ISSN: 2229-6948(ONLINE)
DOI: 10.21917/ijct.2026.0559



# ON THE OUTAGE AND SUM-RATE OF MIMO-NOMA USING IMPROVED FAIR POWER ALLOCATION OVER NAKAGAMI-M FADING CHANNEL

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***Abstract***

***In the present wireless scenario, nonorthogonal multiple access (NOMA) and multiple-input multiple-output (MIMO) aims to achieve substantially improved spectrum efficiency and high performance. In this paper, we analyze the outage and sum-rate performance of MIMO-NOMA using fair and improved fair power allocation (PA) and compare it with MIMO-orthogonal multiple access (OMA). Also, we evaluate system performance over Nakagami-m fading scenario. The weak user is given priority while computing the power coefficient for fair PA. To meet the weak user's target rate, the PA coefficients are computed. We observe that the outage probability steadily increases with the increase in weak user's target rate in fair PA. The likelihood of a weak user reaching the target rate decreases as the target rate rises. Moreover, we make minor alterations to improve efficacy and minimize outages for strong users using improved fair PA. Simulation results show that MIMO-NOMA delivers lesser outages and larger sum rate for both the users using improved PA than MIMO-OMA in Nakagami-m fading.***

***Keywords:***

***Multiple-Input Multiple-Output, Nonorthogonal Multiple Access, Improved Fair Power Allocation, Nakagami-M Fading***

## 1. INTRODUCTION

Non-orthogonal multiple access (NOMA) offers higher spectral efficiency than traditional orthogonal multiple access (OMA), making it a promising technique for 5G and beyond 5G systems. NOMA accomplishes superior spectral efficiency through superposition coding (SC) at the transmitter and successive interference cancellation (SIC) at the receiver. Merging multiple-input and multiple-output (MIMO) and NOMA, known as MIMO-NOMA, is an open and cooperative approach to enhance performance and achieve high spectral efficiency in 5G systems. It provides excellent reliability, low latency, and extensive connectivity [1-5].

The authors of [6] provided an organised analysis of the most advanced NOMA variations with power and code domains serving as the foundation for resource allocation, interference reduction, and QoS management in the context of 5G. Device-to-device (D2D), cooperative communication (CC), MIMO, and heterogeneous networks (HetNets) represent the future of smart communication. According to the literature, most of the problems in the current ideas to provide contention-based grant-free transmissions between various devices can be fixed by NOMA. There is also a thorough discussion of the main distinctions between the OMA and NOMA in 5G.

While MIMO-NOMA offers significant advantages, numerous important concerns still need to be resolved. User grouping, precoding design, and power allocation (PA) are key aspects of NOMA, and effective PA is particularly challenging [7]. This inspired us to conduct our investigation. We observed that weak users in NOMA systems can experience a saturation in their achievable rate at certain transmit power levels [8, 9]. Given NOMA's reliance on power domain multiplexing to aid multiple users non-orthogonally, appropriate PA is essential for the best possible system performance. Given the critical role of PA in NOMA, authors have analyzed the relationship between bit error rate (BER) and PA coefficients in [10].

Additionally, we can observe from [11-13] that while MIMO-NOMA can outperform OMA, the fixed PA fails to meet the proper performance metrics, such as sum-rate, outage probability, and other performance measures. Therefore, choosing an appropriate PA for MIMO-NOMA is crucial, as it directly impacts interference management and overall network efficiency.

This paper investigates the performance of NOMA in a simple MIMO network using our proposed fair PA scheme. Additionally, we compared the outage performance of MIMO-NOMA systems using fair and improved fair PA schemes to MIMO-OMA using fixed PA, demonstrating the enhanced system performance. Since the Nakagami-*m* fading scenario has a generic distribution that can represent various fading environments, we have taken it into consideration for our performance analysis. The key contributions of the work described in this paper is summarized below:

- We analyzed outage performance with fair and improved fair PA, considering target rates under Nakagami-*m* fading,
- Additionally, we calculated and plotted outage probability with respect to transmit power using improved fair PA,
- Finally, we computed the sum rate of MIMO-NOMA after applying the improved fair PA,
- In all the above computation and analysis, we compared the outage and sum rate performance of MIMO-NOMA (fair/improved fair PA) and MIMO-OMA (fixed PA) for both weak and strong users.

Section 2 presents the system and signal models for both MIMO-NOMA and MIMO-OMA. Section 3 describes fair PA schemes, including the derivation of PA coefficients for the dynamic fair PA schemes. Section 4 presents the simulation results and analysis for outage and sum rate performance. Finally, Section 5 concludes the work.

## 2. SYSTEM AND SIGNAL MODEL

### 2.1 SYSTEM MODEL FOR MIMO-NOMA

We considered 2x1 downlink MIMO system depicted in Fig.1. Let $U_1$ and $U_2$'s relative distances from the MIMO transmitter be represented by $d_1$ and $d_2$. In this case, $d_1>d_2$. In other words, $U_2$ is the strong user and $U_1$ is the weak user. We are aware that MIMO can be applied to either diversity gain to reduce BER or spatial multiplexing to boost achievable rate. Now, diversity gain is being achieved by MIMO. Consequently, transmit antennas 1 and 2 are used to send identical data.

Assume that $x_1$ and $x_2$ represent the data meant for $U_1$ and $U_2$. Let $h_{rt}$ represent the Nakagami-m fading channel between the $t^{th}$ transmit and the $r^{th}$ receive antenna, in accordance with MIMO terminology. Nakagami-m fading can simulate a wide range of fading channels by altering the value of m in its equation, making it incredibly flexible. Such versatility allows for more accurate empirical data fitting in diverse settings, like urban or indoor environments, than is possible with basic models. Here, the shape factor is denoted by parameter m. This channel is represented as a function of gamma. In contrast to Rayleigh fading, with $m > 1$, the signal strength fluctuations decreased [14-19].

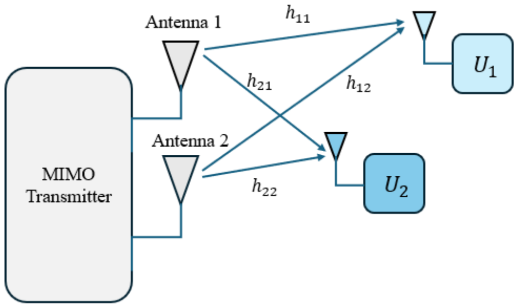


Fig.1. MIMO-NOMA system model

## 2.2 SIGNAL MODEL FOR MIMO-NOMA

### 2.2.1 *Transmit Signal:*

The signals sent by the two transmit antennas are presented by

$$x = \sqrt{P}\left(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2\right) \tag{1}$$

where, the NOMA PA coefficients are denoted by $\alpha_1$ and $\alpha_2$, given that $U_1$ is the weak user, $\alpha_1 > \alpha_2$.

### 2.2.2 *Received Signal:*

Both of the transmit antennas simultaneously send $x$. Consequently, the signal received at $U_1$ is,

$$y_1 = x(h_{11} + h_{12}) + n_1 \tag{2}$$

Likewise, the signal that $U_2$ received is provided by,

$$y_2 = x(h_{21} + h_{22}) + n_2 \tag{3}$$

In this case, $n_1$ and $n_2$ are AWGN noise samples with variance $\sigma^2$ and mean zero.

### 2.2.3 *Decode User 1's Signal:*

Now, $U_1$ must decode $x_1$ from $y_1$. More power is given to $x_1$, as $U_1$ is the weak user. In other words, $\alpha_1 > \alpha_2$. As a result, he can interpret $x_2$ phrase as interference and decode $x_1$ directly from $y_1$. When we expand Eq.(2) and substitute for $x$,

$$y_1 = \sqrt{P\alpha_1}x_1(h_{11} + h_{12}) + \sqrt{P\alpha_2}x_2(h_{11} + h_{12}) + n_1 \tag{4}$$

where, $\sqrt{P\alpha_1}x_1(h_{11} + h_{12})$ is desired and $\sqrt{P\alpha_2}x_2(h_{11} + h_{12})$ is interference. After decoding $x_1$, the SINR equation for $U_1$ can now be expressed as,

$$\gamma_1 = \frac{P\alpha_1 |h_{11} + h_{12}|^2}{P\alpha_2 |h_{11} + h_{12}|^2 + \sigma^2} \tag{5}$$

Thus, the feasible rate at $U_1$ is found using,

$$R_1 = \log_2(1 + \gamma_1) \tag{6}$$

### 2.2.4 *Decode User 2's Signal:*

$\alpha_2$ need to be decoded from $y_2$ by $U_2$. As $U_2$ is a strong user, $x_2$ receives a smaller amount of power. As a result, the power of the $x_1$ phrase dominates in $y_2$. In order to obtain $x_1$, $U_2$ primarily performs complete decoding on $y_2$. After that, $x_1$ is eradicated via SIC, $x_2$ is then decoded.

Substituting $x$ and extending Eq.(3) yields

$$y_2 = \sqrt{P\alpha_1}x_1(h_{21} + h_{22}) + \sqrt{P\alpha_2}x_2(h_{21} + h_{22}) + n_2 \tag{7}$$

where $\sqrt{P\alpha_1}x_1(h_{21} + h_{22})$ is undesired and dominating and, $\sqrt{P\alpha_2}x_2(h_{21} + h_{22})$ is desired. For direct decoding of $x_1$, the SINR at $U_1$ is,

$$\gamma_{12} = \frac{P\alpha_1 |h_{21} + h_{22}|^2}{P\alpha_2 |h_{21} + h_{22}|^2 + \sigma^2} \tag{8}$$

Following SIC, the first expression in Eq.(7) is eliminated and the following signal is obtained:

$$y_2' = \sqrt{P\alpha_2}x_2(h_{21} + h_{22}) + n_2 \tag{9}$$

For $U_2$ to decode its own signal, the SNR is now provided by

$$\gamma_2 = \frac{P\alpha_2 |h_{21} + h_{22}|^2}{\sigma^2} \tag{10}$$

Lastly, the rates that can be achieved at $U_2$ for decoding $x_1$ and $x_2$ are presented by,

$$R_{12} = \log_2(1 + \gamma_{12}) \tag{11}$$

$$R_2 = \log_2(1 + \gamma_2) \tag{12}$$

## 2.3 MIMO-OMA NETWORK

We use a MIMO-OMA system as our criterion to observe the functioning of MIMO-NOMA system. We split our transmission into two identical time slots in MIMO-OMA. Both antennas send signals to $U_1$ during the first time slot and to $U_2$ during the second time slot. $Px_1$ is the signal that both antennas sent to $U_1$ during time slot 1. Similarly, the signal that was received at $U_1$ and $U_2$ is given as follows, respectively, and the signal that sent by both antennas to $U_2$ in time slot 2 is $Px_2$.

$$y_{1,oma} = \sqrt{P}x_1(h_{11} + h_{12}) + n_1 \text{ ,and } y_{2,oma} = \sqrt{P}x_2(h_{21} + h_{22}) + n_2 \tag{13}$$

The SNRs on $U_1$ and $U_2$ can be calculated as,

$$\gamma_{1,oma} = \frac{P|h_{11} + h_{12}|^2}{\sigma^2} \text{ and } \gamma_{2,oma} = \frac{P|h_{21} + h_{22}|^2}{\sigma^2} \tag{14}$$

Consequently, the MIMO-OMA achievable rates for $U_1$ and $U_2$ are given as,

$$R_{1,oma} = \frac{1}{2}\log_2(1 + \gamma_{1,oma}) \text{ and } R_{2,oma} = \frac{1}{2}\log_2(1 + \gamma_{2,oma}) \tag{15}$$

Simply half of the time slot is spent for connecting with every user, which accounts for the factor 1/2 in Eq.(15). Conversely, MIMO-NOMA uses the complete time slot to transmit to both users simultaneously.

# 3. POWER ALLOCATION FOR MIMO-NOMA

We have observed in literature of [20] that the values of $\alpha_1$ and $\alpha_2$ are fixed in fixed PA, regardless of the channel conditions. However, there are more effective methods for dynamically optimizing $\alpha_1$ and $\alpha_2$ depending on the channel state information (CSI) values. A few well-defined dynamic PA techniques are already present, each trying to accomplish a specific goal. The aim is to expand energy efficiency, the total rate, etc. This paper discusses a straightforward PA strategy that aims to guarantee user fairness. This system of PA will be referred to as fair PA.

The weaker or distant user is granted primacy by our fair PA. Moreover, the PA coefficients are determined to meet the target rate for the weak user. The strong user receives all the remaining power only once the weak user's target rate has been reached. To satisfy this requirement, let's proceed to determine the power allocation coefficients. Specifically, the far-user coefficient is derived directly from the target signal quality and the noise levels to ensure the minimum rate is guaranteed. Consequently, the near-user coefficient is strictly defined as the residual power, ensuring the total allocation does not exceed the total available power.

## 3.1 FAIR POWER ALLOCATION

Firstly, we obtain the power allocation coefficients $\alpha_1$ and $\alpha_2$. Let $R_1^*$ be the weak user's target rate. Choosing $\alpha_1$ and $\alpha_2$ so that $R_1 \geq R_1^*$ and setting $R_1 = R_1^*$ is our aim.

$$R_1 = R_1^* = \log_2\left(1+\frac{|h_1|^2 P\alpha_1}{|h_1|^2 P\alpha_2+\sigma^2}\right), \tag{16}$$

where $h_1=h_{11}+h_{12}$.

$$2^{R_1^*}-1=\frac{|h_1|^2 P\alpha_1}{|h_1|^2 P\alpha_2+\sigma^2} \tag{17}$$

The target SINR for the weak user with target rate $R_1^*$ is represented by $\xi = 2^{R_1^*}-1$.

$$\xi=\frac{|h_1|^2 P\alpha_1}{|h_1|^2 P\alpha_2+\sigma^2} \tag{18}$$

Subsequently $\alpha_1+\alpha_2=1$, $\alpha_2=1-\alpha_1$. After computing, we ultimately obtain the following expression,

$$\alpha_1=\frac{\xi(|h_1|^2 P+\sigma^2)}{|h_1|^2 P(1+\xi)} \tag{19}$$

Since $\alpha_1$ must not to be more than 1, we establish a limit as follows:

$$\alpha_1=\min\left(1,\frac{\xi(|h_1|^2 P+\sigma^2)}{|h_1|^2 P(1+\xi)}\right) \tag{20}$$

After applying the equation above to obtain $\alpha_1$, we can quickly determine $\alpha_2$ as follows:

$$\alpha_2=1-\alpha_1 \tag{21}$$

## 3.2 IMPROVED FAIR POWER ALLOCATION

The PA coefficients for fair PA have been determined in section 3.1. Although we improved our fair PA even more, our fair PA approach is having issues mentioned in this section and we did manage to come up with a better power allocation than fixed PA and fair PA. The weak user's channel is weak with the BS. Eq.(20) is carried out when the limiting operation is performed.

In practice, we have constrained $\alpha_1$=1, whenever it is determined to be greater than 1. For instance, we set $\alpha_1$=min(1,50)=1, if we obtain $\frac{\xi\left(|h_1|^2 P+\sigma^2\right)}{|h_1|^2 P(1+\xi)}=50$. This indicates that we can only reach the weak user's target rate $R_1^*$ if we set $\alpha_1$=50. Limiting $\alpha_1$ to 1 is ineffective in the situation. For any value of $\alpha_1$<50 , the weak user experiences an outage. In other words, even if we provide all the power i.e. $\alpha_1$=1 to the weak user, he will still be in outage when $\frac{\xi\left(|h_1|^2 P+\sigma^2\right)}{|h_1|^2 P(1+\xi)}>1$. Further, by putting $\alpha_1$=1, we are necessarily adjusting $\alpha_1$=0, that is undesirable as it puts the strong user in an outage as well because no power is being granted to him.

Thus, we make more adjustments to our fair PA and make a small addition to our fair PA to solve the issue. Since $\frac{\xi\left(|h_1|^2 P+\sigma^2\right)}{|h_1|^2 P(1+\xi)}$ surpasses 1, we set $\alpha_1$=0 rather than restricting it to 1. Consequently, $\alpha_2$=1 is automatically set. The user's outage is unaffected when $\alpha_1$=0 is set. Since we can't get him out of blackout even if we set $\alpha_1$=1, giving him all the power.

# 4. OUTAGE PROBABILITY

## 4.1 MIMO-NOMA

When the achievable rate ($R_1$) of weak user is smaller than his intended rate $R_1^*$, then $U_1$ is in outage. It is denoted mathematically as,

$$P^1_{noma}=Pr(R_1<R_1^*) \tag{22}$$

It is necessary for the strong user to accurately decode both $U_1$'s and his own messages. The strong user should meet the target rates of both $U_1$ and $U_2$. If $U_1$'s target rate is not reached, or if $U_1$'s target rate is reached but $U_2$'s is not, $U_2$ will experience an outage. From a mathematical perspective,

$$P^2_{noma}=Pr(R_{12}<R_1^*)+Pr(R_{12}\geq R_1^*, R_2<R_2^*) \tag{23}$$

## 4.2 MIMO-OMA

The MIMO-OMA outage expressions are simple and given as,

$$P^1_{oma}=Pr(R_{1,oma}<R_1^*)$$
$$P^2_{oma}=Pr(R_{2,oma}<R_2^*) \tag{24}$$

# 5. SIMULATION RESULTS

We examine the suggested MIMO-NOMA network's outage performance and sum rate in this part. Table 1 makes use of the parameters applied for our simulation. First, we illustrate the user outage probabilities as a function of weak user's target rate $R_1^*$ for the MIMO-NOMA and MIMO-OMA techniques in Fig.2. This comparison highlights how NOMA effectively manages interference between users with disparate channel conditions compared to traditional orthogonal methods. By varying the target rate, we can pinpoint the specific threshold where the increased requirements of the weak user begin to impact the overall reliability of the communication link.

The target rates and power allocation coefficients must be carefully chosen and compared the outage performance with OMA. In this case, the total transmit power is set at 10dBm. Additionally, to determine the outage likelihood, we set the same target rate for both strong and weak users. The OMA poor performance is instantly apparent, and when $R_1^* > 0.5$bps/Hz at $m$=1 and $R_1^* > 1$bps/Hz at $m$=3, its likelihood of an outage always reaches 1 for both weak and strong users and the receiver is always in outage.

Table.1. Simulation parameters and value

| Parameter name | Value |
|---|---|
| Far/weak user distance ($d_1$) | 800m |
| Near/strong user distance ($d_2$) | 200m |
| Fixed Power allocation coefficient for weak user ($\alpha_1$) | 0.75 |
| Fixed Power allocation coefficient for strong user ($\alpha_2$) | 0.25 |
| Path loss exponent ($\eta$) | 4 |
| Bandwidth (BW) | 1 MHz |
| Nakagami-$m$ fading parameter ($m$) | 1, 3 |
| Transmit power ($P$) | 10dBm |

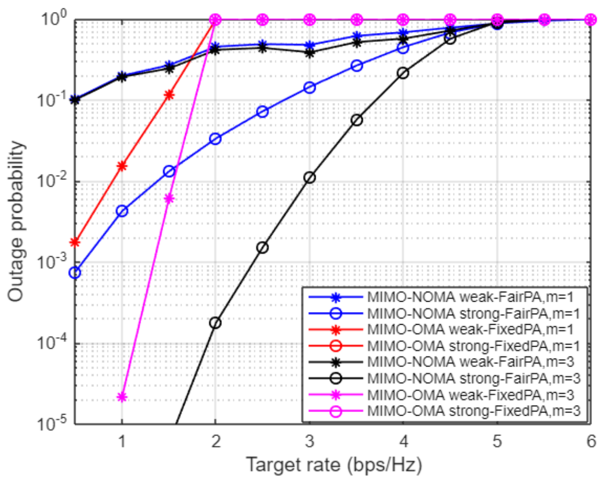


Fig.2. Individual user outage comparison between MIMO-NOMA with fair power allocation and MIMO-OMA with fixed power allocation in Nakagami-$m$ fading

Following the small adjustment outlined in section 3.2, Fig.3 displays an intriguing outage trend for our fair PA. Weak user outages follow the pattern seen in Fig.2. This suggests that our adjustment to put $\alpha_1$=0, when necessary, had no effect whatsoever on the weak user outage. Let's now examine the strong user outage graph. The likelihood of an outage progresses, mounts, and then starts to fall.

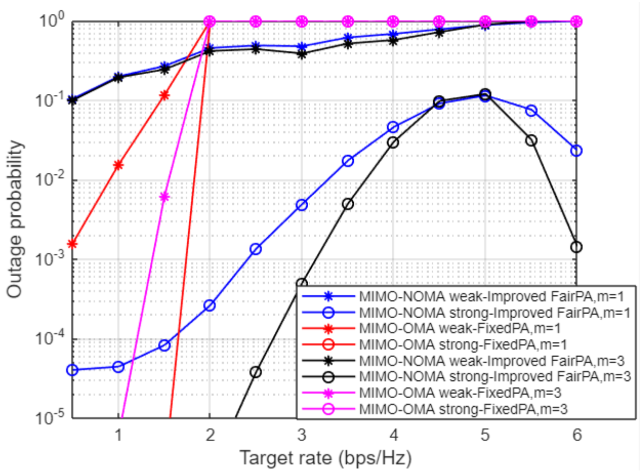


Fig.3. Individual user outage comparison between MIMO-NOMA with improved fair power allocation and MIMO-OMA with fixed power allocation in Nakagami-$m$ fading

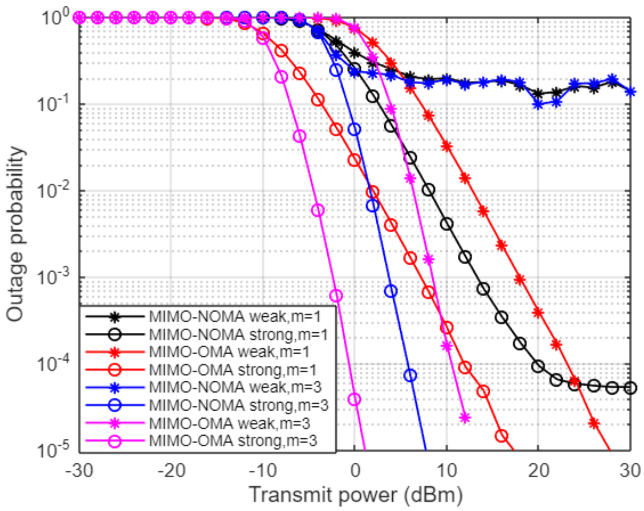


Fig.4. Individual user outage difference between MIMO-NOMA and MIMO-OMA in Nakagami-$m$ fading

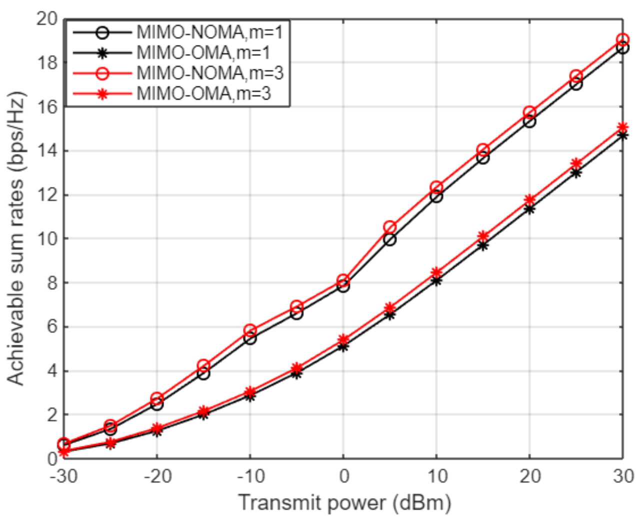


Fig.5. Achievable sum-rate for MIMO-NOMA and MIMO-OMA in Nakagami-$m$ fading

It appears that we are preferring the weak user by giving him ever more power at the expense of the strong user's conduct when $R_1^*$ falls between 0 and 5 bps/Hz. Nevertheless, any value of $\alpha_1$ may not completely meet $R_1^*$ above 5bps/Hz. In this case, we give preference to the user who is closest rather than squandering all our energy on the user who is far away. For $R_1^*$>5bps/Hz, this results in a reduction of the strong user outage without influencing the weak user outage, which is advantageous.

Further, we set the target rate for $U_1$ to be $R_1^*$=1 bps/Hz and for $U_2$ to be $R_2^*$=3 bps/Hz in Fig.4. For our MIMO-NOMA simulation, we are utilizing the improved fair PA technique recommended in section 3.2. We demonstrate the user outage probabilities as a function of transmit power. The Fig.4 makes it evident that, as anticipated, MIMO-NOMA experiences less outages as compared to MIMO-OMA for both users utilizing improved Fair PA.

Next, we explore the sum rate of our improved fair PA for MIMO-NOMA and MIMO-OMA. MIMO-OMA's feasible sum rate is $R_{1,oma}$+ $R_{2,oma}$, whereas MIMO-NOMA's is $R_1$+$R_2$. The Fig.5 makes it evident that, in terms of possible capacity, our improved fair PA MIMO-NOMA performs better than MIMO-OMA. When the same frequency resource is concurrently given to both users, it is clear from Fig.5 that MIMO-NOMA provides a larger sum rate than MIMO-OMA. Additionally, there is 4bps/Hz sum-rate improvement at 10dBm transmit power in MIMO-NOMA with improved fair PA than MIMO-OMA.

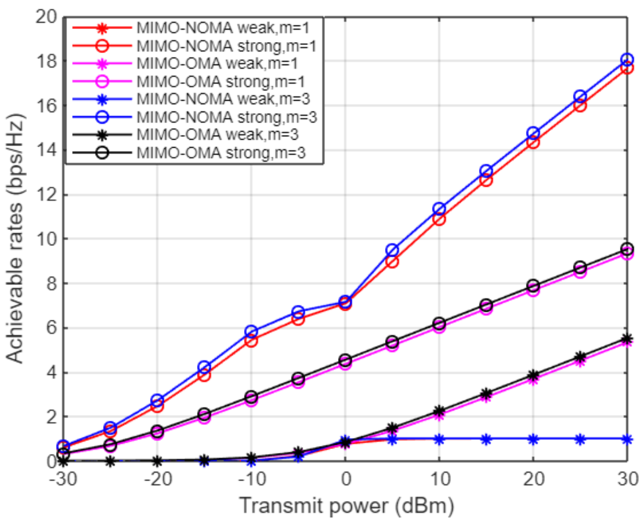


Fig.6. Individual user achievable rates for MIMO-NOMA and MIMO-OMA in Nakagami-*m* fading channel

The individual achievable rates are then plotted in Fig.6. For *m*=1 and *m*=3, we observe that the weak user experiences a saturation in its achievable rate following a transmit power of 0 to 5 dBm, respectively. We discover that this is a typical pattern within all NOMA systems. Weak users encounter interference, which results in a saturation of their achievable rate. If the weak user's needed data rate less than the saturation limit, this saturation of the feasible rate is not an issue. This problem does not exist with OMA, since concurrent transmission does not generate interference for the weak user.

## 6. CONCLUSION

In this paper, we analyzed our fair PA and improved fair PA dynamic schemes to enhance outage and sum-rate performance in Nakagami-*m* fading scenario. Stated otherwise, if the channel changes, the power coefficient values are modified to conform to the standard. The results of the outage and sum-rate simulations indicate that, especially for strong users, improved fair PA MIMO-NOMA performs better than MIMO-OMA. Future studies can show the utilization of beamforming with an efficient power allocation technique to further enhance MIMO-NOMA performance.

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