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# Capacity Performance of Uplink NOMA System with 2K+1 Users over Fisher-Snedecor Composite Fading Channels

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**Abstract:** In this paper, we study an uplink power-domain non-orthogonal multiple access (PD-NOMA) system, in which 2K+1 users are served. The user clustering process based on High-High/High-Low algorithm precedes the utilization of the data-rate based power allocation algorithm. Channels are characterized by Fisher-Snedecor composite fading model interpreted as model with a high level of generality. The influence of different fading/shadowing channel conditions, number of users and their positions is portrayed through the numerical results of data sum rate of the studied PD-NOMA system.

**Keywords:** Fisher-Snedecor fading, NOMA system, Resource allocation, Capacity.

## 1 Introduction

Non-orthogonal multiple access (NOMA), compared to orthogonal multiple access (OMA) approach, maintains user fairness, boosts spectral efficiency, and facilitates large mobile connectivity. Therefore, NOMA is seen as a crucial technology supporting the 5G and beyond networks [1, 2]. NOMA is mostly implemented as either power-domain NOMA (PD-NOMA) or code-domain NOMA (CD-NOMA). The PD-NOMA, discussed in this paper, is easier to implement in an existing network and improves spectral efficiency without using additional bandwidth [3]. Namely, the PD-NOMA enables simultaneous multiuser access to the available frequency and time resources, whereby multiplexing is accomplished by assigning different levels of power to the users according to their channel conditions, all in an effort to maximize system gain. In such multiple access, the interference is disadvantage that has to be overcome by

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successive interference cancellation (SIC). The complexity of the receiver is increased by the SIC, but giving up orthogonality brings the benefit of high connectivity and spectral efficiency [4]. In CD-NOMA, non-orthogonal codebooks/sequences are used as primary tool for multiuser separation. Authors in [5] show that CD-NOMA achieves better sum-rate in comparison to PD-NOMA, at the cost of increased complexity. Therefore, one of the research challenges is to design low complexity CD-NOMA receiver. In addition, NOMA can be included in existing advanced technologies such as multiple-input multiple-output (MIMO), cooperative relay networks, device-to-device (D2D), heterogenous system, etc. [6].

In the PD-NOMA, power allocation and user pairing issues should be taken into account. Namely, appropriate selection of power levels allocated to the users and decision which users can share the system resources allows the base station (BS) to control data rate and user fairness. Actually, to achieve the best possible performance of PD-NOMA, it should be analyzed all possible combinations of clustered users and their particular power levels, which is definitely infeasible in computational terms [7]. Therefore, some works related to PD-NOMA are focused on investigation of a sub-optimal solution for both user clustering and power allocation. All pairing algorithms, in general, can be classified into two categories: those that pair 2K users in groups of two users [8] and those that pair 2K+1 users in groups of one, two, or three users [9, 10]. Recently, some adaptive user clustering methods are proposed in [7, 11]. Two distinguished power allocation algorithms exist: fixed and dynamic. The fixed power allocation model allocates the same power levels to users without taking into account the channel conditions. The algorithm complexity is very low and, consequently, the realized system performance is poor. The power level allocated to the user can be changed in the dynamic manner, according to the instantaneous channel gain. Low-complex dynamic power allocation algorithms can be found in [12, 13]. In order to meet demands for high-capacity in future mobile communication systems, a new dynamic algorithm is proposed in [14]. Unfortunately, its complexity makes practical implementation difficult in a multiuser case. Artificial intelligence based methods for downlink PD-NOMA are presented in [15], to address the computational complexity issue while offering near-optimal performance.

Since the mobile radio propagation channel causes fundamental limits to the wireless communication system performance, its accurate modeling is crucial for the system design. In practice, Rayleigh, Rice, Nakagami-m, and Hoyt are commonly used fading models, while shadowing is usually modeled statistically by lognormal distribution. Analysis of PD-NOMA over aforementioned fading channels can be found in the open technical literature [9, 16, 17, 18, 19]. The Fisher-Snedecor, F, distribution represents a tractable composite fading model (incorporating the effects of both fading and shadowing) that shows excellent fit to the experimental data of D2D communication in both the outdoor and indoor, better than generalized-K model [20]. In addition, F distribution can be simplified to Nakagami-m, Rayleigh, and one-sided Gaussian fading models. Therefore, experimental and theoretical advantages of F distribution are undisputed.

In this paper, we analyze the uplink PD-NOMA system serving 2K+1 users over composite F fading channel. Two-user clusters, in total number of K, are formed using simple based High-High/High-Low algorithm, so only one user is left without pairing. Using the analytical expressions for the outage probabilities (OPs) of users operating in the two-user PD-NOMA system obtained in [21, 22] and the OP of OMA user, the power allocation algorithm intended to maximize sum-rate is applied [23].

## 2 Problem Set

In the system under analysis, 2K+1 users are distributed uniformly within a cell of radius R and grouped in the clusters consisting of one or two users. The cluster composed of large number of users degrades a system performance due to a residual interference, more complex hardware and increased power consumption [24]. Users in the cluster simultaneously transmit their information symbols to the BS over a same resource. It is assumed that each cluster is assigned a single resource block (RB) and that each user is equipped with a single antenna.

The signal received at the BS in an uplink PD-NOMA system is defined as

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

where $l$ is the number of users in the cluster, $s_i$ is the information symbol, $h_i$ is the channel coefficient and $P_i$ is the transmit power of $i$-th user in the cluster. A $g_i$ represents distance-based path gain between the BS and the $i$-th user in the cluster and it can be evaluated as $g_i = g_0 / [H^2 + (x_i^2 + y_i^2)]^{\chi/2}$, with $g_0$ being the reference gain at the reference distance and $\chi$ is the path-loss exponent. The parameters $x_i$ and $y_i$ denotes the coordinates of the user's location, and $H$ is the BS antenna's height. Further, the parameter $n$ denotes additive white Gaussian noise with zero-mean and variance $\sigma^2$. It is assumed that $E\left\{|s_i|^2\right\} = 1$.

Generally, when two users are clustered for uplink communication scenario, the user with the highest channel gain is typically first decoded. If we assume that $g_1 |h_1|^2 > g_2 |h_2|^2$, after decoding $s_1$, which is sent by cell-center user (user positioned close to the center of the cell where BS is mounted), the BS subtracts $\sqrt{g_1 P_1} h_1 s_1$ from the received signal $y$. Then $s_2$ sent by cell-edge user (user located far from BS) is decoded. For scenario under consideration, it holds $P_1 > P_2$, respecting following identities $P_1 = a_1 P$, $P_2 = a_2 P$, $a_1 > a_2$, $0 < a_i < 1$, and $a_1 + a_2 = 1$. Parameter $P$ represents the total power per RB. According to the previously proposed model set, the received signal-to-interference-noise ratio for the *i*-th channel, can be defined as

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

If the user is not grouped in the cluster, all total power is assigned to it, since it is treated as OMA user. Consequently, the interference does not exist, i.e. SIC is not needed. Then, the received signal-to-noise ratio (SNR) for that user channel, can be defined now as

$$\gamma_{i,OMA} = \frac{g_i P |h_i|^2}{\sigma^2}, \quad i = 1. \tag{3}$$

The detailed derivation process of the OPs of the cell-center ($i$ = 1) and the cell-edge ($i$ = 2) users in two-user uplink PD-NOMA over $F$ fading channels can be found in [21] as

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

and

$$\begin{aligned} P_{out,2}(\gamma_{th,2}) = {} & 1 - \left[1 - P_{out,1}(\gamma_{th,1})\right] \\ & \times \left[ 1 - \frac{1}{\Gamma(m_2)\Gamma(k_2)} G_{2,2}^{1,2}\left( \frac{m_2 \gamma_{th,2}}{g_2 k_2 \overline{\gamma}_2} \middle| \begin{matrix} 1-k_2, 1 \\ m_2, 0 \end{matrix} \right) \right], \end{aligned} \tag{5}$$

where $\gamma_{th,i}$ is the threshold, $R_{c,i}$ ($\gamma_{th,i} = 2^{R_{c,i}} - 1$) is the target rate, $m_i$ defines the fading depth, $k_i$ defines the shadowing sharpness and $\overline{\gamma}_i = P_i / \sigma^2$ defines the average SNR of the *i*-th channel. The $G_{p,q}^{m,n}\left( z \middle| \begin{matrix} - \\ - \end{matrix} \right)$ denotes Meijer's $G$ function and $\Gamma(\cdot)$ denotes Gamma function [25].

The OP for OMA user over F composite fading channel is obtained as [1]:

$$P_{out,1}\left(\gamma_{th,1}\right)=\frac{1}{\Gamma\left(m_1\right)\Gamma\left(k_1\right)}G_{2,2}^{1,2}\left(\frac{m_1\gamma_{th,1}}{g_1k_1\overline{\gamma}_1}\middle|\begin{matrix}1-k_1,1\\ m_1,0\end{matrix}\right), \tag{6}$$

where treshold is now defined as $\gamma_{th,1}=2^{2R_{c,1}}-1$ and average SNR is $\overline{\gamma}_1=P/\sigma^2$.

## 3 Resource Allocation

It is not recommended to deploy NOMA on all users at once due to overhead in channel feedback information and error propagation, in addition to the other reasons already mentioned [26]. Therefore, users in the cell are grouped into clusters and users in the cluster share same RB. The system performance of PD-NOMA is highly dependent on both clustering model and power allocation. To accomplish the best performance of PD-NOMA it would be necessary to conduct exhaustive search which would be infeasible in computational terms. Therefore, some sub-optimal solutions for both problems, user clustering and power allocation, should be designed.

The detailed overview of user scheduling algorithms can be found in [27]. More complex scheduling algorithms, determined for odd number of users in the cell, can be found in [9]. In this paper we apply simple scheduling algorithm based on High-High/High-Low pairing algorithms [27]. These algorithms can be explained through the steps below [1]:

1. Arrange users in descending channel gain order.
2. Divide users into following groups: First group consists of users with highest channel gain (the first *K* users $\{h_1,h_2,\ldots,h_K\}$ ) and Second group consists of users with lowest channel gain (the last *K* users $\{h_{K+2},h_{K+3},\ldots,h_{2K+1}\}$ ).
3. Form the *K* two-user clusters as: Paring the first user of First group with the first user of Second group, and so on $\{\{h_1,h_{K+2}\},\{h_2,h_{K+3}\},\ldots\}$ – *High-High*; Paring the first user of First group with the last user of Second group, and so on $\{\{h_1,h_{2K+1}\},\{h_2,h_{2K}\},\ldots\}$ – *High-Low*.
4. The (*K*+1)th cluster consists of one user, (*K*+1)th user.

After users are aggregated into the clusters, the power levels have to be assigned to them. These power levels are obtained to maximize the sum data rate, which is one of the most important performance metrics [23]

$$\max R_{sum}=\max\left\{R_{c,1}\left[1-P_{out,1}\left(P_1\right)\right]+R_{c,2}\left[1-P_{out,2}\left(P_2\right)\right]\right\}, \tag{7}$$
$$P_1+P_2=P,$$

that holds when two users are grouped in the cluster.

Further, all power from the RB is allocated to the user in ($K$+1)-th cluster. In NOMA systems, power allocation significantly affects the total rate. Therefore, in the literature, dynamic power allocation strategies are very often designed to maximize achievable rate [28, 29].

To guarantee quality of service to users far away from BS, authors in [10] treats them as OMA. Therefore, in this paper we modify algorithm proposed in [1, 27] in following way:

1. Arrange users in descending channel gain order.
2. Divide users into following groups: First group consists of users with highest channel gain (the first $K$ users $\{h_1, h_2, \ldots, h_K\}$) and Second group consists of users with lower channel gain (the second $K$ users $\{h_{K+1}, h_{K+2}, \ldots, h_{2K}\}$).
3. Form the $K$ two-user clusters as: Paring the first user of First group with the first user of Second group, and so on $\{\{h_1, h_{K+1}\}, \{h_2, h_{K+2}\}, \ldots\}$ – *High-High*; Paring the first user of First group with the last user of Second group, and so on $\{\{h_1, h_{2K}\}, \{h_2, h_{2K-1}\}, \ldots\}$ – *High-Low*.
4. The ($K$+1)th cluster consists of the last user, (2$K$+1)th user.

## 4 Results and Discussion

In this section, we conduct the performance analysis of the PD-NOMA system under consideration. The following scenario is assumed: all users are uniformly positioned in a 200 m radius circle; the BS's height is 100 m and 3D coordinates defining its position are $(0,0,10)$; the 3D coordinates determining the position of the cell-center and the cell-edge users are $(x_1, y_1, 0)$ and $(x_2, y_2, 0)$, respectively. Parameters $g_0 = 50\,\text{dB}$ and $\chi = 3$ define path loss component; three different wireless fading scenarios (case A, case B, and case C) are supposed (**Table 1**).

**Table 1**
*Characterization of wireless channel.*

| | |
|---|---|
| **Case A** | $m_1 = 1$, $m_2 = 1$, $k_1 = 12$, $k_2 = 3$; 1st ÷ K-th clusters<br>$m_1 = 1$, $k_1 = 3$; ($K$+1)-th cluster |
| **Case B** | $m_1 = 1$, $m_2 = 1$, $k_1 = 1$, $k_2 = 1$; 1st ÷ K-th clusters<br>$m_1 = 1$, $k_1 = 3$; ($K$+1)-th cluster |
| **Case C** | $m_1 = 3$, $m_2 = 1$, $k_1 = 12$, $k_2 = 3$; 1st ÷ K-th clusters<br>$m_1 = 1$, $k_1 = 3$; ($K$+1)-th cluster |

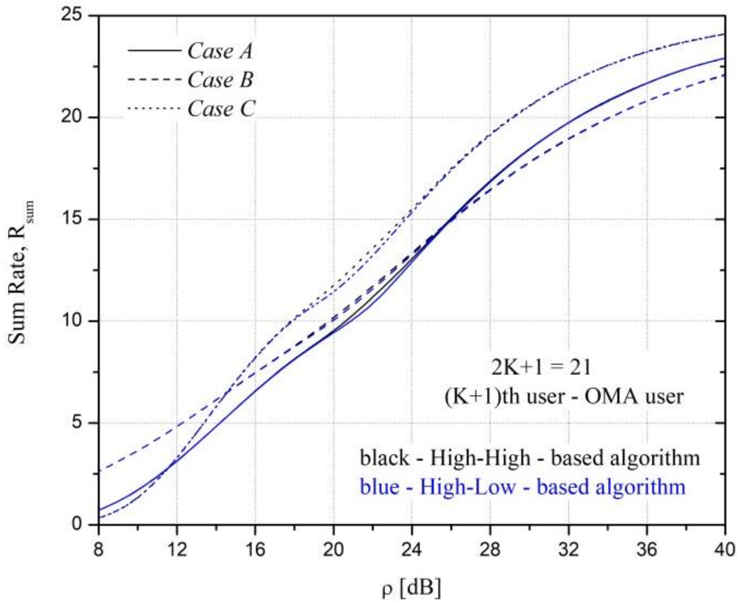



**Fig. 1 –** *Sum data rate versus* ρ ((*K+1)th user – OMA user,* 2*K*+1 = 21).

Fig. 1 depicts the achieved sum data rate versus the SNR, $\rho = P/\sigma^2$ , for the case of twenty one users uniformly located in the cell over different wireless environments in which all users are clustered in the analogue way as in [1]. Results presented in Fig. 1 demonstrate nearly identical sum rate performance of PD-NOMA system for both considered pairing schemes, with very slightly advantage in favor of High-High-based algorithm. This advantage can be explained with constant enough large difference in the channel gain between paired users. Moreover, the realized high sum rate in the case of utilization of High-Low algorithm is the consequence of the applied power allocation algorithm designed to achieve maximum sum data rate. Better conditions in the channel, described by higher values of parameters *k* and *m* (light shadowing and less severe fading conditions), guarantee that for moderate and high SNR values, the system provides higher data rates. In high SNR regime, maximum sum rate, $R_{sum_{\max}} = K(R_{c,1} + R_{c,2}) + R_{c,1}$, is almost achieved for all considered channel conditions. Even if we use users' position in the cell differently from [1], the drawn concluding remarks from Fig. 1 are the same as in [1]. Different user location distribution in the cell leads to a bit lower realized sum rate than in the case considered in [1].

Fig. 2 is depicted to analyse influence of different number of users in the cell on the capacity performance.

Depicted results show that previous mentioned conclusions are relevant for any number of users which should be served by BS. Commonly, achieved system rate is higher for higher number of users in the cell (compare Figs. 1 and 2).

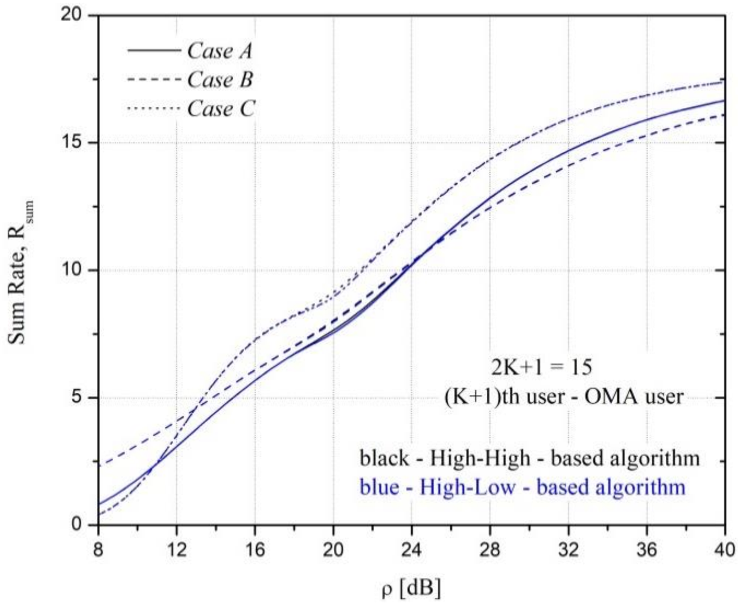
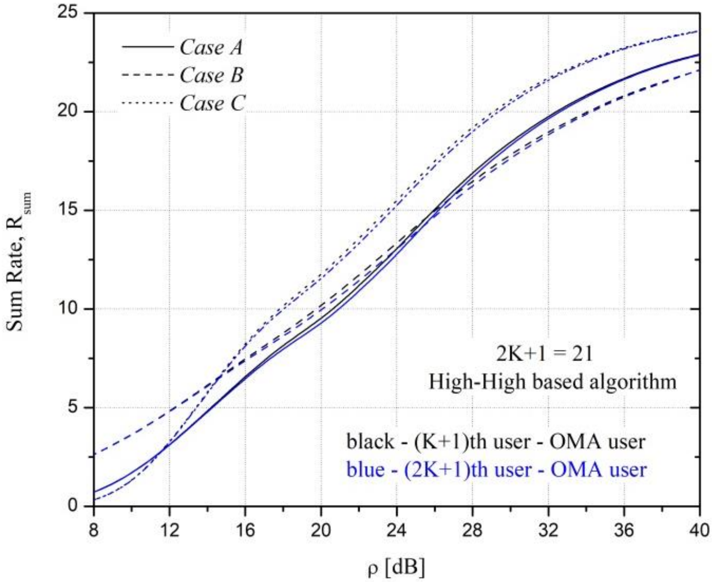



**Fig. 2 –** *Sum data rate versus* ρ ((*K+1)th user – OMA user*, 2*K*+1 = 15).

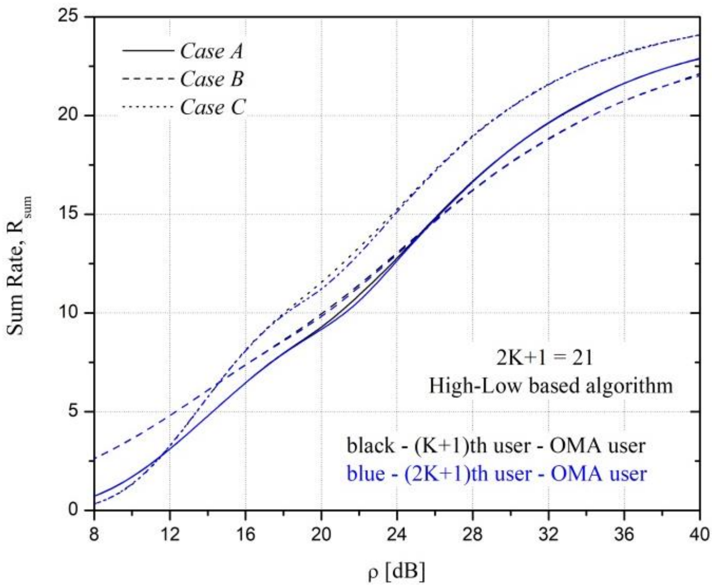
Comparison of the origin and modified High-High/High-Low based algorithms for twenty one and fifteen users is shown in Figs. 3 and 4, respectively.

Authors in [10] treat users closest to the cell edge as OMA users, which in our applied algorithms do not improve the capacity performance of the examined PD-NOMA system. Actually, higher sum rate is achieved for the case when OMA user is (*K+1*)th user in comparison to the case when it is (2*K*+1)th user.

If we compare Fig. 1 from this paper with Fig. 1 from [1], it is obvious that the achieved PD-NOMA system capacity depends on users' position. Therefore, in order to confirm the concluding remarks and make them general we do more fairly approach shown in Fig. 5. We analyze the considered system in average manner. Fig. 5 confirms all conclusions from results depicted in Figs. 1 – 4.

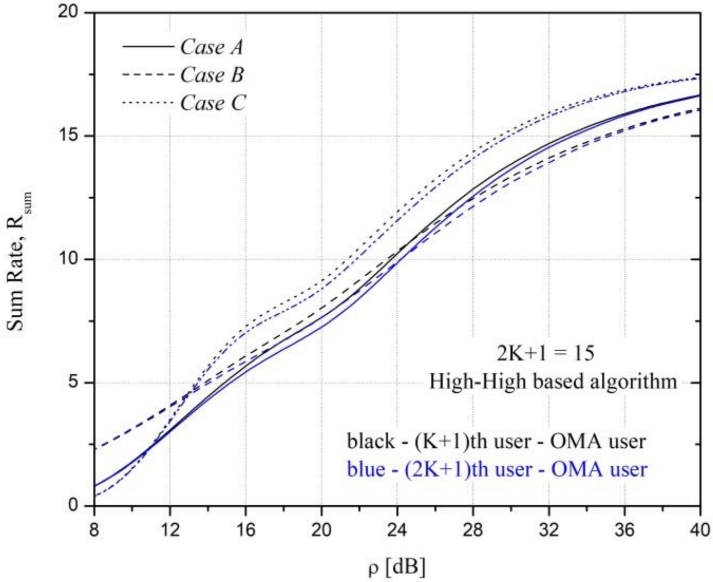



(a)

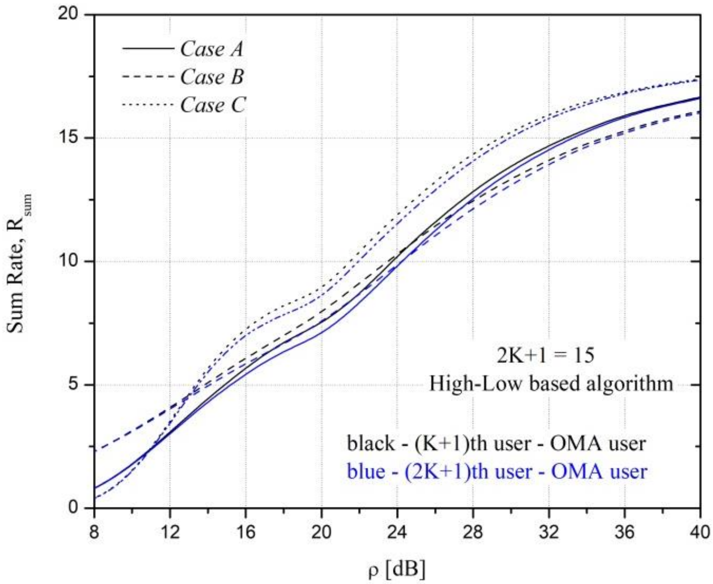



(b)

**Fig. 3 –** *Comparison of the origin and modified clustering algorithms for twenty one users:* (a) *High-High based algorithm;* (b) *High-Low based algorithm.*

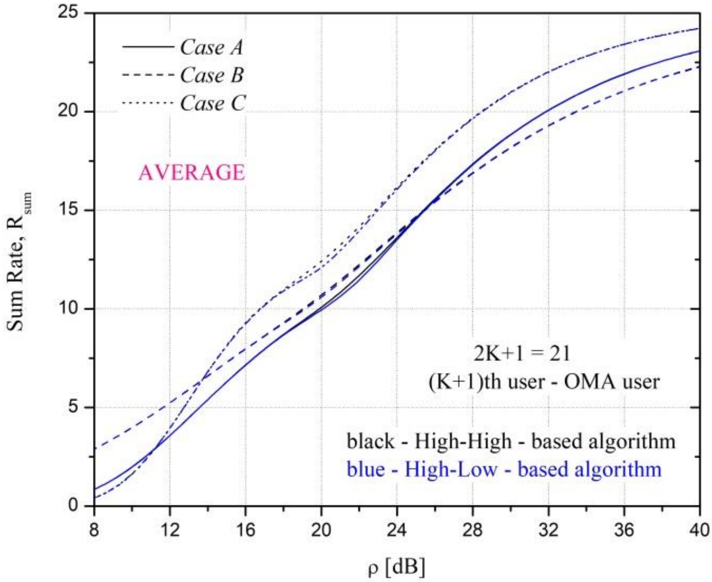



(a)

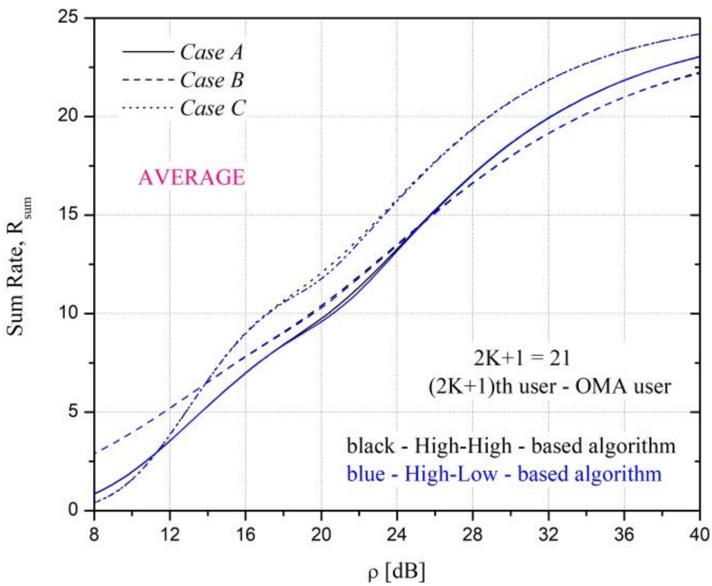



(b)

**Fig. 4 –** *Comparison of the origin and modified clustering algorithms for fifteen users:* (a) *High-High based algorithm;* (b) *High-Low based algorithm.*




(a)




(b)

**Fig. 5 –** *Average sum rate for twenty one users:*
(a) ($K$+1)*th user – OMA user;* (b) (2$K$+1)*th user – OMA user*.

## 6 Conclusion

This paper have shown the extended analysis of uplink PD-NOMA system over F fading channel, in which $2K+1$ users are clustered using origin High-High/High-Low–based algorithm and its modification followed with power allocation scheme with the aim to maximize sum data rate as relevant performance metric. The F fading model has been utilized as accurate model used to describe the combined effects of multipath fading and shadowing, and also attractive for modern communication systems. Obtained results have shown that from the sum-rate point of view, a light advantage is in favor of the origin High-High-based algorithm regardless of the environmental conditions, number of users in the cell and their position.

## 7 Acknowledgments

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