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Outage Capacity Analysis for Next Generation Wireless Communication Using Non-Orthogonal Multiple Access

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Abstract**—**In recent times, Non-Orthogonal Multiple Access (NOMA) has received significant attention as an upcoming candidate in the world of 5G systems. The main reason for getting NOMA in 5G is because of its capacity to provide services to many users who have the same time and frequency resources. It is best used as "multiple-input, multiple-output" (MIMO) technology. In this paper, we are going to investigate outage probability as a function of signal-to-noise ratio (SNR) and target rate user. These methods will be implemented using cooperative communication and fair power allocation, respectively.

Keywords**—**Non-orthogonal Multiple Access, Fair Power Allocation, Outage Probability, Target Rate User, Cooperative Communication, massive multiple input multiple output, MIMO, Successive Interference Cancellation.

I. Introduction

WIRELESS mobile communication systems have become a crucial part of modern lives. The ideal purpose of this study is to learn about wireless communication and networking. Wireless communication had come a long way from only providing analog phone calls to various internet protocol broadband services over several generation of Network services [1]. Demand for the Internet of Things (IoT) is a need to connect every person and object around the world [2]. Today communication has become extremely difficult because so many constraints exist. As a result, developers are unable to improve upon it through changes and improvements. In recent times researchers are working on creating techniques that are suitable for newer generation wireless communication. One of the technologies is NOMA, one of the most promising techniques in today's world for wireless communication. Recently, NOMA schemes have been receiving a lot of attention for the fifth-generation cellular network. In 5G technology, multiple customers are served simultaneously by MIMO technology [3]. The more technology of NOMA gets advanced, the better it is in the world of wireless communication. Several clients can make use of the NOMA technology at the same time using frequency and code [4].

In the world of Internet connectivity 5G is the next big thing that would play a crucial role in the change in connectivity, present everywhere, is currently helpful in both agendas and standardization work [5], [6]. However, 5G can also play an essential role in the IoT in the future; it was intended mainly for future cellular networks. According to recent studies [3], [4], 5G promises to offer a faster connection speed and better reliability than any other prior network. 5G is also more than the fast internet.

As the 5G network has grown in recent years, it has been able to carry more data quickly, which will be beneficial in the world of the IoT. The technology is reliable due to its capacity to supply a quality that is applicable everywhere. It is best in comparison with Ethernet-based technologies like Wi-Fi. Also, in the later release of 5G, the theoretical latency is less than one millisecond as compared to twenty to forty milliseconds in the current generation of Wi-Fi.

In this paper, we have presented a problem and the corresponding solution. Mainly, the issue of outage probability will be investigated in this research work. The goal is to reduce the outage probability using NOMA. Several thesis papers [2], [3] have proven that the chances of a power outage could be minimized by efficient optimization of parameters, though they might not be reduced to zero because of radiating nature of the signals.

II. Previous Work

There have been many studies conducted in the past for NOMA. References [7] and [8] show how NOMA has advanced. Researchers developed the NOMA system in response to the need to communicate new messages to the users. In the next section we are going to see in details some of the previous work in NOMA technology.

A. Comparison between NOMA & OMA

Mobile networks such as 4G, LTE, and 3G have been using the OMA (Orthogonal Multiple Access) standards. In these multiple access schemes, many users are allocated to orthogonal resources in either the frequency or time domain to decrease the user interference. However, to minimize the interference, spectral efficiency needs to be reduced [9]-[12].

For practical reasons this type of access typically assigns the best channel gains to all users to maximize the channel rate. Lower signal strength does not ensure users' resource allocations to confirm received signal security because conventional OMA ignores them a great deal of time [10]. But according to [10], [13]-[15]. NOMA can add resource allocation between multiple paired users, thus benefiting the user with poor

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channel conditions.

B. Non-Orthogonal Multiple Access

The concept of NOMA was proposed while a distributed power control was first introduced. The precoder design of MIMO-NOMA helped in multi-cell networks to maximize the overall sum throughput which was proposed by [15]. The optimal solution is locally optimum. A recently developed algorithm resulted in its discovery. NOMA's advantage in spectral efficiency is greater than that of OMA and this can be proven by Interleave Division Multiple Access (IDMA), a scheme proposed by [16].

C. MIMO – NOMA

MIMO technologies have the capability of increasing the capacity as well as improving the error probability of wireless communication system. Numerous studies (e.g. [15], [16]) have examined the performance of NOMA over OMA networks. There have been few studies done on the effectiveness of MIMO-NOMA [16].

III. System Model

The application of NOMA to cooperative relaying scenarios is getting popular day by day. Now a class of dual-hop relay systems is becoming popular in which there are no direct link relays that use either decode and forward (DF) or amplify and forward (AF) protocols. A downlink communication system would become a cooperative relay network when the cell center user can act as a relay node for cell edge user using Successive Interference Cancellation (SIC). NOMA's superiority over OMA in achieving a sum rate is highly dependent on systems asymmetry. NOMA has enhanced its performance while keeping its balance with near and far effect. But implementing and managing large networks remains a challenge. Yet this presents an opportunity to do so.

As discussed earlier, our research paper consists of 2 parts. At first, we will use Cooperative Communication with NOMA to achieve a graph between SNR & Outage Probability.

The NOMA uses SIC, i.e., the message received from one user is decoded by the opposite receiver, from the superimposed signal. So, it can be said that while performing SIC, this step is mandatory. The message of far user must be decoded by near user anyhow.

Once the new user has received the data, it can assist the far end user by relaying it. Since the far user has a poor channel with the transmitting base station (BS), the data provided by the near user will provide the far user with variety. Now, the far user will receive a double copy of the same message from the BS and the near end user, acting as a relay. Because of this, the probability of the distant user experiencing an outage should decrease. The data encoded by the remote user go to the near user, showing that NOMA is a concept like cooperative communication.

Now that we know what cooperative communication is and some of its advantages, we will design a cooperative NOMA network. Here, in this work, the downlink transmission is considered as the communication link between BS and NOMA user. The two users are a near user which has a strong channel condition and a far user which has a weak channel condition. The transmission will take place in two time slots. The first time slot is known as direct transmission slot and the second one is known as relaying slot.

A. Direct Transmission Slot

During a Direct Transmission Slot, the BS uses NOMA to transmit the data to the near user (x_n) and the far user (x_f). The near user can decode the far user's data through SIC and then decode its data. The task of the far user is to perform decoding. Equations (1) and (2) are the theoretical data rates for the near side and the far side of the direct transmission slot, according to [15].

$$R_n = \frac{1}{2} log_2 \left(1 + \alpha_n \rho |h_n|^2\right. \tag{1}$$

$$R_{f,1} = \frac{1}{2} log_2 \frac{(1+\alpha_n \rho |h_n|^2}{\alpha_n \rho |h_f|^2 + 1} \tag{2}$$

We have the factor $\frac{1}{2}$ in front of the achievable rates in (1) and (2) because there are two time slots of equal duration R_n and R_f are the achievable rate during first time slot only.

In (1) and (2) α_n is the power allocation coefficient for far user, while α_f is the power allocation coefficient for the near user. On the other hand, h_n is the channel between BS and near user while h_f is the channel with BS and far user. The Transmit SNR $'\rho' = \frac{P}{\sigma^2}$ where P is the transmit power and σ^2 is the noise variance. Also, $\alpha_f > \alpha_n$ and also $\alpha_n + \alpha_f = 1$.

B. Relaying Slot

The next half of the time slot is the relaying slot. As seen earlier, the far user's data are with the near user because the near user decoded the far user's data in the previous time slot. In this case the nearer user must relay the information to the further user by bypassing the time slot. At the end of the relaying time slot, the achievable rate of far user according to [15] is:

$$R_{f,2} = \frac{1}{2} log_2 (1 + |\rho h_{nf}|^2) \tag{3}$$

In (3), it can be seen that, h_{nf} is the channel between near user as well as the far user. Also, it can be seen that $R_{f,2} > R_{F,1}$ because there are no interference and fractional power allocation from other transmission. The full transmit power is given to the far user.

C. Diversity Combining

By the end of the two timeslots, the far user has received two copies of the same information from two different channels. As a result, the far user can use various combining techniques, like selection. The achievable rate of a far user after selecting the technique according to [15] is:

$$R_f = \frac{1}{2} log_2 (1 + \frac{\alpha_f \rho |h_f|^2}{\alpha_n \rho |h_f|^2 + 1}) \tag{4}$$

On the other hand, if cooperative relaying is not used,

$$R_f = log_2(1 + \frac{|h_f|^2 \rho \alpha_f}{|h_f|^2 \rho \alpha_n + \sigma^2}) \quad (5)$$

In (5), the factor α_f for the transmission in non- cooperative network and the entire time slot will be properly utilized. Instead of NOMA, for example if we used Time Division Multiple Access (TDMA), half of the time slot for transmission of far user data will be allocated.

D. Numerical Results

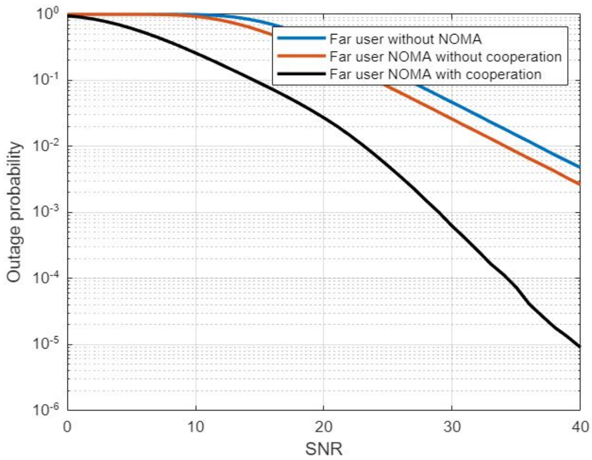

Fig. 1 SNR vs Outage Probability

From Fig. 1 at 20 dB, we can see that the outage probability is high for all the 3 cases. We aim to reduce the value of Outage Probability as much as possible.

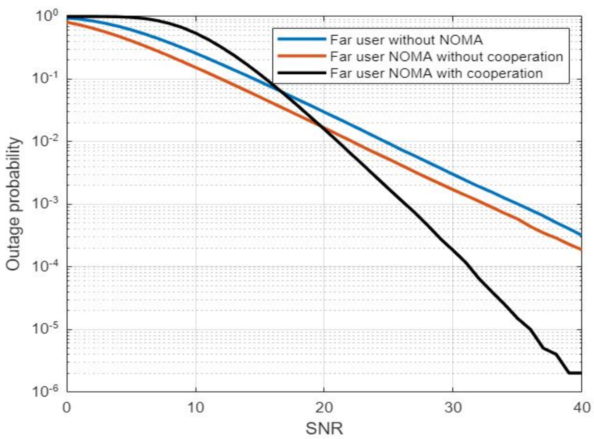

Fig. 2 SNR vs Outage Probability (Result)

In Fig. 2, the updated result can be seen, that is the value of outage probability is reduced in comparison to Fig. 1 at 20 dB.

We need to investigate how to allocate power more efficiently in NOMA, which is the second part of our research. Additionally, we are going to plot the Outage Probability vs. Users Target Rate graph.

One of the main characteristics of fair Power Allocation (PA) is that it will provide preference to the far user. The PA coefficients can be derived in such a way to ensure that the target rate is achieved. The remaining power is assigned to the near user only once the far user has met the target rate. So, in this paper, we are going to derive the PA to fulfill this condition.

From [16] we get capacity equation of NOMA

$$R_f = log_2(1 + \frac{|h_f|^2 \rho \alpha_f}{|h_f|^2 \rho \alpha_n + \sigma^2}) \quad (6)$$

$$R_n = log_2(1 + \frac{|h_n|^2 \rho \alpha_n}{\sigma^2}) \quad (7)$$

Here αn is the PA coefficient of far user and αf is the PA coefficient of near user. *hn* is the Rayleigh fading coefficient for near user while *hf* is the Rayleigh fading coefficient of far user. "P" is the total transmitted power. The value of αn +αf = 1, where the value of αf > αn.

Now we are going to derive the PA coefficients αn and αf in a way such that Rf ≥ R*. Let us consider Rf = R*, from [16] we get

$$log_2 (1 + \frac{|h_f|^2 \rho \alpha_f}{|h_f|^2 \rho \alpha_n + \sigma^2}) = R^* \quad (8)$$

By doing simplification, from (8) we get,

$$1 + \frac{|h_f|^2 \rho \alpha_f}{|h_f|^2 \rho \alpha_n + \sigma^2} = 2R^* \quad (9)$$

$$\frac{|h_f|^2 \rho \alpha_f}{|h_f|^2 \rho \alpha_n + \sigma^2} = 2R^* - 1 \quad (10)$$

Let us consider that 2R*-1 is the target Signal to Noise ratio (SNR) for the far user who has a target rate of R*. From [16] we get,

$$\frac{|h_f|^2 \rho \alpha_f}{|h_f|^2 \rho \alpha_n + \sigma^2} = \varepsilon \quad (11)$$

$$|h_f|^2 \rho \alpha_f = \varepsilon |h_f|^2 \rho \alpha_n + \varepsilon \sigma^2 \quad (12)$$

Since, we saw earlier αn + αf = 1, αn = 1-αf; therefore, substituting the value of αn in (12) we get,

$$|h_f|^2 \rho \alpha_f = \varepsilon |h_f|^2 \rho (1 - \alpha_f) + \varepsilon \sigma^2 \quad (13)$$

$$|h_f|^2 \rho \alpha_f = \varepsilon |h_f|^2 \rho - \varepsilon |h_f|^2 + \varepsilon \sigma^2 \quad (14)$$

Bringing all the αf values to LHS from (14) we get,

$$|h_f|^2 \rho \alpha_f + \varepsilon |h_f|^2 \rho \alpha_f = \varepsilon |h_f|^2 \rho + \varepsilon \sigma^2 \quad (15)$$

$$\alpha_f |h_f|^2 \rho (1 + \varepsilon) = \varepsilon (|h_f|^2 \rho + \sigma^2) \quad (16)$$

$$\alpha_f = \frac{\varepsilon (|h_f|^2 \rho + \sigma^2)}{|h_f|^2 \rho (1 + \varepsilon)} \quad (17)$$

We do not want the value of αf to exceed 1. So, in (17), we are going to set a limit

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$$\alpha_f = \min(1, \frac{\varepsilon(|h_f|^2\rho + \sigma^2)}{|h_f|^2\rho\,(1+\varepsilon)} \qquad (18)$$

Using (18) if we compute αf, αn can be easily computed as:

$$\alpha_n = 1 - \alpha_f \qquad (19)$$

The PA coefficients for our dynamic PA has been derived. Now, let's plot a graph to see how the fair PA performs by comparing the fixed and fair PA.

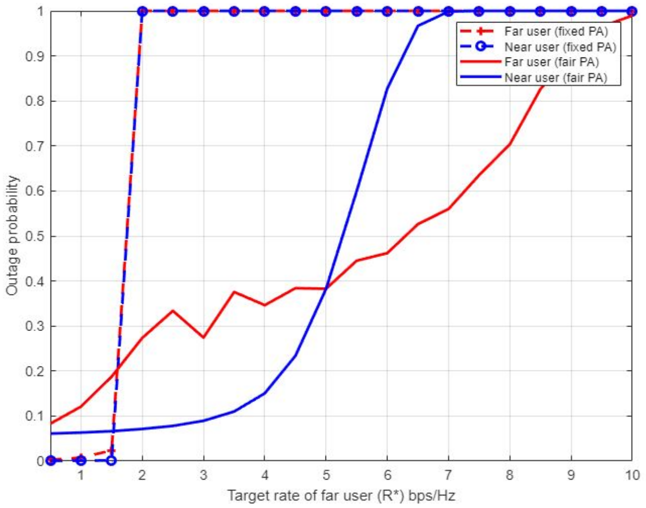

Fig. 3 Target Rate User vs Outage Probability for Fixed PA and Fair PA

Figs. 1-4 show that fixed PA shows poor performance the outage probability value jumps to "1" at all times just before the R* value reaches 1.5 bps/Hz. When using the fixed power supply, the receiver must have an R* value of more than 1.5 bps/Hz; otherwise, the value is always in the outage. Because neither fully utilizes the fixed CSIs nor does it comprehend the target rate requirements, the fixed PA's performance is not satisfactory.

In (18), we saw that the far user has a weak channel with the BS. So, when the limiting operation was done on (1) that is when the value of αf is greater than 1, we limited the value of αf equal to 1. For example, if we get the value of $\frac{\varepsilon(|h_f|^2\rho + \sigma^2)}{|h_f|^2\rho\,(1+\varepsilon)} = 50$, we set the value of *αf= min (1,50) = 1*. Now, we will consider $\frac{\varepsilon(|h_f|^2\rho + \sigma^2)}{|h_f|^2\rho\,(1+\varepsilon)} = 50$. This means if the value of αf is set to 50, the far user's target rate R* will be met. So, it can be said that by limiting αf to 1 is of no use. It is because any value of αf < 50 will result in outage of far user. Also, it can be said that when $\frac{\varepsilon(|h_f|^2\rho + \sigma^2)}{|h_f|^2\rho\,(1+\varepsilon)} > 1$ even if the entire power is allocated to far user, he will still be in outage. So, in order to solve this problem lets add a simple change to our problem.

When the value of $\frac{\varepsilon(|h_f|^2\rho + \sigma^2)}{|h_f|^2\rho\,(1+\varepsilon)}$ exceeds 1, in place of limiting αf = 1, let's set the value of αf = 0. As a result, αn will be automatically set to 1. So, the far user's outage will not be affected by $\alpha_f = 0$. Because we saw earlier that when we allocated the entire power to far user still, we could not bring him out of outage. Also, near user was also in outage since its PA value was 0. So, there is no use of wasting all the powers on far user.

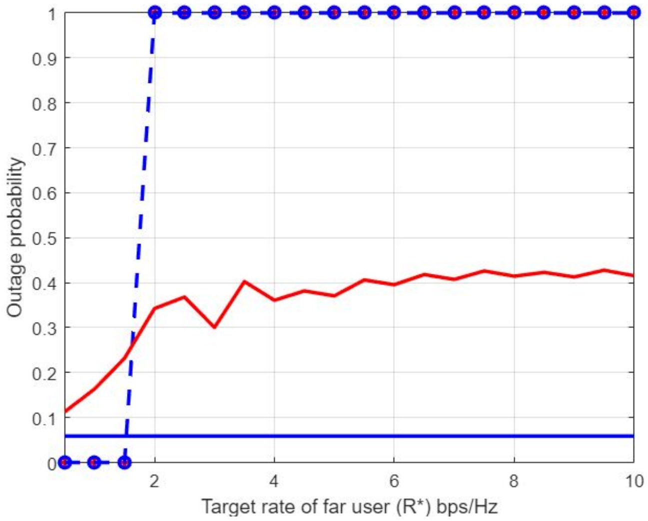

Fig. 4 Target Rate User vs Outage Probability for Fair PA

IV. CONCLUSION

This paper presents the NOMA-related work for 5G communication. We have discussed the effect of outage probability as a function of power allocation, target rate, and SNR. Fixed PA does not take into account users' current channel conditions. The values of αf and αn are not affected by channel conditions. This is where our fair PA is effective. When the channel changes, the values of αf and αn are adjusted accordingly. That is why fair PA can achieve a lower outage probability than fixed PA. NOMA has lots of improvement potential in the future as technology advances. The better the technology, the better the result. With the advent of 5G and NOMA, wireless communications will be much improved.

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