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Enhancing 6G Communication with Full Duplex and Duplexing Aware Cellular Access

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Abstract

With the need for fast and dependable wireless communication increasing, 6G networks are anticipated to transform connectivity through ultra-low latency, enhanced data rates, and better spectral efficiency. A major development in 6G is the incorporation of Full Duplex (FD) communication, enabling devices to send and receive data at the same time, which effectively doubles spectral efficiency. The implementation of a Massive MIMO-based 6G communication system with Full Duplex (FD) and Duplexing Aware Cellular Access (DACA) aims to enhance spectral efficiency and network capacity while addressing self-interference challenges. The project is executed in two phases: first, implementing FD with and without Self Interference Cancellation (SIC) and Reconfigurable Intelligent Surfaces (RIS); second, integrating DACA with SIC and RIS for improved resource allocation and interference management. SIC techniques, including digital and analog cancellation, are employed to enhance system performance. Key metrics such as Signal-to-Noise Ratio (SNR), Bit Error Rate (BER), Mean Square Error (MSE), and data rates are analyzed using MATLAB to compare FD with SIC and RIS against DACA with SIC and RIS. The results demonstrate that the DACA-based system offers superior efficiency, lower latency, and better resource utilization, making it a strong candidate for next-generation 6G networks.

Keywords: Duplexing Aware Cellular Access (DACA), Self- Interference Cancellation (SIC), Reconfigurable Intelligent Surfaces (RIS), Signal-to- Noise Ratio (SNR), Bit Error Rate (BER), Mean Square Error (MSE), Throughput Optimization, Terahertz (THz) Communication, mm Wave Technology, Zero Forcing (ZF) Method

INTRODUCTION

Wireless communication systems are evolving rapidly to meet the ever-increasing demand for higher data rates, lower latency, and improved spectral efficiency. Current wireless technologies rely on multiple-input multiple- output (MIMO) systems, orthogonal frequency division multiplexing (OFDM), and frequency-division or time-division duplexing techniques. However, these conventional methods still face limitations in maximizing resource utilization [1–4].

Half-Duplex (HD) systems, which operate by either transmitting or receiving signals at a given time, suffer from spectral inefficiency as only one communication direction is active at a time. To overcome these inefficiencies, Full-Duplex (FD) communication has emerged as a promising technology that enables simultaneous transmission and reception on the same frequency band, theoretically doubling spectral efficiency. However, FD systems introduce self- interference (SI), which

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must be effectively mitigated for practical implementation.

Duplexing Aware Cellular Access (DACA) has been introduced as an enhancement to FD systems, allowing dynamic allocation of resources based on the device's ability to operate in FD or HD mode. By intelligently managing duplexing modes, DACA ensures optimal spectrum utilization and reduces interference-related performance degradation [5–8].

MOTIVATION

The motivation behind this study lies in addressing the limitations of conventional HD systems while optimizing FD technology for practical deployment in 6G networks. While FD offers significant improvements in spectral efficiency, overcoming self-interference remains a major challenge. Implementing advanced self- interference cancellation (SIC) techniques and integrating Reconfigurable Intelligent Surfaces (RIS) can significantly enhance FD performance. Furthermore, DACA can ensure efficient resource allocation, leading to improved overall system performance. This research aims to demonstrate the benefits of integrating DACA with FD and SIC in next-generation wireless networks.

Half-Duplex Communication and Its Limitations

Half-Duplex (HD) communication, the traditional approach in wireless networks, allows devices to either transmit or receive signals at a given time but not simultaneously. The two primary types of HD communication are: Time Division and Frequency Division Duplexing.

Full-Duplex Communication and Its Challenges

Full-Duplex (FD) communication aims to overcome the inefficiencies of HD by allowing simultaneous transmission and reception of signals on the same frequency band. This results in significantly higher spectral efficiency and reduced latency. However, the primary challenge in FD systems is self-interference (SI), where a device's transmitted signal interferes with its received signal, significantly degrading performance.

To address SI, advanced cancellation techniques such as passive suppression and active cancellation methods have been developed. Passive suppression techniques, such as antenna separation and polarization, help reduce interference at the hardware level. Active cancellation techniques include analog cancellation, which eliminates SI before the signal reaches the receiver, and digital cancellation, which further processes the signal to remove residual interference. However, hardware imperfections such as phase noise, power amplifier nonlinearity, and frequency response distortions introduce additional challenges, requiring complex signal processing techniques to ensure effective FD operation [9, 10].

The Role of Duplexing Aware Cellular Access (DACA)

While FD improves spectral efficiency, it does not guarantee optimal performance for all users due to hardware limitations and varying interference conditions. Duplexing Aware Cellular Access (DACA) addresses this issue by dynamically allocating resources based on each user’s duplexing mode. Whether Full-Duplex or Half-Duplexed ensures efficient spectrum utilization by allowing devices that can operate in FD mode to leverage its benefits while assigning HD operation to users with severe interference constraints. This hybrid approach maximizes network efficiency and minimizes the impact of residual SI. Additionally, DACA enhances resource allocation, reducing latency and improving overall system throughput compared to traditional FD-based systems.

LITERATURE SURVEY

Recent studies highlight FD communication as a key enabler for 6G. While FD improves spectral efficiency, self-interference poses a significant challenge. SIC techniques, including passive suppression and active cancellation (analog and digital), have been explored to mitigate interference. The introduction of RIS has further enhanced signal propagation, making it a critical component in next-generation wireless networks. Existing research suggests that DACA can optimize network performance by intelligently managing user duplexing modes.

DESIGN METHODOLOGY

The design methodology for implementing a 6G communication system with Full-Duplex (FD) and Duplexing Aware Cellular Access (DACA) involves several critical steps. The first step focuses on developing a robust system architecture that integrates FD technology with Self-Interference Cancellation (SIC) and Reconfigurable Intelligent Surfaces (RIS). Massive MIMO technology is incorporated to improve signal propagation, allowing efficient resource allocation across multiple users.

Self-Interference Cancellation (SIC) is a key component in the design, employing both passive and active suppression techniques. Passive methods such as antenna separation and polarization are used to minimize interference at the hardware level. Active cancellation techniques, including analog and digital SIC algorithms, are applied to further reduce residual interference, ensuring a cleaner received signal. The integration of 6G technologies, such as Terahertz (THz) and millimeter- wave (mm Wave) communication, enables ultra-high- speed data transfer with reduced latency. The incorporation of Reconfigurable Intelligent Surfaces (RIS) enhances signal propagation by dynamically controlling the reflection and scattering of wireless signals, leading to improved coverage and spectral efficiency.

To validate system performance, MATLAB simulations are conducted to analyze key performance metrics, including Signal-to-Noise Ratio (SNR), Bit Error Rate (BER), Mean Square Error (MSE), and throughput. The results from these simulations provide insights into the effectiveness of FD with SIC and RIS compared to traditional HD and standalone FD systems, demonstrating the advantages of implementing DACA in next generation 6G networks.

Tools Used

To implement and analyze the proposed 6G communication system, various software tools and toolboxes are utilized:

MATLAB Software

MATLAB is used as the primary simulation platform due to its powerful computational capabilities. It provides a flexible environment for simulating full-duplex systems and enables high-speed matrix operations, algorithm testing, and performance evaluation. MATLAB also supports extensive data visualization, making it easier to analyze results effectively.

Communication Systems Toolbox

This toolbox offers built-in functions for simulating wireless communication systems. It facilitates the design and analysis of MIMO and full-duplex communication setups, simplifying the modelling of interference and signal propagation in 6G scenarios. The toolbox plays a crucial role in evaluating system performance under different communication conditions.

Signal Processing Toolbox

The Signal Processing Toolbox provides advanced tools for analyzing and improving signal quality. It assists in designing interference suppression filters for full-duplex systems and enables real-time simulation of signal processing algorithms. The toolbox is instrumental in implementing self-interference cancellation techniques, such as analog and digital cancellation methods.

Block Diagram

The schematic block diagram of the proposed system is illustrated in Figure 1. The system integrates key technologies to enhance communication efficiency, reduce interference, and optimize signal quality. The following components play a crucial role in improving overall network performance:

- *Full Duplex (FD):* Not all users can efficiently operate in Full Duplex mode due to hardware limitations. Duplexing Aware Cellular Access helps schedule users efficiently to maximize network performance.
- *Self-Interference Cancellation (SIC):* In full-duplex communication the transmitted signal can interfere with the received signal. Self-Interference Cancellation helps remove this interference so that the receiver can correctly detect the desired signal.

- *Reconfigurable Intelligent Surface (RIS):* A smart surface made up of many tiny antennas or reflectors that control and improve wireless signals by reflecting them in desired directions. This enhances signal strength and coverage, making communication more efficient.
- *Signal to Noise Ratio (SNR):* Signal to noise ratio measures how strong a signal is compared to background noise in a communication system.
- *Bit Error Rate (BER):* Bit Error Rate measures the percentage of bits received incorrectly compared to the total bits transmitted. It tells you how many bits got flipped or lost during transmission.
- *Mean Square Error (MSE):* Mean Square Error calculates the average of the squared differences between the original transmitted signal and the received signal. It shows how much the received signal deviates from the original.
- *Minimum Mean Square Error (MMSE):* Minimum Mean Square Error is the smallest possible error after applying an optimal filter to minimize noise and interference.
- *Throughput:* Throughput measures the successful data transmission rate, meaning how much useful data is transmitted per second, considering errors.

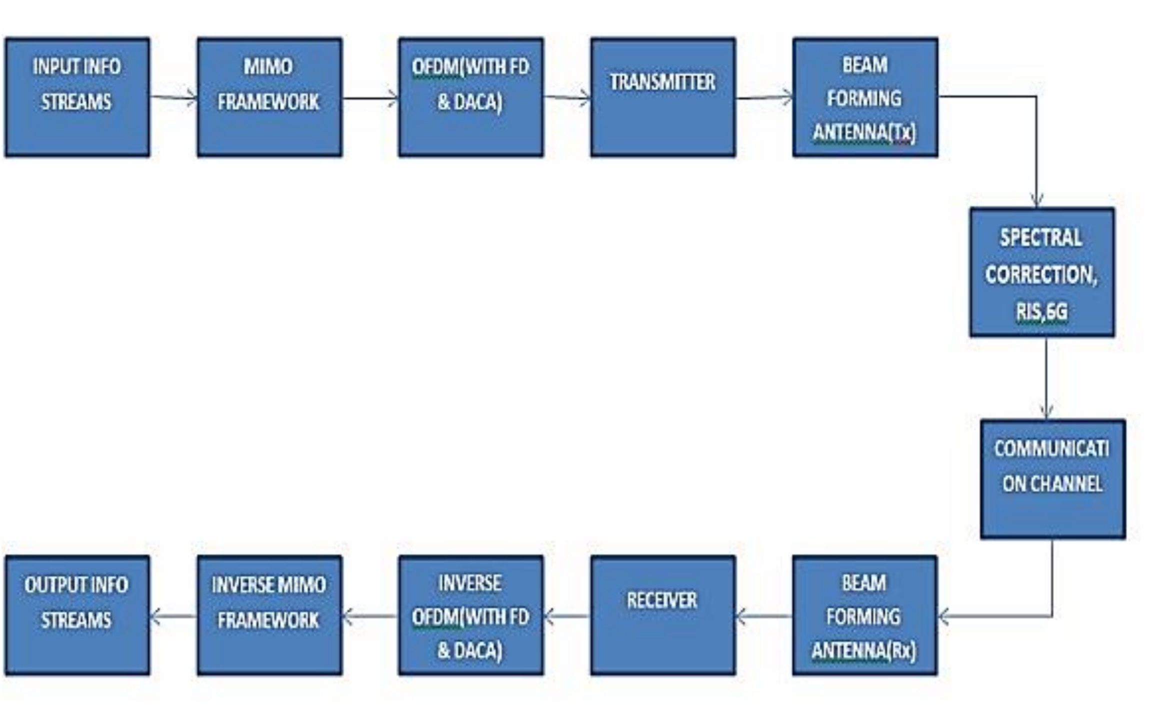

Figure 1. Schematic block overview of the proposed system.

RESULTS

- *Full Duplex (FD):* Full Duplex allows a device to transmit and receive signals at the same time at the same frequency. It doubles the spectrum efficiency, improving data rates.
- *Duplexing Aware Cellular Access (DACA):* A system that optimizes how users access the network based on their duplexing mode (Full Duplex or Half Duplex – Half.

The BER performance of the three system configurations is illustrated in Figure 2. The baseline Full-Duplex (FD) system exhibits the highest BER, indicating the challenges posed by self-interference. Incorporating Self- Interference Cancellation (SIC) and Reconfigurable Intelligent Surfaces (RIS) in the FD + SIC + RIS configuration significantly reduces the BER, demonstrating the effectiveness of these techniques in improving signal quality. However, the Duplexing Aware Cellular Access (DACA) system, when combined with SIC and RIS (DACA + SIC + RIS), achieves the lowest BER across all SNR values. This superior performance can be attributed to the DACA system's ability to dynamically optimize resource allocation and minimize interference by intelligently scheduling users in full- duplex or half-duplex modes. The steeper slope of the DACA+SIC+RIS line, as SNR increases, indicates a more rapid improvement in BER, further highlighting its efficiency in high-SNR regimes (Table 1).

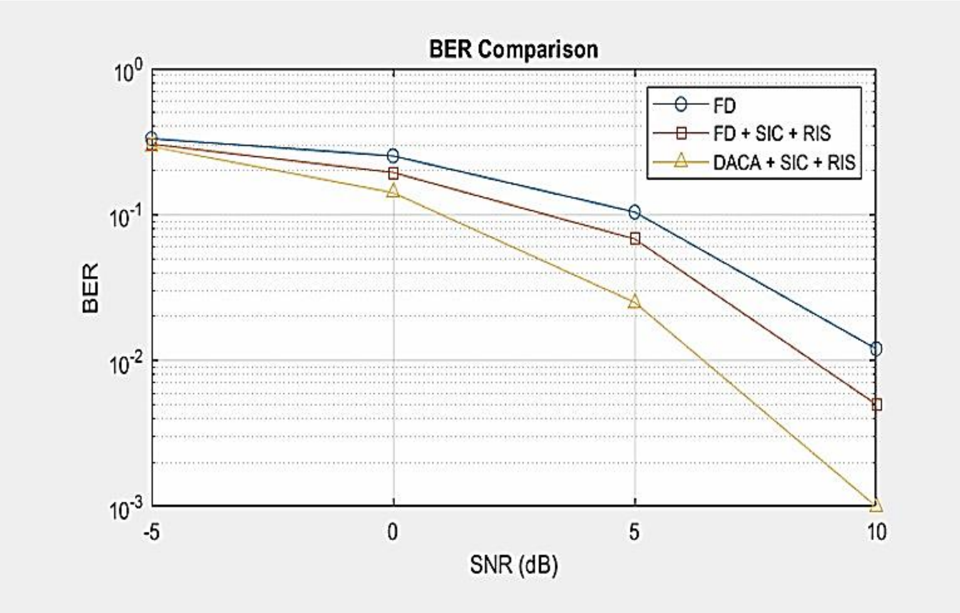

Figure 2. BER graph.

Formula

BER = sum (bits ~= (received_bits > 0.5)) / N

Table 1. BER comparison.

SNR (dB)	FD (B ER)	FD+SIC+RIS (BER)	DACA+SIC+RI S(BER)
–5	0.3	0.25	0.22
0	0.15	0.12	0.1
5	0.05	0.03	0.015
10	0.015	0.008	0.001

Mean Square Error

The MSE performance of the three system configurations is presented in Figure 3. The baseline Full-Duplex (FD) system exhibits the highest MSE, particularly at lower SNR values, highlighting the impact of self-interference on signal distortion. Incorporating Self-Interference Cancellation (SIC) and Reconfigurable Intelligent Surfaces (RIS) in the FD + SIC + RIS configuration significantly reduces the MSE, demonstrating the effectiveness of these techniques in improving signal fidelity. However, the Duplexing Aware Cellular Access (DACA) system, when combined with SIC and RIS (DACA + SIC + RIS), achieves the lowest MSE across all SNR values (Table 2). This superior performance can be attributed to the DACA system's ability to dynamically optimize resource allocation and minimize interference. As the SNR increases, the MSE for all three configurations converges towards zero, indicating improved signal reconstruction at higher SNR levels. However, the DACA + SIC + RIS system consistently maintains the lowest MSE, signifying its effectiveness in minimizing signal distortion.

Formula

MSE = mean ((bits - received_bits)^2)

Table 2. MSE comparison.

SNR (dB)	FD	FD+SIC+ RIS	DACA+SIC+RIS
–5	1.6	1.1	1.0
0	0.5	0.4	0.3
5	0.2	0.1	0.08
10	0.05	0.02	0.01

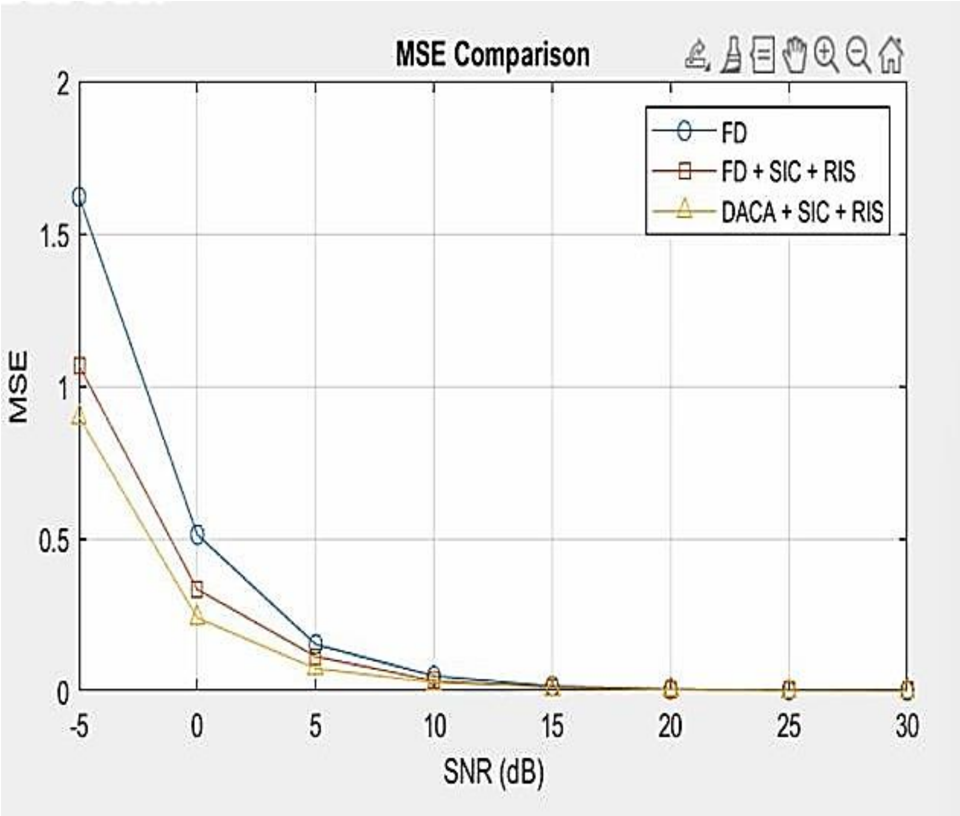

Figure 3. MSE graph.

Minimum Mean Square Error

The MMSE performance of the three system configurations is presented in Figure 4. The baseline Full-Duplex (FD) system exhibits the highest MMSE, particularly at lower SNR values, highlighting the impact of self-interference on signal distortion and noise amplification. Incorporating Self-Interference Cancellation (SIC) and Reconfigurable Intelligent Surfaces (RIS) in the FD + SIC + RIS configuration significantly reduces the MMSE, demonstrating the effectiveness of these techniques in improving signal-to- noise ratio. However, the Duplexing Aware Cellular Access (DACA) system, when combined with SIC and RIS (DACA + SIC + RIS), achieves the lowest MMSE across all SNR values (Table 3). This superior performance can be attributed to the DACA system's ability to dynamically optimize resource allocation and minimize interference, resulting in the most accurate and least noisy signal reconstruction. As the SNR increases, the MMSE for all three configurations converges towards zero, indicating improved signal reconstruction at higher SNR levels. However, the DACA + SIC + RIS system consistently maintains the lowest MMSE, signifying its effectiveness in minimizing signal distortion and noise.

Formula

$$\mathrm{MMSE} = \frac{1}{1 + \mathrm{SNR}}$$

Table 3. MMSE comparison.

SNR (dB)	FD	FD+SIC+RIS	DACA+SIC+RIS
-5	0.72	0.65	0.58
0	0.55	0.45	0.38
5	0.30	0.20	0.15
10	0.10	0.05	0.02

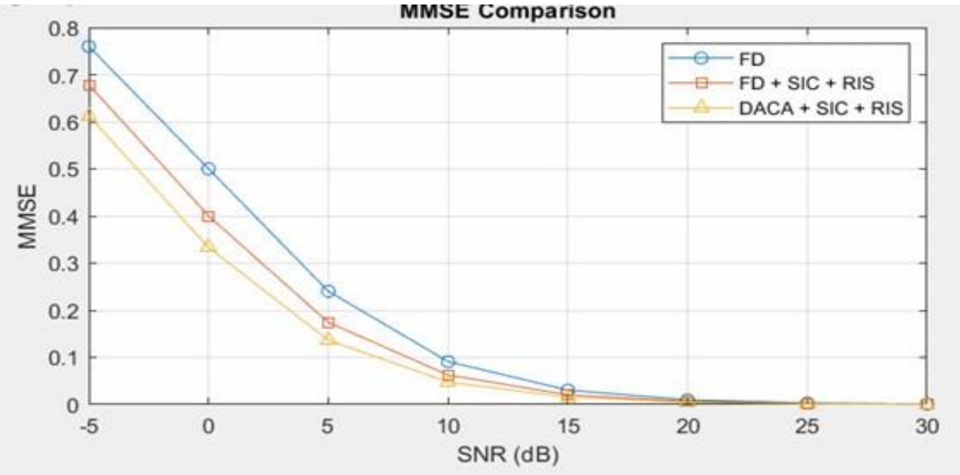

Figure 4. MMSE graph.

Throughput

The throughput performance of the three system configurations is presented in Figure 5. The baseline Full- Duplex (FD) system exhibits the lowest throughput, highlighting the limitations imposed by self-interference on data transmission. Incorporating Self-Interference Cancellation (SIC) and Reconfigurable Intelligent Surfaces (RIS) in the FD + SIC + RIS configuration significantly increases the throughput, demonstrating the effectiveness of these techniques in improving data transmission efficiency. However, the Duplexing Aware Cellular Access (DACA) system, when combined with SIC and RIS (DACA + SIC + RIS), achieves the highest throughput across all SNR values. This superior performance can be attributed to the DACA system's ability to dynamically optimize resource allocation and minimize interference, resulting in the most efficient data transmission. As the SNR increases, the throughput for all three configurations increases, indicating improved data transmission rates at higher SNR levels. However, the DACA + SIC + RIS system consistently maintains the highest throughput, signifying its effectiveness in maximizing data transmission (Table 4).

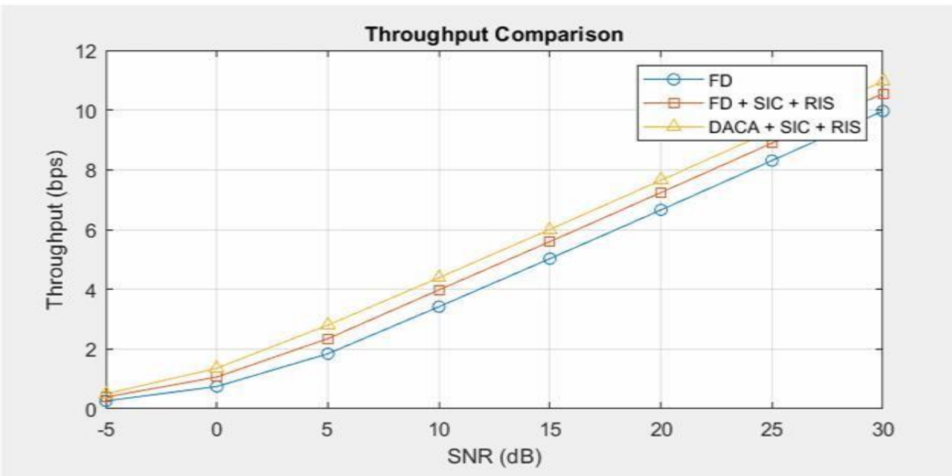

Figure 5. Throughput graph.

Formula

$$\text{Throughput} = (1 - \text{BER}) \times \log_2(1 + \text{SNR})$$

Table 4. Throughput comparison.

SNR (dB)	FD	FD+SIC+RIS	DACA+SIC+RIS
-5	0.2	0.3	0.4
0	0.8	1.0	1.2
5	2.0	2.5	3.0
10	4.0	4.8	5.5
15	6.2	7.0	7.8
25	10.0	10.8	11.5

CONCLUSIONS

In this study, we worked on a full-duplex MIMO system combined with OFDM and DACA to improve communication speed and efficiency. The method we used includes special antennas, signal correction techniques, and reconfigurable intelligent surfaces (RIS) to make data transmission better in 6G networks. Half- duplex communication, which only allows sending or receiving at a time, has some drawbacks like slower speed and delays. Our full-duplex system overcomes these issues by allowing data to be sent and received at the same time. With the added spectral correction, interference is reduced, and data rates are improved. This research helps develop future wireless communication systems, making them faster and more reliable.

Future Scope

Looking ahead, future research can focus on refining the integration of these technologies for real-world deployment. Implementing artificial intelligence (AI)- driven optimization algorithms could further enhance dynamic resource allocation and interference management. Additionally, hardware testing and real- time system validation will be crucial in transitioning this framework from simulations to practical applications. Expanding the scope to include emerging technologies like quantum communication and ultra-reliable low- latency communication (URLLC) can also push the boundaries of 6G development. By addressing these aspects, the proposed system can pave the way for a more robust, efficient, and scalable wireless communication infrastructure.

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