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A NOVEL POWER ALLOCATION ALGORITHM FOR UPLINK NOMA OVER FISHER-SNEDECOR F FADING CHANNEL

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Abstract: *The growing demands for massive connectivity and data-hungry applications and services in wireless systems, stand out the non-orthogonal multiple access (NOMA) as a promising technique for 5G and beyond against orthogonal multiple access (OMA). Therefore, in this paper, we propose a novel power allocation algorithm based on the sum data rate for a power-domain two-user NOMA uplink system. Namely, the closed-form expression for the sum data rate is derived, for the system under consideration, over a composite Fisher-Snedecor (F) fading channel. Based on the proposed analytical presentation of the sum data rate, numerical results are also provided. The impact of the interplay of different fading/shadowing channel conditions and various users' positions on the performance metric is examined. Presented results have a high level of generality since 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, uplink communication*

1. Introduction

The 5G networks face challenges in terms of supporting large-scale heterogeneous data traffic due to the ubiquity of modern multimedia applications such as ultra-high-definition video, virtual reality, as well as numerous use of Internet of things (IoT) and machine-to-machine (M2M) in different aspects of life [1]. Besides increasing demands of data traffic, all of these technologies require significant high spectral efficiency, massive connectivity, and capacity providing, at the same time, fairness among the users/devices. Unfortunately, the conventional orthogonal multiple access (OMA) techniques, such as time division multiple access (TDMA), frequency division multiple access (FDMA), and code division multiple access (CDMA), which have a limited number of available orthogonal resources, can not answer to those challenges. Additional problem is that despite using orthogonal domain resources, the channel induced impairments almost inevitably destroy their orthogonality. This definitely degrades theoretical performance of OMA systems.

The concept of non-orthogonal multiple access (NOMA) has been proposed to support more users than the number of available domain resources, at the ultimate cost of increased receiver complexity caused by separating the non-orthogonal signals. The superiority of NOMA over conventional OMA is not seen only through massive connectivity, but also through higher sum rate, better fairness, less transmission latency, and relaxed channel feedback [2, 3]. In addition, state of the art research on 6G integrates NOMA with the new emerging technologies that may be used in 6G. For instance, NOMA has been integrated with reconfigurable intelligent surfaces (RIS), unmanned aerial vehicle (UAV), terahertz, ambient backscatter communication (AmBC), simultaneous wireless information and power transfer (SWIPT), and cell-free massive multi-input multiple-output (MIMO) [4].

NOMA techniques can be divided into two major categories: power-domain NOMA and code-domain NOMA. For the first one, different power levels are allocated to different users in accordance to their channel conditions with the aim to achieve better system performance. In code-domain NOMA, different users are allocated with different codes and multiplexed over the same time-frequency resources, such as multiuser shared access (MUSA), sparse code multiple access (SCMA), and low-density spreading (LDS) [5]. The code-domain NOMA can enhance spectral efficiency, but it requires high transmission bandwidth and it is not easily applicable in the current systems. Opposite, the implementation of the power-domain NOMA does not require considerable changes in the existing networks, and also improves spectral efficiency without using additional bandwidth [6]. Therefore, our attention in this paper is focused on the power-domain NOMA. The process of power allocation plays a critical role in the design and strongly affects the performance of the power-domain NOMA. It can be classified as fixed power allocation and dynamic power allocation. Fixed power allocation model assigns the same power level to each user, while in the case of the dynamic power allocation model the power level for each user can be changed depending on the instantaneous channel state information (CSI). In the mobile environment, the dynamic power allocation model is shown as more effective than the other one.

There is a difference in work principle between downlink and uplink power-domain NOMA system. In downlink power-domain NOMA, multiple users share the same resource domains, but different power levels are allocated to them at the base station (BS)/transmitter. Due to the concept of NOMA system, demultiplexing of the transmitted signals should be done at receivers applying successive interference cancelation (SIC). In uplink power-domain NOMA, users also share the same resources, but they transmit signals to a common receiver/BS, simultaneously. Thus, the received signal is the superposed signal comprising of signals transmitted from all users. The SIC is employed at BS to decode the information transmitted from multiple users [7].

Fading is often caused by the interaction of signal components, formed by multipath and shadowed signal propagation mechanisms. Therefore, the characterization of this composite fading in the propagation channel is important for improving system performance. In general, the composite fading model is composed of a superposition of lognormal shadowing and a fading distribution (Rayleigh, Rice, Nakagami-*m*, and Hoyt). 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) [8,9]. 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.

There are several studies dealing with various performance metrics for the uplink power-domain NOMA systems with perfect SIC. In [10], one can find a detailed overview of analyzed performance metrics of uplink NOMA systems over different fading channels.

Bearing in mind, the importance and actuality of F fading model, the outage performance of the uplink power-domain NOMA system over F composite fading channels has been already analyzed in our previous work. Since the applied power allocation algorithm influences the system performance, in this paper we propose a novel power allocation algorithm. Namely, relying on the analytical expressions for outage probabilities of users operating in the NOMA system, the new power algorithm is proposed to achieve the maximal sum data rate of uplink NOMA transmission [11].

2. System and channel model

In the system under consideration, 2K cellular users are uniformly-distributed within a cell and grouped in clusters composed of two users. Grouping a large number of users in the NOMA cluster is not recommended because of the performance degradation due to residual interference, increased complexity, and power consumption. In addition, a high capacity gain can be achieved if users in the cluster have a significant disparity in channel gain, which can not be realized with a large number of users in clusters [11]. Each group consists of a cell-center, i.e. near user, U_{C-C} , a cell-edge, i.e. far user, U_{C-E} , and BS 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 the same resource. One resource block (RB) is allocated to every cluster and all users are equipped with a single antenna (Fig. 1).

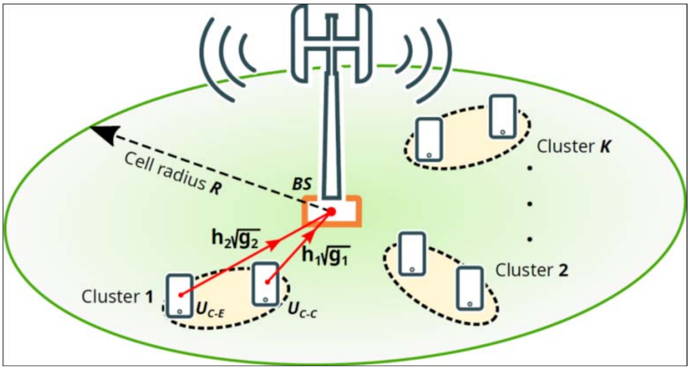

Figure 1. The system model of considered uplink NOMA

In the uplink NOMA system under consideration, 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 the i-th user, with P representing the total power per RB. A distance-based path gain between the BS and the i-th user can be defined as $g_i = g_0 \Big/ \left[H^2 + \left(x_i^2 + y_i^2 \right) \right]^{\beta/2}$ [10], 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 in the cell, and H is the BS antenna height. It is satisfied that $E\left\{|s_i|^2\right\}=1$, while n denotes additive white Gaussian noise (AWGN) with zero-mean and variance σ^2.

In uplink NOMA, the index of users follows the order of decreasing channel gains. Therefore, stronger channel user is decoded at the BS experiencing interference from all other users in the cluster with weaker channels. In other words, the transmission of the highest channel gain user encounter interferences from all users in the cluster, while the transmission of the lowest channel gain user experiences zero interference. Thus, 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 cell-center user, s_1, the BS subtracts $\sqrt{g_1P_1}h_1s_1$ 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 is

$$\gamma_{i,NOMA}=\begin{cases}\dfrac{g_1P_1|h_1|^2}{g_2P_2|h_2|^2+\sigma^2}, & i=1\\[2ex] \dfrac{g_2P_2|h_2|^2}{\sigma^2}, & i=2\end{cases}. \tag{2}$$

The transmit power of the near and far users are P_1 and P_2, respectively. They can be defined as $P_1=a_1P, P_2=a_2P, a_1>a_2$, and $0<a_1<1$, where $a_1+a_2=1$.

The outage performance of the considered uplink NOMA system has been already analyzed in our previous work. Following that analysis, the outage probability of cell-center, U_{C-C}, and cell-edge, U_{C-E}, users are determined as

$$P_{out,1}\left(\gamma_{th,1}\right)=\frac{1}{\Gamma(m_1)\Gamma(k_1)\Gamma(m_2)\Gamma(k_2)}\sum_{r=0}^{+\infty}\frac{(-1)^r g_1^r k_1^r \overline{\gamma_1}^r}{m_1^r\gamma_{th,1}^r r!}$$
$$\times G_{4,4}^{3,3}\left(\frac{m_2g_1k_1\overline{\gamma_1}}{m_1g_2k_2\overline{\gamma_2}\gamma_{th,1}}\middle|\begin{matrix}1,1-k_2,r-m_1+1,r+1\\ m_2,r+k_1,r,r+1\end{matrix}\right)$$
(3)

and

$$P_{out,2}\left(\gamma_{th,2}\right)=1-\left[1-P_{out,1}\left(\gamma_{th,1}\right)\right]\left[1-G_{2,2}^{1,2}\left(\frac{m_2\gamma_{th,2}}{g_2k_2\overline{\gamma_2}}\middle|\begin{matrix}1-k_2,1\\ m_2,0\end{matrix}\right)\right], \tag{4}$$

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

3. Power allocation algorithm

The performance of the NOMA system depends on user clustering, power allocation, and SIC. When we analyse the power allocation issue, the important parameters for the design of the algorithm are CSI availability, channel conditions, quality of service (QoS) requirements, total power constraints, etc. Some of the performance metrics that can be taken into consideration in determining of the power allocation algorithm are the sum rate, fairness, energy efficiency, number of admissible users, etc. Retrospective of some well-known power allocation algorithms can be found in [12].

In this paper, we propose a novel power allocation algorithm based on the achievable sum data rate of two-user NOMA transmission. Namely, the powers levels allocated to two users are determined to maximize the sum data rate, in the following way

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

4. Numerical results

In this section, we analyze the previously determined power allocation algorithm. In the simulation setup, it is assumed that two users are uniformly distributed within a circle with radius of 200 m. BS is located in the center of the circle, mounted at height of 100 m. So, using notation (x, y, H), the position of BS can be marked as $(0,0,100)$. Therefore, the position of cell-center and cell-edge users are marked as $(x_1, y_1, 0)$ and $(x_2, y_2, 0)$, respectively. The additional used parameters are $g_0 = 50dB$ and $\beta = 3$.

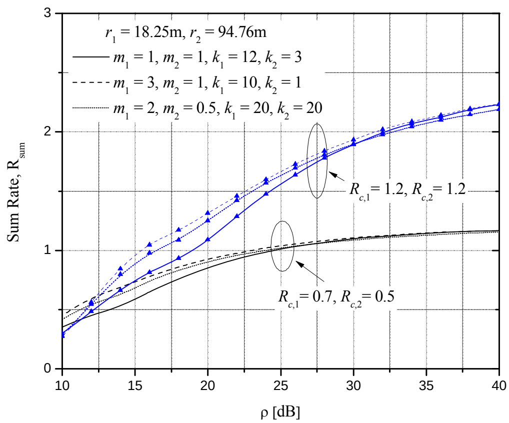

Figure 2. Sum data rate versus ρ

Figure 2 presents the achievable sum data rate as a function of the signal-to-noise ratio (SNR), $\rho = P/\sigma^2$, for different channel conditions and different target data rates. It is evident that the increase in transmit power leads to growth in data sum rate. Moreover, data sum rate curve saturation, i.e. data sum rate maximum, is reached for high SNR regime. This can be justified by the fact that the appropriate power allocation algorithm is applied. Otherwise, this upper limit value would not be achieved. In addition, in high SNR regime, the influence of channel parameters on the rate performance is insignificant. The parameter *k* defines the sharpness of the shadowing phenomenon, while the parameter *m* defines fading severity. Better channel conditions, i.e. higher values of parameters *k* and *m* (light shadowing and less severe fading conditions) ensure that system can offer higher data rate to users for small and moderate SNR values. In addition, results presented in Fig. 2 show that the channel conditions of stronger channel gain user play more important role in realization of upper value of data rate than the channel conditions of weaker channel gain user.

Figure 3 depicts the power level allocated to cell-center user, $P_1 = a_1 P$, to achieve the sum data rate shown in Fig. 2. The presented value of the power coefficient a_1 is determined by Eq. (5). Power coefficient increment used in the numerical analysis

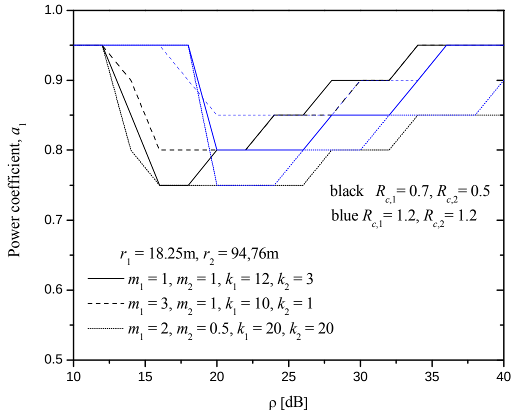

Figure 3. Power coefficient a_1 versus ρ

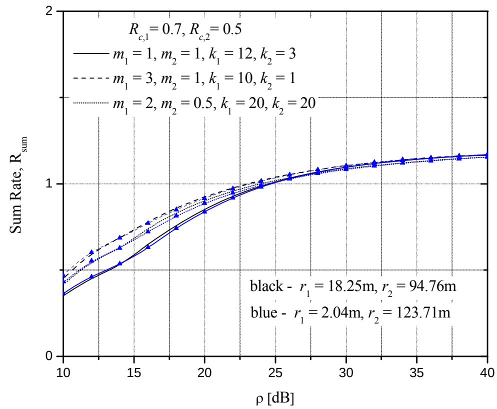

Figure 4. Sum data rate versus ρ

is □$a_1 = 0.05$. Large fluctuations in the channel and system parameters do not provoke large fluctuations in allocated power since the value of the power coefficient a_1 is in the range $\left[0.75, 0.95\right]$.

In Fig. 4 the sum data rate versus SNR is also presented again. Namely, the achieved sum data rate of two-user NOMA system is analyzed when two different user positions in the cluster exist. Above all, the determined results show the main advantage of the proposed power allocation algorithm. More specifically, it provides the highest sum data rate as possible regardless of user positions.

At the end of this section, it should be discussed about the convergence of Eq. (3), since it is expressed in an infinite sum. Through the numerical analysis, it is confirmed that only a few terms (<10) are required to achieve accuracy at the fourth significant digit.

5. Conclussions

In this study, a new power allocation algorithm for an uplink two-user NOMA system has been proposed. It is designed to enable maximum possible data rate that can be provided to users in NOMA. It is given in the form of infinite sum which is characterized by rapid convergence. Presented results have shown that user position relative to BS does not influence on effectiveness of the proposed algorithm. That presents its main advantage.

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References

[1] Z. Liu, Y. Qin, M. Elkashlan, Y. Ding, A. Nallanathan, and L. Hanyo, "Non-orthogonal multiple access for 5G and beyond", *Proceedings of the IEEE*, vol. 105, no. 12, pp. 2347-2381, December 2017. DOI: 10.1109/JPROC.2017.2768666.

[2] L. Dai, B. Wang, Z. Ding, Z. Wang, S. Chen, and L. Hanzo, "A survey non-orthogonal multiple access for 5G", *IEEE Communications Surveys & Tutorials,* vol. 20, no. 3, pp. 2294-2323, May 2018. DOI: 10.1109/COMST.2018.2835558.

[3] Z. Chen, Z. Ding, X. Dai, and R. Zhang, "An optimization perspective of superiority of NOMA compared to conventional OMA", *IEEE Transactions on Signal Processing,* vol. 65, no. 19, pp. 5191-5202, October 2017. DOI: 10.1109/TSP.2017.2725223.

[4] M. Mounir, M. B. El Mashade and A. M. Aboshosha, "On the selection of power allocation strategy in power domain non-orthogonal multiple access (PD-NOMA) for 6G and beyond", *Emerging Telecommunications Technologies,* May 2022. DOI: 10.1002/ett.4289.

[5] M. Aldababsa, M. Toka, S. Göçkeli, G. K. Kurt, and O. Kucur, "A tutorial on nonorthogonal multiple access for 5G and beyond", *Wireless Communications and Mobile Comupting,* 2018. DOI: 10.1155/2018/9713450.

[6] L. Dai, B. Wang, Y. Yuan, S. Han, and Z. Wang, "Nonorthogonal multiple access for 5G: solutions, challenges, opportunities and future research trends", *IEEE Communications Magazine,* vol. 53, no. 9, pp. 74-81, September 2015. DOI: 10.1109/MCOM.2015.7263349.

[7] A. Agarwali, R. Chaurasiya, S. Rai, and A. K.. Jagannatham, "Outage probability analysis for NOMA downlink and uplink communication system with generalized fading channel", *IEEE Access,* vol. 8, pp. 220461 - 220481, December 2020. DOI: 10.1109/ACCESS.2020.3042993

[8] P. R-. Espinosa and F. J. L-. Martínez, "Composite fading models based on inverse gamma shadowing: theory and validation", *IEEE Transactions on Wireless Communications,* vol. 20, no. 8, pp. 5034-5045, August 2021. DOI: 10.1109/TWC.2021.3065141

[9] D. K. Yoo, P. C. Sofotasios, M. Valkama, and G. K. Karagiannidis, "The Fisher-Snedecor *F* distribution: a sample and accurate composite fading model", *IEEE Communications Letters,* vol. 21, no. 7, pp. 1661-1664, July 2017. DOI: 10.1109/LCOMM.2017.2687438

[10] N. P. Lee, L. C. Trab, X. Huang, J. Choi, E. Dutkiewicz, S. L. Phung, and A. Bouzerdoum, "Performance analysis of uplink NOMA systems with hardware impairments and delay constraints over composite fading channels", *IEEE Transactions on Vehicular Technology,* vol. 70, no. 7, pp. 6881-6897, July 2021. DOI: 10.1109/TVT.2021.3086045

[11] Z. Zhang, H. Sun, and R. Q. Hu, "Downlink and uplink non-orthogonal multiple access in a dense wireless network", *IEEE Journal on Selected Areas in Communications,* vol. 35, no. 2, pp. 2771-2784, July 2017. DOI: 10.1109/JSAC.2017.2724646

[12] T. Sanjan and M. N. Suma, "Investigation of power allocation schemes in NOMA", *International Journal of Electronics,* 2021. DOI: 10.1080/00207217.2021.1939434

Rezime: *Masovna konekcija i sve veći broj zahteva za aplikacije i servise sa velikim protokom podataka, istakle su NOMA kao obećavajuću tehniku za 5G i buduće mreže u odnosu na OMA. Zbog toga smo u ovom radu predstavili novi algoritam za dodelu snage korisnicima, na osnovu agregatne bitske brzine u NOMA sistemu sa uzlaznim linkom i dva korisnika u klasteru. Naime, izveden je izraz u zatvorenom obliku za izračunavanje agregatne bitske brzine za dati sistem u kanalu sa Fisher-Snedecor (F) fadingom. Koristeći izvedeni analitički izraz, prikazani su i numerički rezultati. Razmatran je međusobni uticaj fedinga i efekta senke u kanalu i pozicije korisnika u ćeliji na performanse sistema. Prikazani rezultati imaju veliki stepen generalnosti obzirom da F model fedinga obezbeđuje tačan opis uslova u kanalu sa fedingom i efektom senke za mnoge značajne komunikacione scenarije.*

Ključne reči: *kanal sa kompozitnim fedingom, NOMA, agregatna bitska brzina, uzlazni link*

NOVI ALGORITAM ZA RASPODELU SNAGE ZA UZLAZNI NOMA LINK SA FIŠER-ŠNEDEKOROVIM F FEDINGOM

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