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Analyzing the Bit Error Rate of NOMA over Rayleigh Fading Model.

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Abstract: Our work investigates the performance characteristics of Non-Orthogonal Multiple Access (NOMA) in the context of wireless communication systems that are affected by Rayleigh fading channels. Here the characteristic performance is nothing but calculating the Bit-Error Rate (BER), capacity, and outage probability of the wireless communication system in the integration of Non-Orthogonal Multiple Access (NOMA). Non-orthogonal multiple Access (NOMA) is one of the multiple access schemes that aimsat enhancing the efficiency of the spectrum. It alsoensures that multiple users can accommodate the samefrequency band. In this research, we will be developinga network of two users: a near user and a far user. By utilizing the MATLAB simulations, we can access the Bit-Error Rate (BER), capacity, and outage probability. Here we will have a base station from which a down-link transmission is connected to the users. To uphold fairness across the users, power allocation factors are duly managed. The main reason behind the addition of Rayleigh's fading effect is, that itenables the realistic behavior of the channel. In Rayleigh's fading, each transmitted bit will somehow encounter varying degrees of attenuation and phase shifts due to the multipath phenomenon. Simulation outcomes shed light on the ramifications of altering transmit power levels on key system performance metrics, thus providing valuable insights into the intricate interplay between Bit-Error Rate (BER), capacity, and outage probability. The above findings will play a vital role in efficient power allocation strategies and Successive Interference Cancellation (SIC) techniques in increasing the efficiency of NOMA. Overall, this paper study contributes to a deeper comprehension of NOMA's operational dynamics within real-world wireless communication environments and also offers some significant implications for future system design.

Keywords: *Non-Orthogonal Multiple Access (NOMA), Rayleigh Fading, Bit-Error Rate (BER), Successive Interference Cancellation (SIC), Power allocation strategies.*

1. Introduction

Today's interconnected world needs wireless communication. It plays a vital role. It facilitates seamless transmission of data over airwaves without having any physical connection. It has a greater application worldwide ranging from mobile phones to satellite communications. Wireless communication provides flexibility, mobility, andaccessibility.

Actually, at its core level, the transmission of information in wireless communication is through electromagnetic waves. Here the data can be of various forms like analog or digital signals and based on the frequency levels, they are used to get controlled and can be transmitted. The transmitter will begin the process of wireless communication in such a way that it modulates the data onto a carrier wave. This modulated signal is then propagated through space via antennas and received by a compatible receiver, which will demodulate the signal to retrieve the original form of the information.

The electromagnetic spectrum is one of the fundamental concepts in wireless communication. Depending upon factors like required bandwidth and transmission distance, different applications utilize a specific portion of the spectrum. There are some modulation techniques in wireless communication like Amplitude Modulation (AM), Frequency Modulation (FM), and Phase Shift Keying (PSK). Wireless communication systems can be categorized into Local Area Networks (LAN), Wide Area Networks (WAN),etc. Wireless communication systems have become indispensable in our interconnected world, enabling seamless transmission of data across various devices and applications.

NOMA is an excellent technology in wireless communication that provides a way for multiple users to share the same communication resources, such as frequency, code, or time. It is quite different from traditional Orthogonal Multiple Access (OMA) schemes like FDMA, TDMA, and CDMA, which will allocate separate resources to every individual user. In the technology of NOMA, there is a concept of power domain multiplexing. Here, in this case, users are served in the same time-frequency resources but with

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different power levels. The users with different channel conditions can also be served in the same block. Here we will be achieving the higher spectral efficiency. The key advantage of NOMA is, it has the great ability to increase the capacity and spectral efficiency of wireless communication systems. These play a vital role in a large number of users and will perfectly increase the capacity of the system. It offers some form of fairness and user diversity as well. Here the channels which are having the better conditions are allocated with lower power levels and vice-versa.

NOMA can be easily implemented in existing wireless communication systems with minimal modifications to the infrastructure. It makes the signal flexible and versatile and increases the spectral efficiency in wireless networks. To decode the signals of the multiple users, NOMA requires sophisticated processing techniques at both the transmitter and receiver sides to decode the signals of the multiple users sharing the same resources. These techniques include Successive Interference Cancellation (SIC). It allows the receiver to decode the signals of multiple users by removing interference from previously decoded signals. Overall, NOMA increases the capacity, spectral efficiency, fairness, and user diversity.

The Bit-Error Rate (BER) of NOMA systems can be influenced by various factors including channel conditions, modulation schemes, interference, power allocation strategies, and decoding techniques. BER of NOMA will generally have some complex mathematical modeling and simulations. BER performance can be affected by inter-user and intra-user interference.

In practice, NOMA BER performance can be evaluated through computer simulations or test bed experiments under realistic conditions. Advanced signal performance techniques and error correction coding schemes can improve the BER performance of the NOMA system.

2. Problem Statement and Proposed Solution

In wireless communication systems, nowadays there is a growing demand for increased spectral efficiency and reduced Bit-error Rate (BER). This will support the huge number of devices that are connected to a network. We have some traditional multiple access schemes such as Orthogonal Multiple Access (OMA), but usage of this scheme will face some limitations like having low spectral efficiency and high Bit-Error Rate (BER). Hence there is a huge need for innovative techniques to increase the spectral efficiency and decrease the BER while accommodating different requirements.

So, to overcome the above-mentioned problem, we have come up with a solution to use Non-Orthogonal Multiple Access (NOMA). This NOMA will be addressing all the challenges of the above-mentioned problems. It increases the spectral efficiency and decreases the BER. It allows multiple users to share the same time frequency. NOMA allocates different power levels to different users based on the conditions of the channel. The user who has better channel conditions will be utilizing high power levels and will maintain the orthogonality of the signals.

3. Literature Survey

Performance Analysis of NOMA Systems with Rayleigh Fading Channels: It is a paper by Smith, J. Johnson. It was published in the year 2020. This paper presents a comprehensive paper analysis of NOMA systems employing Rayleigh Fading channels. This paper will mainly tell us about how the Bit-Error Rate (BER) performance will vary if we vary some of the parameters such as the number of users, power allocation schemes, and modulation techniques in the NOMA systems. Here the simulation results are provided to prove the theoretical analysis and demonstrate the effectiveness of NOMA. BER Performance of NOMA Systems over Rayleigh Fading Channels with Imperfect SIC: It is a paper by Wang. It was published in the year 2019. This paper will give us information on the BER performance of NOMA systems over Rayleigh Fading channels by having the Imperfect Successive Interface Cancellation (SIC) at the receiver’s side. It gives an overview of the major impact of imperfect SIC on the performance of NOMA systems. Here the simulation results are provided to prove the theoretical analysis and demonstrate the channel conditions and SIC imperfection levels.

Adaptive Power Allocation for NOMA Systems over Rayleigh Fading Channels: It is a paper by Kim. It was published in the year 2017. This paper proposes an adaptive power allocation scheme for NOMA systems working on the Rayleigh Fading channels. This paper will give us an overview of how the performance of BER of NOMA systems will vary by varying the power allocations. Here the simulation results are provided to prove the theoretical analysis and demonstrate the power allocation in improving the reliability and efficiency of NOMA communication systems.

4. System Model

Let us consider two cases for this system model. Case-1 represents the calculation of Bit-Error Rate (BER) in wireless communications without having the concept of Non-Orthogonal Multiple Access

(NOMA). Whereas, Case-2 represents the calculation of Bit-Error Rate (BER) in wireless communications with the additional concept of Non-Orthogonal Multiple Access (NOMA).

Case-1:

Let us consider our first case.

In wireless 5G communication systems without Non-Orthogonal Multiple Access (NOMA), we can calculate the Bit-Error Rate (BER) of two users i.e. user-1 is considered a far user whereas user-2 is considered a near user. The calculation of BER is such that we need to keep track of some sort of information like modulation, transmit power allocation, and channel modeling.

When it comes to modulation technique, here we use Binary Phase Shift Keying (BPSK).

Every user will be allocated a certain amount of power based on factors like distance from the transmitter, Quality of Service (QoS), and channel conditions as well. The near user will be allocated more power than the far user to compensate for the high path loss experienced by user-1.

These transmitted signals will propagate through wireless channels and will be added with some extra formalities likenoise and fading.

Case-2:

Let us consider two users and we name them user-1 (U1) and user-2 (U2) respectively. Here U1 is far away i.e., having greater distance than that of U2. We can also say that U1 is a weak user as it is far from the base station whereas U2 is a strong user as it is near to the base station. Let d1 and d2 be the distances of U1 and U2 respectively.

As we have two users, the base station will have to send two messages individually to both users i.e., x1(far user) and x2(near user). Let $p1$ and $p2$ be the power allocation factors for far and near users respectively.

It should be considered that $p1 + p2 = 1$.

In NOMA, to have the best user fairness, more power is allocated to the far user and less power is allocated to the near user. Therefore, $\alpha1>\alpha2$.

For instance, let us assume that

$p1 = 0.80 \ and \ p2 = 0.20$.

Let h1 and h2 be the channel gains of U1 and U2 respectively.

NOMA Encoding and Transmission:

The transmitted signal is the superposition of two signals intended for U1 and U2 and is mathematically described below:

This is a main important case than that of the previous case.The main reason is, it is because we will be getting a higher spectral efficiency and lower Bit-Error Rate (BER) in case of usage of Non-Orthogonal Multiple Access (NOMA).

We consider a downlink transmission to the two users from the Base Station (BS). So based on that, our system looks like:

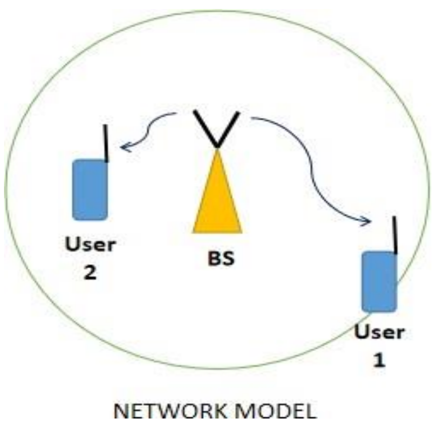

Fig 1: Network Model Diagram

$$x = \sqrt{P}\,(\sqrt{p1}x1 + \sqrt{p2}x2)$$

Where P is the Transmitted power. The copy of x is received at the near user is:

$$y1 = h1x + w1$$

Similarly, the copy of x received at far user is:

$$y2 = h2x + w2$$

Where w1 and w2 are the Noise signals of U1 andU2 respectively.

NOMA Decoding at User-1 (Far user):

By expanding the received signal at user-1, we get:

y1 = h1x + w1

=h1 $\sqrt{P}$ ($\sqrt{p1}$ x1 + $\sqrt{p2}$ x2) + w1

=h1$\sqrt{P}$ $\sqrt{p1}$ x1 + h1$\sqrt{P}$ $\sqrt{p2}$ x2 + w1

Since p1>p2, direct decoding of y1 would yield x1. The term containing the x2 component will be treated as interference. The SNR is given below:

$$(SNR)_1 = \frac{|h1|^2Pp1}{|h1|^2Pp2 + \sigma^2}$$

The achievable data rate is:

$$R1 = \log_2(1 + (SNR)_1)$$

$$= \log_2(1 + \frac{|h1|^2Pp1}{|h1|^2Pp2 + \sigma^2})$$

NOMA Decoding at User-2 (Near user):

By expanding the received signal at user-2, we get:

$$y2 = h2x + w2$$

$$= h2\sqrt{P}(\sqrt{p1}x1 + \sqrt{p2}x2) + w2$$

$$= h2\sqrt{P}\sqrt{p1}x1 + h2\sqrt{P}\sqrt{p2}x2 + w2$$

Here, User-2 must first perform Successive Interference Cancellation (SIC) before decoding his signal. SIC is carried out as follows:

1. $y2$ is directly decoded to obtain $x1$ or can have an estimation of $x1$, what is $\widetilde{x1}$.
2. $\widetilde{y2}$ = $y2 - \sqrt{\alpha 1}\widetilde{x1}$ is computed.
3. $\widetilde{y2}$ is decoded to obtain an estimate of $x2$.

As we are assuming a perfect SIC assumption here, hence we need to go for some steps to get the required result.

The signal-to-interference noise ratio at the user2 for decoding the user 1 signal (before SIC) is:

$$(SNR)_{1,2} = \frac{|h1|^2Pp1}{|h1|^2Pp2 + \sigma^2}$$

The corresponding achievable data rate is:

$$R_{1,2} = \log_2(1 + (SNR)_{1,2})$$

$$= \log_2(1 + \frac{|h1|^2Pp1}{|h1|^2Pp2 + \sigma^2})$$

After the cancellation of user-1's signal using SIC, the signal-to-noise ratio at the user-2 for decoding its signal is:

$$(SNR)_1 = \frac{|h1|^2Pp2}{\sigma^2}$$

Here the corresponding achievable data rate is:

$$R2 = \log_2(1 + (SNR)_2)$$

$$= \log_2\left(1 + \frac{|h1|^2Pp2}{\sigma^2}\right)$$

5. Graphical Representation of Results

Through graphical representation, we can able exactly know the results. By seeing them, we can able to know the whole information that we have gathered. In this also we will be going across two cases. Case-1 will give us the graphical representation of the Bit-Error Rate (BER) of wireless 5G communications without having the concept of Non-Orthogonal Multiple Access (NOMA). Case 2 will give us the graphical representation of the Bit-Error Rate (BER) of wireless 5G communications with the concept of Non-Orthogonal Multiple Access (NOMA).

Case-1: Graphical representation of BER without NOMA

Here BER curves for both the users exhibit similar behavior in such a way that their performances are similar across different transmitted powers.

There may be a slight difference in BER due to the different channel conditions.

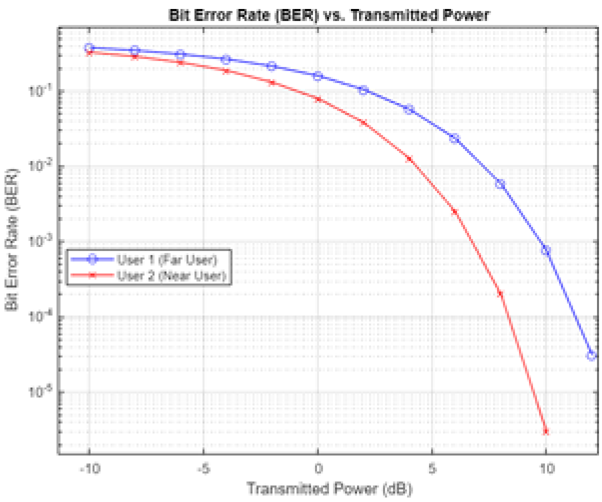

Fig 2: BER of wireless communication systemwithout NOMA

Case-2: Graphical representation of BER with NOMA

A graph is derived by analyzing the BER of NOMA in Rayleigh's fading model.

The BER curve for the far user may degrade more rapidly as the transmitted power decreases, as it's more susceptible to noise due to its lower SNR.

Several key elements are illustrated to get the required output. They are mainly:

1. The BER is often plotted against the SNR, which represents the quality of the relative to the noise level.
2. The BER is always depicted on a logarithmic scale to show the exponential relationship between SNR and BER.
3. As SNR increases, BER will decrease and hence will increase the reliability of communication.

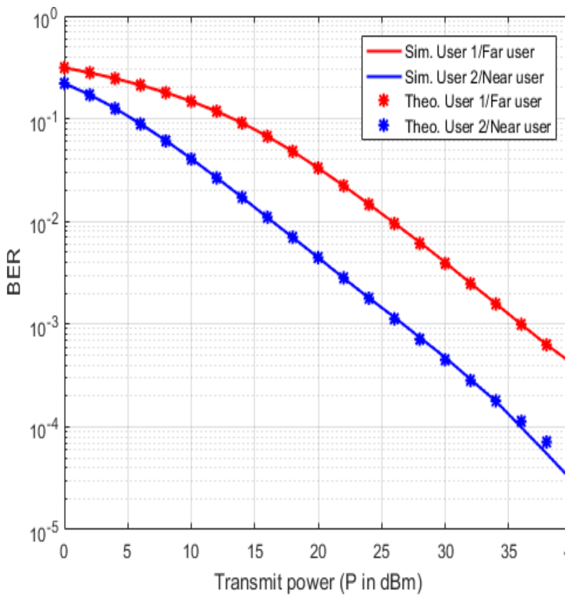

Fig 3: BER of a wireless communicationsystem with NOMA

Outage Probability and Capacity Graphical Representation:

1. Outage probability is always depicted on a logarithmic scale.
2. One of the common representations is plotting outage probability against SINR.
3. As SINR increases, outage probability decreases.
4. Graphical representation allows multiple curves corresponding to different power allocation strategies.

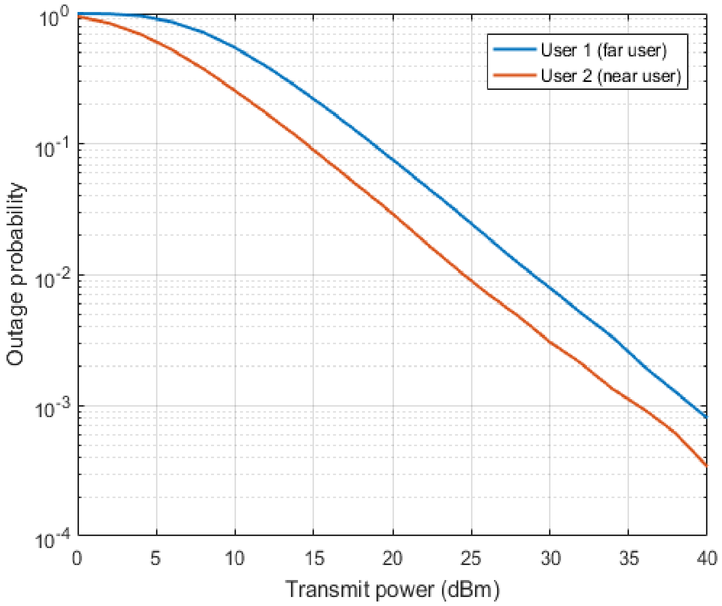

Fig 4: Outage Probability of NOMA

When it comes to the capacity:

1. Capacity is always plotted against SINR.
2. SINR is typically depicted on a logarithmic scale.
3. The capacity curve shows the maximum achievable data rate as a function of SINR, indicating the system's performance under different channel conditions

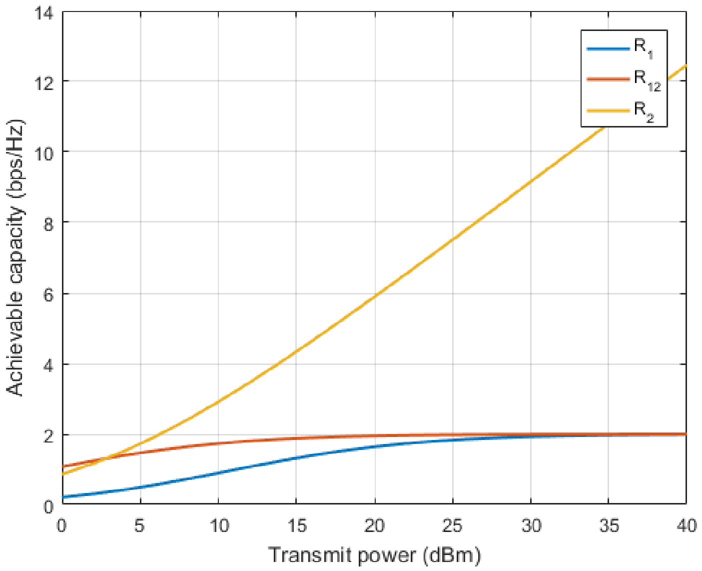

Fig 5: Achievable Capacity of NOMA

6. Conclusion

In conclusion, the simulation-based analysis of Bit- Error Rate (BER), outage probability, and capacity in Non-Orthogonal Multiple Access (NOMA) systems within Rayleigh fading channels provides critical insights essential for understanding the performance and optimizing the efficiency of NOMA-based communication networks. These simulation results not only validate theoretical models but also inform critical decision-making processes in system design, optimization, and protocol development, ultimately contributing to the realization of efficient and reliable wireless communication networks of the future.

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