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Outage probability analysis of power domain ordered NOMA under various channel conditions

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Abstract

Purpose – Among the proposed radio access strategies for improving system execution in 5G networks, the non-orthogonal multiple access (NOMA) scheme is the prominent one.

Design/methodology/approach – Among the most fundamental NOMA methods, power-domain NOMA is the one where at the transmitter, superposition coding is used, and at the receiver, successive interference cancellation (SIC) is used. The importance of power allocation (PA) in achieving appreciable SIC and high system throughput cannot be overstated.

Findings – This research focuses on an outage probability analysis of NOMA downlink system under various channel conditions like Rayleigh, Rician and Nakagami-m fading channel. The system design's objectives, techniques and constraints for NOMA-based 5G networks' PA strategies are comprehensively studied.

Practical implications – From the results of this study, it is found that the outage probability performance of downlink ordered NOMA under Rayleigh, Rician and Nakagami-m fading channel was good.

Originality/value – Outage probability analysis of downlink ordered NOMA under various channel conditions like Rayleigh, Rician and Nakagami-m fading channels were employed. Though the performance of Nakagami-m fading channel is lesser compared to Rayleigh channel, the performance for user 1 and user 2 are good.

Keywords NOMA, PA, SIC, Outage probability, Fading channel

Paper type Research paper

1. Introduction

The non-orthogonal multiple access (NOMA) scheme is intended as an upcoming radio access mechanism for 5G networks with high bit-rate and capacity. Researchers are interested in finding an alternate system to the existing orthogonal multiple access (OMA) because to the ever-increasing demand for capacity by consumers. Under poor channel conditions, the OMA technique's bandwidth resource allocation provided a low spectral efficiency. The NOMA

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system, on the other hand, regardless of channel condition, tends to allocate bandwidth to users. NOMA has the ability to provide large capacity, while also improving spectral efficiency. However, implementing the NOMA method in 5G networks poses numerous hurdles for a variety of reasons. The most common concerns are the complexity of user pairings as well as the needs for channel state information (CSI). Furthermore, the difficulty of employing successive interference cancellation (SIC) procedures is a crucial factor to consider (Lei, Yuan, Ho, & Sun, 2016; Zhu *et al.*, 2017).

The types such as power-domain, code-domain, pattern division, spatial division, interleave and bit division are the most common NOMA solutions in 5G (Ali *et al.*, 2017; Islam *et al.*, 2017) (Figure 1). The resource allocation (RA) and power allocation (PA) systems will be examined in depth to overcome different challenges connected to throughput maximization in NOMA-based 5G networks (Hojeij, Nour, Farah, & Douillard, 2017; Xing, Liu, Nallanathan, Ding, & Poor, 2018; Makki, Chitti, Behravan, & Alouini, 2020). Bit error rate performance of downlink NOMA under various channels for different modulation techniques and coding rates are analyzed (Sadia, Zeeshan, & Sheikh, 2018). To increase power and energy efficiency, MIMO-NOMA (Multiple-Input Multiple-Output - Non Orthogonal Multiple Access) is employed where deep learning-based power allocation method is proposed (Huang *et al.*, 2020).

These novel used cases are driving massive increases in mobile traffic, which has resulted in radio spectrum scarcity becoming important pressing concerns that 5G and beyond must address. This research emphasizes on power-domain NOMA which employs PA algorithms and analyze downlink ordered NOMA under various channel conditions. Section 5 contains the work's concluding notes.

2. NOMA

(1) Power-domain NOMA and (2) code-domain NOMA are the two broad classification of NOMA. In power-domain NOMA, each user is differentiated by their allocated power and all the users share at the same time, the frequency and code resource. The user having the highest channel gain is assigned with lower power and the user with low channel gain is assigned with higher Power. In NOMA, each user experiences interference and can be eliminated by a technique called SIC (Higuchi & Benjebbour, 2015). In code domain NOMA, different channel codes, interleavers and code books were used to separate the users.

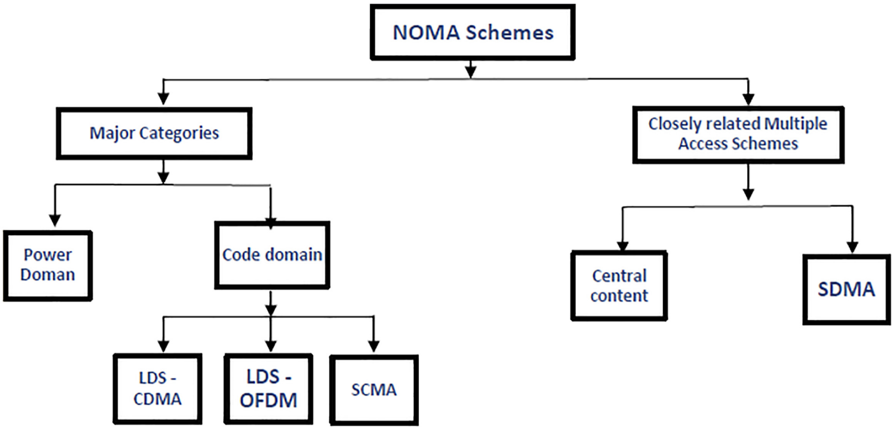

Figure 1.
NOMA schemes

2.1 Power-domain downlink NOMA

A basic NOMA system made up of just one base station (BS) and two users with one antenna each. Assume that x_1 and x_2 are the signals sent to users 1 and 2, independently, by the BS. The BS transmits the superposition coded signal as:

$$y = \sqrt{P_1} h_1 x_1 + \sqrt{P_2} h_2 x_2 \tag{1}$$

where h_1 and h_2 are the channel coefficients of user 1 and user 2 and P_i, $i = 1{,}2$ is the transmit power for user I and user 2, and x_i, $i = 1{,}2$ is a unit power message signal, i.e. $E|xi|^2 = 1$, with E (expectation operator). Users 1 and 2's total transmit power can thus be expressed as $P = P_1 + P_2$. In practice, P is assigned to a certain system configuration and is divided into P_1 and P_2 based on the PA scheme employed (Figure 2).

$$y_i = h_i s + n_i \tag{2}$$

where s is the superimposed signal obtained at Base station by linearly combining the signals x_1 and x_2. Here, h_i is the channel gain between the BS and user I and n_i is represented by Gaussian noise with interferences at the receiver and the power spectral density of n_i is $N_{f,i}$. In a multi-cell setup, inter-cell interference included in n_i. In equation (2), s is given by:

$$s = \sum_{i=1}^{M} \alpha_i P x_i \tag{3}$$

At the receivers, SIC is used to segregate the signals of various users. The ideal SIC decoding order is specified by $|h_i|^2/N_{f,\,i}$ and is in descending order of the users' channel strengths. Each user can greatly reduce interference based on the signals sent by users whose decoding instructions arrive after their own with this order. As a result, user 1, also known as the strong user, is able to cancel interference from user 2, also known as the weak user (Ali, Tabassum, & Hossain, 2016; Higuchi & Benjebbour, 2015; Akash, Chaurasiya, Rai, & Jagannatham, 2020).

NOMA is further classified in fixed NOMA and ordered NOMA. In fixed NOMA, the decoding order is fixed. But in case of ordered NOMA, the weaker user is decoded first, who has channel gain

$$\widetilde{\beta}_1 = \left|\widetilde{h}_1\right|^2 = min\left\{|h_1|^2,\ |h_2|^2\right\} = min\{\beta_1, \beta_2\} \tag{4}$$

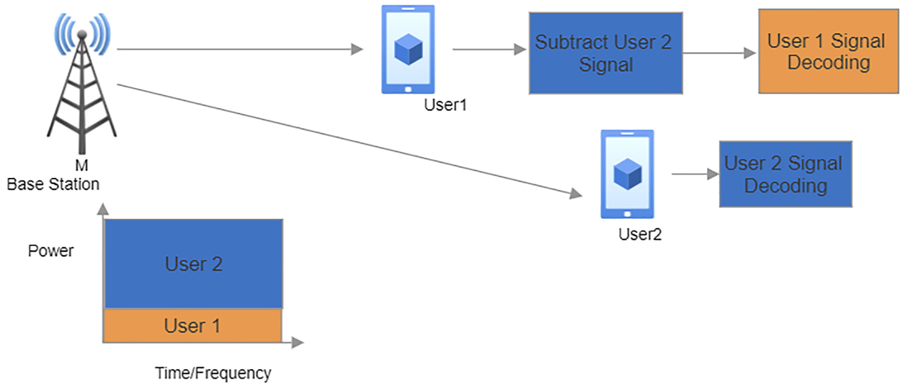

Figure 2.
Power domain downlink ordered NOMA system model

Hence, received signal for ordered NOMA at user 1 is:

$$y_i = \widetilde{h_i} s + n_i \tag{5}$$

A probability that certain data rate will not be supported due to poor channel conditions is called outage probability. Outage probability of ordered NOMA user 1 is given by:

$$P_{out1} = 1 - e^{\left(-\frac{R1}{\delta_3^2 P(p1 - p2R1)}\right)} \tag{6}$$

where $\mathrm{E}\{\beta_1\} = \delta_1^2$, $\mathrm{E}\{\beta_2\} = \delta_2^2$ and $\frac{1}{\delta_3^2} = \frac{1}{\delta_1^2} + \frac{1}{\delta_2^2}$. R_1 is the data rate of user 1.

Outage probability of ordered NOMA user 2 is given by.

$$P_{out2} = 1 - e^{\left(-\frac{\phi}{\delta_2^2}\right)} - e^{\left(-\frac{\phi}{\delta_1^2}\right)} + e^{\left(-\frac{\phi}{\delta_3^2}\right)} \tag{7}$$

where $\phi = \max\left\{\frac{R_2}{(p1 - p2R_1)P}, \frac{R_2}{P_2 P}\right\}$.

3. Power allocation in NOMA

The power domain multiplexes its users and so PA is critical in NOMA (Islam, Zeng, & Dobre, 2017b; Thakre & Pokle, 2022). It has a direct influence on system performance, including interference control, rate distribution and user admission. A bad PA can result not only in an unequal rate of allocation among consumers but also in SIC failure in system outage. In NOMA, the purpose of PA is to obtain through (1) more admitted users, (2) higher sum rate with (3) energy efficiency, while using the least amount of electricity. Equal power cannot be allocated to users, as SIC becomes complicated (Khan *et al.*, 2020).

The optimal value of P_2 is

$$P_2 = \frac{P\beta_1 - R_1}{P\beta_1(1 + R_1)} \tag{8}$$

R_1 is the data rate of user 1.

4. Performance analysis of downlink ordered NOMA under various channel conditions

Two user NOMA downlink performance is considered. Outage probability of downlink ordered NOMA under various channel models like Rayleigh, Rician and Nakagami-m channels were analyzed using MATLAB. Here the PA of user 1 and 2 is taken as $P_1 = 0.9$ and $P_2 = 0.1$, respectively. Figure 3 displays the likelihood of an outage probability of ordered NOMA of user 1 and 2 under Rayleigh fading scenario. In Rayleigh fading, the receiver cannot receive direct signal from transmitter. Probability density function of Rayleigh fading is given by.

$$P_{Rayleigh}(r) = \frac{\frac{2r}{\Omega} e^{-r^2}}{\Omega} \quad Where\ r \geq 0 \tag{9}$$

Outage probability performance of user 2 (weak) is good compared to user 1 at high SNR values.

In 5G scenario, more number of users are there within small cell area. Hence, line of sight (LOS) transmission is also possible. Rayleigh fading channel lacked the effect of LOS propagation. Rician channel model can be employed when there is an LOS (Akash *et al.*, 2020). For evaluation of system performance, Rician fading channel model are less convenient due to the occurrence of Bessel function in the Rician probability density function.

Outage probability of ordered NOMA of user 1 and 2 under Rician Channel is shown in Figure 4.

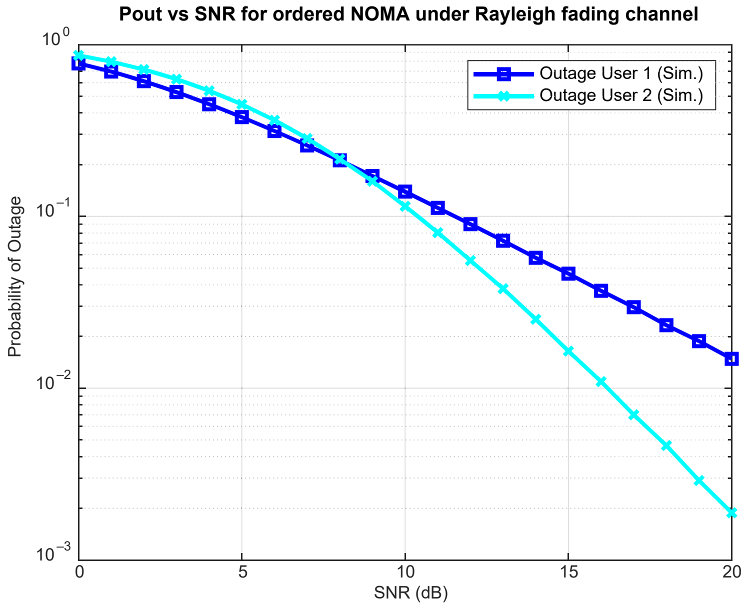

Figure 3.
Pout vs SNR in ordered NOMA under Rayleigh fading channel

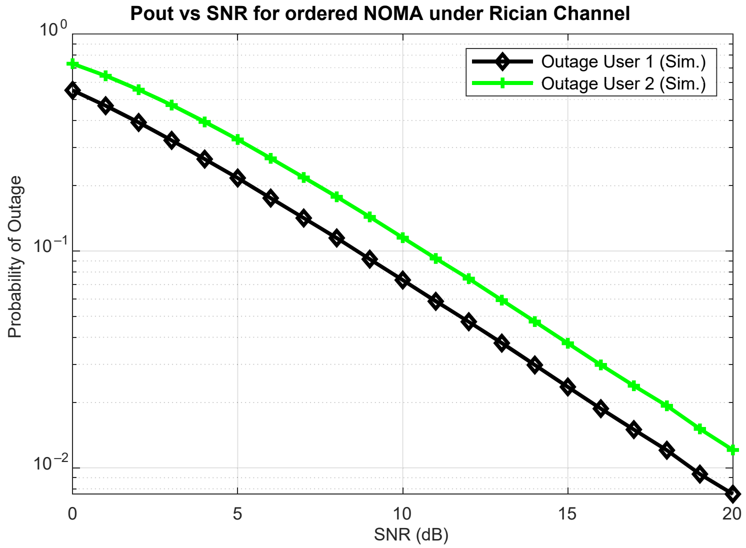

Figure 4.
Pout vs SNR in ordered NOMA under Rician channel

$$P_{Rician}(r) = 2\frac{(k+1)r}{\Omega}\, e^{-\left[k+(k+1)r^2/\Omega\right]}\, XI_0\left[2\sqrt{\frac{k(k+1)}{\Omega}}\; r\right] \quad Where\, r \geq 0 \tag{10}$$

where I_0 is the Bessel function.

As Nakagami-m fading channel model is used in case of small-scale fading scenario, the same performance of NOMA is employed in Nakagami-m channel model without any channel coding techniques. The major advantages of Nakagami fading are that the empirical data matches with the model and the sum of multiple independent and identically distributed Rayleigh fading signals. It also describes the amplitude of received signal after maximum ratio diversity combining.

The probability density function of Nakagami-m channel is:

$$P_{Nakagami-m}(r) = \frac{\frac{2m^m r^{2m-1}}{\Omega^m \Gamma(m)}\, e^{-mr^2}}{\Omega} \quad where\, r > 0 \tag{11}$$

Outage probability of ordered NOMA of user 1 and 2 is shown in Figure 5. From the figure it is found that the performance of Nakagami-m channel fading techniques is almost as good as Rayleigh fading. Performance of user 1 is good compared to user 2 in the signal to noise ratio range from 0 to 20 dB.

5. Conclusion

To increase the throughput of NOMA-based 5G networks, the study offers a throughput performance in PA techniques. The number of multiplexed users on the same subcarrier may be one strategy to improve network performance. High spectrum efficiency, enormous connection and low latency are all advantages of employing NOMA as a radio access

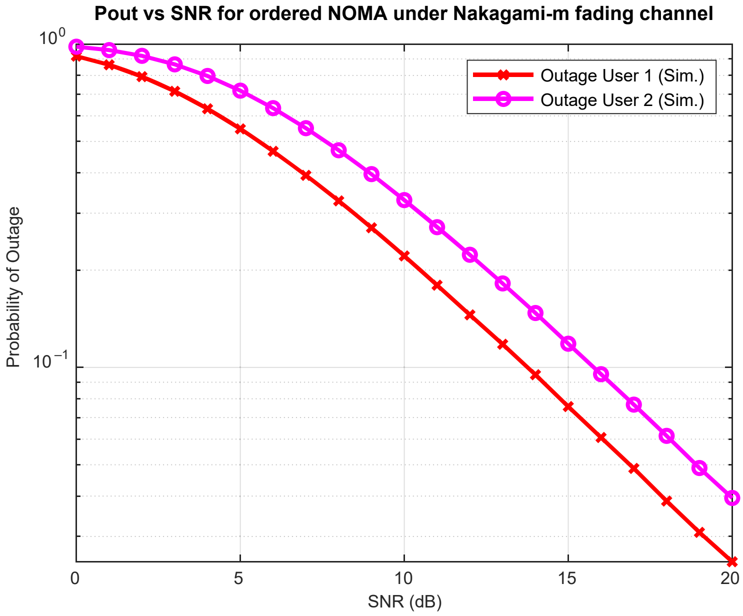

Figure 5.
Pout vs SNR in ordered NOMA under Nakagami – m fading channel

innovation for 5G and later. NOMA provides better user fairness and hence improves cell-edge user experiences with proper power distribution. Mainly the power allocation and downlink NOMA is good for outage probability. Outage probability of ordered NOMA of user 1 and 2 were interpreted under different channel conditions. From the analysis and the comparison of different channel fading techniques like Rayleigh, Rician and Nakagami-m, it was found that the outage probability performance of downlink NOMA was good for both user 1 and 2. As a future work, Channel coding techniques can be implemented to improve the performance.

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