



Performance Analysis of Non-Orthogonal Multiple Access for 5G Wireless Networks

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Abstract

Non-Orthogonal Multiple Access (NOMA) has emerged as a key enabler for 5G and beyond wireless networks, offering improved spectral efficiency, user fairness, and massive connectivity compared to conventional Orthogonal Multiple Access (OMA) schemes. This paper presents a comprehensive performance analysis of NOMA and OMA in terms of spectral efficiency, outage probability, and bit error rate (BER) under various channel conditions. We model a downlink communication system where multiple users are served simultaneously using power-domain NOMA, employing Successive Interference Cancellation (SIC) at strong users. Comparative simulations are performed to evaluate the impact of key parameters such as transmit power allocation, user pairing strategies, and channel fading conditions (Rayleigh and Rician). Results demonstrate that NOMA outperforms OMA in spectral efficiency and connectivity, particularly in high-user-density scenarios, while highlighting the trade-offs in SIC complexity and error propagation. These findings provide insights into the feasibility of NOMA for next-generation wireless networks, optimizing resource allocation strategies for enhanced system performance.

Keywords: Non-Orthogonal Multiple Access (NOMA), Power Allocation, Successive Interference Cancellation (SIC), User Pairing.

I. INTRODUCTION

With the increase in demand for higher data rates, massive connectivity and efficient spectrum utilization, non-orthogonal multiple access (NOMA) has emerged as the key candidate for next generation wireless communication systems (Beyond 5G and 6G). Unlike orthogonal multiple access (OMA) schemes, which allocate distinct frequency resources to users, NOMA enables multiple users to share the same spectrum by utilizing power and code domain multiplexing [1]. This enables higher spectral efficiency and facilitates massive connectivity in dense network environments. With the anticipation of increase in connectivity density to exceed the capabilities of traditional OMA schemes, NOMA is proven to be suitable for future wireless communication systems because of its ability to serve a large number of users simultaneously [2].

In NOMA, there are two channel conditions as good channel condition and poor channel condition and users with different channel conditions are multiplexed over the same frequency. The user with good channel condition is referred as strong user and the user with poor channel condition is referred as weak user [3]. NOMA has two major classifications: Power domain NOMA (PD-NOMA) and code domain NOMA (CD-NOMA). PD-NOMA operates by assigning different power levels to users, with the weak user receiving higher power to compensate for their poorer channel quality [4]. In contrast, CD-NOMA assigns distinct codes to each user, enabling simultaneous transmission over the same frequency channel [5, 6]. Both these schemes leverage successive interference cancellation (SIC) at the receiver end, which decodes the users' signals sequentially based on channel condition starting from the strongest user [7]. However, the performance of SIC is critically dependent on the channel estimation accuracy and the quality of interference cancellation, which can be impacted by practical imperfections [8, 9]. Optimal user pairing, and gradual resource allocation in massive MIMO-NOMA have been developed [10]. The feasibility and challenges of integrating MIMO-NOMA are analysed using interference management and beamforming techniques [11]. The impact of user pairing strategies on the system performance is significant, as suboptimal pairing can degrade system throughput and fairness [12]. With the advent of 6G, NOMA is being explored in THz communication networks [13]. The outage performance, energy-efficient resource allocation, and user pairing strategies in NOMA-THz systems are studied [14]. A joint power and subcarrier allocation method is designed to improve system efficiency, and the impact of molecular absorption loss in the THz band is considered in the resource allocation problem [15]. Spatial multiplexing and beamforming techniques to mitigate the high path loss in THz bands was introduced [16]. In [17], user clustering and pairing algorithm to optimize spectral efficiency was developed, and power allocation strategy to maximize sum-rate performance in multi-carrier NOMA was introduced. The remainder of the document is structured as follows: The proposed system model is explained in Section II, Performance analysis is given in section III, and conclusion is presented in Section IV.

II. SYSTEM MODEL

Figure 1 depicts a downlink Non-orthogonal multiple access (NOMA) system where a base station (BS) simultaneously transmits signals to multiple users over the same frequency and time resources. The power domain is used for multiple access, differentiating users based on their channel conditions. The BS transmits a superimposed signal containing information for both the strong user (near user) and the weak user (far user). The weak user has a poor channel condition, so it is allocated a higher power. Conversely, the strong user, with better channel conditions, receives a lower power allocation. The strong user first detects the weak user's signal using Successive Interference Cancellation (SIC). Once the weak user's signal is detected, it is subtracted from the received signal. After removing the weak user's signal, the strong user detects its own signal without interference. The weak user directly detects its own signal without performing SIC, as it treats the strong user's signal as noise.

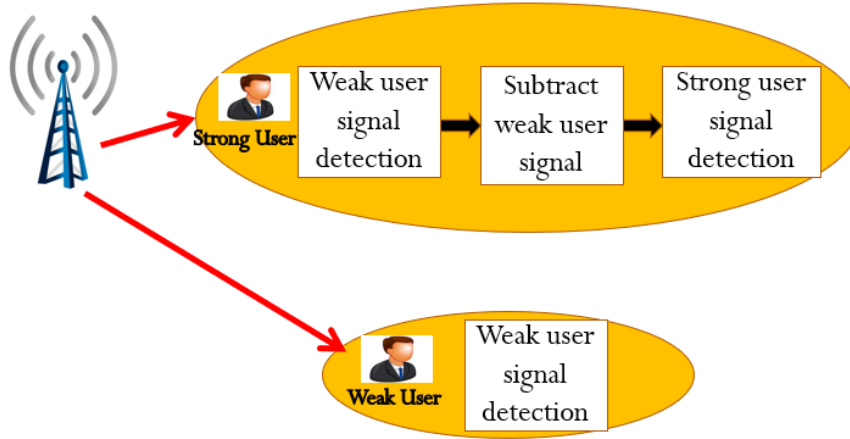


Figure 1: depicts a downlink Non-orthogonal multiple access (NOMA) system

Let us consider the data are transmitted to N users from the base station (BS) as $x_0, x_2, \dots, x_{N-1}$. In PD-NOMA, using superposition coding each user data are multiplied with its associated power by the BS. The resultant signal transmitted by the BS signal is given by,

$$x_{bs} = \sqrt{P} \sum_{k=1}^{N-1} \sqrt{\alpha_k} x_k \quad (1)$$

where, P is the total transmit power and, α is the power allocation coefficient. The power allocation coefficients are ordered in such a way that the $\alpha_0 > \alpha_1 > \dots \alpha_{N-1}$ for $h_0 < h_1 < \dots h_{N-1}$. The received signal at the k th user is written as,

$$y_k = x_{bs} h_k + n_k \quad (2)$$

where, h_k is the channel gain for k th user and, n_k is the additive white Gaussian noise (AWGN) with zero mean and variance σ^2 . On substituting (1) in (2) we get,

$$y_k = \left(\sqrt{P} \sum_{k=1}^{N-1} \sqrt{\alpha_k} x_k \right) h_k + n_k \quad (3)$$

From (3), we get to know that each user terminal receives its own signal along with other users signal as interference. But in NOMA each user tend to receive interference from other users whose signal power is higher than its intended signal. Now let us consider a two user NOMA systems with one weak user (UE0) and one strong user (UE1). In the following subsection, the detection of weak and strong user signals under perfect SIC (pSIC) and imperfect SIC (iSIC) conditions are given.

Detection Of Strong User Signal:

At the strong user terminal, the received signal is represented as,

$$y_1 = \sqrt{P}(\sqrt{\alpha_1} x_1 + \sqrt{\alpha_0} x_0) h_1 + n_1 \quad (4)$$

In (4), the first term corresponds to strong user and the second term corresponds to weak user. Since the second term is dominating with higher power than the first term before decoding its own data, the strong user needs to remove this higher power term. This can be done by performing SIC at the strong user terminal. It involves the following steps:

- (1) The weak user power is divided in the receiver signal. This will give the estimate of weak user data.
- (2) Then the weak user data is multiplied with its associated power and then the resultant signal is subtracted from the receiver signal. This will remove the weak user data.
- (3) Finally the strong user power is divided to decode its own data.

In the case of pSIC, the signal to interference noise ratio (SINR) at the strong user to decode the weak user data is,

$$\gamma_{1,2} = \frac{\alpha_0 P |h_1|^2}{\alpha_1 P |h_1|^2 + \sigma^2} \quad (5)$$

The corresponding achievable data rate is,

$$R_{1,2} = (1 + \gamma_{1,2}) = \left(1 + \frac{\alpha_0 P |h_1|^2}{\alpha_1 P |h_1|^2 + \sigma^2}\right) \quad (6)$$

After removing the weak user signal, the resultant SINR to decode the strong user data is,

$$\gamma_2 = \frac{\alpha_1 P |h_1|^2}{\sigma^2} \quad (7)$$

The corresponding achievable data rate is,

$$R_2 = (1 + \gamma_2) = \left(1 + \frac{\alpha_1 P |h_1|^2}{\sigma^2}\right) \quad (8)$$

Thus the signal to interference noise ratio (SINR) for the weak user to decode its own signal is,

$$\gamma_1 = \frac{\alpha_1 P |h_1|^2}{\sigma^2} \quad (9)$$

Now, in the case of iSIC, a residue of weak users power is still present at interference in the denominator. As a result, the achievable rate reduces to

$$R'_2 = \left(1 + \frac{\alpha_1 P |h_1|^2}{\Omega \alpha_0 P |h_1|^2 + \sigma^2}\right) \quad (10)$$

Detection Of Weak User Signal

The SINR to decode the weak user data is,

$$\gamma_1 = \frac{\alpha_0 P |h_0|^2}{\sigma^2} \quad (11)$$

The corresponding achievable data rate is,

$$R_1 = (1 + \gamma_1) = \left(1 + \frac{\alpha_0 P |h_0|^2}{\sigma^2}\right) \quad (12)$$

Power Allocation In NOMA:

Let R^* denote the target data rate of weak user such that $R_1 \geq R^*$. When $R_1 = R^*$

$$\left(1 + \frac{\alpha_0 P |h_0|^2}{\alpha_1 P |h_0|^2 + \sigma^2}\right) = R^* \quad (13)$$

$$1 + \frac{\alpha_0 P |h_0|^2}{\alpha_1 P |h_0|^2 + \sigma^2} = 2^{R^*}$$

$$\frac{\alpha_0 P |h_0|^2}{\alpha_1 P |h_0|^2 + \sigma^2} = 2^{R^*} - 1 \quad (14)$$

Let $\rho = 2^{R^*} - 1$ is the target SINR for the weak user who has target rate R^* . Therefore,

$$\frac{\alpha_0 P |h_0|^2}{\alpha_1 P |h_0|^2 + \sigma^2} = \rho \quad (15)$$

$$\alpha_0 P |h_0|^2 = \rho \alpha_1 P |h_0|^2 + \rho \sigma^2$$

$$\text{Since, } \alpha_0 + \alpha_1 = 1, \alpha_1 = 1 - \alpha_0$$

$$\alpha_0 P |h_0|^2 = \rho(1 - \alpha_0) P |h_0|^2 + \rho \sigma^2$$

$$\alpha_0 P |h_0|^2 + \rho \alpha_0 P |h_0|^2 = \rho P |h_0|^2 + \rho \sigma^2$$

$$\alpha_0 P |h_0|^2 (1 + \rho) = \rho (P |h_0|^2 + \sigma^2)$$

$$\alpha_0 = \frac{\rho (P |h_0|^2 + \sigma^2)}{P |h_0|^2 (1 + \rho)} \quad (16)$$

In (16), α_0 should not exceeds 1. Therefore the limit is,

$$\alpha_0 = \left(1, \frac{\rho (P |h_0|^2 + \sigma^2)}{P \ln d^2 (1 + \rho)}\right) \quad (16)$$

III. PERFORMANCE ANALYSIS

In this section, we present the simulation results comparing the performance of NOMA and OMA in terms of spectral efficiency, outage probability, and bit error rate (BER). The simulations were conducted using a downlink NOMA system with users experiencing Rayleigh fading. The impact of power allocation and SIC efficiency on NOMA performance is also analyzed.

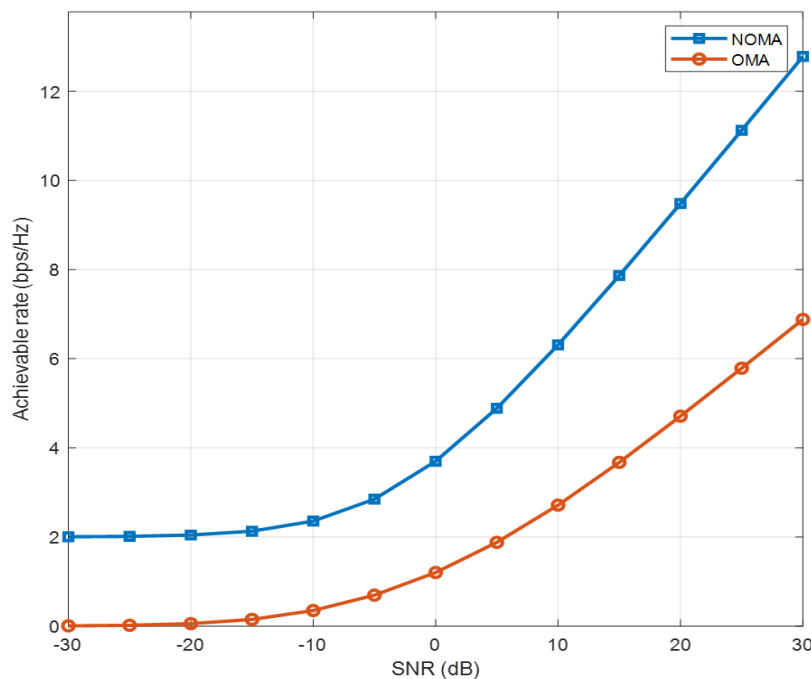


Figure 2: SNR versus achievable rate performance of OMA and NOMA

Figure 2 compares the SNR versus achievable rate performance of OMA and NOMA. Figure 2 illustrates the achievable rate (bits/s/Hz) as a function of Signal-to-Noise Ratio (SNR) in dB for Non-Orthogonal Multiple Access (NOMA) and Orthogonal Multiple Access (OMA). It is evident that NOMA outperforms OMA across all SNR values due to its power-domain multiplexing capability, which allows multiple users to share the same frequency-time resources efficiently. At low SNR values, both NOMA and OMA achieve relatively low data rates, but NOMA maintains a slight advantage. As the SNR increases, the gap between the two schemes widens, with NOMA achieving significantly higher spectral efficiency, especially at higher SNR values where successive interference cancellation (SIC) plays a crucial role. Unlike OMA, which follows a linear increase in achievable rate, NOMA exhibits an exponential growth pattern, demonstrating its superiority in maximizing spectral efficiency. This result confirms that NOMA is a more efficient multiple access scheme compared to OMA, making it a promising candidate for high-data-rate applications in 5G and beyond.

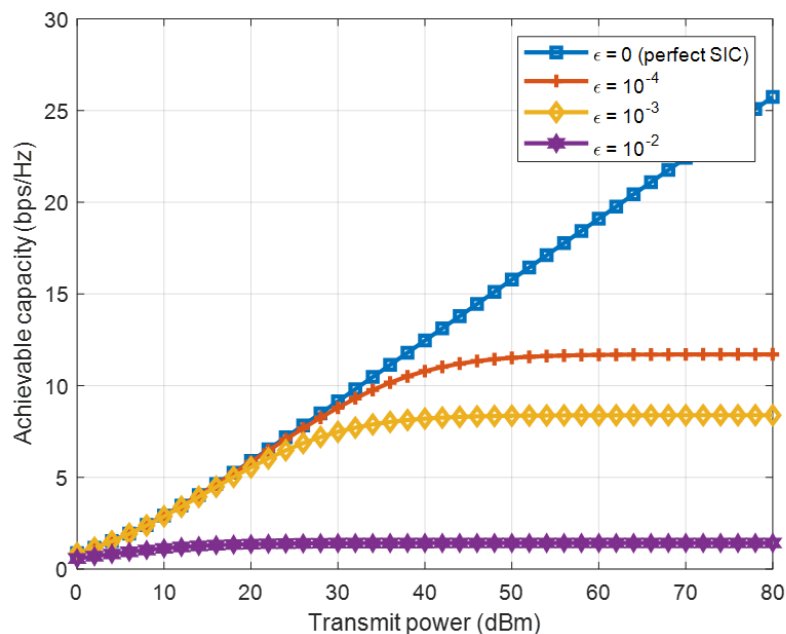


Figure 3: Transmit power versus achievable capacity performance for pSIC and iSIC

Figure 3 presents the achievable capacity (bits/s/Hz) as a function of transmit power (dBm) for different levels of successive interference cancellation (SIC) imperfection, denoted by ϵ . The case of perfect SIC ($\epsilon=0$) exhibits the highest achievable capacity, demonstrating the ideal performance of NOMA when interference is perfectly eliminated. As ϵ increases, representing increasing SIC errors, the achievable capacity degrades significantly. For $\epsilon = 10^{-4}$, the system still maintains a relatively high capacity but starts to saturate at higher transmit power levels. With further degradation ($\epsilon = 10^{-3}$), the capacity curve flattens earlier, indicating

that error propagation in SIC severely limits performance. In the worst-case scenario ($\epsilon = 10^{-2}$), the capacity remains very low, even as the transmit power increases, highlighting the adverse impact of imperfect SIC. These results emphasize the critical role of accurate SIC in NOMA systems and the necessity of advanced interference cancellation techniques to maximize spectral efficiency.

Figure 4 illustrates the outage probability as a function of transmit power (dBm) for two users in a NOMA system: User 1 (far user) and User 2 (near user). The outage probability decreases as the transmit power increases for both users, indicating improved reliability at higher power levels. However, the far user (User 1) consistently experiences a higher outage probability compared to the near user (User 2) across all transmit power levels. This is expected since the far user suffers from weaker channel conditions and greater interference, making it more vulnerable to outages. In contrast, the near user benefits from better channel conditions and a stronger received signal, resulting in a lower outage probability. The logarithmic scale on the y-axis further emphasizes the exponential decrease in outage probability with increasing transmit power. These results highlight the inherent trade-off in NOMA systems, where power allocation and interference management play a crucial role in maintaining reliable communication, especially for users with weaker channel conditions.

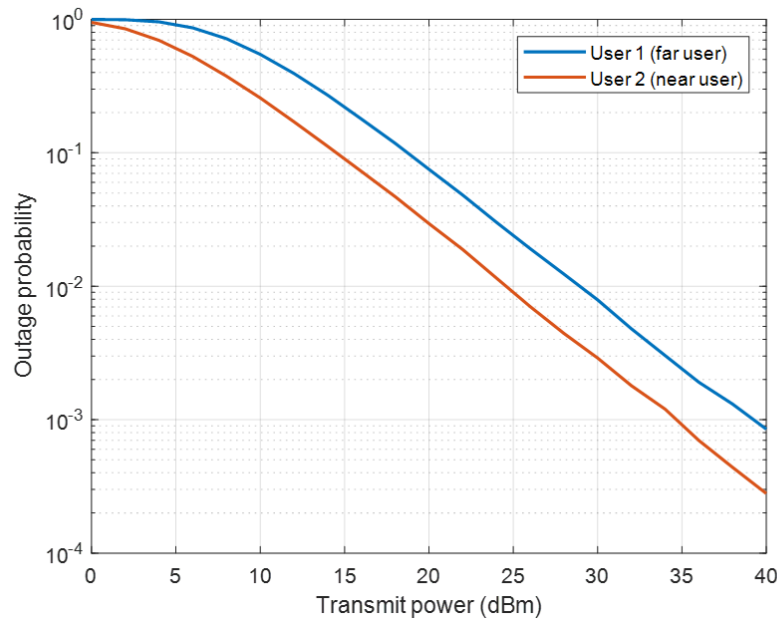


Figure 4: Transmit power versus outage probability performance for OMA and NOMA

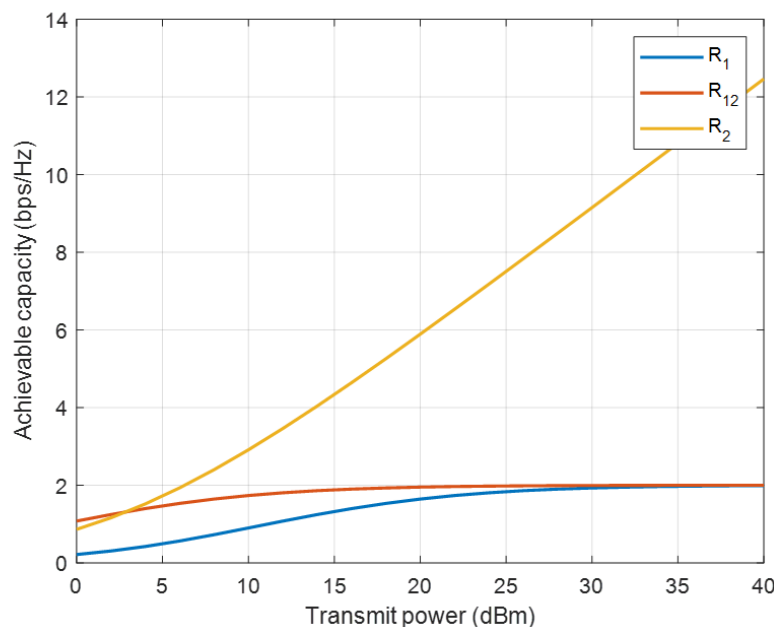


Figure 5: Transmit power versus achievable rate performance for NOMA

Figure 5 presents the achievable capacity performance of the NOMA system as a function of transmit power. The capacity curves for different users, denoted as R_1 , R_{12} , and R_2 indicate how the system's spectral efficiency evolves with increasing transmit power. The capacity of User 2 (R_2) who experiences better channel conditions, increases significantly with higher transmit power, demonstrating its advantage in data rate. Conversely, the capacity of User 1 (R_1) who is farther from the base station and subject to higher interference, grows at a slower rate. The sum rate (R_{12}) remains relatively stable at higher power levels due to interference-limited conditions. These results validate the fundamental principle of NOMA, where power allocation plays a key role in balancing capacity distribution between users, and optimal power control strategies are necessary to enhance system efficiency while ensuring fairness among users.

IV. CONCLUSION

The simulation results demonstrate that NOMA effectively enhances spectral efficiency by allowing multiple users to share the same frequency resources through power domain multiplexing. The outage probability analysis highlights the trade-off between near and far users, where power allocation significantly impacts system performance. Additionally, the achievable capacity results validate the superiority of NOMA in improving the data rate for users with better channel conditions while maintaining fairness for weaker users. Given its ability to support massive connectivity and improve spectral efficiency, NOMA is a promising multiple access technique for future wireless networks, including 6G and beyond. By integrating NOMA with advanced technologies such as IRS and machine learning-based optimization, future networks can achieve even greater performance gains in terms of capacity, reliability, and energy efficiency.

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