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Peformance Evaluation of Modulation and Power Allocation Effects on BER in NOMA with SIC over AWGN Channels

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Abstract— This study evaluates the performance of a Non-Orthogonal Multiple Access (NOMA) system implementing Successive Interference Cancellation (SIC) over Additive White Gaussian Noise (AWGN) channels, focusing on the effects of modulation schemes and power allocation on Bit Error Rate (BER). Three modulation schemes BPSK, QPSK, and 16QAM are studied in combination with different power allocation configurations (e.g., $\alpha = 0.1, 0.3$) for two users in an OFDM-based NOMA downlink scenario. The signal superposition process is performed at the transmitter side, while SIC is applied at the receiver side to separate the user signals. The simulation results show that the BER performance is greatly affected by the modulation level and power allocation ratio. Lower-order modulations (such as BPSK and QPSK) provide better performance at low SNR, especially for users with poorer channel quality. On the other hand, improper power distribution can cause error propagation in the SIC process, degrading the demodulation accuracy. This study emphasizes the importance of selecting adaptive modulation schemes and power allocation strategies in NOMA system design. These findings provide important contributions to the development of future wireless communication systems, especially 5G and later generations, which demand high spectral efficiency and multi-user service reliability.

Keywords— *NOMA, SC, SIC, Modulation, Network Generation*

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I. INTRODUCTION

In the era of 5G generational communication, network efficiency and capacity are crucial for meeting ever increasing data service requests[1][2]. As the number of devices connected to the network increases, a more efficient multiple access technology is needed to optimize the utilization of limited spectrum resources[3][4]. One of the intangible natural resources that are essential to modern living is radio frequency. Radio frequency, the primary medium in wireless communication, enables the wireless transmission of information using electromagnetic waves[5][6]. To prevent interference, mobile communication systems have historically relied on orthogonal access techniques like TDMA, FDMA, or OFDMA, in which users are separated in time, frequency, or code domains[7][8]. Conventional technologies, such as Orthogonal Frequency Division Multiple Access (OFDMA) utilized in 4G networks, face challenges in effectively managing a large number of users[9]. This is particularly evident in congested network environments and scenarios involving the Internet of Things (IoT)[10].

Non-Orthogonal Multiple Access (NOMA) has emerged as a crucial technology in fifth generation (5G) wireless communication systems and beyond due to its ability to improve spectrum efficiency, system capacity, and support massive connectivity with low latency[11]. This method can increase network capacity, reduce latency levels, and optimize spectrum usage efficiency[12].

Superposition Coding (SC) at the transmitter side (base station) and Successive Interference Cancellation (SIC) at the receiver side (user equipment) are two of NOMA's primary features[13]. Depending on the channel condition of each user, Superposition Coding allows the merging of numerous user signals into a single composite signal using varying power allocations[14]. In actuality, customers who are farther away from the base station and have worse channel quality are usually provided more power, whereas users who are closer to the base station and have better channel conditions are given less power[15].

This method eliminates the necessity for orthogonal separation by allowing numerous users' signals to be sent simultaneously over the same frequency and time. As a result, the spectral efficiency is better than with traditional techniques like OFDMA[16]. With varying power weights based on the power allocation technique, Superposition Coding generates a single composite signal that includes data from every user[17].

However, Successive Interference Cancellation (SIC), a sophisticated processing method, is needed to separate these signals at the receiver side. Prior to successively decoding the subsequent signal with lower power, SIC first decodes the user's signal with the highest power and subtracts it from the composite signal[18]. In a two-user scenario, for instance, the receiver nearer the base station will decode its own signal after subtracting the signal of the distant user (whose signal has higher power) from the composite signal[19].

The precision of the channel estimation and decoding procedure are critical to the success of SIC. Error propagation may occur if the initial signal's decoding is unsuccessful and the error spreads to the next signal's decoding[20]. To guarantee the best NOMA performance, it is therefore essential to optimize the SIC algorithm and adjust to channel conditions like fading. NOMA provides a more adaptable and effective multiple access solution with the integration of SC and SIC, which makes it ideal for 5G and next-generation networks that need to support high throughput, low latency, and huge interconnection[21].

According to the description given above, the main goal of this study is to evaluate how well the Successive Interference Cancellation (SIC) technique performs in a NOMA system using different digital modulation schemes, including BPSK, QPSK, and 16-QAM[22]. To ascertain how different modulation types affect SIC's ability to separate user signals, an evaluation is conducted using Bit Error Rate (BER) and Spectral Efficiency metrics[23]. It is anticipated that this study's findings will help determine the best modulation plan for deploying NOMA in fifth-generation (5G) and future communication networks[24].

II. METHOD

The following is the NOMA model system:

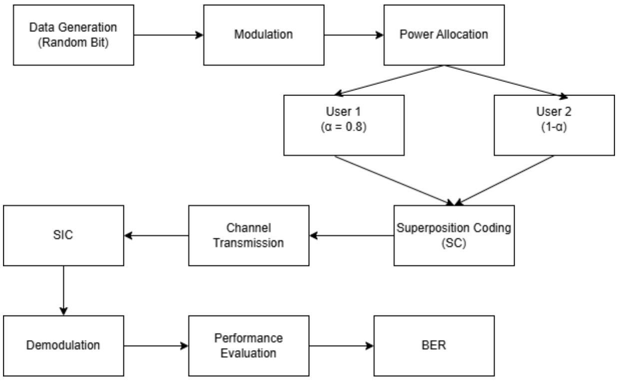

Figure 1. Flowchart NOMA Model System

The system's initial step involves creating random binary data that each user (User 1 and User 2) must communicate. A random number generator is usually used to replicate a series of 0s and 1s in this data. Representing the information meant to be conveyed is the goal. In order to get acceptable statistical accuracy while assessing the system's performance, the number of bits created during simulation implementation can be changed, for instance, to 10^5 bits.

A digital modulation approach is then used to modulate the binary data from both users. For the bits to be sent over a wireless channel, modulation transforms them into intricate symbols. BPSK (1 bit/symbol), QPSK (2 bits/symbol), and 16-QAM (4 bits/symbol) are examples of frequently used modulation techniques. The system's data rate and noise resistance may be impacted by the modulation selection.

Following modulation, the system allocates power to each user according to their channel circumstances. An unequal distribution of power occurs in a NOMA situation. While users with better channel circumstances receive less power (e.g., $1-\alpha = 0.2$ for User 2), users with poorer channel conditions (e.g., those farther from the base station) receive more power (e.g., $\alpha = 0.8$ for User 1). Stronger users can decode and remove interference, while weaker users can still receive signals with sufficient quality thanks to this power allocation.

The Superposition Coding (SC) technique is used to combine the signals from both users following modulation and power allocation. After multiplying the user signals by the square root of their individual power levels, SC adds them up. The end product is a single composite signal with varying power levels that includes data from both users in the same time and frequency domain. Since it permits non-orthogonal multiplexing, which permits two signals to share a channel at the same time, this method forms the basis of the NOMA principle.

After the Superposition Coding procedure, the combined signal is sent across a wireless channel that is characterized as AWGN (Additive White Gaussian Noise)[25]. Only random noise with a Gaussian distribution, zero mean, and a specific variance is introduced by the AWGN channel, a basic yet straightforward channel model. Since there are no fading or multipath effects in this model, the signal just gains noise while being transmitted[26].

For example $\mathrm{h}^{(i)} = [h_0^{(i)}, \dots, h_{N_{ch}}^{(i)}]^{\mathrm{T}}$ where N_{ch} is the channel length, represents the time-domain channel impulse response for user i. The signal that was received can be written as[27]

$$r_k = \mathrm{H}^{(1)} s_k^{(1)} + \mathrm{H}^{(2)} s_k^{(2)} + \mathrm{w}_k. \quad (1)$$

where $\mathrm{H}^{(i)}$ is the Toeplitz channel matrix of user i with

The vector $w_k \sim \mathcal{CN}(\mathbf{0}, N_0\,\mathbf{I})$ describe additive white Gaussian noise (AWGN) of power spectral density N_0. The system's signal to noise ratio is defined as SNR = P/N_0[28].

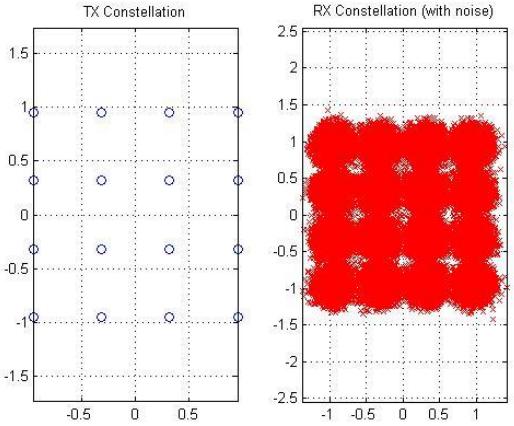

Figure 2. Transceiver Constellation before and after noise

Every user receives the identical signal at the receiver side, but they all process it in various ways. In order to accomplish SIC (Successive Interference Cancellation), the user with the stronger channel (User 2) first decodes the signal of the other user (User 1), subtracts it from the combined signal, and then decodes its own signal. Since User 2's power is comparatively low and is seen as noise, User 1, the user with the weaker channel, decodes its own signal straight without eliminating User 2's signal. Because it makes it possible to separate user signals in the power domain, SIC is essential to NOMA's success.

On first user that have large power, a *single-user decoder* $g_1{:}C^T \rightarrow \{0,1\}^{2TR_1}$ decode message S_1(n) by considering S_2(n) as a *noise*. User 2 that have smaller powernperforms the following steps to sequentially retrieve their message from the received signal Y_n(n):

Decoding user message 1 S_1(n) by using single-user decoder $g_1{:}C^T \rightarrow \{0,1\}^{2TR_1}$.

Reduce $\sqrt{P\beta_1}h_2S_1$(n) from the received signal Y_2(n)

$$Y'_2(\mathrm{n}) = Y_2(\mathrm{n}) - \sqrt{P\beta_1}h_2S_1(\mathrm{n}) \tag{2}$$

where h_2 is the complex channel gain at user 2.

Decode user 2's message by applying another single-user decoder $g_2{:}C^T \rightarrow \{0,1\}^{2TR_2}$ on Y'_2(n)[29].

The segregated user signals are demodulated back into binary data following either direct decoding (for User 1) or the SIC method (for User 2). Recovering the original bits that the users sent is the aim. The correctness of the system will next be assessed by comparing the outcome of this procedure with the original data.

The final step is system performance evaluation. Two main metrics are used: Bit Error Rate (BER). Measures the number of incorrectly received bits compared to the total number of transmitted bits. BER reflects the reliability of the system[30].

$$\mathrm{BER} = \frac{N_{error}}{N_{total}} \tag{3}$$

where:

N_{error} = number of incorrectly received bits (bit errors)

N_{total} = total number of transmitted bits

III. RESULT AND DISCUSSION

A. Noma with SIC (Succesive Interference Cancellation)

After the system simulation was carried out, the results were obtained:

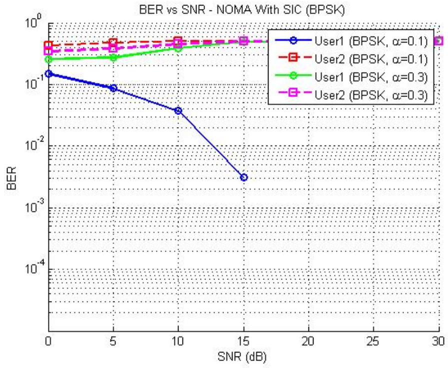

Figure 3. BER vs SNR on NOMA with SIC using BPSK Modulation

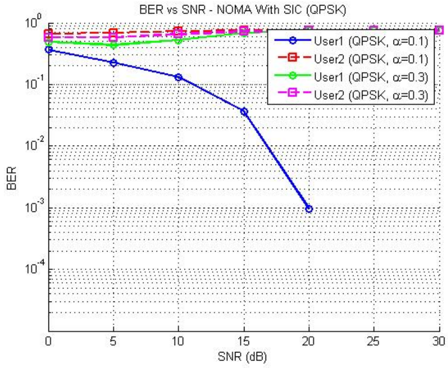

Figure 4. BER vs SNR on NOMA with SIC using QPSK Modulation

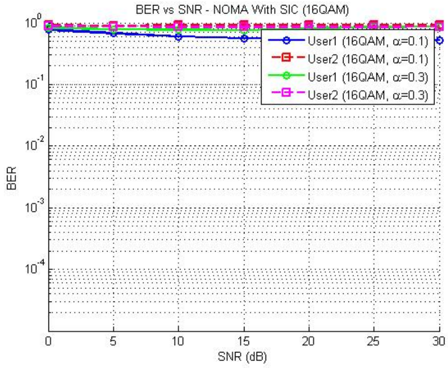

Figure 5. BER vs SNR on NOMA with SIC using 16-QAM Modulation

In figure 3 shows the performance of the NOMA system with Successive Interference Cancellation (SIC) using BPSK modulation. In the graph, it can be seen that user 1 who gets a higher power allocation (with α = 0.1, meaning User 1 gets 90% of the total power), has very good BER performance, especially at SNR above 10 dB. This shows that SIC works effectively on simple modulation schemes such as BPSK. On the other hand, User 2 who gets a smaller power allocation experiences high BER and tends to stagnate, even though the SNR increases. This is caused by the low signal power and residual interference from User 1 that has not been completely eliminated, especially if SIC is not running optimally.

Figure 4 show the NOMA system is implemented with QPSK modulation. The results show a similar trend to BPSK, where User 1 still shows a significant decrease in BER as the SNR increases. However, in general, the BER in QPSK is higher than BPSK for the same SNR range. This is because QPSK carries 2 bits per symbol, making it more sensitive to noise and interference between users. Meanwhile, User 2 again experiences high BER, although there is a slight improvement at very high SNRs. This indicates that increasing modulation complexity begins to reduce the effectiveness of SIC in eliminating interference from other users' signals.

And figure 5 shows the performance of the NOMA system with 16-QAM modulation, which is the modulation scheme with the highest symbol density in this test. The results show that both User 1 and User 2 have high BER and do not show significant degradation, even up to 30 dB SNR. This indicates that 16-QAM modulation is not suitable for the NOMA scenario with SIC, especially under uneven power allocation conditions. The high complexity of the 16-QAM signal constellation makes the system very sensitive to phase and amplitude errors, so that small errors in the SIC process have a large impact on the decoding accuracy. The effectiveness of SIC in this scenario is very limited and cannot compensate for the high complexity of the modulation signal.

Table 1 BER vs SNR with SIC

Modulation	Power Allocation	BER vs SNR		
		(5dB)	(15dB)	(25dB)
BPSK	0,1 0,9	0.08760	0.00330	0.00000
	0,9 0,1	0.47340	0.49933	0.50228
	0,3 0,7	0.27180	0.48857	0.50132
	0,7 0,3	0.38458	0.49787	0.50132
QPSK	0,1 0,9	0.22205	0.03772	0.00000
	0,9 0,1	0.68744	0.75202	0.75178
	0,3 0,7	0.43949	0.68436	0.75002
	0,7 0,3	0.57931	0.72416	0.75002
16-QAM	0,1 0,9	0.67772	0.55940	0.52984
	0,9 0,1	0.90329	0.90692	0.92339
	0,3 0,7	0.79288	0.76172	0.85383
	0,7 0,3	0.86305	0.85449	0.85911

Table 1 presents the Bit Error Rate (BER) performance of a NOMA system employing Successive Interference Cancellation (SIC) under three modulation schemes: BPSK, QPSK, and 16-QAM, with varying power allocations and SNR levels. The results demonstrate that SIC significantly improves BER performance for users with higher power allocations, particularly under low-complexity modulations like BPSK and QPSK. For example, at 25 dB SNR and a power allocation of (0.1, 0.9), User 1 achieves a BER of

0.00000 with both BPSK and QPSK. However, User 2, receiving only 10% of the total power, consistently suffers from high BER values, indicating that SIC alone is insufficient to fully mitigate interference for low-power users. Furthermore, in 16-QAM scenarios, even the high-power user experiences high BER, highlighting the limitations of SIC when dealing with complex modulations. These findings emphasize that while SIC is effective for improving NOMA performance, especially at lower modulation orders, its capability diminishes with increased modulation complexity and highly imbalanced power allocations.

B. Noma with NON-SIC (Succesive Interference Cancellation)

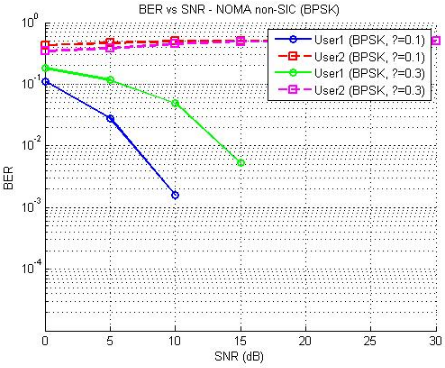

Figure 6. BER vs SNR on NOMA Non- SIC using BPSK Modulation

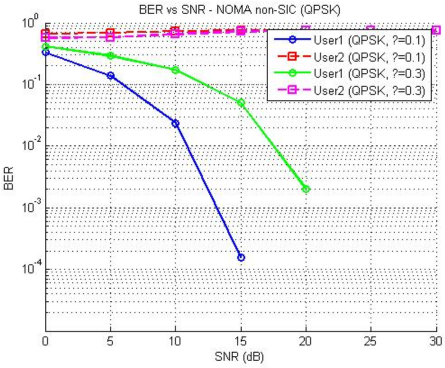

Figure 7. BER vs SNR on NOMA Non- SIC using QPSK Modulation

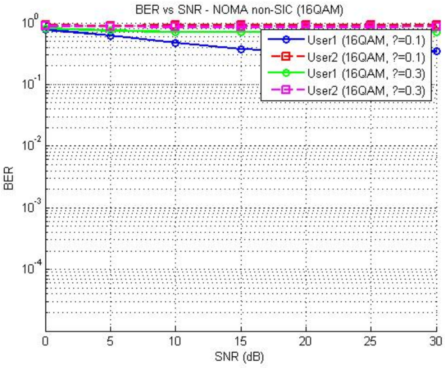

Figure 8. BER vs SNR on NOMA Non- SIC using 16-QAM Modulation

Figure 6 shows the performance of the NOMA system without Successive Interference Cancellation (non-SIC) with BPSK modulation. In this graph, it can be seen that User 1 who receives a larger power allocation (e.g. 90% power when α = 0.1) has an improved BER performance as the SNR increases. However, the performance of User 1 with α = 0.3

deteriorates compared to α = 0.1 because the power received is smaller. On the other hand, User 2 consistently experiences high BER without any significant decrease, even though the SNR increases. This is because without the application of SIC, User 2 is unable to eliminate interference from the strong signal of User 1, making decoding very difficult, especially when less power is allocated to it.

Figure 7 shows the same system, but using QPSK modulation. The performance trend is similar to BPSK, namely User 1 shows a significant decrease in BER as SNR increases, especially for large power allocations. However, because the complexity of the QPSK constellation is higher than BPSK, the BER is initially higher. Meanwhile, User 2 again experiences a high and stagnant BER, indicating that interference from User 1's signal still cannot be handled effectively without SIC. This further emphasizes the importance of implementing SIC techniques in NOMA, especially when more complex modulations are used.

And last figure 8 shows the performance of the non-SIC NOMA system with 16-QAM modulation, which has the highest complexity among the three modulation schemes. From the graph, it can be seen that both User 1 and User 2 have very high BER, even at high SNR up to 30 dB. This shows that without SIC, the decoding performance becomes very poor, mainly because interference cannot be eliminated, and signals with high modulation are more susceptible to noise and interference. The BER tends to plateau at high levels, indicating that the non-SIC NOMA system is not suitable for the use of 16-QAM modulation without interference mitigation techniques.mitigasi interferensi.

Table 2. BER vs SNR with NON- SIC

Modulation	Power Allocation	BER vs SNR		
		(5dB)	(15dB)	(25dB)
BPSK	0,1 0,9	0.02746	0.00000	0.00000
	0,9 0,1	0.47547	0.50012	0.50195
	0,3 0,7	0.11672	0.00574	0.00000
	0,7 0,3	0.38227	0.49293	0.50203
QPSK	0,1 0,9	0.13828	0.00016	0.00000
	0,9 0,1	0.68551	0.74945	0.74695
	0,3 0,7	0.28512	0.05109	0.00000
	0,7 0,3	0.57789	0.72207	0.74988
16-QAM	0,1 0,9	0.62047	0.37727	0.34281
	0,9 0,1	0.90152	0.90891	0.92207
	0,3 0,7	0.74453	0.70887	0.70000
	0,7 0,3	0.86328	0.85117	0.85559

Table 2 shows the Bit Error Rate (BER) performance of a NOMA system without the use of Successive Interference Cancellation (non-SIC) under BPSK, QPSK, and 16-QAM modulation schemes. The results highlight that in the absence of SIC, interference between users significantly degrades system performance, especially for the user with lower power allocation. While the high-power user (e.g., $\alpha = 0.1$) achieves near-zero BER at high SNR, the low-power user consistently experiences high BER values across all SNR levels, indicating an inability to overcome strong interference. Compared to the SIC scenario, BER performance for both users is generally worse, particularly under higher-order modulations such as 16-QAM, where even the strong user sees minimal BER improvement despite increasing SNR. These results emphasize that without SIC or equivalent interference mitigation techniques, NOMA systems suffer from severe user unfairness and degraded reliability, making non-SIC configurations impractical for real-world deployment, especially when complex modulation schemes are used.

IV. CONCLUSION

This study analyzes the performance of the Non-Orthogonal Multiple Access (NOMA) system using the Successive Interference Cancellation (SIC) technique and without SIC, on various digital modulation schemes, namely BPSK, QPSK, and 16-QAM. The evaluation is carried out by measuring the Bit Error Rate (BER) against variations in the Signal-to-Noise Ratio (SNR). The simulation results reveal that the NOMA system without SIC can, under certain conditions, provide more stable or even better performance, particularly in scenarios where power allocation is highly skewed or when the complexity of SIC introduces additional decoding errors. Without SIC, User 1 (typically the stronger user) receives the combined signal directly and decodes it without the risk of SIC-induced distortion. This results in consistently low BER for User 1, especially at lower modulation levels like BPSK and QPSK. Meanwhile, although User 2 faces interference, a carefully optimized power allocation can mitigate this to some extent. Furthermore, when higher-order modulation such as 16-QAM is applied, the sensitivity of SIC to noise and imperfect cancellation becomes more pronounced. In such cases, the system without SIC may avoid error propagation caused by incorrect interference subtraction, which can otherwise degrade performance. These findings suggest that while SIC is theoretically advantageous, its practical benefits are conditional. In systems where decoding complexity must be minimized or power disparity is significant, operating without SIC may offer a more robust and lower-latency alternative. Therefore, the decision to implement SIC should be made based on a thorough evaluation of channel conditions, user requirements, modulation choices and accuracy in detecting users with greater power. In conclusion, while SIC remains a powerful technique for enhancing NOMA performance, there are practical scenarios in which a non-SIC approach may be more beneficial. This emphasizes the importance of flexibility in NOMA system design, encouraging adaptive strategies that consider the trade-offs between complexity, reliability, and spectral efficiency.

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