Zipf Distribution Power Allocation Approach 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 connected devices, and reduced latency. This multi-user NOMA 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.

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.
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 gNodeB 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&C/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 schemes. The author of [18] proposed 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:

$$\sum_{k=1}^{n} p_k = 1$$

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

$$S_x = \{p_1, p_2, \ldots, p_k, \ldots, p_N-1, p_N \}$$

$$p_k = \frac{1}{c_N} k^P; k = 1, 2, \ldots, N$$

$$c_N = 1 + \frac{1}{2} + \frac{1}{3} + \ldots + \frac{1}{N}$$

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 $k = 1, 2, 3, \ldots, N$ Users transmit their signals by sharing the same time-frequency code resources through Rayleigh fading transmission channels, $d_k$ 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:

$$\sum_{k=1}^{N} p_k = 1$$

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

$$|d_1| > |d_2| > |d_3| > \ldots > |d_n| \propto |p_1| > |p_2| > |p_3| > \ldots > |p_N|$$

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

$$X = \sum_{k=1}^{N} \sqrt{P_k} x_k$$

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:

$$y_k = h_k X + w_k$$  \hspace{1cm} (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 \(k\)th use, the instantaneous ratio \(s_k\) between the received signal and noise at the \(k\)th receiving antenna where \(\sigma\) is the noise power of the Channel and \(P\) is the average received power expressed in watts is given by:

$$s_k = \frac{|h_k|^2 p}{\sum_{i=1}^{k} \left( \frac{1}{\sum_{j=1}^{i} \frac{k}{k+1}} \right) \sigma^2}$$  \hspace{1cm} (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]:

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

By substituting equation (9) into equation (10), the capacity for 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).

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 path loss attenuation factor \(\epsilon = 4\), 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.

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].
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.
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.

References


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