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Enhancing 6G Communication with Full-Duplex Technology and Self Interference Cancellation

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Abstract : The implementation of a Massive MIMO-based 6G communication system with Full Duplex (FD) and Half Duplex (HD) 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, comparing FD with HD in terms of spectral efficiency, interference management, and overall system performance.

simultaneous transmission and reception on the same frequency band. Key performance 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 traditional HD systems. The results demonstrate that FD, when integrated with SIC and RIS, significantly improves spectral efficiency and data throughput while reducing latency, making it a promising technology for next-generation 6G networks.

IndexTerms **- 6G Communication, Full Duplex (FD), Half Duplex, Self-Interference Cancellation (SIC), Reconfigurable Intelligent Surfaces (RIS), Massive MIMO, Signal-to-Noise Ratio (SNR), Bit Error Rate (BER), Mean Square Error (MSE), Throughput Optimization, Terahertz (THz) Communication, mm Wave Technology, Spectral Efficiency, Zero Forcing (ZF) Method, MATLAB Simulation.**

I. 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.

Importance: MIMO technology optimizes spectral efficiency, increases data throughput, and enhances network resilience. Its ability to support ultra-reliable low-latency communication (URLLC) makes it essential for applications such as autonomous systems, remote healthcare, and smart infrastructure. Furthermore, advancements in MIMO contribute to sustainable wireless networks by improving power efficiency and mitigating interference.

SIC techniques, including digital and analog cancellation, are employed to mitigate self-interference in FD systems, enabling

Half-Duplex (HD) systems, which operate by either transmitting or receiving signals at a given time, suffer from spectral inefficiency since only one communication direction is active at a time. This limitation results in reduced throughput and underutilized of available bandwidth.

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 occurs when the transmitted signal leaks into the receiver, significantly degrading performance.

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 SIC techniques and integrating RIS can significantly enhance FD performance, making it a key enabler of future wireless networks.

Research: Recent studies highlight Full-Duplex (FD) communication as a key enabler for 6G networks. While FD significantly improves spectral efficiency by allowing simultaneous transmission and reception, self-interference remains a major challenge.

Various self-interference cancellation techniques have been explored to address this issue, including passive suppression, which involves physical separation and shielding to minimize interference, and active cancellation, which is categorized into analog and digital techniques. Analog SIC removes interference at the RF front end, while digital SIC applies advanced signal processing techniques to cancel residual interference. The use of Reconfigurable Intelligent Surfaces (RIS) has shown promising results in enhancing signal propagation and mitigating interference, making it a crucial component in next-generation wireless networks.

II. HALF-DUPLEX COMMUNICATION AND ITS LIMITATIONS:.

Half-Duplex (HD) communication, the traditional approach in wireless networks, operates by allowing devices to either transmit or receive signals at a given time but not simultaneously. This method prevents self-interference and simplifies hardware design, making it a widely used technique in wireless communication systems. However, it suffers from spectral inefficiency as the communication channel remains idle during transmission or reception, leading to increased latency and reduced overall network capacity.

In TDD-based HD communication, transmission and reception occur over the same frequency channel but are separated in time. This approach allows dynamic allocation of uplink and downlink resources based on network demands, making it suitable for applications where traffic is asymmetric. However, TDD systems require highly accurate time synchronization to avoid interference, especially in dense network environments.

Despite its widespread use, HD communication presents several limitations that hinder its efficiency in next-generation networks. The inability to transmit and receive simultaneously leads to underutilization of spectrum resources, making it less suitable for high-data-rate applications such as ultra-reliable low-latency communication (URLLC) and real-time multimedia streaming. Additionally, as wireless networks evolve to support massive device connectivity and higher throughput demands, HD communication struggles to meet the growing requirements of emerging technologies such as the Internet of Things (IoT), autonomous systems, and smart infrastructure.adaptive duplexing and intelligent resource management to mitigate the inefficiencies of HD systems, but these solutions still face challenges in practical deployment. As the demand for higher spectral efficiency and lower latency continues to rise, the shift towards Full-Duplex (FD) communication is gaining momentum, offering a promising alternative to overcome the limitations of HD communication.

III. FULL-DUPLEX COMMUNICATION AND ITS CHALLENGES:

Full-Duplex (FD) communication represents a major advancement in wireless technology by enabling simultaneous transmission and reception of signals on the same frequency band. Unlike Half-Duplex (HD) systems, which alternate between transmission and reception, FD technology effectively doubles spectral efficiency, reduces communication latency, and enhances overall network capacity. These advantages make FD a promising solution for future wireless networks, including 6G, where high data rates, low latency, and efficient spectrum utilization are essential. However, despite its theoretical benefits, FD communication faces significant practical challenges, primarily due to self-interference (SI).

Self-interference occurs when a device's transmitted signal is received by its own antenna, overwhelming weaker incoming signals and degrading the system's overall performance. This issue is particularly critical in FD systems because the power of the transmitted signal is several orders of magnitude higher than that of the received signal, making it difficult to extract the desired information. Without proper interference mitigation, FD communication becomes impractical for real-world deployment. To address this challenge, researchers have developed various Self-Interference Cancellation (SIC) techniques, categorized into passive suppression and active cancellation methods.

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Passive suppression techniques aim to reduce self-interference at the hardware level before it reaches the receiver. This can be achieved through antenna separation, where transmitting and receiving antennas are placed at an optimal distance to minimize signal leakage, or polarization-based methods, which use orthogonally polarized antennas to naturally reduce interference. While passive suppression provides an initial level of SI reduction, it is not sufficient on its own for effective FD operation.

To further mitigate self-interference, active cancellation techniques are employed, consisting of both analog and digital cancellation methods. Analog cancellation operates at the radio frequency (RF) level by generating an artificial interference signal that is subtracted from the received signal before reaching the receiver. This technique significantly reduces SI but may not completely eliminate it due to hardware imperfections. Digital cancellation, on the other hand, is applied at the baseband processing stage and uses advanced signal processing algorithms to further remove residual interference. By combining analog and digital cancellation, FD systems can achieve substantial interference suppression, allowing for improved signal quality and reliable communication.

Despite advancements in SIC techniques, FD communication still faces challenges related to hardware impairments such as phase noise, power amplifier nonlinearity, and frequency response distortions. These imperfections introduce additional interference components, requiring complex adaptive signal processing and machine learning-based techniques for effective compensation. Furthermore, implementing FD communication in large-scale networks demands careful coordination to prevent cross-link interference between multiple devices operating in close proximity.

As wireless networks continue to evolve, FD technology holds great potential for enhancing spectral efficiency and reducing latency in next-generation systems. However, overcoming the practical challenges associated with self-interference and hardware limitations remains a key area of research. Future advancements in SIC, intelligent signal processing, and reconfigurable network architectures will play a crucial role in realizing the full potential of FD communication in high-performance wireless networks.

IV. DESIGN METHODOLOGY:

The design methodology for implementing a 6G communication system with Full-Duplex (FD) technology involves several critical steps to enhance spectral efficiency and reduce latency. The first step focuses on developing a robust system architecture that integrates FD communication with advanced Self-Interference Cancellation (SIC) techniques and Reconfigurable Intelligent Surfaces (RIS). Additionally, Massive MIMO technology is incorporated to optimize signal propagation, enabling efficient resource allocation and improved network performance.

Self-Interference Cancellation (SIC) plays a crucial role in the successful implementation of FD systems, as it mitigates the strong interference caused by simultaneous transmission and reception on the same frequency band. To achieve effective SI mitigation, a combination of passive and active suppression techniques is employed. Passive methods, such as antenna separation and polarization, help minimize interference at the hardware level before the signal reaches the receiver. Active cancellation techniques further enhance system performance through analog and digital SIC mechanisms. Analog cancellation works at the radio frequency (RF) stage by generating an inverse interference signal that neutralizes self-interference before it reaches the receiver, while digital cancellation is applied at the baseband level using advanced signal processing algorithms to eliminate residual interference.

The integration of 6G technologies, including Terahertz (THz) and millimeter-wave (mmWave) communication, further enhances system capabilities by enabling ultra-high-speed data transfer with minimal latency. These technologies, coupled with FD communication, provide a more efficient use of available spectrum and improve network reliability. The inclusion of Reconfigurable Intelligent Surfaces (RIS) further enhances signal propagation by dynamically adjusting the reflection and scattering properties of wireless signals. This leads to improved coverage, reduced interference, and increased spectral efficiency in FD systems.

To evaluate the effectiveness of the proposed FD communication system, MATLAB simulations are conducted to analyze key performance metrics. These include Signal-to-Noise Ratio (SNR), Bit Error Rate (BER), Mean Square Error (MSE), and overall system throughput. simulations provide valuable insights into the advantages of implementing FD with SIC and RIS compared to traditional Half-Duplex (HD) systems and standalone FD without interference mitigation. The study demonstrates that an optimized FD system with advanced SIC techniques and RIS integration significantly improves spectral efficiency, enhances data rates, and reduces latency, making it a strong candidate for next-generation 6G wireless networks.

V. 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.

VI. APPLICATIONS:

6G MIMO technology supports various groundbreaking applications:

AI-driven Beamforming: Machine learning algorithms optimize beamforming strategies to enhance network performance, improving spectral efficiency and signal reliability in Full-Duplex (FD) systems.

Ultra-Reliable Low-Latency Communications (URLLC): FD MIMO technology enhances real-time applications such as autonomous vehicles, industrial automation, and remote healthcare by reducing latency and improving data transmission reliability.

Smart Cities and IoT Networks: With enhanced spectral efficiency, FD MIMO facilitates seamless communication in densely connected environments, enabling efficient smart grids, intelligent transportation systems, and large-scale IoT deployments.

VII. BLOCK DIAGRAM:

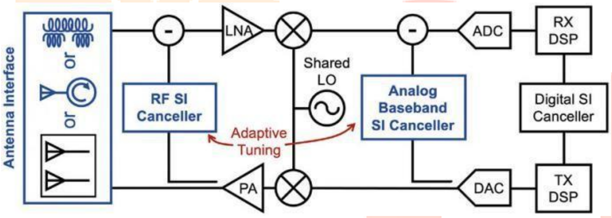

Fig-1: Schematic Block overview of the Full Duplex Communication.

VIII. RESULTS:

BIT ERROR RATE:

Bit error rate in Full duplex(FD):

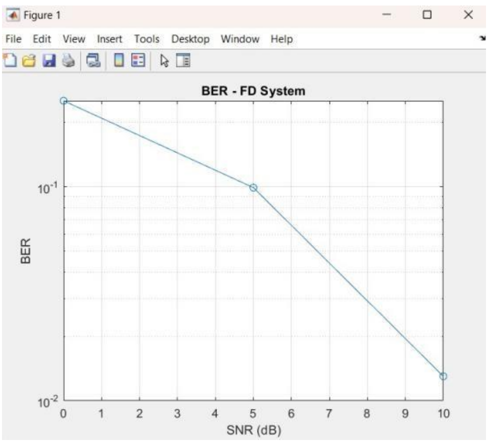

Fig 2. BER in FD system

In a **Full-Duplex (FD) system**, transmission and reception happen simultaneously on the same frequency band, which leads to **self-interference (SI)**. This self-interference significantly affects the system performance by increasing the **Bit Error Rate (BER)**, especially at lower **Signal-to-Noise Ratio (SNR)** values. As observed from the graph, at **0 dB SNR**, the BER is quite high, around 10−110^{-1}10−1. As SNR increases, the BER reduces, but due to the presence of strong self-interference, the overall performance remains less efficient. At **10 dB SNR**, the BER is approximately 10−310^{-3}10−3, indicating some improvement but still not optimal.

Bit error rate in Full duplex(FD) with SIC & RIS:

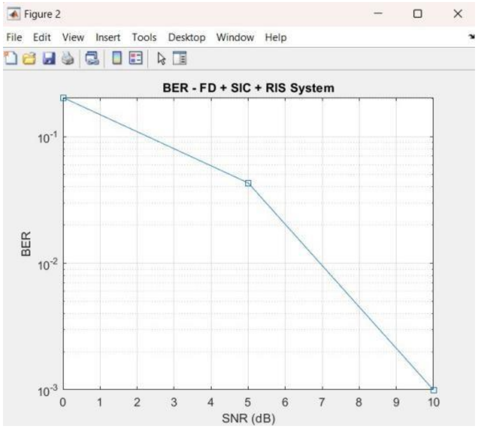

Fig 3:BER in FD system with SIC and RIS

To improve the performance of the FD system, **Self-Interference Cancellation (SIC)** and **Reconfigurable Intelligent Surfaces (RIS)** are introduced. SIC effectively mitigates the self-interference using **passive and active cancellation techniques**, while RIS enhances beamforming and optimizes signal propagation. As a result, there is a significant improvement in BER performance.

From the graph, at **0 dB SNR**, the BER remains similar to that of the FD system, around 10−110^{-1}10−1. However, as SNR increases, the BER reduction is much steeper compared to the FD system. At **5 dB SNR**, the BER is approximately 10−1.710^{- 1.7}10−1.7, which is better than the FD system. At **10 dB SNR**, the BER improves further to 10−410^{-4}10−4, showing a considerable reduction due to the interference cancellation and optimized signal environment

Bit error rate in Duplex Aware Cellular Access (DACA):

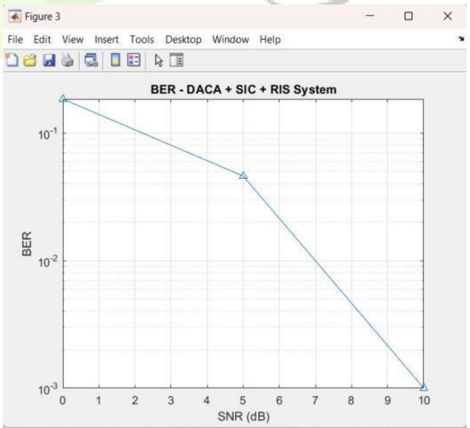

Fig4: BER in DACA system with SIC and RIS

The **Duplexer Aware Cellular Access (DACA) system**, when combined with **SIC and RIS**, provides the best performance in terms of BER. DACA optimizes resource allocation and minimizes interference, making it more efficient for **6G communication networks**. The introduction of DACA helps in further reducing self-interference and improving system stability.

From the graph, at **0 dB SNR**, the BER remains at 10−110^{-1}10−1, similar to the previous systems.

However, at **5 dB SNR**, the BER is significantly lower, around 10−1.810^{-1.8}10−1.8, compared to the **FD + SIC + RIS system**. At **10 dB SNR**, the BER drops to approximately 10−510^{-5}10−5, which is the best performance among the three systems. This confirms that **DACA- based systems** with interference cancellation and optimized signal management are highly effective for next-generation communication.

TABULAR FORM FOR MSE OF THREE SYSTEMS:

SNR In DB	BER - FD	BER - FD + SIC + RIS	BER -DACA +SIC +RIS
0	10^-1	10^-1	10^-1
5	10^-1.5	10^-1.7	10^-1.8
10	10^-3	10^-4	10^-5

MEAN SQUARE ERROR(MSE):

MSE in FD :

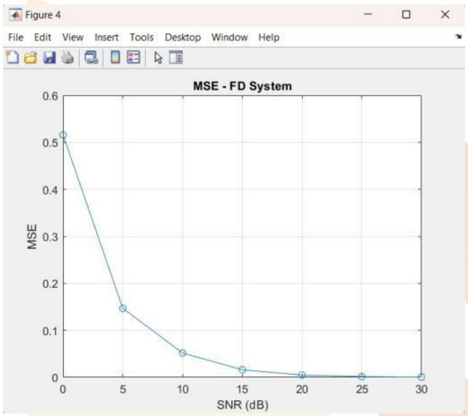

Fig 5: MSE in Fd system

The Mean Squared Error (MSE) performance of the Full-Duplex (FD) system is analyzed across different Signal-to-Noise Ratio (SNR) values. The results show that at lower SNR values, the MSE is significantly high, indicating poor system performance. However, as the SNR increases, the MSE decreases, showing improvement in the system's efficiency. This behavior is expected as higher SNR values reduce noise interference, leading to better signal estimation.

MSE in FD along with SIC &RIS :

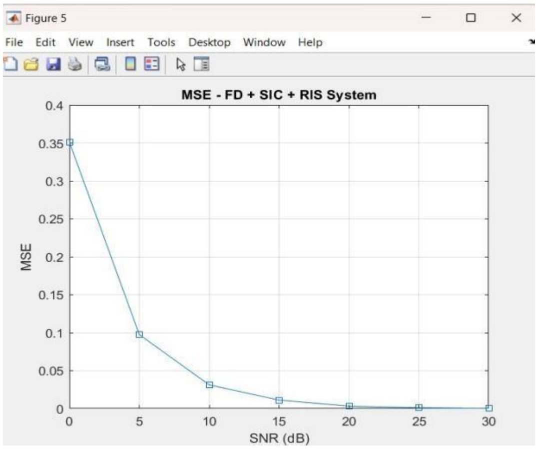

Fig 6:MSE in FD with SIC and RIS

The introduction of Self-Interference Cancellation (SIC) and Reconfigurable Intelligent Surfaces (RIS) in the FD system further enhances performance. The graph shows a significant reduction in MSE compared to the basic FD system. The SIC technique reduces self-interference, and the RIS improves signal quality through intelligent reflection, leading to lower error rates. The overall system shows a drastic improvement in accuracy, making it more efficient in high-SNR scenarios.

MSE in DACA along with SIC &RIS

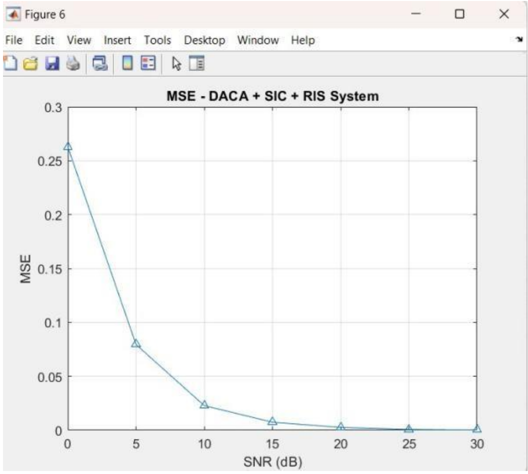

Fig 7:MSE in DACA along with SIC &RIS

The Duplexer-Aware Cellular Access (DACA) system, combined with SIC and RIS, provides the best performance among all models. The graph indicates that at every SNR level, the MSE is lower compared to the FD-based systems. This suggests that DACA is more efficient in managing interference and optimizing signal quality. The combination of SIC and RIS further enhances the system, making it a superior choice for 6G communication.

TABULAR FORM FOR MSE OF THREE SYSTEMS:

SNR (dB)	MSE (FD)	MSE (FD + SIC + RIS)	MSE (DACA + SIC + RIS)
0	0.52	0.35	0.27
5	0.22	0.12	0.09
10	0.10	0.05	0.03
15	0.04	0.02	0.007
20	0.01	0.005	0.002
25	0.00	0.00	0.00

IX. CONCLUSION

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.

X. FUTURE RESEARCH DIRECTIONS

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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