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Zipf Distribution Power AllocationAapproach for NOMA Systems

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Abstract—**Non-orthogonal multiple access (NOMA) has received tremendous attention for the development of 5G and beyond wireless networks. Power-domain NOMA works on the concept of assigning varying power levels to users within the same frequency and time block. In this paper we propose a novel power allocation approach that uses the Zipf distribution law that satisfies the basic condition of a NOMA system. The Zipf PA is characterized by the simplicity and ease of implementation that allows to extend the capacity of the system to support a large number of users. The numerical results show that the system achieves high throughput and energy efficiency without any parameter optimization constraints as well as improved capacity by increasing the number of users compared to the NOMA system with existing power allocation techniques.**

Keywords—**NOMA; wireless networks; power domain; Zipf distribution law; 5G networks**

I. INTRODUCTION

THE advent of mobile network technologies has changed people's lives, and as a result, the demand for wireless network services, applications and devices that have become indispensable elements of our daily lives is increasing [1].

The current fourth generation (4G) mobile networks are about to reach their capacity limit, which means that the transition from 4th to 5th generation is inevitable [2].With a broadened spectrum of uses, the deployment of 5G will introduce increased data rates, a large number of connected devices, and reduced latency. Its goal is to transform our society into an ultra-connected society [3]- [4]. These three segments will unlock three important usage families Enhanced Mobile Broadband (eMBB): enabling very high transmission speeds, Ultra-reliable and low-latency communications (URLL): Concerns applications that require extreme responsiveness and very short network traversal times, and Massive Machine Communications (mMTC): supports a very large number of devices with limited coverage and throughput [5]. Wireless connectivity in mobile communications is directly associated with frequency spectrum and multiple access method [6].The challenge is to increase the number of users, the throughput rate and the spectral efficiency of the system. Various orthogonal and non-orthogonal multiple access methods are being researched and studied. Previous generations of mobile communication used the orthogonal multiple access method. 2G systems use FDMA (Frequency Division Multiple Access) and TDMA (Time Division Multiple Access) techniques. 3G systems use CDMA (Code Division Multiple Access), while 4G systems use OFDMA (Orthogonal FDMA) [7].
In order to ensure this new type of connectivity, 5th generation networks require a scalable and adaptable access technique such as Non-Orthogonal Multiple Access (NOMA) [8].
NOMA is a multiple access technology, which realizes the transmission on the same temporal, frequency or spatial resources by simple coding and superimposing the signals of several users at the transmitter, and separates the different signals of the users by applying successive interference cancellation (SIC) at the receiver [9].NOMA technology is divided into two main categories NOMA in the code domain (CD-NOMA) and in the power domain (PD-NOMA) respectively for user multiplexing [10].
The main idea of NOMA in the power domain is to ensure that multiple users can be served at the same time/frequency with different power level. The total transmit power is divided among the users preserving the performance and robustness of the system [11]- [13], hence power allocation is very important in non-orthogonal multiple access (NOMA) [14].There are different power allocation schemes, each trying to achieve a specific objective. In this paper, we have presented a power allocation method that can have a great impact on wireless communication networks due to its power to achieve a high sum rate with a large number of users. This paper is divided into several parts organised as follows: Part 1 presents a summary of related work in the area of power allocation in NOMA systems, Part 2 presents the basic operation of a NOMA downlink system, Part 3 gives an overview of power allocation in NOMA systems, and in the 4th part we present our power allocation approach and confirm its reliability with an application example. Our model of a multi-user NOMA system using the Zipf power allocation method is discussed in Part 5. Part 6 is devoted to the analysis and comparison of the performances of the proposed model with other power allocation methods of the theory. The last part is for the conclusion and an overall evaluation was carried out.

II. RELATED WORKS

In [15] the author analyzes the BER capacity and performance in a NOMA system with two users and then 3 users, with different constellation order in a Gaussian channel and with an arbitrary power distribution.To maintain fairness among users, the weakest user is given the highest power

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allocation, while the weakest power is given to the strongest user. The results assert that the complexity of the system increases along with the number of users. The author in [16] arbitrarily allocates power based on the distance between the user and the gNodB and calculates the BER performance for the four-user PD-NOMA uplink. The received signal power is more attenuated for the users located at a greater distance with lower channel gains than the others. The proposed study uses the D&F Cop-PD-NOMA technique to improve the performance of the weak users and a user grouping technique to reduce the probability of outage that occurs in PD-NOMA systems. The paper [17] presents in summary some concepts of power allocation in NOMA, and proposes a new dynamic eigenvalue based PA method. To evaluate his PA scheme, the author compares the performance of the proposed system in terms of SER versus SNR with nine PA schemes for the case of two users in a Rayleigh channel. The eigenvalue based power allocation performs well compared to other power allocation schemes. The author of [18] proposed a power allocation method based on a genetic algorithm GAPA which is defined as an optimization method based on a powerful heuristic, to maximize the sum rate of the NOMA system. The results are evaluated by comparing the performance with FSPA, and show that the proposed GAPA algorithm outperforms FSPA with a large number of users. To increase the capacity and maximize the bit rate and energy efficiency of the network, the author in [19]- [23] presents an optimal power allocation strategy. The simulation results show that the proposed schemes can converge and achieve higher total capacity compared to the non-optimal NOMA and orthogonal multiple access OMA schemes. In [24] a method based on a dynamic set of power coefficients is used by implementing these different generic matching approaches for NOMA Hungarian, Gale-Shapley, random and exhaustive.The results on network user sizing show that the proposed scheme can have the capacity to cope with the high data demand expected for 5G.

III. POWER ALLOCATION IN NOMA SYSTEMS

In NOMA several users are allowed to share simultaneously the same sub-band at the same time/frequency. In order to differentiate each user from another the set of users is multiplexed at the power level [25]or each user is allocated a part of the total power taking into account the limit of the maximum transmission power of the base station [26]. There are different methods and algorithms of power allocation in dynamic downlink methods, which are generally characterized by the complexity of use where the allocation of power is done according to the channel state information (CSI) [27]-[29]. The fixed methods are simple and easy to implement but is limited by a small number of users [30], and as well as the coefficients can be assigned arbitrarily or according to a distribution law, the system will require optimization techniques to have satisfactory results [31]- [32] .

IV. ZIPF POWER ALLOCATION

The choice of the power allocation method has a great impact on the NOMA system [33] , so it is necessary to adapt efficient methods. For a better resource management; we propose a power allocation approach that uses the Zipf distribution law that satisfies the basic condition of a NOMA system. Zipf PA is characterized by the simplicity and ease of implementation that allows to extend the capacity of the system to support a large number of users. Regardless of the number of users, Zipf power allocation guarantees a non-identical distribution for each user equipment UE while respecting the NOMA power sum condition:

$$\sum_{1}^{n} p_n = 1 \tag{1}$$

The random behavior of the power distribution allows to model it with a zipf random variable that is the following [34]:

$$S_x = \{p_1, p_2, \dots, p_k, ..., p_{N-1}, p_N \} \tag{2}$$

$$p_k = \frac{1}{c_N}\frac{1}{k}P; k = 1, 2, \dots, N \tag{3}$$

$$c_N = \sum_{k=1}^{N} \frac{1}{k} = 1 + \frac{1}{2} + \frac{1}{3} + ... + \frac{1}{N} \tag{4}$$

Where N is a positive integer and P is total power. For best performance the power allocated to the near user should be less than that of the far user [35]- [36]. The power allocation Zipf is proportional with the propagation distance between the different UEs of the Bs.

V. SYSTEM MODEL

In this section we present the general concept of NOMA downlink transmission for a single-input, single-output channel, where the base station Bs serves a multiple set of users $k = 1, 2, 3 \dots, N$ Users transmit their signals by sharing the same time-frequency code resources [37]- [39] through Rayleigh fading transmission channels, d_n represents the variable distance between each UE and the Bs We assume a NOMA system in the power domain where the total power of the system P is shared by all users in order to create a difference that allows to identify each user separately at the power level respecting the limit principle:

$$\sum_{1}^{N} p_k = 1 \tag{5}$$

The power allocation coefficients p_k should be proportional to the distance d_k that separates each UE from the Bs such that:

$$|d_1| > |d_2| > |d_3| > .. > |d_n| \propto |p_1| > |p_2| > |p_3| > .. > |p_N| \tag{6}$$

On the transmitter side, the superposition coded signal transmitted by the Bs is as follows:

$$X = \sum_{k=1}^{N} \sqrt{P}(\sqrt{p_k}.x_k) \tag{7}$$

Where P is the total power required for transmission and x_k denotes the messages sent by the Bs to all users, p_k is the power allocation factor for the kth user in the system, given by the equation(3). At the receiver, the signal received by all users can be expressed by the following relationship:

$$y_k = h_k X + w_k \tag{8}$$

Where X is the source signal transmitted by the Bs, y_k represents the signal received by the set of users, h_k is the channel through which the message is transmitted from the Bs to the set of users, w_k is An additive white Gaussian noise (AWGN). To have good transmission condition, the NOMA uses the SIC technique at the receiver to eliminate the interference due to the chaining of the information of the different users in the same channel [40]. Sequential Interference Cancellation (SIC) is a promising physical layer technique that can improve the efficiency of the wireless networks with relatively low additional complexity [41] . The idea of SIC is to sequentially decode all of the different users in the network by decreasing the error rate [42]- [43]. For the kth use, the instantaneous ratio s_k between the received signal and noise at the kth receiving antenna where σ is the noise power of the Channel and P is the average received power expressed in watts is given by:

$$s_k = \frac{|h_k|^2 p \frac{1}{\sum_{i=1}^{k} \frac{1}{i}} \frac{1}{k}}{p|h_k|^2 (\sum_{i+1}^{k} (\frac{1}{\sum_{i=1}^{k} \frac{1}{i}} \frac{1}{k+1}))\sigma^2} \tag{9}$$

$|h_k|^2$ Is the channel gain expression.
For a Rayleigh fading channel model, the capacity of a NOMA downlink is given by the following formula [44]:

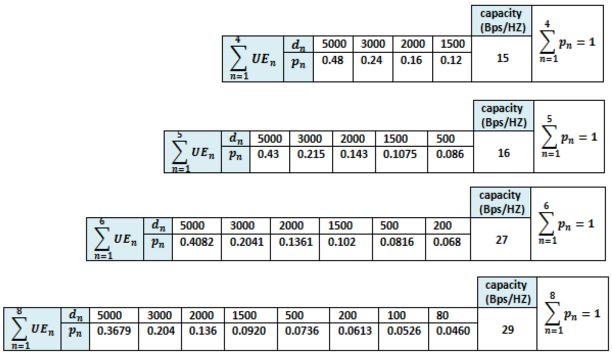
$$c = \log_2(1 + s_k) \tag{10}$$

By substituting equation (9) into equation (10), the capacity for a Noma system with Zipf PA can be expressed as:

$$c_Z ipf = \log_2(1 + \frac{|h_k|^2 p \frac{1}{\sum_{i=1}^{k} \frac{1}{i}} \frac{1}{k}}{p|h_k|^2 (\sum_{i+1}^{k} (\frac{1}{\sum_{i=1}^{k} \frac{1}{i}} \frac{1}{k+1}))\sigma^2}) \tag{11}$$

VI. SIMULATION RESULTS AND ANALYSIS

This section evaluates the results of simulating the NOMA system model with the Zipf power allocation scheme, and with matlab software, in a Rayleigh fading environment with patch loss attenuation factor ϵ = 4, and the power spectral density $N0 = -174dBm/Hz$. The base station serves a set of users randomly distributed in a single cell, where the minimum distance from the Bs to the nearest user is set to 200 m. The sum rate (capacity) performance of a NOMA system with the Zipf power allocation scheme with different number of users is evaluated. Figure (3) shows the achievable capacity of a set of NOMA systems with the proposed Zipf PA power allocation method as a function of transmit power with different number of users with simulation parameters presented in Figure (1) and Figure(2).The achievable capacity increases when the number of users increases. This asserts that Zipf power allocation is an effective approach for NOMA systems.See Fig. 1 2 3. The convergence behavior of our proposed Zipf power allocation scheme for different number of users is shown in Figure (4), where the sum of the capacities (bps/Hz) of UEs as a function of the transmission power is plotted. It can be seen that the capacity curves converge quickly as well as the system requires high transmission power when the number of users is high [45]. See Fig. 4.



						capacity (Bps/HZ)	$\sum_{n=1}^{4} p_n = 1$
$\sum_{n=1}^{4} UE_n$	d_n	5000	3000	2000	1500	15	
	p_n	0.48	0.24	0.16	0.12		

							capacity (Bps/HZ)	$\sum_{n=1}^{5} p_n = 1$
$\sum_{n=1}^{5} UE_n$	d_n	5000	3000	2000	1500	500	16	
	p_n	0.43	0.215	0.143	0.1075	0.086		

								capacity (Bps/HZ)	$\sum_{n=1}^{6} p_n = 1$
$\sum_{n=1}^{6} UE_n$	d_n	5000	3000	2000	1500	500	200	27	
	p_n	0.4082	0.2041	0.1361	0.102	0.0816	0.068		

										capacity (Bps/HZ)	$\sum_{n=1}^{8} p_n = 1$
$\sum_{n=1}^{8} UE_n$	d_n	5000	3000	2000	1500	500	200	100	80	29	
	p_n	0.3679	0.204	0.136	0.0920	0.0736	0.0613	0.0526	0.0460		

Fig. 1. Application parameters of the Zipf PA method in a NOMA system

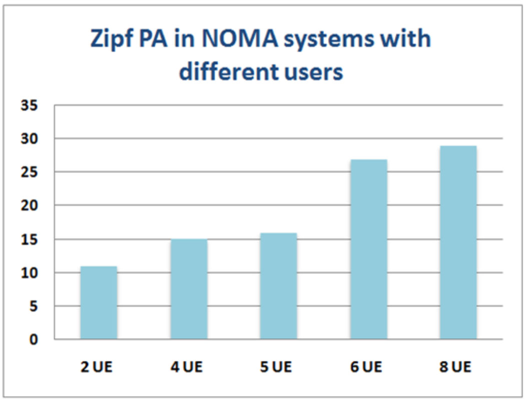


Fig. 2. Achievable capacity of Zipf PA scheme in a NOMA system

VII. PERFORMANCE COMPARISON WITH PREVIOUS PUBLISHED LITERATURE

Due to the explosion of connected devices in 5G networks, the number of users that the system will serve is usually very large, Non-orthogonal transmission is designed to be the solution for 5G networks to have the ability to support a large number of users with better reliability and reduced latency [46].

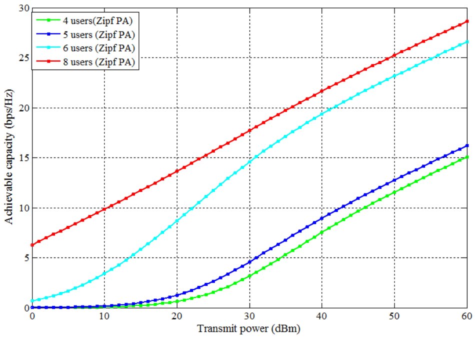


Fig. 3. Achievable capacity depending on the transmission power for different NOMA systems with Zipf PA

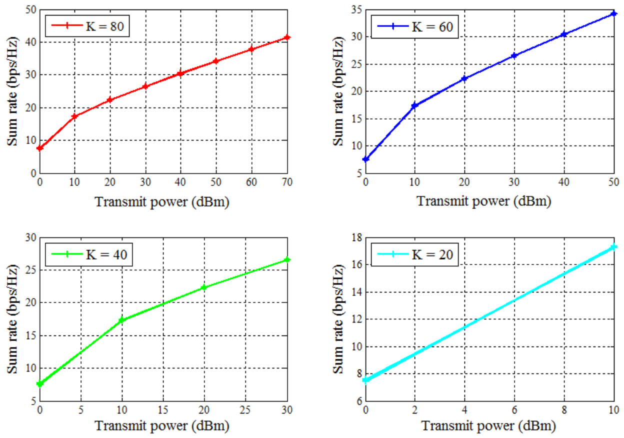


Fig. 4. NOMA system with Zipf PA for different number of users

This section illustrates the performance of a NOMA downlink system with three different power allocation methods using the same simulation parameters. The simulation compares the performance of Zipf PA with Pair PA cited in [47]- [49] and Generalized PA that emerged in [50], [17]. The results are presented in terms of achievable capacity, SNR, spectral efficiency SE and energy efficiency EE, with a large number of users network model. From Figure (5) we can see that the sum rate performance of the proposed ZIPF PA method in NOMA outperforms the other power allocation schemes and reveals a higher sum rate for a very high number of users. Similarly, Pair PA presents good results and preserves a satisfactory sum rate by increasing the number of users. On the other hand, Generalized PA gives weak results where the total capacity of the network increases for a number of users lower than 10 UE, then falls and saturates. Thus we conclude that the NOMA system with the generalized PA method supports a number of UE limited to 20 UE. Therefore, we can see that NOMA with Zipf PA allows to obtain a very high achievable capacity and outperforms the fair PA and Generalized PA. Figure (6) shows the comparison of the sum rate versus SNR between the three PA methods, with an equal number of users $k = 80$. The simulation results indicate that for a SNR rate that varies between [130-220 (dB)] Zipf PA presents an obvious performance gain compared to Fair PA and Generalized PA. This is explained by the fact that the signal transmitted with Zipf PA is more resistant to noise and interference in a NOMA system, and can obtain a higher transmission quality. The trade-off relationship between SE and EE for different NOMA system with the same number of users $k = 80$ and three PA methods Zipf, Pair, Generalized is shown in Figure (7). It can be seen that the NOMA system with Zipf PA clearly outperforms and achieves higher EE and SE than the other PA methods. Figures(8) present the effects of the Zipf PA method and the Fair PA and the Generalized PA on the spectral efficiency SE of the multi-user NOMA system As can be seen, the spectral efficiency of the system With the Zipf PA method increases with the number of users and the Fair PA reaches a near-optimal SE. However, it is interesting to note that SE of the system with Generalized PA increases and then decreases when the number of users $k = 10$ which is incompatible with a multi-user NOMA system. See figure 5 6 7 8.

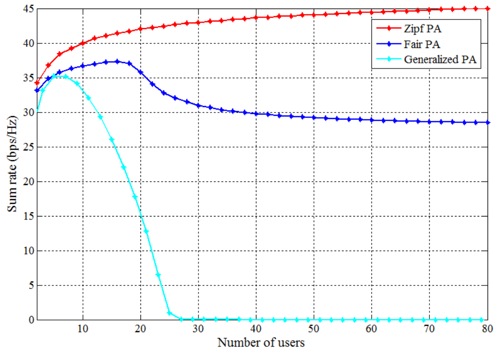


Fig. 5. Sum rate versus number of users for Zipf PA,Fair PA and Generalized PA

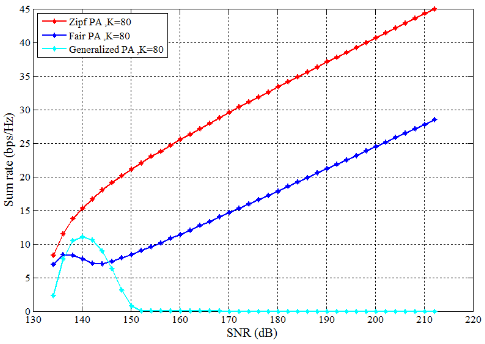


Fig. 6. Sum rate versus SNR pour Zipf PA,Fair PA and Generalized PA

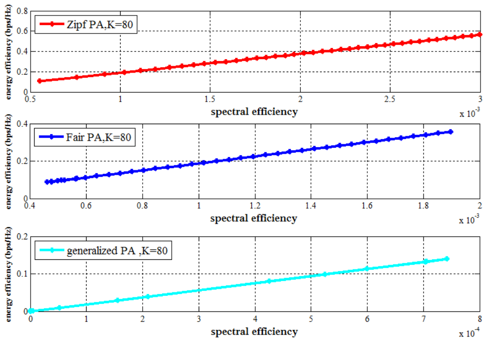


Fig. 7. Comparison of spectral efficiency in terms of energy efficiency for Zipf PA,Fair PA and Generalized PA

The simulation results show that the Zipf PA is more suitable for the needs of NOMA system, as mentioned above, and ensures the reliability and transmission efficiency of NOMA networks with a large number of users.

VIII. CONCLUSION

The non-orthogonal multiple access NOMA technology is a leading technology in the field of wireless communications.

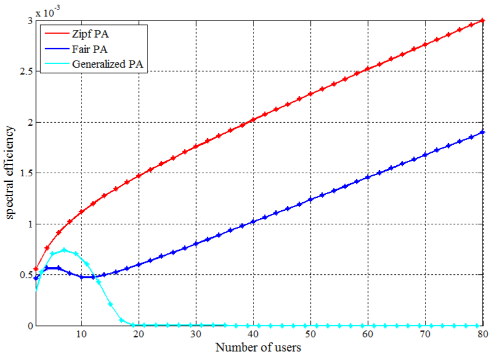


Fig. 8. comparison of spectral efficiency as a function of the number of users for Zipf PA,Fair PA and Generalized PA

It has been adopted by the 5th generation networks and can be used for future generations. In this paper we present a model of NOMA system with a new power allocation method based on Zipf distribution law. The simulation results showed that the use of Zipf PA in a NOMA system with a large number of users is able to provide significant network capacity, which improves the spectral efficiency. This performance also results in an arbitrarily low amount of error, which allows the NOMA system with Zipf PA to achieve a higher energy efficiency compared to other PA schemes. In addition to its ease of implementation which reduces its operating cost, Zipf power allocation satisfies all the objectives of a wireless communication system design.

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