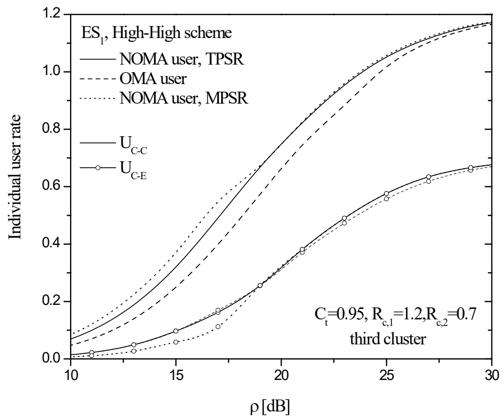


Fig. 3. Sum rate comparison for ES_1 and $2K = 10$ (High-High).



(a)



(b)

Fig. 4. Individual user rate for ES_1 and $2K = 10$ (High-High): (a) the first cluster; (b) the third cluster.

tions are perceived by varying parameters m_i, α_i, and μ_i, as shown in Tab. 1. In addition, independent Monte Carlo simulations are presented in Figs. 3, 5, 7 and 9, for sum rate comparison analysis. Good agreement of simulations and theoretical results is evident. In the other figures, simulations are avoided just in purpose not to impair their readability.

Figure 3 plots the sum rate for the OMA, NOMA with power allocation algorithm maximizing system sum rate (MPSR), and NOMA with power allocation algorithm based on tolerance coefficient (TPSR), which is proposed in this work. We use High-High pairing scheme. It is assumed that the total number of users in the cell is 10, and that the tolerance coefficient is 0.95. Actually, the achieved individual rate of OMA users have not be greater in amount of 5 percent then obtained individual rates of NOMA users. Moreover, the users' targeted rates are $R_{c,1} = 1.2$, $R_{c,2} = 0.7$. The obtained results show noticeable gap between NOMA and OMA concept in terms of sum rate. In addition, we notice very small difference in sum rate between NOMA system with TSPR and MPSR, in advantage to MPSR, for low SNR regime.

Figure 4 shows the individual user rates under the same scenario. The rate performance of users paired into two different clusters is presented. The first cluster consists of the first and the sixth user, and the third cluster consists of the third and the eighth user. It is evident that user far away from BS accomplishes lower rates. If we compare curves depicted in Fig. 4(a), i.e. Fig. 4(b), we can draw conclusion that difference in rate between the cell-center and the cell-edge user is smaller for TPSR than MPSR algorithm, in low SNR regime, which shows targeted fairness. The noticed difference in low SNR regime does not stand for high SNR regime.

Figures 5 and 6 are counterparts of Figs. 3 and 4, respectively and illustrate High-Low pairing scheme. In this scenario, the first cluster consists of the first and the tenth user, provoking much more pronounced differences already noticed in NOMA with High-High scheme, but drawn concluding remarks are the same.

In Figs. 7–10, we illustrate the impact of the fading/shadowing on the rate performance of NOMA and

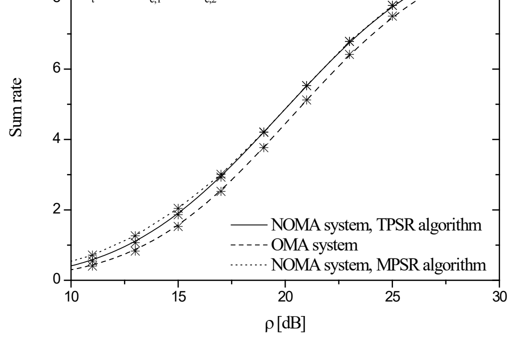


Fig. 5. Sum rate comparison for ES_1 and $2K = 10$ (High-Low).

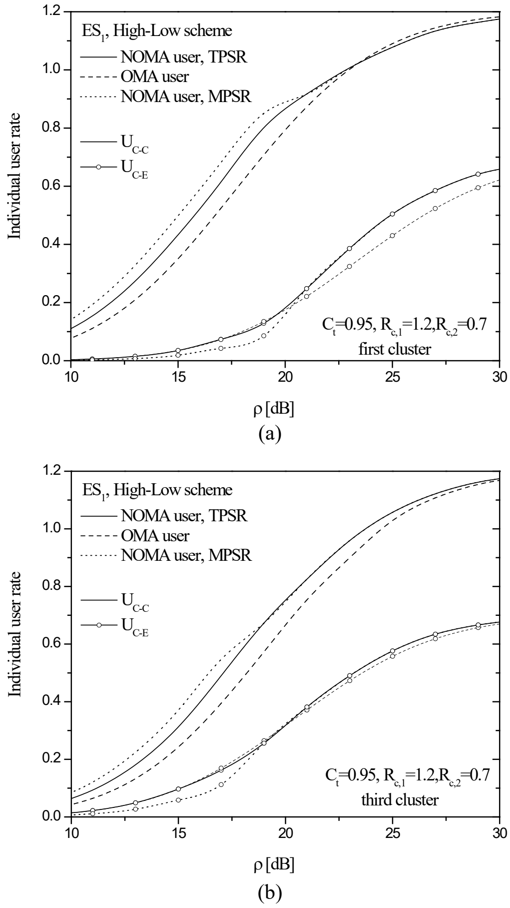


Fig. 6. Individual user rate for ES_1 and $2K = 10$ (High-Low): (a) the first cluster; (b) the third cluster.

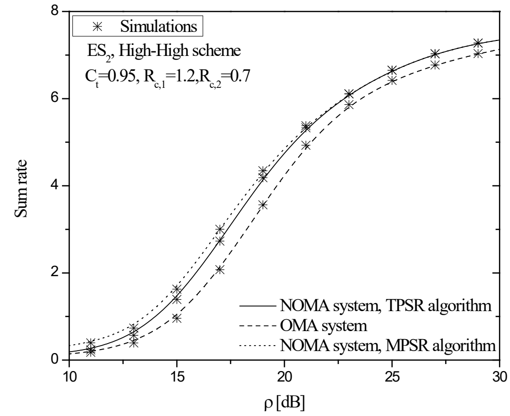
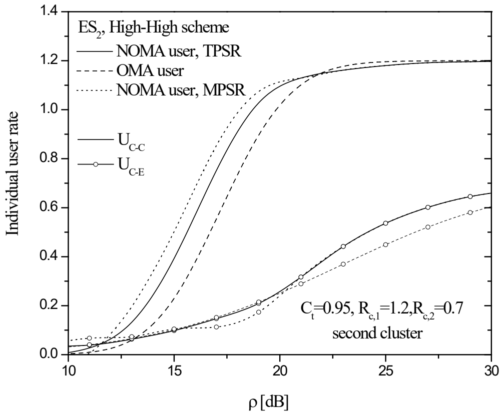


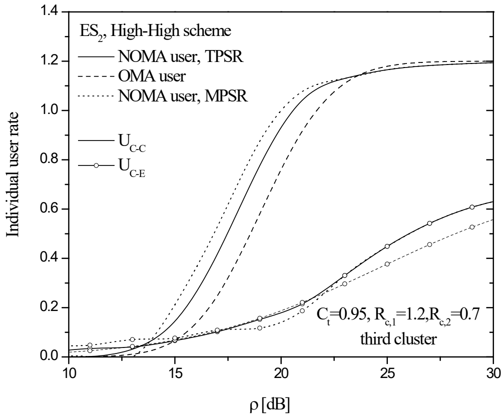
Fig. 7. Sum rate comparison for ES_2 and $2K = 8$ (High-High).

OMA in the cell with 8 users. The cell-edge users are influenced by stronger effects of fading, shadowing and nonlinearity. By comparing Figs. 3 and 7 in regards to Figs. 5 and 9, we notice a more evident advantage of NOMA over OMA when systems operate in the worst environment conditions. Moreover, the cell-edge users for both OMA and NOMA approach, achieve lower rate over deeply faded and severe shadowed channels. Also, in low SNR region, when MPSR is applied, the individual rate variation of the cell-edge users is caused by the feature of MPSR algorithm not to take into account the individual rates of clustered users and their mutual relation, since its only aim is to maximize the aggregate rate.

Due to stronger influence of wireless phenomena on the strength and quality of cell-edge user signal, the cell-center user achieves maximum rate for small total power per RB (rate curve is characterized with conspicuous slope). This is not the case for the cell-edge user (Figs. 8 and 10). In addition, results of comparison between Figs. 8 and 10 show a noticeable difference in accomplished rate of the cell-edge users depending of pairing algorithm.



(a)



(b)

Fig. 8. Individual user rate for ES_2 and $2K = 8$ (High-High): (a) the second cluster; (b) the third cluster.

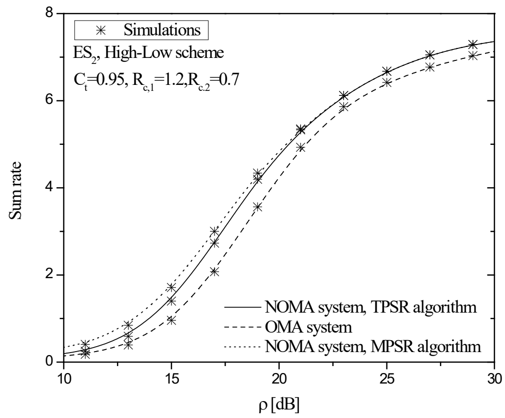
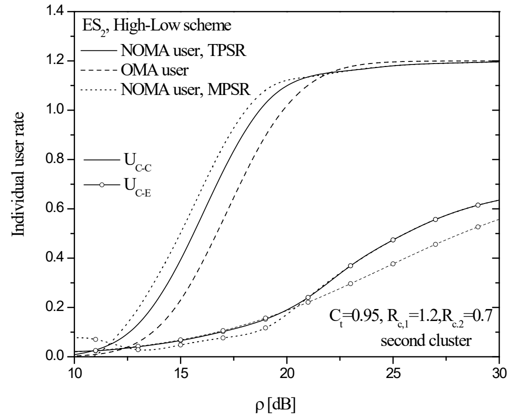


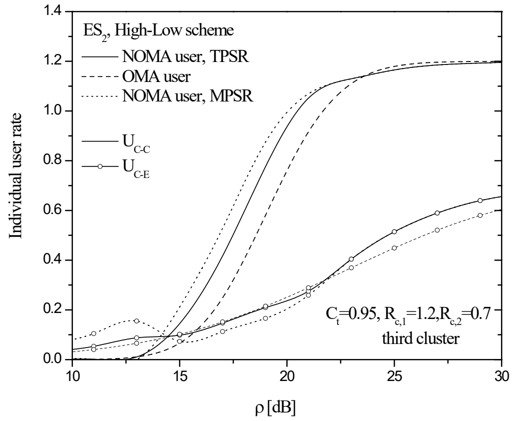
Fig. 9. Sum rate comparison for ES_2 and $2K = 8$ (High-Low).

In high SNR region, independent of the channel conditions or applied scheme, the total power per RB is large enough, and regardless of power allocation factors, the allocated powers to both users are enough to achieve maximal possible rates, which are defined by target rates.

Results presented in Fig. 11 confirm all conclusions which arise from Figs. 3 and 5. However, significantly higher sum rate is obtained for lower mounted antenna that serves users over wider area. This can be explained by higher distance-based path gain and significantly higher channel gain difference between clustered users.

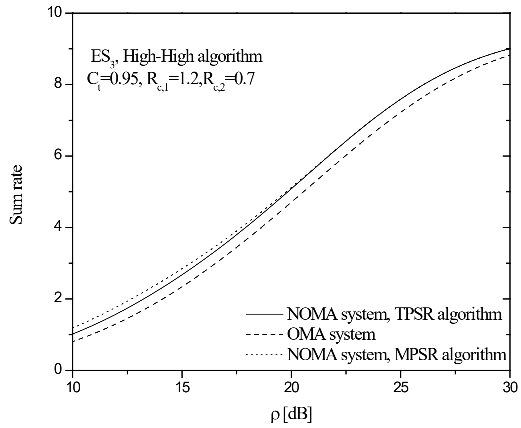


(a)

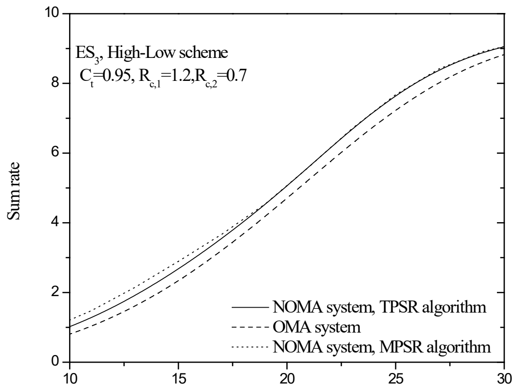


(b)

Fig. 10. Individual user rate for ES_2 and $2K = 8$ (High-Low): (a) the second cluster; (b) the third cluster.



(a)



(b)

Fig. 11. Sum rate comparison for ES_3 and $2K = 10$: (a) High-High; (b) High-Low.

6. Conclusion

In this work, we investigated the downlink two-user NOMA system over α-$\mathcal{F}$ fading with High-High/High-Low pairing scheme. The novel power allocation algorithm, TPSR, considering the users' fairness by implying the tolerance coefficient, was proposed. For the purpose of comparison, OMA system was also analyzed. From the sum rate point of view, the TPSR algorithm provides better rate performance of NOMA in comparison to OMA, but at the same time very close to performance reachable by MPSR algorithm. The differences between achieved aggregate rates are more distinguishable over the channels with deep fading and severe shadowing. In addition, the difference in achieved individual rates of the cell-center and cell-edge users is less than in the case of applying MPSR algorithm. Besides, the accomplished rate of NOMA user is not significantly lower than the rate of OMA user. Finally, it is worth of mentioning that TSPR algorithm does not allow instability of the cell-edge user rate in low SNR region for bad channel conditions.

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