IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

SPECIAL SECTION ON GREEN INTERNET OF THINGS

Received July 19, 2019, accepted August 6, 2019, date of publication August 9, 2019, date of current version August 22, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2934111

Dynamic User Grouping-Based NOMA Over Rayleigh Fading Channels

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This work was supported in part by the Jiangsu Specially Appointed Professor Program under Grant RK002STP16001, in part by the Program for Jiangsu Six Top Talent under Grant XYDXX-010, in part by the Program for High-Level Entrepreneurial and Innovative Talents Introduction under Grant CZ0010617002, and in part by the 1311 Talent Plan of Nanjing University of Posts and Telecommunications.

ABSTRACT With the development of wireless communications and internet of things (IoT), non-orthogonal multiple access (NOMA) has been considered as one of effective schemes to meet the rapidly growing user access requirements. Two types of NOMA, i.e., NOMA-2000 and power-domain NOMA (PD-NOMA), have been proposed in recent years. The first one is a superposition of a set of orthogonal frequency division multiple access (OFDMA) signals and a set of spread-spectrum multicarrier-code division multiple access (MC-CDMA) signals while the second one is a direct superposition of a MC-CDMA signal and an OFDMA signal. This paper proposes a dynamic user grouping method for classifying users and then compares the performance between NOMA-2000 and PD-NOMA over Rayleigh fading channels. Simulation results show that the PD-NOMA can always exhibit lower bit error rate (BER) than the NOMA-2000 under different signal-to-noise ratios. Under the Rayleigh fading environment, the performance of the PD-NOMA after user grouping is better than that of NOMA-2000.

INDEX TERMS Non-orthogonal multiple access (NOMA), power-domain NOMA (PD-NOMA), dynamic user grouping, rayleigh fading channel.

I. INTRODUCTION

With the rapid development of mobile communications and internet of things (IoT), the demand for spectrum efficiency and system capacity has grown fast, and the traditional orthogonal multiple access (OMA) has been unable to meet the user needs [1]–[14]. In order to meet the heavy demand for mobile services, non-orthogonal multiple access (NOMA) [15] and massive multiple-input multiple-output (MIMO) [16] are considered as potential key technologies for the fifth generation mobile communications (5G) [17]–[19]. In OMA, only one user can be assigned a single radio resource, such as frequency division or time division, while NOMA can allocate one resource to multiple users. NOMA uses non-orthogonal transmission at the transmitting end to actively introduce interference between users, and achieves correct demodulation through the successive interference cancellation (SIC) technology at the receiving end. Compared to orthogonal transmission, NOMA improves receiver complexity in exchange for higher spectral efficiency. NOMA is divided into two types, one is the power domain NOMA (PD-NOMA), and the other is the code domain NOMA. The most typical one in the code domain NOMA is NOMA-2000. The research objects of this paper are NOMA-2000 and PD-NOMA.

Since the research on NOMA has started from year 2000, it is called NOMA-2000 [20]. In [21], H. Sari et al. investigated a code-division multiple access (CDMA) and time-division multiple access (TDMA) system which supports a number of users that is larger than the number of orthogonal spectrum. In [22], F. Nadal et al. combined two orthogonal signal waveforms, i.e., TDMA signal and CDMA signal. TDMA used quaternary phase-shift keying (QPSK) modulation and CDMA used 16-state quadrature amplitude modulation (16QAM). The result showed that this system can offer substantial overloads. In [23], A. Maatouk et al. used orthogonal frequency division multiple access (OFDMA) signal waveform and MC-CDMA signal waveform to combine

The associate editor coordinating the review of this article and approving it for publication was Zhenyu Zhou.

in NOMA-2000. At the receiving end, NOMA-2000 detects two sets of orthogonal signals by iterative interference cancellation [24].

Nowadays, the most widely studied NOMA by scholars is the PD-NOMA [25], [26]. The basic idea of the PD-NOMA [27] is to use the non-orthogonal transmission of the user's transmit power at the transmitting end, introduce interference, and pass the SIC receiver at the receiving end to eliminate interference and implement quadrature demodulation. The sub-channel transmission of PD-NOMA [28] still adopts orthogonal frequency division multiplexing. The sub-channels are orthogonal and do not interfere with each other, but one sub-channel is no longer only allocated to one user, but shared by multiple users. At the transmitting end, different users on the same sub-channel are transmitted by using power multiplexing technology, and signal powers of different users are allocated according to relevant algorithms, so that the signal power of each user arriving at the receiving end is different. Non-orthogonal transmission between different users on the same sub-channel will cause interference between users, which is the reason why multi-user detection uses SIC technology at the receiving end. In [29], S. K. Zaidi et al. studies a hybrid NOMA-based wireless system. In this system, users harvest energy from the received downlink signals to transmit on the uplink. J. W. Kim et al. proposed an integration of NOMA and generalized space shift keying to improve the spectral efficiency by exploiting the spatial domain [30].

In NOMA, it is especially important to make reasonable groupings of users [31], [32]. If users are grouped by a suitable method, the accuracy of the system detection at the receiving end can be greatly improved, and the system error rate can be reduced. In [33], X. Lu et al. proposed a joint resource allocation algorithm combining dynamic user grouping, which achieves better system throughput with bite error rate guarantee than other proposed schemes in the literature. In [34], J. Kang et al. study the user grouping for the downlink non-orthogonal multiple access system and the system they proposed significantly outperform the existing schemes.

In this paper, we propose a new user grouping method in PD-NOMA and NOMA-2000 over different Rayleigh fading channels. NOMA-2000 combines OFDMA signal and multi carrier-code division multiple access (MC-CDMA) signal. MC-CDMA waveform is spread and then superposed to OFDMA waveform.

The rest of this paper is organized as follows: Section II introduces the principle of NOMA-2000 and illustrates the process of detecting the signal at the receiver. Section III provides the basic principle of PD-NOMA and analyzes the power imbalance of users. Section IV introduces the user grouping scheme for NOMA-2000 and PD-NOMA. Section V gives the simulation results of use grouping and illustrates the comparison of NOMA-2000 and PD-NOMA. Section VI provides a summary of the present paper.

II. REVIEW OF NOMA2000

Some scholars purposed the concept of NOMA as early as 2000 which uses two sets of orthogonal signal waveforms. In [35], the first set of orthogonal signal waveform used CDMA and the other set used TDMA. CDMA is for the first N users in N subcarriers and they augment it with TDMA when the number of users exceeds the number of subcarriers N. In this paper, we use OFDMA for the first N users and use MC-CDMA for the rest M users. Within the OFDMA signal, there is no interference between users, as is the case in orthogonal MC-CDMA. However, there is a strong interference between OFDMA users and MC-CDMA users. NOMA-2000 solves the problem of inter-user interference by adopting iterative interference cancellation at the receiver.

The total number of users in NOMA-2000 system is K, $K = N + M$. It is worth mention that the number of MC-CDMA users M cannot be larger than the number of OFDMA users N. MC-CDMA symbols spread on OFDMA symbols by spreading sequence. The bandwidth of MC-CDMA symbols is equal to the total bandwidth which is $1/T$ and the spectrum density of MC-CDMA symbols is D. So, the total energy of MC-CDMA symbols is D/T. Because each subcarrier is assigned to one OFDMA user, the spacing of each subcarrier is $1/NT$. The spectrum density of OFDMA symbols is ND. The energy of OFDMA symbols is D/T which is same as that of MC-CDMA symbols. By this way, the normalized power of the interference from MC-CDMA to OFDMA is $1/N$ when the power of OFDMA symbols is 1.

Spread spectrum technology is defined as a radio frequency communication system that spreads a baseband signal into a wider frequency band by injecting a higher frequency signal. The energy of the transmitted signal is spread into a wider frequency band, making it look like noise. Spread spectrum technology simply introducing a corresponding spreading code somewhere and spreads the information into a wider frequency band. Conversely, the spreading code is removed prior to data recovery in the receive link, known as dispreading. Dispreading reconstructs information on the original bandwidth of the signal. Obviously, the spreading code needs to be known in advance at both ends of the information transmission path. The direct result of spreading is to occupy a wider frequency band, thus wasting limited frequency resources. However, the occupied frequency band can be compensated by sharing the same extended frequency band by multiple users. In modern communication, the spreading code must be long enough to be as close as possible to a random number sequence similar to noise. However, they must remain recoverable. Otherwise, the receiver will not be able to extract the transmitted information. Therefore, this sequence is approximately random. A spreading code is often referred to as a pseudo random code or a pseudo random sequence. The more complex the sequence set used by the spread spectrum communication link, the higher its reliability. However, the price paid is that the electronics which are required for the dispreading operation are also more complex.

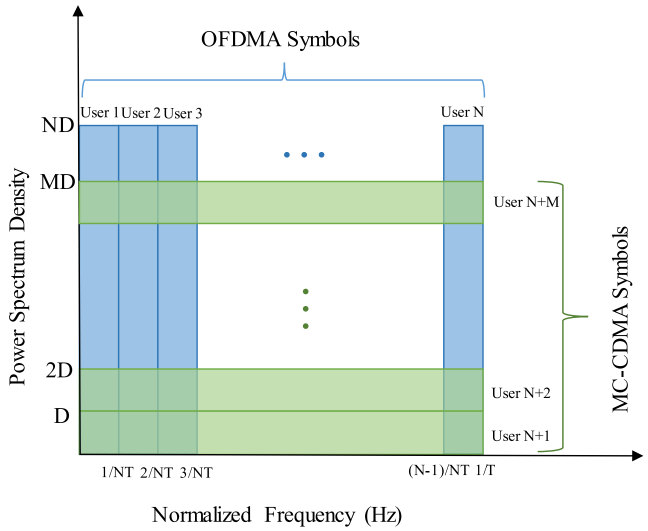

FIGURE 1. The principle of NOMA-2000 with two orthogonal signal waveforms.

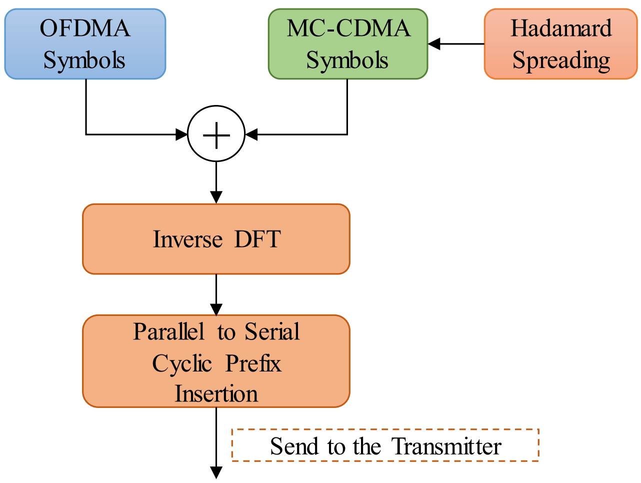

FIGURE 2. The transmitter block diagram of NOMA-2000.

Before the MC-CDMA symbols is superposed on the OFDMA signal, we use the Hadamard matrix to spread the MC-CDMA signal. Hadamard matrix is an orthogonal square matrix of $+1$ and -1 elements. Any two rows or two columns of it are orthogonal, and the sum of the squares of all elements of any row or column is equal to the order of the square matrix. The order of the Hadamard matrix is either 2 or a multiple of 4.

At the receiver, we use two different detection methods that are hard decision and soft decision to analyze which method is better. The hard decision is to simply judge the output signal by setting the threshold. The value which is above the threshold is considered to be 1, and the value below the threshold is considered to be 0. The hard decision will lose the statistical characteristic information about the channel interference contained in the waveform signal, resulting in the high BER of the system.

The soft decision is to first quantize the decision input into some values, and calculate the most likely original value of each value by the maximum posterior probability. The algorithm is complex but its BER is generally lower than that of the hard decision. We assume OFDMA symbols are $s_n, 1 \leq n \leq N$ and MC-CDMA symbols are $g_m, 1 \leq m \leq M$.The spreading sequence used to spread MC-CDMA symbols on OFDMA symbols are donated $W_m = (w_{m,1}, w_{m,2}, \ldots, w_{m,N}), 1 \leq m \leq M$.The channel coefficients of Rayleigh Fading Channel are donated $h_n, 1 \leq n \leq K$. The transmitted signal on subcarrier n is

$$x_n = h_n s_n + \frac{1}{\sqrt{N}} \sum_{m=1}^{M} h_{n+m} w_{m,n} g_m + n_n \tag{1}$$

where n_n is additive white Gaussian noise. The purpose of the division by $\sqrt{N}$ is to conserve MC-CDMA symbol energy during the symbol spreading. Because M is smaller than N, the power of MC-CDMA symbols are smaller than that of OFDMA symbols. We detect OFDMA symbols firstly and assume MC-CDMA symbols are noise. At the receiver, x_n is sent to threshold detector and we can receive the decision of OFDMA symbols which are donated $\hat{s}_n$.

$$r_n = x_n - h_n \hat{s}_n \tag{2}$$

If $\hat{s}_n$ is equal to s_n,

$$r_n = \frac{1}{\sqrt{N}} \sum_{m=1}^{M} h_{n+m} w_{m,n} g_m + n_n \tag{3}$$

Then, r_n is performed to dispread and finally sent to threshold detector to achieve the decision of MC-CDMA symbols.

III. PD-NOMA

Let us focus on an uplink transmission scenarios of two-user NOMA system consisting of one base station, one cell-center user and one cell-edge user. Assuming that User-1 is the cell-center user and its power P_1 is strong. User-2 is the cell-edge user and its power P_2 is weak. After the base station receives two users' signals and noise, it uses SIC receiver to separate two signals. The principle of SIC is to send the received signal to a threshold detector to get User-1 signal because its symbol power is larger than User-2. User-2 signal is buried in User-1 symbols, so it cannot be detected directly. Then, the base station subtracts User-1 signal from the received signal and send it to another threshold detector. Finally, we can get User-1 signal and User-2 signal. The most important part of SIC is User-1 symbol power must be much larger than User-2. Otherwise, User-2 will cause big interference to User-1 and the receiver will fail to detect User-1 signal. In most case, the communication system assigns power to two users at the transmitter to ensure the accuracy of detection at the receiver.

In the communication system, there are N OFDMA users and M MC-CDMA users. The total number of users is K, $K = N + M$. Different with NOMA-2000, power-domain NOMA superposes MC-CDMA signal on OFDMA signal directly without spreading spectrum.

Compared with OMA, PD-NOMA promises a significant channel capacity gain because it allows more users use the

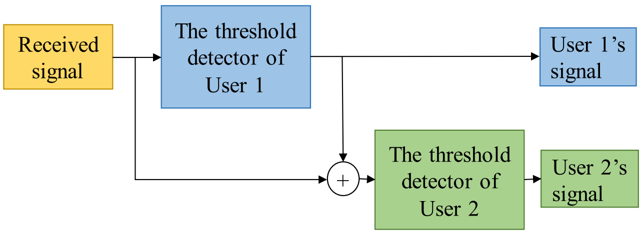

FIGURE 3. The process of SIC receiver.

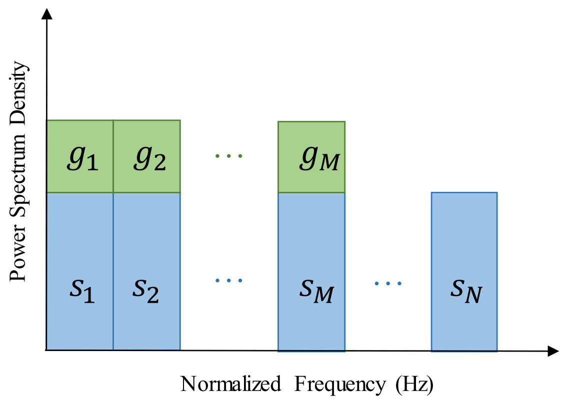

FIGURE 4. The principle of PD-NOMA.

same spectrum at the same time. However, everything has two aspects and PD-NOMA also brings an important problem. It will make users have unequal quality of service (QoS). We will identify this problem by Shannon formula as follows. We assume the channel is Rayleigh fading channel with additive white Gaussian noise. The channel's bandwidth is normalized by $W = 1$Hz. User 1's channel capacity is illustrated as:

$$R_1 = \log_2\left(1 + \frac{P_1}{P_2 + N_0}\right) \tag{4}$$

where N_0 is the spectrum density of additive white Gaussian noise. After we detect User-1 signal, we should minus it from the received signal to get User-2 signal,

$$R_2 = \log_2\left(1 + \frac{P_2}{N_0}\right) \tag{5}$$

and the total capacity in a channel is:

$$\begin{aligned} R_{total} &= R_1 + R_2 \\ &= \log_2\left(1 + \frac{P_1}{P_2 + N_0}\right) + \log_2\left(1 + \frac{P_2}{N_0}\right) \\ &= \log_2\left(1 + \frac{P_2}{N_0} + \frac{P_1}{P_2 + N_0} + \frac{P_1 P_2}{P_2 N_0 + {N_0}^2}\right) \\ &= \log_2\left(1 + \frac{P_{total}}{N_0}\right) \end{aligned} \tag{6}$$

where $P_{total} = P_1 + P_2$. When P_{total} is stable, if the P_1 we set is much larger than P_2, R_1 will be close to R_{total} and R_2 will approaching zero. It is unfair to User-2. When we allocate power to users, we should consider the accuracy of the receiver and the fairness between users at the same time.

IV. DYNAMIC USER GROUPING

In this paper, we assume that users' signal transmit in uplink Rayleigh fading channel. The Rayleigh fading channel is a statistical model of the radio signal propagation environment. In the wireless communication channel environment, after the electromagnetic wave propagates through multiple paths, the strength of the total signal obeys the Rayleigh distribution. At the same time, due to the movement of the receiver and other reasons, the characteristics of signal strength and phase are fluctuating, which is called Rayleigh fading channel. The Rayleigh fading model is suitable for describing wireless channels in densely populated urban centers. Dense high buildings and other objects in city make that there is no direct path between the transmitter and receiver of the wireless device, the wireless signal is attenuated, reflected, refracted, and diffracted. There are totally K users in NOMA-2000 and PD-NOMA, so there are K Rayleigh fading channels in the wireless communication system. As mentioned above, K Rayleigh fading channel coefficients are donated h_n with $1 \leq n \leq K$.

Users of NOMA-2000 are randomly assigned OFDMA or MC-CDMA resources when they are without user grouping. The system has no flexibility and cannot guarantee the QoS of some important users under special circumstances. Reasonable user grouping and power allocation algorithms can reduce interference between user signals and increase system capacity. The base station can select a corresponding subchannel for each user according to a certain user grouping algorithm. The power of each user at the receiving end is:

$$P_{n-received} = |h_n|^2 P_{n-transmitted} \tag{7}$$

Without user grouping, at the receiving end, we cannot guarantee that the energy of the MC-CDMA users is much less than the energy of the OFDMA user. The receiving method is to send the received signal to the threshold decision machine to obtain the decision result of the OFDMA signal firstly. The received signal then subtracts the determined OFDMA signal in order to obtain MC-CDMA signals. Then, this signal is dispread by despreading code and then sent to another threshold decision machine to obtain the decision of the MC-CDMA signal. If the energy of the MC-CDMA signal is not much different from the energy of the OFDMA signal, the MC-CDMA user will generate strong inter-user interference when determining the OFDMA signal, resulting in a large difference between the result of the decision and the actual one, resulting in a high bit error rate and poor performance in the communication system.

In PD-NOMA, the receiver also separates users by distinguishing the power of the two users who occupy the same channel. Usually we assign high power to User-1 and assign lower power to User-2 and its signal will be buried in User-1 signal. SIC receiver firstly detect User-1 signal according to the power and subtract it from the received signal to detect User-2 signal. The greater the power difference between the two users, the higher the accuracy of user detection.

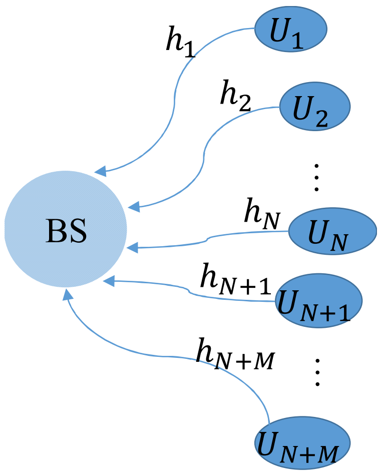

FIGURE 5. Illustration of $(N+M)$ mobile users in a base station.

We adopt a dynamic user grouping scheme to increase the detection accuracy. The channel coefficients are sorted from large to small and are sequentially assigned to the first to the K-th channels, so that the power difference between the two users occupying the same channel will increase. In the NOMA-2000, a channel with a large gain is allocated to an OFDMA user, and the channel with small gain is allocated to an MC-CDMA user. In the PD-NOMA, User-1 and User-2 are assigned same power to avoid unfairness between user. We use user grouping scheme to assign first N channels with high pain to user1s in every subchannel and assign the rest M channels with low pain to User-2 in subchannels, so as to reduce the system error rate and improve system performance.

V. SIMULATION RESULTS

In this section, we show the comparisons of NOMA-2000 and PD-NOMA with user grouping and without user grouping over uplink Rayleigh fading channels under different channel overload conditions. And, we introduce the concept of overloading factor (OF), that is $OF = M/N$. All symbols are modulated as QPSK. We use average bit error rate (BER) to evaluate the performance of communication system,

$$BER_{Ave} = \frac{N}{N+M} BER_{OFDMA} + \frac{M}{N+M} BER_{CDMA} \quad (8)$$

As shown in Fig. 6, increasing the number of MC-CDMA users will increase the capacity of the communication system and the efficiency of spectrum, but it also increases inter-user interference, reducing user's QoS and system accuracy. Both the increase in system capacity and the reduction in bit error rate should be considered when assigning users.

The Fig. 7 shows the BER of NOMA-2000 and PD-NOMA in the case of 256 OFDMA users and 64 MC-CDMA users. We use two judgment methods, hard decision and soft decision, for NOMA-2000. The hard decision is simply to determine the output by setting a threshold. In binary terms, a penalty of 1 is generally greater than 0, and a penalty of 0 is less than 0. The soft decision is to first quantize the decision input into N values, and calculate the most likely original value of each value by the maximum posterior probability. The algorithm is more complicated, and the general bit error rate is also lower. The two dotted blue curves represent the bit error rate of the NOMA-2000 using the hard decision at the first iteration detection and the fifth iteration detection, respectively. The two solid blue curves represent the bit error rate of the NOMA-2000 using soft decision during the first iteration detection and the fifth iteration detection. The red

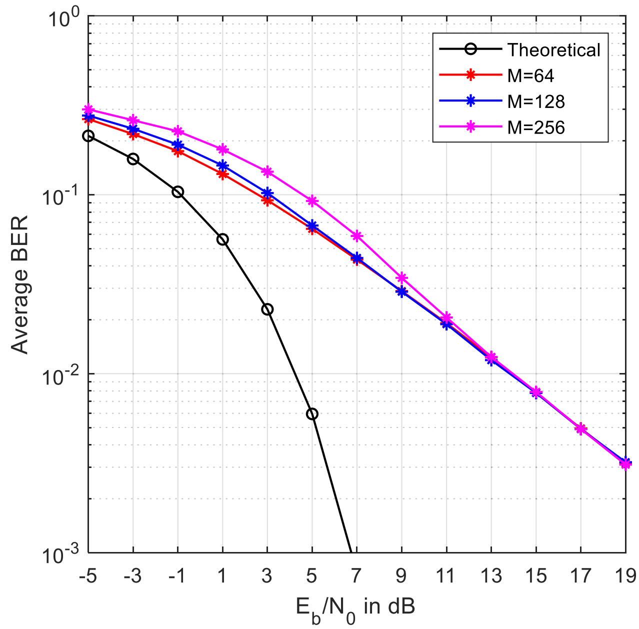

FIGURE 6. BER curves of PD-NOMA under different overload conditions (i.e., $M \in \{64, 128, 256\}$).

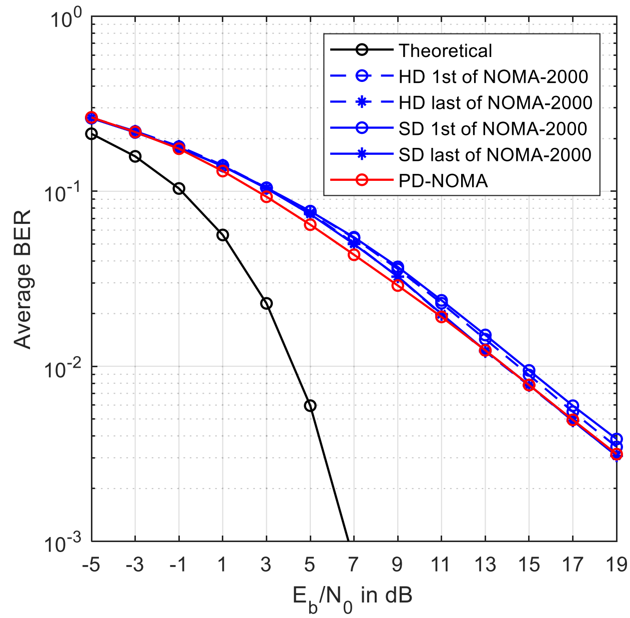

FIGURE 7. The comparison of NOMA-2000 and PD-NOMA with user grouping with $N = 256$, $M = 64$.

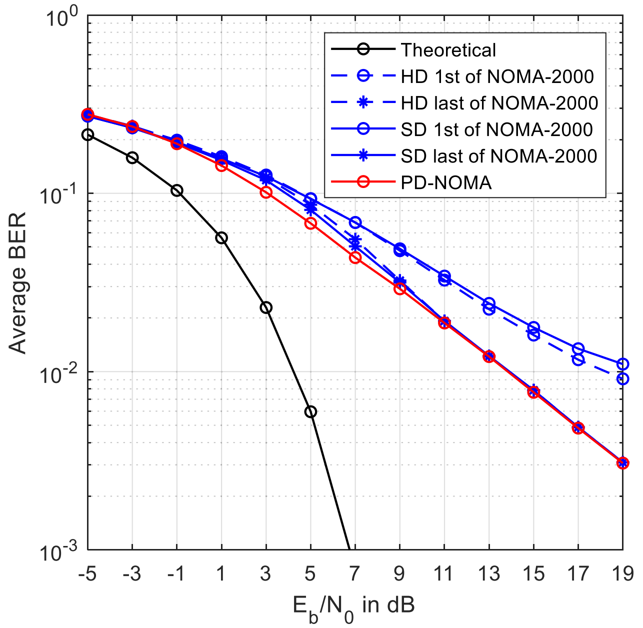

FIGURE 8. The comparison of NOMA-2000 and PD-NOMA with user grouping with $N = 256$, $M = 128$.

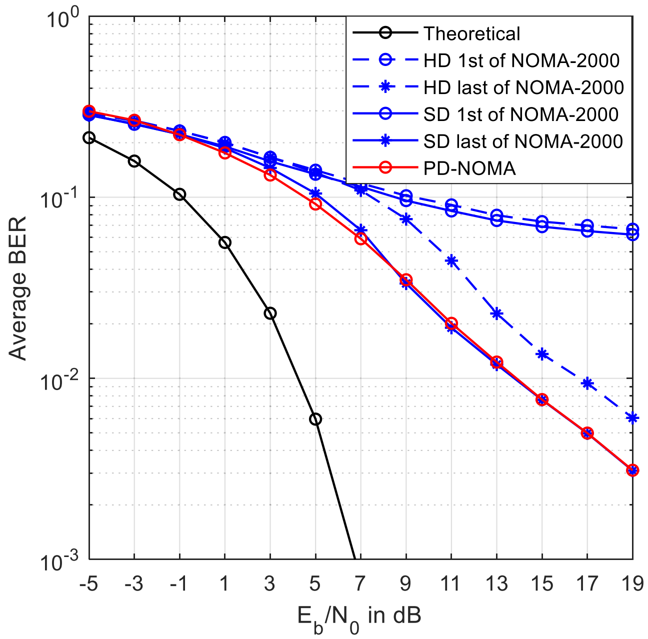

FIGURE 9. The comparison of NOMA-2000 and PD-NOMA with user grouping with $N = 256$, $M = 256$.

curve is the BER of the PD-NOMA at the SIC receiver. In the signal-to-noise ratio range of −5 to 20dB, the PD-NOMA has a lower bit error rate than the NOMA-2000. The PD-NOMA basically coincides with the theoretical curve at a signal-to-noise ratio of 7dB, while the NOMA-2000 begins to coincide with the theoretical curve at 11dB. The Fig. 8 shows the BER of NOMA-2000 and PD-NOMA in the case of 256 OFDMA users and 128 MC-CDMA users. Fig. 9 shows the BER of NOMA-2000 and PD-NOMA in the case of 256 OFDMA users and 256 MC-CDMA users. The PD-NOMA has lower bit error rates than the NOMA-2000.

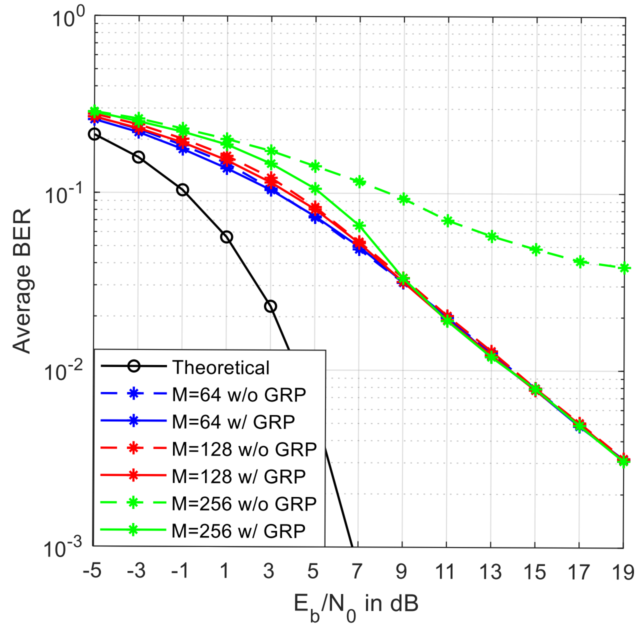

FIGURE 10. The comparison of NOMA-2000 with user grouping and without user grouping (i.e., $M \in \{64, 128, 256\}$).

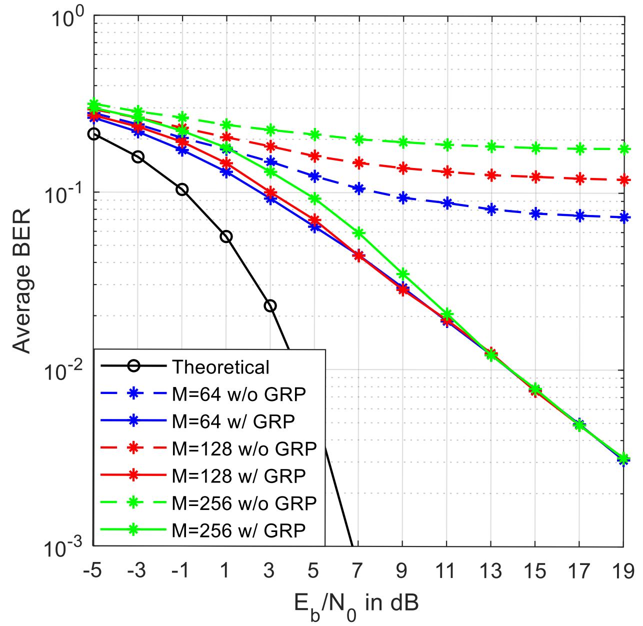

FIGURE 11. The comparison of PD-NOMA with user grouping and without user grouping (i.e., $M \in \{64, 128, 256\}$).

We also analyze the performance comparison of NOMA-2000 and PD-NOMA with user grouping and without user grouping. In our figures, GRP represents user grouping. Fig. 10 and Fig. 11 show the superiority of the approach we use to group users in NOMA-2000 and PD-NOMA respectively. Especially, when the number of MC-CDMA users is up to the number of OFDMA users, the performance of NOMA-2000 and PD-NOMA is obviously good with our user grouping. At the same time, we also make comparisons between NOMA-2000 and PD-NOMA with user

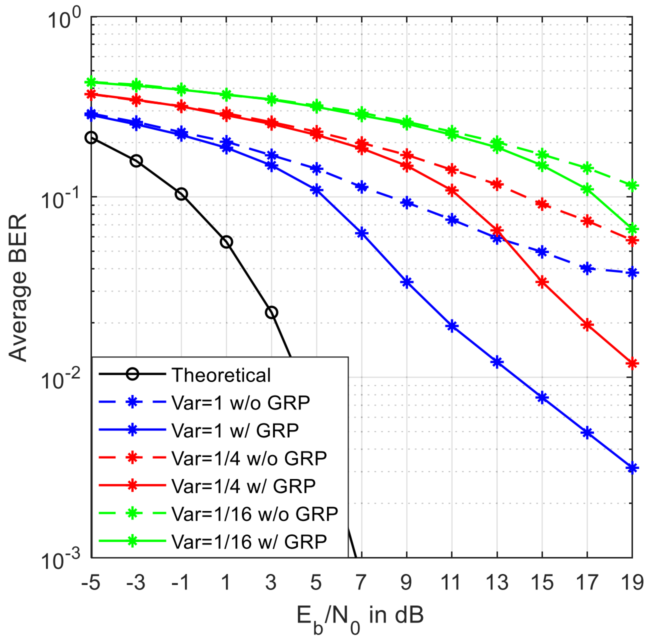

FIGURE 12. **The comparison of NOMA-2000 with user grouping and without user grouping with $N = 256$, $M = 256$ over different Rayleigh fading channels (i.e., *variance* $\in \{1, 1/4, 1/16\}$).**

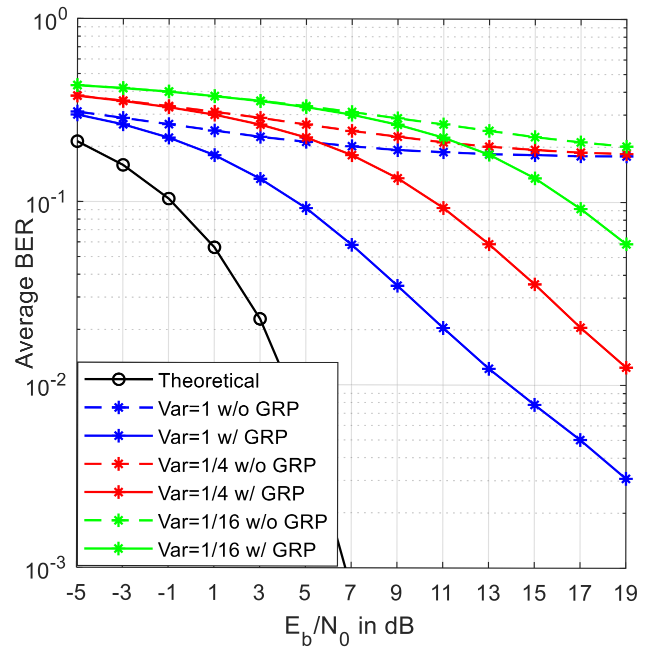

FIGURE 13. **The comparison of PD-NOMA with user grouping and without user grouping with $N = 256$, $M = 256$ over different Rayleigh fading channels (i.e., *variance* $\in \{1, 1/4, 1/16\}$).**

grouping and without user grouping in different Rayleigh fading channels to make sure our method perform well in different environment. Fig. 12 and Fig. 13 show that our user grouping scheme can reduce average BER and improve system accuracy over multiple Rayleigh channels.

VI. CONCLUSION

This paper proposes a new user grouping scheme and compares the scheme's performance of NOMA-2000 and PD-NOMA over different Rayleigh fading channels. Comparing the NOMA-2000 with the PD-NOMA, we find that the PD-NOMA showed better performance than the NOMA-2000 under different channel overload conditions. With a signal-to-noise ratio of −5 to 20dB, the PD-NOMA has a lower bit error rate than the NOMA-2000 and is closer to the theoretical curve. Simulation results shows that our user grouping method performs much better in NOMA systems compared with that without user grouping. And we find our user grouping scheme have high superiority over different channels.

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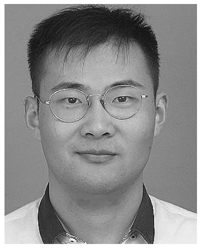

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