Simplified Implementation of NOMA in 5G Networks

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Abstract

Non-Orthogonal Multiple Access (NOMA) is a key multiple access technique proposed for fifthgeneration (5G) and beyond wireless networks to improve spectral efficiency and support multiple
users simultaneously. In this paper, a practical uplink power-domain NOMA system is implemented using low-cost Internet of Things (IoT) hardware. Two ESP32 devices are configured as uplink users and transmit data simultaneously to a Raspberry Pi acting as the base station. One ESP32 operates as a strong user with low transmit power, while the other operates as a weak user with higher transmit power. The received signals overlap at the base station, and Successive Interference Cancellation (SIC) is applied to separate the users. Experimental results and simulation-based analysis demonstrate the effectiveness of power-domain NOMA in supporting simultaneous transmissions and improving spectral efficiency compared to orthogonal multiple access techniques.

Keywords— Non-Orthogonal Multiple Access, NOMA, ESP32, Raspberry Pi, Successive Interference Cancellation, IoT, 5G.

I. INTRODUCTION

The evolution of mobile communication systems from first-generation (1G) to fifth-generation (5G) networks has been driven by the continuous demand for higher data rates, lower latency, improved reliability, and support for a massive number of connected devices. Early wireless systems relied on traditional multiple access techniques such as Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), and Code Division Multiple Access

(CDMA) to allow multiple users to share the available spectrum. These techniques ensured user separation by assigning orthogonal resources in frequency, time, or code domains. With the introduction of fourth-generation (4G) networks, Orthogonal Frequency Division Multiple Access (OFDMA) became the dominant multiple access scheme. OFDMA improved spectral efficiency by dividing the available bandwidth into multiple orthogonal subcarriers and allocating them dynamically to users. Although OFDMA significantly enhanced system performance, it still follows the principle of
Orthogonal Multiple Access (OMA), where users are assigned non-overlapping resources to avoid interference.

Despite its advantages, OMA has inherent limitations. Since each user occupies a dedicated resource block, the number of users that can be supported simultaneously is restricted. Moreover, when users experience different channel conditions, strict orthogonality results in inefficient spectrum utilization, as users with poor channel quality require more resources to achieve acceptable performance.

To address these challenges, Non-Orthogonal Multiple Access (NOMA) was introduced as a key enabling technology for 5G and beyond wireless networks. Unlike OMA, NOMA allows multiple users to share the same time–frequency resource block simultaneously. In power-domain NOMA, users are distinguished by allocating different power levels based on their channel conditions. Users with weaker channels are assigned higher transmission power, while users with stronger channels are assigned lower power. This approach improves spectral efficiency, increases system capacity, and enhances user fairness.

At the receiver, Successive Interference Cancellation (SIC) is employed to separate the superposed signals. The receiver first decodes the signal with the highest power, reconstructs it, and subtracts it from the received signal before decoding the remaining signals. The effectiveness of NOMA strongly depends on appropriate power allocation and accurate SIC processing. This paper presents a simplified and practical implementation of an uplink power-domain NOMA system using low-cost Internet of Things (IoT) hardware. Two ESP32 devices are configured as uplink users and transmit data simultaneously to a Raspberry Pi acting as a base station. One ESP32 operates as a strong user with low transmit power, while the other operates as a weak user with higher transmit power. The received signals overlap at the Raspberry Pi, where SIC is applied to separate the users. Unlike purely theoretical or simulation-based studies, this work demonstrates NOMA behavior using real hardware and measured channel conditions. The proposed implementation provides an accessible and low-cost platform for understanding NOMA principles and is well suited for educational and experimental research purposes.

II. SYSTEM ARCHITECTURE

A. Hardware Components

The proposed system consists of the following components:

- Raspberry Pi acting as the base station and receiver
- ESP32 (Strong User)
- ESP32 (Weak User)

B. User Classification

The strong user is placed close to the Raspberry Pi and configured with low transmit power, resulting in a strong channel gain. The weak user is placed farther away or behind obstacles and configured with higher transmit power to compensate for its poorer channel conditions. This setup follows the fundamental principle of power-domain NOMA.

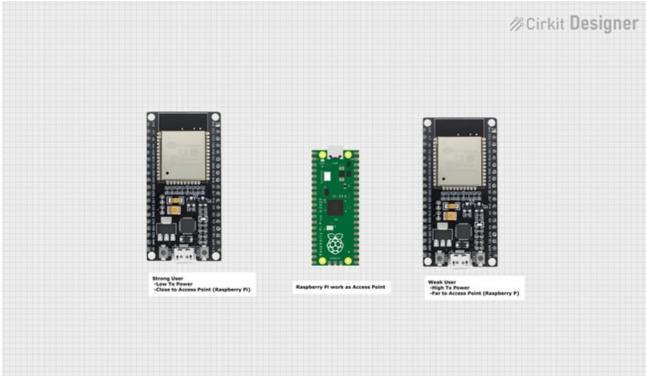


Fig. 1 illustrates the overall architecture of the proposed uplink power-domain NOMA system.

The strong ESP32 user is located close to the Raspberry Pi and transmits with low power, while the weak ESP32 user is located farther away and transmits with higher power. Both users share the same wireless resource, and the Raspberry Pi applies Successive Interference Cancellation to separate the received signals.

III. METHODOLOGY

A. ESP32 CONFIGURATION

BOTH ESP32 DEVICES CONNECT TO THE SAME WIFI NETWORK AND TRANSMIT TCP PACKETS TO THE RASPBERRY PI. TRANSMIT POWER LEVELS ARE CONFIGURED TO CREATE A CLEAR DIFFERENCE BETWEEN THE STRONG AND WEAK USERS. PACKET TRANSMISSION INTERVALS ARE KEPT SIMILAR TO ENSURE SIMULTANEOUS UPLINK ACTIVITY.

B. Receiver Operation

The Raspberry Pi listens on a predefined TCP port and receives packets from both ESP32 devices. Received Signal Strength Indicator (RSSI) values are measured to confirm channel gain differences between users. Packet captures are recorded to verify simultaneous uplink transmissions IV.

IV.SYSTEM MODEL

A. Superposition Coding

Superposition Coding (SC) is a fundamental component of power-domain Non-Orthogonal Multiple Access (NOMA). It enables multiple users to transmit their signals simultaneously over the same time–frequency resource by assigning different power levels to each user. Each user's signal is scaled according to its allocated power and combined over the wireless channel.

For a system with N users, the received signal can be expressed as

$$" y = \underline{\$}\ \%P_{!}\ x_{!} + n$$

$$!\#\$$$

where $x_!$ represents the transmitted signal of user i, $P_!$ denotes the allocated power, and n represents additive noise.

In this work, a two-user uplink NOMA system is considered. The weak user is assigned higher transmit power, while the strong user is assigned lower transmit power. Consequently, the signals transmitted by both ESP32 devices overlap at the Raspberry Pi receiver, forming a superposed signal that is later separated using Successive Interference Cancellation (SIC).

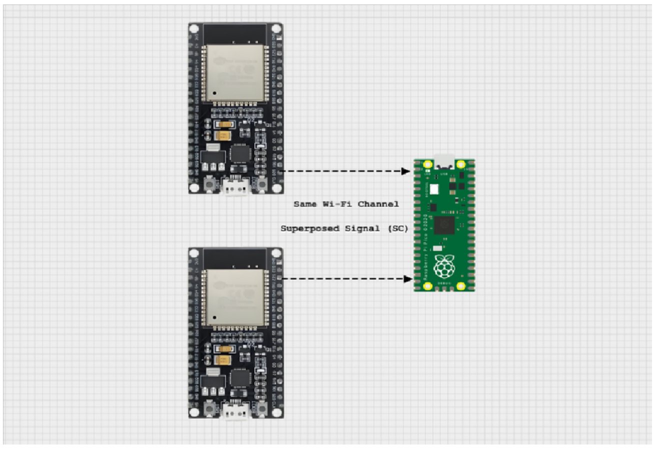


Fig. 2. Superposition coding principle in the proposed uplink NOMA system, where strong and weak user signals are combined over the same wireless channel.

Superposition Coding enables simultaneous transmission of multiple users, while Successive Interference Cancellation is applied at the receiver to separate the superposed signals.

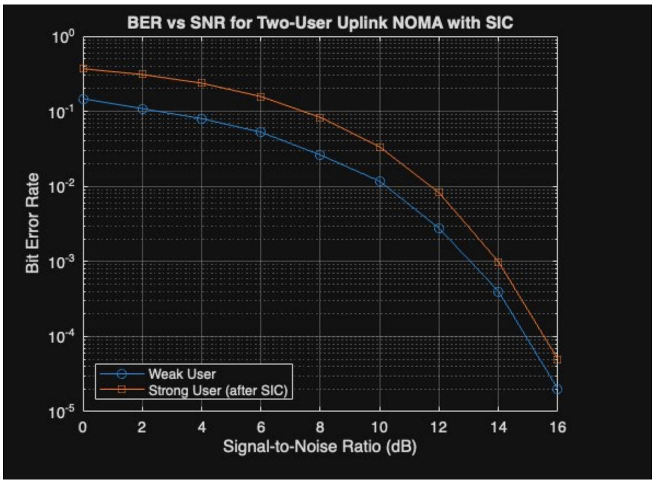


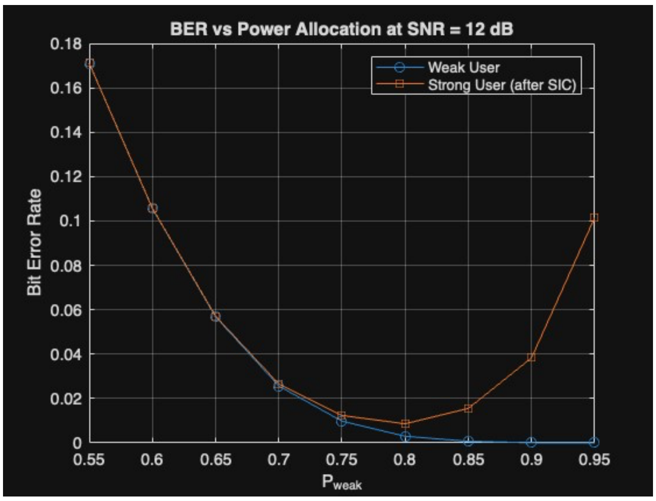
Fig. 3. *BER versus SNR for the proposed two-user uplink NOMA system using SIC, showing weakuser detection followed by strong-user decoding after interference cancellation.*

B. Power Allocation Strategy

This work adopts a Fixed Power Allocation (FPA) strategy due to its simplicity and suitability for practical implementation. A two-user scenario is considered with the following power allocation:

- Weak user: $P_{\text{weak}} = 0.8$
- Strong user: $P_{\text{strong}} = 0.2$

This allocation ensures that the weak user receives sufficient power to compensate for poorer channel conditions, enabling reliable decoding and effective SIC processing at the receiver.



Fif.4 *BER performance versus power allocation for the proposed two-user uplink NOMA system at a fixed SNR, showing the impact of* P_{weak} *on weak- and strong-user detection with SIC.*

V. RELATED WORK

Non-Orthogonal Multiple Access (NOMA) has attracted significant research attention as a promising multiple access technique for 5G and beyond wireless networks. Islam *et al.* [1] provided a comprehensive survey of powerdomain NOMA, discussing its fundamental principles, key advantages, and practical challenges. Their study highlighted the critical role of power allocation strategies and the importance of reliable Successive Interference Cancellation (SIC) for achieving acceptable system performance.

Ding *et al.* [3] investigated the integration of NOMA into modern wireless communication systems and demonstrated its performance gains in terms of spectral efficiency and user fairness, particularly in heterogeneous channel environments. Their results showed that NOMA can significantly outperform conventional Orthogonal Multiple Access (OMA) schemes when users experience different channel conditions.

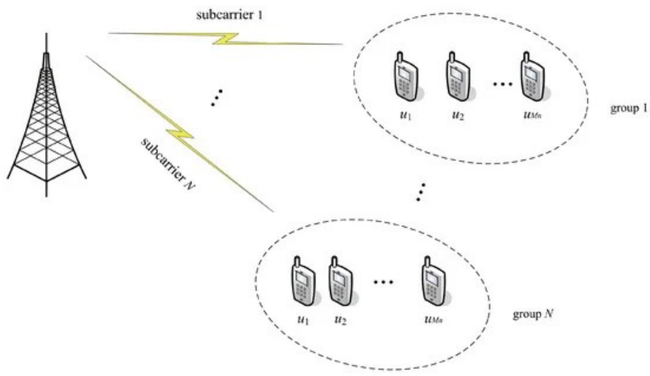
Atrouche *et al.* [2] compared fairness-based power allocation methods with Fixed Power Allocation (FPA) and concluded that FPA provides a suitable low-complexity baseline for simplified and educational NOMA implementations. Their findings support the use of FPA in prototype systems, where implementation simplicity and clarity are prioritized over optimization complexity.

Overall, existing literature consistently indicates that NOMA offers clear advantages over OMA in dense and high-demand scenarios. However, many studies rely primarily on analytical models or simulations. In contrast, the present work focuses on a practical and low-cost hardwarebased implementation, providing experimental insights into power-domain NOMA and SIC behavior using real devices.

$$y = \overline{\%P_{\%\&'(}}\, x_{\%\&'(} + \overline{1P_{)*+,-.}}\, x_{)*+,-.} + n$$

WHERE x_{WEAK} AND x_{STRONG} REPRESENT THE TRANSMITTED SIGNALS OF THE WEAK AND STRONG ESP32 USERS, RESPECTIVELY, P_{WEAK} AND P_{STRONG} DENOTE THEIR ALLOCATED TRANSMIT POWERS,

AND n REPRESENTS ADDITIVE



VI. SUCCESSIVE INTERFERENCE CANCELLATION

Successive Interference Cancellation (SIC) is applied at the receiver to separate the superposed signals in the proposed uplink power-domain NOMA system. Since multiple users transmit simultaneously over the same wireless resource, the received signal at the Raspberry Pi is a combination of both users' signals with different power levels.

In the SIC process, the signal with the highest received power is decoded first. In this work, the weak user is allocated higher transmit power; therefore, its signal is decoded before the strong user's signal. After successful decoding, the weak user's signal is reconstructed and subtracted from the received composite signal. This subtraction reduces the interference experienced by the remaining signal.

Once the high-power signal is removed, the receiver decodes the low-power signal corresponding to the strong user. This step-wise decoding process allows reliable detection of both users' signals despite their simultaneous transmission over the same channel. The effectiveness of SIC depends on the power difference between users and the accuracy of the initial decoding stage.

To further evaluate the performance of SIC, a Python-based simulation is conducted. The simulation analyzes the Bit Error Rate (BER) performance of both users under different noise levels and power allocation settings. The results demonstrate that higher power allocation improves the decoding reliability of the weak user, while the strong user benefits from reduced interference after SIC processing.

VII. RESULTS AND DISCUSSION

The experimental results obtained from the implemented uplink NOMA system demonstrate clear and consistent performance differences between the strong and weak users. Measurements collected at the Raspberry Pi receiver show a noticeable separation in Received Signal Strength Indicator (RSSI) values between the two ESP32 devices. The strong user, which is located closer to the base station and configured with low transmit power, exhibits higher RSSI values, while the weak user, positioned farther away and transmitting with higher power, exhibits lower RSSI values. This RSSI separation confirms correct user classification and validates the applied power-domain NOMA configuration.

Simultaneous packet reception from both ESP32 users was successfully observed at the Raspberry Pi. Since both users transmit over the same wireless channel and during overlapping time intervals, this behavior confirms uplink NOMA operation rather than orthogonal access. The ability of the Raspberry Pi to receive packets from both users without resource separation demonstrates the effectiveness of non-orthogonal transmission in practical scenarios.

In addition to experimental observations, a Python-based simulation was used to evaluate the Bit Error Rate (BER) performance under different noise and power allocation conditions. Simulation results show that the weak user achieves a lower BER due to its higher allocated power, which improves its robustness against noise and channel impairments. After decoding and subtracting the weak user's signal, the strong user benefits from Successive Interference Cancellation (SIC), resulting in improved detection performance despite its lower transmit power.

Overall, the combined experimental and simulation results confirm that power-domain NOMA can effectively support multiple simultaneous users while maintaining acceptable performance. The results highlight the importance of proper power allocation and accurate SIC processing, and they demonstrate that NOMA principles can be successfully implemented and evaluated using low-cost hardware platforms.

Limitations:
Although the proposed implementation successfully demonstrates uplink power-domain NOMA, it is subject to several limitations. The system considers only two users and fixed power allocation, and it does not account for user mobility or fast channel variations. In addition, Wi-Fi-based transmission is used instead of a cellular physical layer, which limits direct comparison with real 5G systems. Nevertheless, the setup effectively captures the fundamental behavior of NOMA and SIC in a simplified and practical manner.

Comparison with OMA:
In traditional OMA systems, users are assigned separate time or frequency resources, which prevents simultaneous transmission. In contrast, the proposed NOMA system allows both users to transmit at the same time over the same wireless channel. Although a direct experimental comparison with OMA is not performed, the observed simultaneous packet reception highlights the potential spectral efficiency advantage of NOMA over OMA.

TABLE I. EXPERIMENTAL PARAMETERS OF THE PROPOSED NOMA SYSTEM

Parameter	*Strong User (ESP32)*	*Weak User (ESP32)*
Device	ESP32	ESP32
Distance from Base Station	Near (≈ 1–2 m)	Far (≈ 8–15 m)
Transmit Power	Low (2 dBm)	High (19.5 dBm)
RSSI at Raspberry Pi	−45 to −55 dBm	−65 to −80 dBm
Transmission Type	TCP Uplink	TCP Uplink
Access Scheme	PowerDomain NOMA	PowerDomain NOMA

VIII. CONCLUSION

This paper presented a simplified and practical implementation of an uplink power-domain NonOrthogonal Multiple Access (NOMA) system using low-cost ESP32 devices and a Raspberry Pi. The proposed setup demonstrated how multiple users can transmit simultaneously over the same wireless resource by exploiting power differences, which is the fundamental concept of powerdomain NOMA. By configuring one ESP32 as a strong user with low transmit power and the other as a weak user with higher transmit power, realistic NOMA channel conditions were created and experimentally verified.

The Raspberry Pi successfully received the superposed signals and applied Successive Interference Cancellation (SIC) to separate the users. Experimental observations, including RSSI measurements and simultaneous packet reception, confirmed correct user classification and effective uplink NOMA operation. In addition, a Pythonbased simulation was used to analyze the Bit Error Rate (BER) performance, further validating the effectiveness of SIC under different noise and power allocation conditions.

The results indicate that power-domain NOMA can improve spectral efficiency and support multiple users compared to traditional orthogonal multiple access schemes, even when implemented using simple and low-cost hardware. The proposed implementation provides an accessible platform for understanding and experimenting with NOMA concepts, making it well suited for educational laboratories and introductory research.

The proposed system also serves as an effective educational platform for understanding NOMA concepts. By using low-cost and widely available hardware, students can observe signal superposition, power-domain multiplexing, and SIC behavior in a real environment, bridging the gap between theory and practice.

Future work may extend this system by considering dynamic power allocation, increasing the number of users, and evaluating performance under mobility and varying channel conditions. Integration with advanced wireless architectures, such as software-defined networking or 5G testbeds, may also be explored to further enhance the applicability of the proposed approach.

TABLE II. POSSIBLE EXTENSIONS OF THE PROPOSED SYSTEM

Extension	*Description*
Dynamic Power Allocation	Adjust power levels based on RSSI or channel conditions
Multiple Users	Extend system to three or more ESP32 devices
Mobility	Evaluate performance with moving users
Different PHY	Replace Wi-Fi with SDR-based transmission
Access Scheme	Power-Domain NOMA

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