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MITIGATING THE EFFECTS OF IMPERFECT SUCCESSIVE INTERFERENCE CANCELLATION (SIC) ON NON-ORTHOGONAL MULTIPLE ACCESS (NOMA) SYSTEMS

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Abstract

The study delves into the impact of imperfect Successive Interference Cancellation (SIC) on Non-Orthogonal Multiple Access (NOMA) system performance in wireless communication. The study focused on evaluating the effects of imperfect SIC on metrics like achievable rate and bit error rate and seeks to mitigate these effects using a TDMA-NOMA approach. This approach combines NOMA and orthogonal methods and investigates user pairing based on distance in a TDMA-integrated context. The findings reveal that Single Carrier (SC) NOMA performs poorly compared to TDMA due to interference from loading users onto a single carrier. However, pairing near and far users significantly improves the sum rate, emphasizing the benefits of distinct channel conditions. Furthermore, the Near-Near and Far-Far pairings in NOMA outperform TDMA, indicating the significance of user pairing for system efficiency. For enhancing imperfect SIC management, the study suggests exploring machine learning algorithms for adaptive decision-making. The study introduced a TDMA-NOMA pairing technique and evaluated its performance in various fading channels, and underscores the importance of intelligent user pairing for optimizing wireless communication efficiency. The findings reveal that the Near - Far pairing performs 10.01% better than Near - Near, Far - Far pairing across all the SNR levels and all Transmit Power levels, $\in = 10^{-4}$, $\in = 10^{-3}$, and $\in = 10^{-2}$ underperforms $\in = 0$ by 0.7743% in achievable data rate.

Keywords: NOMA, TDMA, Successive Interference Cancellation (SIC), User Pairing

Introduction

Wireless communication systems have witnessed remarkable advancements in recent years, driven by the exponential growth in data traffic and the increasing demand for seamless connectivity. Non-Orthogonal Multiple Access (NOMA) has emerged as a promising multiple access scheme for future wireless communication systems. NOMA enables the simultaneous transmission of multiple user signals over the same time and frequency resources, thereby improving spectral efficiency and accommodating a larger number of users (Chikezie *et al.*, 2022). One of the key techniques used in NOMA is Successive Interference Cancellation (SIC), which allows users with stronger channel conditions to decode their intended signals while treating the interference from other users as noise.

However, in practical scenarios, the SIC process is not perfect and can be susceptible to various imperfections. Imperfect SIC arises due to factors such as imperfect channel estimation, non-ideal interference cancellation, and hardware impairments. These imperfections can degrade the performance of NOMA systems and limit their potential benefits.

Mitigating the effects of imperfect SIC is of paramount importance to fully exploit the advantages offered by NOMA. By developing effective techniques to address the challenges associated with imperfect SIC, we can enhance the system performance, increase the user capacity, and improve the overall quality of service in NOMA systems.

Statement of the Research Problem

In NOMA systems, multiple users can share the same resource (such as frequency or time slot) by exploiting the power domain. However, this approach leads to the need for SIC (Successive Interference Cancellation), which is a crucial process in NOMA systems. However, due to the presence of noise, channel imperfection, and other practical constraints, the performances of NOMA systems are affected by the quality of the SIC. Therefore, there is a need to develop effective methods for mitigating the effects of imperfect SIC on the performances of NOMA systems.

Scope of the Study

The scope of this study is to investigate the impacts of imperfect successive interference canceling (SIC) on the performance of non-orthogonal multiple access (NOMA) systems. The research focuses on assessing how imperfect SIC affects the performance metrics of NOMA, such as achievable rate and bit error rate and mitigates the impact. The study employed the MATLAB simulation software to evaluate the performance of the proposed technique.

Justification for the Study

In recent years, NOMA has emerged as a promising technology for future wireless communication networks. The use of NOMA allows multiple users to access the same resource simultaneously, thus increasing the overall system capacity. However, the success of NOMA depends on proper successive interference cancellation, which is used to cancel the interference caused by the signals of other users. However, in practical scenarios, the performance of SIC may be affected by system parameters, channel conditions, and other practical constraints, leading to imperfect SIC. The presence of imperfect SIC may adversely affect the performance of NOMA systems, leading to a decrease in system capacity and an increase in error rates. To mitigate the effects of imperfect SIC on the performance of NOMA systems, it is essential to develop effective technique that can effectively mitigate the impact of imperfect SIC on NOMA systems.

Overview of Non-Orthogonal Multiple Access (NOMA) Systems

Non-Orthogonal Multiple Access is an advanced multiple access scheme that has gained considerable attention in the realm of wireless communication systems. NOMA offers a promising solution to enhance spectral efficiency and accommodate a large number of users by allowing simultaneous access to the same time and frequency resources (Ashish and Kumar, 2023).

In traditional orthogonal multiple access schemes, such as Orthogonal Frequency Division Multiple Access (OFDMA) and Code Division Multiple Access (CDMA), each user is assigned orthogonal resources (Salameh *et al.*, 2023). However, NOMA departs from this orthogonality constraint and enables multiple users to share the same resources through power domain or code domain multiplexing.

In power domain NOMA, users are allocated different power levels, allowing them to be distinguished at the receiver based on their power differences. The user with stronger channel conditions is allocated higher power, while the user with weaker channel conditions is assigned lower power. This power imbalance enables the receiver to perform successive interference cancellation (SIC), decoding the stronger user's signal first and then canceling it to extract the weaker user's signal (Nie *et al.*, 2022; Silva *et al.*, 2023).

In code domain NOMA, users are allocated different signature codes that overlap in the same time and frequency resources. The receiver utilizes advanced multi-user detection techniques to separate and decode the user signals based on their unique code signatures (Jehan and Zeeshan, 2022; Shukla *et al.*, 2021).

The key advantages of NOMA include increased spectral efficiency, improved user capacity, and enhanced system throughput compared to orthogonal multiple access schemes. By enabling simultaneous transmission and reception of multiple user signals, NOMA systems can efficiently utilize available resources and accommodate a larger number of users within the same bandwidth (Darus *et al.*, 2023; Talla *et al.*, 2023).

NOMA has found applications in various wireless communication scenarios, including 5G and beyond, Internet of Things (IoT), and machine-to-machine (M2M) communications. Its ability to provide high spectral efficiency and support massive connectivity makes it a compelling choice for future wireless networks (Al-Dulaimi *et al.*, 2023).

However, the implementation of NOMA systems is not without challenges. Imperfect SIC, which can arise due to channel estimation errors, non-ideal interference cancellation, and hardware impairments, poses a significant hurdle. Imperfect SIC can degrade system performance, reduce user capacity, and introduce interference that affects the quality of user signals (Torres *et al.*, 2023).

Addressing the challenges of imperfect SIC and optimizing the performance of NOMA systems are crucial research areas. By developing techniques to mitigate the effects of imperfect SIC, this study aims to enhance the capacity, reliability, and overall performance of NOMA systems, paving the way for widespread deployment in future wireless communication networks.

Concept of Successive Interference Cancellation

Successive interference cancellation is a technique used in non-orthogonal multiple access systems to cancel the interference caused by the signals of other users. It works by iteratively canceling the interference from the strongest user to the weakest user until all users in the same power domain are decoded without any error. SIC is a key component of NOMA systems and plays a vital role in achieving high system performance (Campello *et al.*, 2022; Ghazi and Wesolowski, 2019).

In NOMA systems, multiple users share the same radio frequency resource. Each user modulates its signal using a unique power domain, and the system uses powerful signal processing techniques, such as OFDM, CDMA, and SDMA, for multiplexing users within the same power domain. However, the self- and inter-user interference is still a major challenge in NOMA systems, which can affect the performance of the system. This is where SIC comes into play.

SIC uses an iterative process to cancel the interference caused by the signals of other users in the same power domain. In each iteration, the signal of the strongest user is decoded, and its interference is then cancelled from the signals of the weaker users. This process is repeated until all users in the same power domain are decoded (Azam and Shin, 2023).

To effectively cancel the interference, SIC techniques require accurate channel state information at the receiver, which can be challenging in practical environments. In addition, the performance of SIC can be adversely affected by the presence of channel fading, noise, and other practical constraints. Therefore, effective algorithms that can mitigate the effects of imperfect SIC on the performance of NOMA systems are essential for the future of wireless communication. This study aims to address this issue by proposing an algorithm that can effectively mitigate the effects of imperfect SIC on NOMA systems.

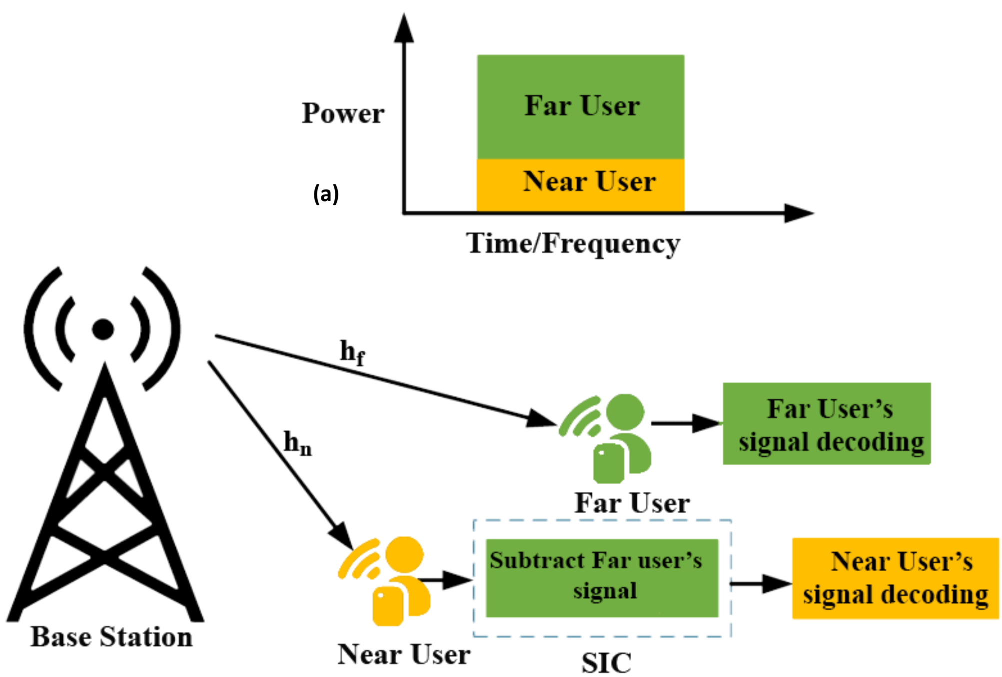


Figure 1: (a) Superposition Coding (SC) technique
(b) NOMA downlink transmission (Chikezie *et al.*, 2022)

Signal detection for NOMA users

Signal detection for each user in NOMA involves various approaches to extract the individual user signals from the received NOMA signal at their respective terminals. To detect the signal of the furthest user (U_f) from the base station (BS), the receiver will treat signals from other users as additive noise due to their low Power Allocation Factor (PAF). On the other hand, for users with low PAFs, like the near user (U_n), successive interference cancellation is necessary. This involves detecting the signal of the user of higher order ($U_n + 1$) with a higher PAF and then subtracting it from the entire received NOMA signal. To remove channel effects, equalization using techniques like zero-forcing (ZF) or minimum mean squared error (MMSE) is employed. After equalization, detection mechanisms such as minimum Euclidean distance or log-likelihood detection can be used to detect the equalized signals (McWade *et al.*, 2023).

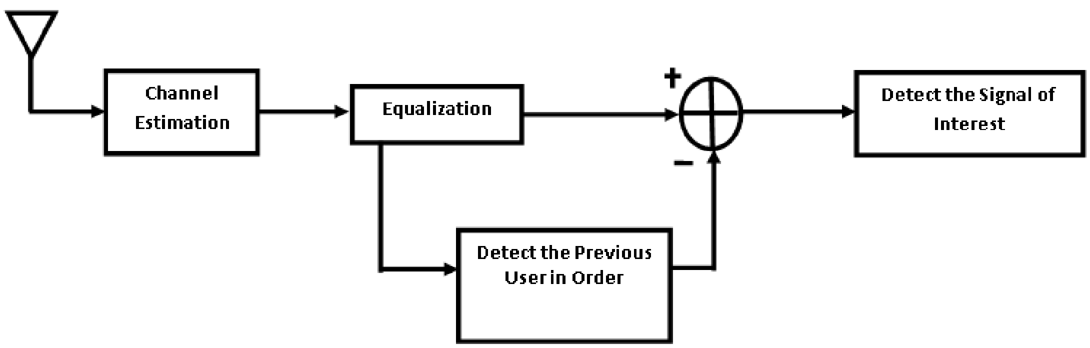


Figure 2: Block Diagram of SIC after applying equalization (David *et al.*, 2023)

Effect of Imperfect Successive Interference Cancellation (SIC)

Improper or imperfect successive interference cancellation can have a significant impact on the overall performance of non-orthogonal multiple access systems, leading to a decrease in system capacity and an increase in bit error rate (BER). Imperfect SIC can be caused by a variety of factors, including noise, channel fading, and inter- and self-user interference. These factors can lead to errors in the cancellation process, and the performance of the system is adversely affected (Kazachkov and Soldatenkova, 2021).

In NOMA systems, the goal is to decode all users in the same power domain simultaneously. However, the presence of noise, channel fading, and inter- and self-user interference can cause the system performance to degrade. With imperfect SIC, the interference from the signal of one user is not fully cancelled from the signals of the weaker users, and the performance of these users is adversely affected. This is because the cancellation process is not perfect, and errors can occur in the cancellation process.

An imperfect SIC can result in a decrease in the capacity of the system, and the system's ability to support a large number of users is adversely affected. The presence of imperfect SIC can cause the bit error rate of the system to increase, leading to a higher number of information packet transmissions and retries, thereby increasing the latency and energy consumption of the system (Fakhrildin *et al.*, 2021).

For NOMA systems to achieve high performance, it is essential to address the issue of imperfect SIC and to develop algorithms that can effectively cancel interference in NOMA systems and mitigate the effects of imperfect SIC. In this paper, we propose an algorithm that can overcome the limitations of existing approaches and effectively mitigate the effects of imperfect SIC on the performance of NOMA systems.

NOMA Capacity

The following are the achievable rate formulae for NOMA (Chikezie *et al.*, 2022):

$$\mathrm{R_f} = \log_2\left(1 + \frac{|\mathrm{h_f}|^2 \mathrm{P}\alpha_\mathrm{f}}{|\mathrm{h_f}|^2 \mathrm{P}\alpha_\mathrm{n} + \sigma^2}\right) \tag{1}$$

$$\mathrm{R_n} = \log_2\left(1 + \frac{|\mathrm{h_n}|^2 \mathrm{P}\alpha_\mathrm{n}}{\sigma^2}\right) \tag{2}$$

$\mathrm{R_n}$ is derived once the far user has implemented SIC.

where,

α_n is the near user's coefficient for power allocation
α_f is the far user's coefficient for power allocation
h_n is the near user's coefficient for channel gain
h_f is the far user's coefficient for channel gain
P is the total transmit power
σ^2 is the Noise Power

The fundamentals of a NOMA technique

The core principles of NOMA involve superposition coding at the transmitter and successive interference cancellation at the receiver (Azam and Shin, 2023; Hamza

et al., 2022). In wireless channels, fading and multipath propagation can occur, and different channel models, such as the Rayleigh fading model, are used to capture these effects. Rayleigh fading is characterized by small-scale fading due to reflection, scattering, diffraction, and shadowing, resulting in varying attenuation and phase shift for each transmitted bit.
In NOMA, the far user is granted additional transmission power, it treats the messages of other users as noise to decode its own message (Ding *et al.*, 2017). Conversely, the near user first identifies its message partner under a stronger channel state, subtracts the far user's message, and then decodes its own message. This process is known as successive interference cancellation.

Imperfect SIC (Successive Interference Cancellation)

Imperfect SIC refers to the degradation in performance that can occur in NOMA systems when attempting to cancel interfering signals from the received signal. In NOMA, multiple users share the same time-frequency resource, and the signals are separated at the receiver using SIC. However, due to various factors such as channel estimation errors, noise, and interference from other users, the SIC process may not be perfect, leading to residual interference that can adversely affect system capacity and performance. Mitigating the effects of imperfect SIC is crucial for enhancing the spectral efficiency and throughput of NOMA systems.
An SIC is considered perfect when the near user accurately estimates the data of the far user by directly decoding it from y_n. The near user correctly multiplies the estimate of the far user's data with $\sqrt{\alpha_n}$ and subsequently subtracts this result from y_n.
Ideally, in a perfect SIC scenario, y_n would be transformed as follows:

$$y_n = h_n P\sqrt{\alpha_f x_f} + h_n P\sqrt{\alpha_n x_n} + w_n - h_n P\sqrt{\alpha_f x_f} \quad (3)$$

$$= h_n P\sqrt{\alpha_n x_n} + w_n \quad (4)$$

after SIC.
If anything goes wrong, then SIC would be imperfect. By imperfect SIC, it means that a residue of x_f component is still present in y_n after SIC. That is, after imperfect SIC, y_n becomes

$$y_n^{-} = \sqrt{\in}\ h_n P \sqrt{\alpha_f x_f} + h_n P \sqrt{\alpha_n x_n} + w_n \quad (5)$$

Residual term

where $\in$ represents the fraction of the remaining residue of the x_f component resulting from the error in SIC.

The impact of imperfect SIC on achievable data

The near user's achievable rate for decoding the far user's data is given as:

$$R_{f,n} = \log_2\left(1 + \frac{|\mathrm{h_f}|^2 \mathrm{P}\alpha_\mathrm{f}}{|\mathrm{h_f}|^2 \mathrm{P}\alpha_\mathrm{n} + \sigma^2}\right) \quad (6)$$

After applying SIC, the interference term x_f is completely eliminated, and the resulting achievable capacity for the near user to decode its own data is:

$$\mathrm{R_n} = \log_2\left(1 + \frac{|\mathrm{h_n}|^2 \mathrm{P}\alpha_\mathrm{n}}{\sigma^2}\right) \quad (7)$$

However, imperfect SIC leaves a residue of the far user's power, causing interference in the denominator, leading to a reduced achievable rate:

$$R_n^{-} = \log_2\left(1 + \frac{|\mathrm{h_n}|^2 \mathrm{P}\alpha_\mathrm{n}}{\in |\mathrm{h_n}|^2 \mathrm{P}\alpha_\mathrm{f} + \sigma^2}\right) \quad (8)$$

where $\in$ represents the fraction of the residue of x_f component due to SIC error. We observe that $R_n^{-} < \mathrm{R_n}$, indicating that imperfect SIC negatively impacts the data rate of the near user, who is performing SIC.

Note that $R_n^{-} = \mathrm{R_n}$ when $\in = 0$, which indicates perfect SIC.

NOMA Encoding and Transmission

The NOMA signal transmitted by the Base Station (BS) using superposition coding is represented as:

$$x = \sqrt{P}\left(\sqrt{\alpha_f\, x_f} + \sqrt{\alpha_n\, x_n}\right) \quad (9)$$

where P is the transmit power.

The received signal at the near user after propagating through channel h_f is given by:

$$y_f = h_f x + w_f \tag{10}$$

Likewise, the received signal at the far user after propagating through channel h_n is given by:

$$y_n = h_n x + w_n \tag{11}$$

NOMA Decoding at the Far User

Expanding the signal received by the far user, we have:

$$y_f = h_f x + w_f \tag{12}$$

$$= h_f \sqrt{P} \left(\sqrt{\alpha_f x_f} + \sqrt{\alpha_n x_n} \right) + w_f \tag{13}$$

$$= h_f \sqrt{P} \left(\sqrt{\alpha_f x_f} + h_f \sqrt{P} \sqrt{\alpha_n x_n} \right) + w_f \tag{14}$$

where:

$h_f \sqrt{P} \sqrt{\alpha_f x_f}$ is the desired and dominating signal,

$h_f \sqrt{P} \sqrt{\alpha_n x_n}$ is the interference and low power signal,

w_f is noise.

Direct decoding of y_f would yield x_f since $\alpha_f > \alpha_n$. The term x_n component was considered as an interference. For the far user, the signal-to-interference plus noise ratio is given as follows:

$$\gamma_f = \frac{|h_f|^2 P \alpha_f}{|h_f|^2 P \alpha_n + \sigma^2} \tag{15}$$

and its achievable data rate is given as follows:

$$R_f = log_2 \left(1 + \gamma_f \right) = log_2 \left(1 + \frac{|h_f|^2 P \alpha_f}{|h_f|^2 P \alpha_n + \sigma^2} \right) \tag{16}$$

NOMA Decoding at the Near User

Expanding the signal received by the near user:

$$y_n = h_n x + w_n \tag{17}$$

$$= h_n \sqrt{P} \left(\sqrt{\alpha_f x_f} + \sqrt{\alpha_n x_n} \right) + w_n \tag{18}$$

$$= h_n \sqrt{P} \left(\sqrt{\alpha_f x_f} + h_n \sqrt{P} \sqrt{\alpha_n x_n} \right) + w_n \tag{19}$$

where:

$h_n \sqrt{P} \sqrt{\alpha_f x_f}$ is the interference and dominating signal,

$h_n \sqrt{P} \sqrt{\alpha_n x_n}$ is the interference and low power signal,

w_n is noise.

Prior to decoding its own signal, the near user is required to carry out successive interference cancellation (SIC). The steps involved in SIC are as follows:

The near user performs direct decoding of y_n to obtain x_f, or more precisely, an estimate of x_f, denoted as $\bar{x}$.

$y_n^{-} = y_n - \sqrt{\alpha_f \bar{x}_f}$ is computed

y_n^{-} is decoded to obtain an estimate of x_n

Before SIC, the signal-to-interference noise ratio at the near user for decoding the signal of the far user is given as;

$$\gamma_{f,n} = \frac{|h_n|^2 P \alpha_f}{|h_n|^2 P \alpha_n + \sigma^2} \tag{20}$$

The corresponding achievable data rate is given as follows:

$$R_{f,n} = log_2 \left(1 + \gamma_{f,n} \right) = log_2 \left(1 + \frac{|h_n|^2 P \alpha_f}{|h_n|^2 P \alpha_n + \sigma^2} \right) \tag{21}$$

Complexity of SIC for Near Users

When implementing superposition coding at the transmitter side in NOMA, users are arranged based on their channel conditions, with the weakest user receiving the most power. This power allocation ensures that the strongest users' data dominates the received signal, while other users' data is treated as interference. At the receiver side, each user must perform SIC to cancel interference from other users' data before decoding their own signal.

For instance, the weakest user (U_1) performs direct decoding since it has the most dominant data. However, the second-strongest user (U_2) needs to perform SIC to remove U_1's data before decoding its own. The process continues for the subsequent users. The strongest user (U_k) has to perform SIC K-1 times to eliminate data from all other users before its own data becomes dominant. This complexity grows significantly as the number of users increases.
The computational complexity and processing delay become considerable when multiplexing a large number of users on the same carrier. SIC error propagation occurs when decoding errors happen. If one user decodes data in error, subsequent users' decoding processes will be affected, leading to a chain of decoding errors.

The issue of interference affecting Far Users.
Assuming we have K users, with U_k as the weakest user and U_n as the strongest user. While U_n faces challenges with complex and time-consuming signal processing, U_k encounters a different problem. U_k performs direct decoding while treating all other users' data as interference. Consequently, the achievable rate equation for U_k will include K-1 interference terms, resulting in a more complicated expression as follows:

$$R_f = log_2\left(1 + \frac{\alpha_f\, P|h_f|^2}{(\alpha_2\ +\ \alpha_3 + .\ .\ .\ .\alpha_k\,)P|h_f|^2 +\ \sigma^2}\right) \tag{22}$$

Similarly, the achievable data rate equation for the Strong User will be:

$$R_n = log_2\left(1 + \frac{\alpha_n\, P|h_n|^2}{(\alpha_3\ +\ \alpha_4 + .\ .\ .\ .\alpha_k\,)P|h_n|^2 +\ \sigma^2}\right) \tag{23}$$

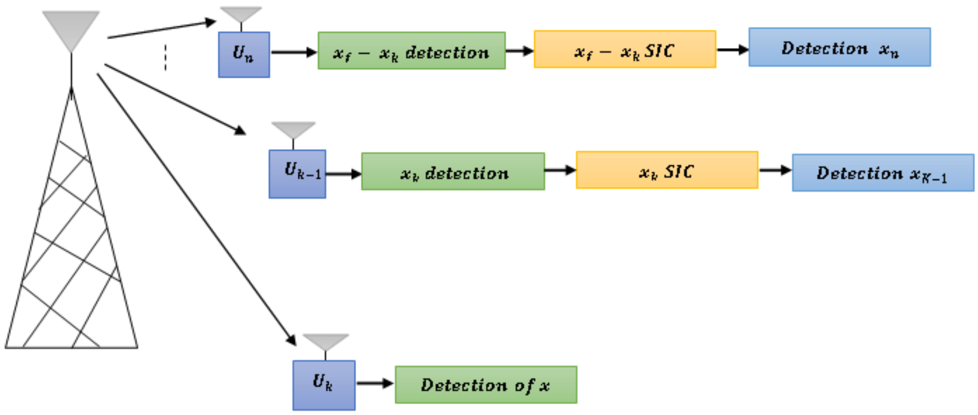


Figure 3: Downlink NOMA for multi-user scenario with varying channel conditions.

System Model and Notation

The study proposed a downlink NOMA system comprising the far and near users. At the base station (BS), there are two distinct messages to be transmitted, one intended for the far user (U_f) referred to as the weak user, and the other for the near user (U_n) known as the strong user. The received signals at the near user (U_n) and far user (U_f) can be represented as follows:

$$y_f = h_f x + w_f$$
$$= h_f\left[P\left(\sqrt{\alpha_f x_f} + \sqrt{\alpha_n x_n}\right)\right] + y_f \quad (24)$$
$$y_n = h_n x + w_n$$
$$= h_n\left[P\left(\sqrt{\alpha_f x_f} + \sqrt{\alpha_n x_n}\right)\right] + y_n \quad (25)$$

where,

$$x$$
$$= P\left(\sqrt{\alpha_f x_f} + \sqrt{\alpha_n x_n}\right) \quad (26)$$

Notations:

x_i : data intended for the i^{th} user

α_i : fraction of power allocated for the i^{th} user

h_i : Rayleigh fading coefficient from BS to the i^{th} user

According to the principles of NOMA, $\alpha_f > \alpha_n$. Thus, the far user (U_f) can directly decode its data, while the near user (U_n) needs to perform Successive Interference Cancellation (SIC) to retrieve its data (Jain *et al.*, 2020).

Time Division Multiple Access (TDMA) and NOMA Integration Technique

Time Division Multiple Access (TDMA) and NOMA Integration Technique combines the benefits of NOMA and orthogonal access methods. This technique strikes a balance between NOMA and OMA, leveraging their respective advantages to optimize the system's performance and accommodate diverse user requirements. The study examined the integration of Time Division Multiple Access (TDMA) and NOMA, as illustrated in Fig. 3.1. In this scenario, a time slot with a duration of 4 ms is needed to accommodate 4 users. With TDMA, the 4 ms slot will be divided into four 1 ms slots, and each user will be allocated one of these slots. With NOMA, the entire 4 ms slot will be assigned to all four users. However, this pproach will increase the complexity of SIC and will introduce processing delays. The proposed TDMA-NOMA takes a different approach by splitting the 4 ms slot into 2 ms slots and assigning two NOMA users to each of these slots.
The study further evaluated the sum-rate comparison between the integrated NOMA and TDMA

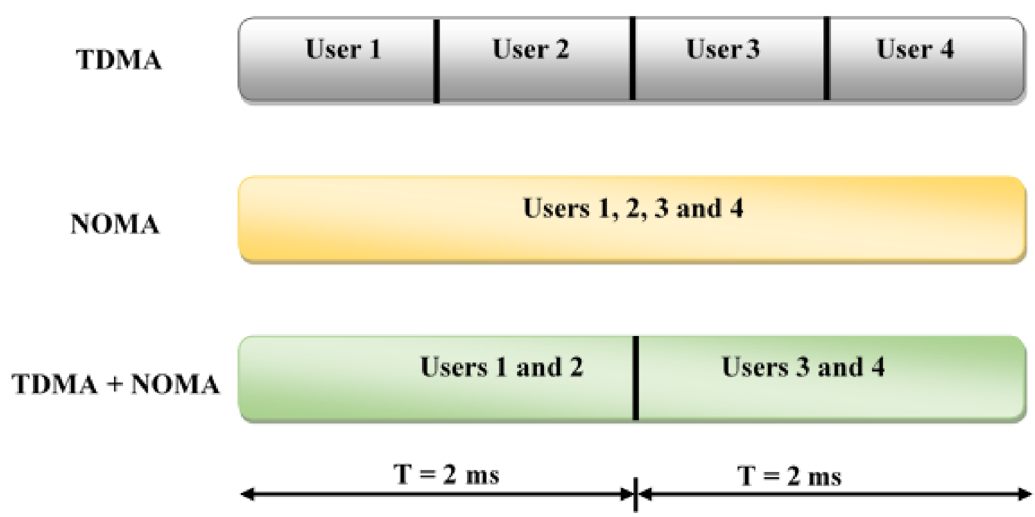


Figure 4: Allocation of Users in various Multiple Access Schemes

TDMA-NOMA Pairing Technique addresses the challenges posed by imperfect SIC in NOMA systems. In NOMA, multiple users share the same frequency resources by superposing their signals with different power levels to achieve spectral efficiency gains. SIC is used at the receiver to decode the signals from different users, allowing simultaneous transmission and reception.
However, imperfect SIC can lead to decoding errors, especially when the signals from different users significantly overlap. This can result in degraded system performance, increased error rates, and reduced sum rates.

The proposed TDMA-NOMA pairing technique addresses the challenges of imperfect SIC in NOMA systems. It intelligently combines users based on their channel conditions and interference levels to optimize resource allocation. This approach improves error performance, enhances spectral efficiency, and makes the system more robust to imperfect SIC. The proposed technique offers flexible adaptation, leading to better overall system performance in future wireless communication systems.

This study will model a four scenario. $U_1, U_{2,}$ U_3 and U_4 will be denoted as the users and $d_1, d_{2,}$ d_3 and d_4 will be denoted as the users distances from the base station between respectively. The users are located at different distances from the base station, with U_1 being the nearest and U_4 being the farthest. As a result, their channel conditions are ranked in the following order: $|h_1|^2 > |h_2|^2 > |h_3|^2 > |h_4|^2$. The system has two orthogonal resource blocks (time slots or frequency subcarriers) available, and the objective is to assign two users to each block. The user pairing will be based on their respective distances, and there are two simple methods to achieve this:

i. Near-Far Pairing (N-F)
ii. Near-Near, Far-Far Pairing (N-N, F-F)

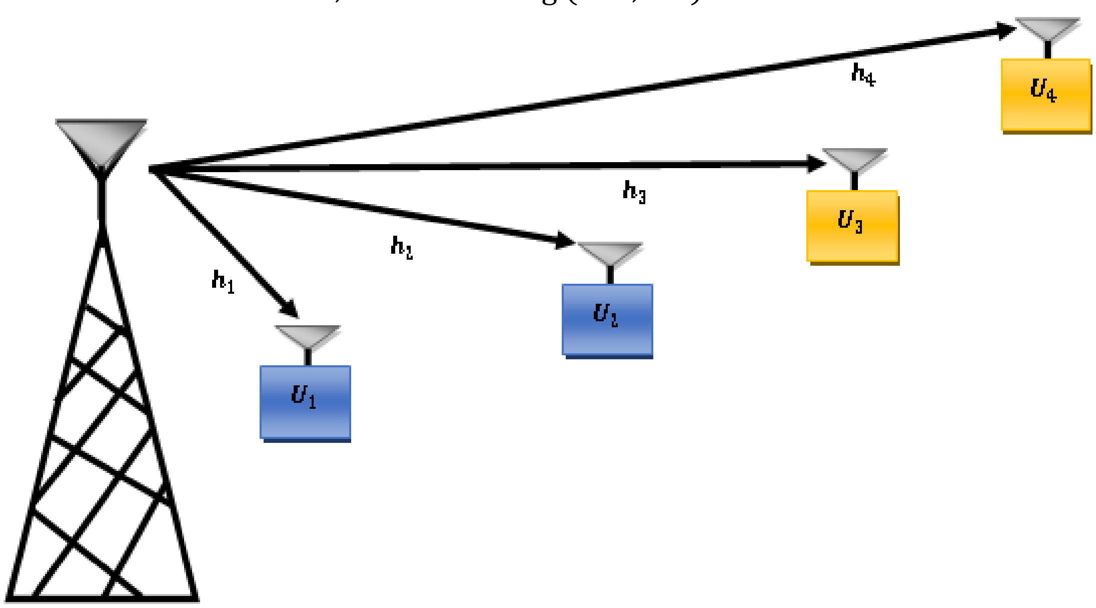


Figure 5: Network Scenario

Near-Far (N-F) Pairing Technique

In this approach, the user pairing is based on the distances from the base station, where the nearest user is paired with the farthest user, and so on. For an example

provided, U_1 (nearest) is paired with U_4 (farthest) in one resource block, and U_2 (next nearest) is paired with U_3 (next farthest) in the next resource block.
In the first pair (U_1 and U_4), with U_1 being the near user and U_4 being the far user, the power allocation coefficients will be chosen as $\alpha_1 < \alpha_4$. Consequently, U_1 will perform successive interference cancellation, while U_4 will undergo direct decoding.
Similarly, in the second pair (U_2 and U_3), with U_2 being the near user and U_3 being the far user, the power allocation coefficients will be chosen as $\alpha_2 < \alpha_3$. In this case, U_2 will perform SIC, and U_3 will use direct decoding.
The achievable rates for the users in the first pair are given as:

$$R_{1,nf} = \frac{1}{2} log_2 \left(1 + \frac{P\alpha_1 |h_1|^2}{\sigma^2}\right) \tag{27}$$

After the application of SIC

$$R_{4,nf} = \frac{1}{2} log_2 \left(1 + \frac{P\alpha_4 |h_4|^2}{P\alpha_1 |h_4|^2 + \sigma^2}\right) \tag{28}$$

Likewise, in the case of the second pair,

$$R_{2,nf} = \frac{1}{2} log_2 \left(1 + \frac{P\alpha_2 |h_2|^2}{\sigma^2}\right) \tag{29}$$

After the application of SIC

$$R_{3,nf} = \frac{1}{2} log_2 \left(1 + \frac{P\alpha_3 |h_3|^2}{P\alpha_2 |h_3|^2 + \sigma^2}\right) \tag{30}$$

The Sum rate achieved by the N-F scheme will be:

$$R_{nf} = R_{1,nf} + R_{2,nf} + R_{3,nf} + R_{4,nf} \tag{31}$$

Near-Near, Far-Far (N-N, F-F) Pairing Technique

An alternative approach for user pairing is to group the nearest user with the next nearest user, and the farthest user with the next farthest user. Following this strategy, in the given example, U_1 will be paired with U_2 in one resource block, and U_3 will be paired with U_4 in the next resource block.
In the first pair of users (U_1 and U_2), U_1 is closer to the base station compared to U_2. Therefore, the power allocation coefficients should be chosen as $\alpha_1 < \alpha_2$.

Consequently, U_1 will perform successive interference cancellation (SIC), while U_2 will employ direct decoding.
Similarly, in the second pair of users (U_3 and U_4), U_3 is closer to the base station than U_4. Thus, we should choose $\alpha_3 < \alpha_4$. In this case, U_3 will perform SIC, while U_4 will undergo direct decoding.
The achievable rates for the users in the first pair are given as:

$$R_{1,nn} = \frac{1}{2} log_2 \left(1 + \frac{P\alpha_1 |h_1|^2}{\sigma^2}\right) \quad (32)$$

After the application of SIC

$$R_{2,nn} = \frac{1}{2} log_2 \left(1 + \frac{P\alpha_2 |h_2|^2}{P\alpha_1 |h_2|^2 + \sigma^2}\right) \quad (33)$$

Likewise, in the case of the second pair,

$$R_{3,ff} = \frac{1}{2} log_2 \left(1 + \frac{P\alpha_3 |h_3|^2}{\sigma^2}\right) \quad (34)$$

After the application of SIC

$$R_{4,ff} = \frac{1}{2} log_2 \left(1 + \frac{P\alpha_4 |h_4|^2}{P\alpha_3 |h_4|^2 + \sigma^2}\right) \quad (35)$$

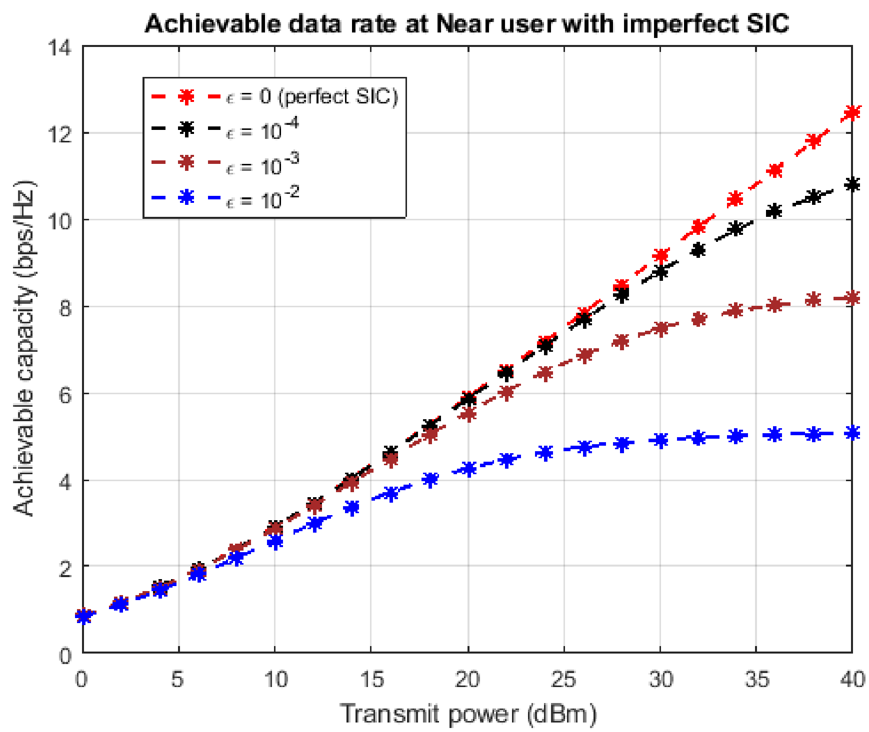
The Sum rate achieved by the N-N, F-F scheme will be:

$$R_{nn,ff} = R_{1,nn} + R_{2,nn} + R_{3,ff} + R_{4,ff} \quad (36)$$

Effect of imperfect SIC at $\in = \mathbf{0}$ (Perfect SIC), $\in = \mathbf{10^{-4}}$, $\in = \mathbf{10^{-3}}$ and $\in = \mathbf{10^{-2}}$

As the error rate increases from $\in = 0$ (Perfect SIC) to $\in = 10^{-4}$, $\in = 10^{-2}$, and $\in = 10^{-2}$ at all Transmit Power levels, the achievable data rates generally decrease. This is expected, as higher error rates lead to more interference and degradation in data transmission, resulting in lower achievable data rates.

As the Transmit Power increases, the achievable data rates also generally increase for all error rates. This is consistent with the fact that higher Transmit Power levels provide stronger signals, allowing for better data transmission and



compensation for interference effects, regardless of the error rate.
Figure 6: Compared Achievable Capacity (bps/Hz) Vs Transmit Power (dBm)

Table 1: Compared Achievable Data Rate Comparison

Achievable Data Rate Comparison at Near User				
Transmit Power (dBm)	$\in = 0$ (Perfect SIC)	$\in = 10^{-4}$	$\in = 10^{-3}$	$\in = 10^{-2}$
0	0.86631	0.86631	0.83991	0.83991
2	1.1654	1.1654	1.1592	1.1191
4	1.5237	1.5237	1.514	1.4452
6	1.9385	1.9385	1.9234	1.8098
8	2.4044	2.4044	2.3808	2.2003
10	2.9142	2.9142	2.8772	2.6014
12	3.4602	3.4602	3.4023	2.9966
14	4.0343	4.0343	3.9446	3.3705
16	4.6294	4.6294	4.4921	3.7108
	5.2652	5.2384	5.032	4.0088

18	5.8972	5.8551	5.5514	4.2609
20	6.5388	6.4729	6.0377	4.4674
22	7.1873	7.0852	6.4804	4.6315
24	7.8407	7.6842	6.8713	4.7586
26	8.4976	8.2615	7.2063	4.8549
28	9.1569	8.8075	7.4847	4.9263
30	9.8178	9.3126	7.7098	4.9784
32	10.4799	9.7684	7.887	5.0159
34	11.1428	10.1683	8.0232	5.0425
36	11.8061	10.5094	8.1257	5.0611
38	12.4698	10.792	8.2014	5.0741
40				

The table shows the impact of different error rates on the achievable data rates at various Transmit Power levels. Lower error rates result in higher achievable data rates, especially at higher Transmit Power levels.

As the error rate increases from $\in = 0$ (Perfect SIC) to $\in = 10^{-4}$, $\in = 10^{-2}$, and $\in = 10^{-2}$ at all Transmit Power levels, the achievable data rates generally decrease. This is expected, as higher error rates lead to more interference and degradation in data transmission, resulting in lower achievable data rates.

As the Transmit Power increases, the achievable data rates also generally increase for all error rates. This is consistent with the fact that higher Transmit Power levels provide stronger signals, allowing for better data transmission and compensation for interference effects, regardless of the error rate.

At each Transmit Power level, the achievable data rate with lower error rates $\in = 0$

$\in = 10^{-4}$, $\in = 10^{-3}$ is higher than the achievable data rate with a higher error rate

$\in = 10^{-2}$. The difference between the data rates becomes more pronounced as the Transmit Power level increases.

At $\in = 0$ (Perfect SIC), the achievable data rates remain the same, as there is no interference due to perfect interference cancellation. As the error rate increases (imperfect SIC), the achievable data rates decrease slightly but the difference is not significant until higher Transmit Power levels.

The average percentage performance across all Transmit Power levels is approximately 0.7743%. This means that, on average, $\in = 10^{-4}$, $\in = 10^{-3}$, and

$\in = 10^{-2}$ underperform $\in = 0$ by approximately 0.7743% in achievable data rate.

Mitigating Imperfect SIC with the TDMA-NOMA Pairing Technique

TDMA-NOMA Pairing Technique addresses the challenges posed by imperfect SIC in NOMA systems. In NOMA, multiple users share the same frequency resources by superposing their signals with different power levels to achieve spectral efficiency gains. SIC is used at the receiver to decode the signals from different users, allowing simultaneous transmission and reception.

However, imperfect SIC can lead to decoding errors, especially when the signals from different users significantly overlap. This can result in degraded system performance, increased error rates, and reduced sum rates.

To mitigate this effects, the study's TDMA-NOMA pairing technique intelligently combines users based on their channel conditions and interference levels to optimize resource allocation. This approach improves error performance, enhances spectral efficiency, and makes the system more robust to imperfect SIC. The TDMA-NOMA pairing technique offers flexible adaptation, leading to better overall system performance in future wireless communication systems.

Sum Rate Comparison of SC-NOMA, TDMA and TDMA-NOMA Pairing Technique

SC-NOMA enables higher spectral efficiency by allowing non-orthogonal signal superposition, while TDMA provides fair access to the channel with simplicity. TDMA-NOMA pairing technique offers a flexible approach, leveraging the strengths of the combination of both NOMA and OMA to optimize system performance in scenarios with varying user conditions.

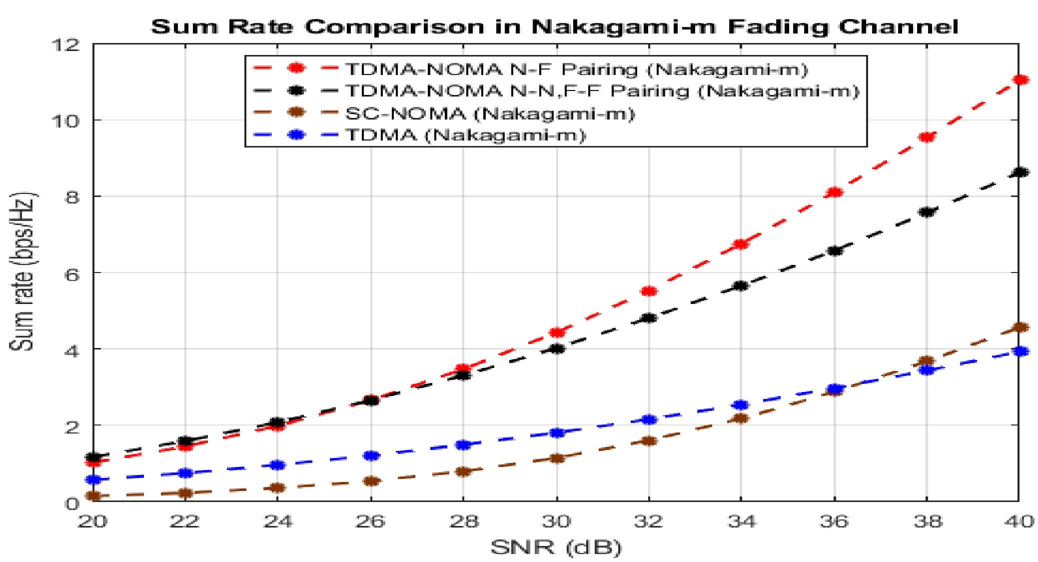


Figure 7: Sum Rate Comparison of SC-NOMA, TDMA and TDMA-NOMA

Table 2: Sum Rate Comparison of SC-NOMA, TDMA and TDMA-NOMA User Pairing in Nakagami Fading Channel

Sum Rate Comparison of SC-NOMA, TDMA and TDMA-NOMA User Pairing in Nakagami Fading Channel				
SNR (dB)	SC-NOMA	TDMA	N-F Pairing	N-N, F-F Pairing
20	0.15252	0.57376	1.0245	1.169
22	0.23563	0.75334	1.4409	1.5806
24	0.35975	0.96612	1.9768	2.0747
26	0.54066	1.2127	2.6479	2.6479
28	0.79651	1.4934	3.455	3.2947
30	1.1457	1.8089	4.4086	4.0104
32	1.6038	2.1599	5.5032	4.7925
34	2.1799	2.5475	6.7294	5.6411
36	2.874	2.9722	8.0705	6.5574
38	3.6757	3.4336	9.5041	7.5424
40	4.5653	3.9304	11.0033	8.5942

At an SNR of 20 dB, TDMA, N-F pairing, and N-N, F-F pairing all perform significantly better than SC-NOMA. At an SNR of 22 dB, TDMA, N-F pairing, and N-N, F-F pairing continue to outperform SC-NOMA. At an SNR of 24 dB, TDMA, N-F pairing, and N-N, F-F pairing continue to show better performance compared to SC-NOMA. At an SNR of 26 dB, TDMA, N-F pairing, and N-N, F-F pairing still exhibit better performance compared to SC-NOMA. At an SNR of 28 dB, TDMA, N-F pairing, and N-N, F-F pairing continue to outperform SC-NOMA. At an SNR of 30 dB, TDMA, N-F pairing, and N-N, F-F pairing continue to demonstrate better performance compared to SC-NOMA. At an SNR of 32 dB, TDMA, N-F pairing, and N-N, F-F pairing maintain their advantage over SC-NOMA. At an SNR of 34 dB, TDMA, N-F pairing, and N-N, F-F pairing still maintain their performance advantage over SC-NOMA. At an SNR of 36 dB, TDMA, N-F pairing, and N-N, F-F pairing still show a performance advantage over SC-NOMA. At an SNR of 38 dB, TDMA's advantage over SC-NOMA slightly diminishes, and it performs around 6.56% worse than SC-NOMA. However, N-F pairing and N-N, F-F pairing still maintain their performance advantage over SC-NOMA. At an SNR of 40 dB, both TDMA and SC-NOMA exhibit similar sum rates, with TDMA performing around 13.92% worse than SC-NOMA. However, N-F pairing and N-N, F-F pairing continue to maintain their performance advantage over SC-NOMA.

The percentage performance difference reveals that the superiority of each user pairing scheme (TDMA, N-F Pairing, and N-N, F-F Pairing) over SC-NOMA varies with different SNR levels. TDMA performs well at lower SNR levels but its advantage diminishes as SNR increases. On the other hand, N-F pairing and N-N, F-F pairing show consistent and significant improvements over SC-NOMA, making them more desirable choices, particularly at higher SNR levels.

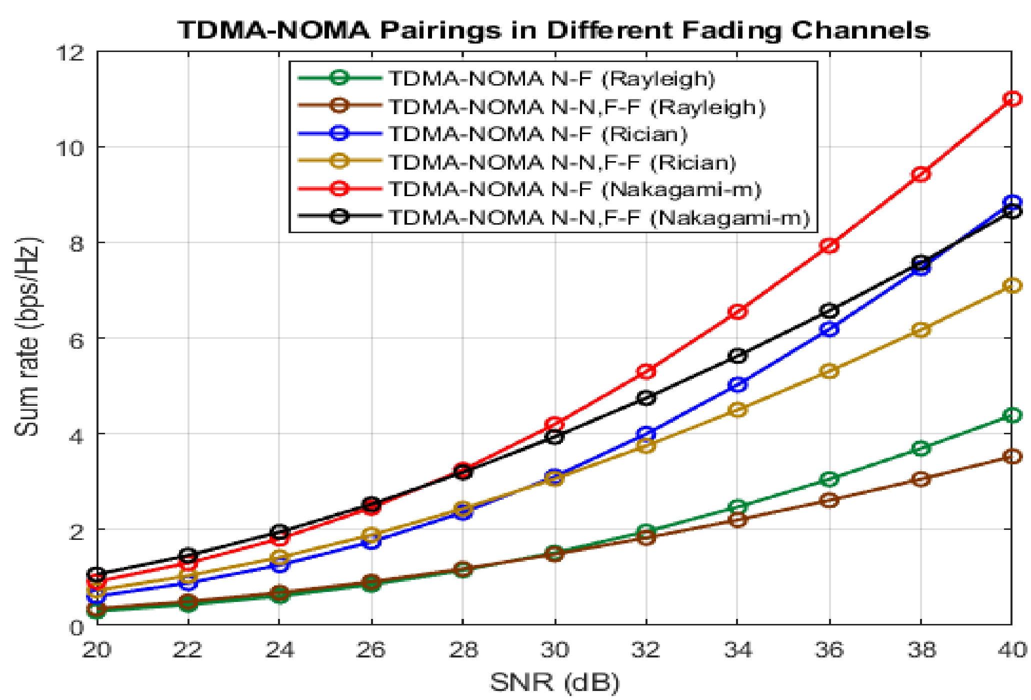
Evaluating TDMA-NOMA pairing technique in Different Fading Channels

Evaluating TDMA-NOMA pairing technique in different fading channels based on sum rate involves analyzing the performance of N-F and N-N, F-F pairings across various fading environments. The sum rate, measured in bits per second per Hz (bps/Hz), is used as the key metric to assess the efficiency of user pairing strategies.

In Nakagami fading, Rician fading, and Rayleigh fading channels, TDMA-NOMA pairing technique was tested and compared at different Signal-to-Noise Ratio (SNR) levels. The sum rate data obtained from simulations analysis provided insights into the pairing strategy's effectiveness under different fading scenarios.

TDMA-NOMA Pairing Technique in Different Fading Channels

The performance of TDMA-NOMA pairing technique varies across different fading channels. Understanding the differences in the performance of the



proposed TDMA-NOMA user pairing will aid in optimizing TDMA-NOMA systems based on the specific channel conditions and SNR requirements. The fading channel characteristics play a significant role in shaping the performance of TDMA-NOMA pairing technique.
Figure 8: TDMA-NOMA pairing technique in Different Fading Channels

Table 3: Sum Rate Comparison of TDMA-NOMA User Pairing in Different Fading Channel

Sum Rate Comparison of TDMA-NOMA User Pairing in Different Fading Channel						
	Nakagami		**Rician**		**Rayleigh**	
SNR (dB)	N-F Pairing	N-N, F-F	N-F	N-N, F-F	N-F	N-N, F-F
20	1.0245	1.169	0.59274	0.70884	0.29683	0.35439
22	1.4409	1.5806	0.86316	1.002	0.43173	0.50033
24	1.9768	2.0747	1.2285	1.3757	0.61377	0.68622
26	2.6479	2.6479	1.7061	1.8329	0.85158	0.91357
28	3.455	3.2947	2.3108	2.3716	1.1525	1.1815
30	4.4086	4.0104	3.0531	2.9867	1.5219	1.4877
32	5.5032	4.7925	3.9388	3.6726	1.9628	1.8293
34	6.7294	5.6411	4.9679	4.4251	2.4752	2.2045
36	8.0705	6.5574	6.1341	5.2432	3.0561	2.6126
38	9.5041	7.5424	7.4243	6.1275	3.6991	3.0541
40	11.0033	8.5942	8.8186	7.0795	4.3945	3.5296

Nakagami Fading Channel
At lower SNR levels (SNR 20 dB to 26 dB), the performance difference between N-F and N-N, F-F pairings isn't much noticeable. At higher SNR levels (SNR 34 dB to 40 dB), the performance difference between the two pairings becomes more significant. N-F pairing continues to improve in data rates, while N-N, F-F pairing struggles to catch up. N-F pairing achieves higher data rates compared to N-N, F-F pairing. This advantage is due to the fact that in N-F pairing, one user is assigned to the non-orthogonal (stronger) resource, resulting in better data rates for that user. Meanwhile, the other user uses the orthogonal (weaker) resource, which still provides acceptable data rates. The benefit of assigning one user to the stronger resource becomes more pronounced at higher SNR levels, leading to larger rate gaps between the pairings.

Rician Fading Channel

The performance difference between N-F and N-N, F-F pairings in the Rician fading channel is relatively subtle compared to Nakagami fading. At lower SNR levels (SNR 20 dB to 28 dB), N-N, F-F pairing either performs slightly better or is on par with N-F pairing.

The Rician fading channel has both line-of-sight and scattered components. This configuration provides a stronger signal component for all users, making the performance difference between N-F and N-N, F-F pairings less pronounced. However, at higher SNR levels (SNR 34 dB to 40 dB), N-F pairing shows improvement and starts to outperform N-N, F-F pairing due to the more dominant interference effects at higher SNR.

Rayleigh Fading Channel

The Rayleigh fading channel, which only has scattered components, exhibits similar behavior to the Rician fading channel in terms of the performance difference between N-F and N-N, F-F pairings. At lower SNR levels (SNR 20 dB to 28 dB), N-N, F-F pairing outperforms N-F pairing. As the SNR increases (SNR 31 dB to 40 dB), N-F pairing performance improves, catching up with N-N, F-F pairing, and even surpassing it at higher SNR levels. In Rayleigh fading, the performance of both pairings converges at higher SNR levels due to the absence of a line-of-sight component and more prominent fading effects affecting all users equally.

Conclusion

Aiming to mitigate the effects of imperfect Successive Interference Cancellation on the performance of Non-Orthogonal Multiple Access in wireless communication systems. This study employed a TDMA-NOMA technique which combines the benefits of NOMA and orthogonal access methods. The study examined the integration of TDMA (Time Division Multiple Access) and NOMA in a downlink communication scenario involving four users in a time slot with a duration of 4 ms. The system comprises of two orthogonal resource blocks (time slots or frequency subcarriers) available, and the objective is to assign two users to each block. The user pairing was based on their respective distances from the base station.

The study observed that the performance of Single Carrier (SC) NOMA is poor when compared to TDMA. This is due to the interference issues caused by overloading all users onto the same carrier. However, the study found that when a near user is paired with a far user, a larger sum rate is achieved. This pairing strategy was further confirmed to be beneficial for NOMA, as it performs better when the channel conditions between the two users are distinct.

Furthermore, the study revealed that when near-near and far-far pairings are used in NOMA, it still achieves higher sum rates than TDMA, although the improvement is not as substantial as in the near-far pairing scenario. This suggests that user pairing has a significant impact on the performance of NOMA, and pairing users with different channel conditions leads to better system performance.

Recommendation

Further studies may explore machine learning-based algorithms to learn and adapt to the characteristics of imperfect SIC. Machine learning can help in making intelligent decisions and improving SIC performance based on historical data and feedback.

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