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Reducing Interference in Wireless Communication Systems Using High-Pass Filtering and Sampling Techniques with Python Implementation

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***Abstract**: Interference remains a significant challenge in modern wireless communication systems, as it degrades signal quality and reduces overall system performance. This research presents an approach to mitigating interference by combining high-pass filtering and adaptive sampling techniques, implemented using Python. The primary objective of the study is to enhance signal clarity and communication reliability by effectively isolating the desired signal from unwanted interference. The methodology involves applying a high-pass filter to remove low-frequency noise and varying the number of sampling points per pulse—specifically testing 10, 50, and 100 samples. The results demonstrate that increasing the sampling resolution leads to improved signal reconstruction, with matching rates observed at approximately 40%, 70%, and 90%, respectively. These findings confirm that optimal sampling plays a critical role in detecting and suppressing interference. Moreover, the study highlights the potential integration of machine learning algorithms to dynamically adjust sampling strategies in real-time environments, further enhancing interference suppression efficiency. The proposed approach not only improves the quality of the received signal but also lays the groundwork for more intelligent and adaptive communication systems. Future research could explore the use of deep learning models for automatic interference classification and mitigation, as well as the implementation of adaptive filtering methods that respond to environmental changes. This work contributes to advancing the reliability and scalability of wireless communication networks, particularly in high-demand applications such as 5G and the Internet of Things (IoT), where maintaining signal integrity is crucial for performance and user experience.*

***Keywords**: High-Pass Filtering, Interference, Signal, Wireless Communication Systems.*

Abbreviations
IoT: Internet of Things
SDR: Software Defined Radio
AI: Artificial Intelligence
RNN: Recurrent Neural Network
LSTM: Long Short-Term Memory
Bi-LSTM: Bi-directional Long Short-Term Memory
GRU: Gated Recurrent Unit
Wi-Fi: Wireless Fidelity
CoMP: Cooperative Multi-Point Systems
MMO: Multiple Input Multiple Output

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I. INTRODUCTION

Wireless communication technologies include wireless printers, surveillance cameras, and various Internet-connected devices [1]. These systems allow communication without wires or physical links. This makes them important for how we communicate today. The rise of wireless networks has changed how we communicate. They enable data exchange over large areas with little infrastructure [2]. In places where wired connections are hard to set up—like remote areas—wireless access points are crucial [3]. This approach uses strategically placed points to manage data flow and signal transmission among devices, such as smartphones and tablets [4]. However, wireless communication has challenges. Signal interference is a major issue that can hurt communication quality and efficiency [5]. This interference, along with security risks, threatens the reliability of these networks. Many studies in different countries have explored these problems [6]. For example, a study in Romania during October and November 2016 looked at wireless network security and interference. It collected data from nearly 100,000 unique wireless access points in urban and rural areas [7]. The research used the Wigle Engine Geolocation Android app to reveal security concerns and vulnerabilities [8]. The findings were compared to earlier studies from 2012 to see how wireless security in Romania has changed [9]. In Morocco, another 2016 study analyzed about 10,000 networks in Rabat and Nahda. It found that only 13% of networks were unsecured, showing that most networks had good protection [10].

Our current research aims to improve wireless communication by tackling signal interference. We use Python programming to implement and test methods for reducing interference. By analyzing samples and comparing the accuracy of transmitted and received signals, we aim to find the best strategies for minimizing interference.

After this introduction, the paper is organized as follows: Section 2 reviews related literature and past studies on wireless interference and security. Section 3 methodology for interference reduction. Section 4 presents experimental results and analysis, emphasizing the link between sample size and signal accuracy. Section 5 discusses the implications of the findings and suggests future research and technology improvements in wireless communication systems.

II. LITERATURE SURVEY

(Xin, Y (2011)) The paper aims to address the problem of joint power control and beamforming to maximize the utility function in the network. The paper proposes a convergent alternating optimization algorithm that can be applied to decentralized wireless networks. In the presence of noisy measurements and estimates, the authors analyze the proposed algorithm in the context of stochastic approximation theory and study the convergence property of the proposed algorithm via simulation [11].

(Ahmed, f et al (2020)) This research uses Software Defined Radio (SDR) and artificial intelligence (AI) to create a self-managed communication system. It can adjust to different node locations. It focuses on three key parameters that affect wireless signals: channel frequency, bandwidth, and modulation type. SDR collects and analyzes signal components. Meanwhile, AI monitors data and processes it in real time, detecting unwanted information. AI then integrates the decisions about the data read and relays them to the communication nodes to find their correct locations. This method increases the connection ratio and coverage area by almost two times. Adjusting node locations during peak times doubles the number of connected subscribers [12].

(J. R. Mohammed (2021)) This study aimed to reduce interference in wireless communication signals. Improving performance is vital due to the crowded spectrum and increasing demand for new applications. Antenna arrays with adaptive algorithms offer a promising solution. However, there are real challenges, especially with large arrays of controllable elements. Other issues include lengthy convergence times and complex beamforming networks. In this paper, we propose using a limited number of adaptive elements in the array. We found that the center elements can be adaptive, while the less influential elements can remain fixed. This method provides advantages over fully adaptive arrays and ensures strong interference suppression. The simulation results show that the proposed array creates deep nulls and quickly converges [13].

(H. Shakhatreh, et al (2023)) This study gives an overview of techniques to reduce interference in wireless communication. It covers linear filtering, equalization, and diversity combination as key methods [14].

(M. A. S. Sejan et al (2024)) This study examines how RNN methods address channel interference in wireless communications. We focus on the long short-term memory (LSTM) network, bidirectional LSTM network (Bi-LSTM), and gated recurrent unit (GRU) in two network setups. The first network has 10 connected devices, while the second has 20. Bi-LSTM beats both LSTM and GRU in three areas: mean squared error, normalized mean squared error, and sum rate. LSTM and GRU yield similar results, but LSTM has a slight edge over GRU. We explored a combined RNN approach. This method shows improved performance in dense networks [15].

Table–I: Summary of Studies on Interference Mitigation

Researcher(s)	Year	Main Idea	Achieved Results	Challenges	Strengths
Xin, Y. et al [11]	2011	This paper focuses on joint power control and beamforming. It aims to maximize the network's utility function.	An alternating optimization algorithm was developed for decentralized wireless networks, and its convergence properties were analyzed using simulations.	The presence of noisy measurements may affect the accuracy of the results derived from the algorithm.	Ability to enhance performance in decentralized networks through an effective optimization algorithm.
Ahmed, F. et al [12]	2020	Use SDR and AI to build a self-managed communication system. This system will allow for changing node locations.	The proposed method achieved a connection ratio and coverage area that were almost twice as high.	Challenges in real-time system implementation due to the complexity of changing data.	Significant improvement in connection ratio through AI analysis of real-time data.
Mohammed, A. et al [13]	2021	The study focused on reducing interference from wireless signals. This was aimed at boosting system performance.	Results showed that it can select center elements in the array as adaptive. This choice improves interference suppression performance.	Practical limitations in implementing fully adaptive arrays, especially with many controllable elements.	Keep strong performance while simplifying with fewer adaptive parts.
Oyedepo, J. et al [14]	2023	This study gives an overview of ways to reduce interference in wireless communication systems.	Methods to reduce interference include linear filtering, equalization, and diversity-combination techniques.	There is a need to improve interference mitigation techniques. This is important to keep up with fast changes in communications.	Providing comprehensive information on various interference mitigation techniques.
Sejan, M. et al [15]	2024	This study looks at how recurrent neural network (RNN) methods can reduce channel interference in wireless communications.	Experimental results show that Bi-LSTM outperforms LSTM and GRU in mean squared error and sum rate.	The need for different network settings may complicate implementation.	High performance of Bi-LSTM compared to other methods in dense network environments.

III. BACKGROUND ON INTERFERENCE REDUCTION IN WIRELESS COMMUNICATION

Wireless communication methods face the problem of interference in transmitted and received signals, which leads to a decrease in the efficiency and quality of communication, which is manifested by voice and network interruptions. This ultimately diminishes the quality of communication and negatively affects customer satisfaction. Therefore, it is imperative to address the issue of interference, especially in light of technological advancements and improvements in communication quality.

The importance of our current research stems from the necessity to enhance wireless communication quality and mitigate interferences that can

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occur at any moment in our lives, as we heavily rely on modern communication applications. This necessitates that such communication be of high quality. Through this research, we have also been able to understand the causes of interference and how to address them, improving overall communication performance. This benefits every individual or company utilizing wireless communication systems. Additionally, the results of this research provide an advanced approach and new technology that contributes to reducing interference. The major contributions of the research are as follows:

- Identify the factors that can lead to interference in wireless communications.
- Explore effective solutions and modern strategies to reduce the impact of interference.
- Utilize the Python programming language and its libraries to find solutions to the interference problem.
- Improving the quality of wireless communication.

A. Types of Interference in Wireless Communication Systems

The possibility of interference between signals occurs when these two signals have the same frequency or a close frequency. This leads to each signal being noise relative to the other [16]. Interference is considered one of the most significant problems facing Wi-Fi networks, as it leads to a decrease in network performance. Interference in networks can arise from two main sources [17]:

- Interference from devices operating with Wi-Fi technology: Such as devices using Bluetooth technology and microwave ovens.
- Interference from Wi-Fi devices: A widespread issue where access points interfere with each other, which is noticeable in environments with many Wi-Fi devices.

This type of interference can be further divided into two subcategories:

- Common Channel Interference: This refers to the use of the same channel to transmit data by different nearby Wi-Fi devices.
- Overlap between adjacent points. This type is less dangerous than the previous one [18].

B. Effects of Interference On Signal Quality And System Performance

Interference weakens the signal quality, as when there is interference, the received signal appears clearly, and therefore we cannot be sure whether the data was sent correctly or not. The most important negative effects of interference are:

- Poor performance: This weakness is embodied in the difficulty of understanding the information by the receiving device, which is embodied
- Delay in delivering information: There is a relatively long period between sending the information by the sender and receiving it by the receiver.
- Loss of information: The inability to obtain it again, and therefore it must be requested and sent again, which in turn constitutes a burden and pressure on the network.
- Decrease in the number of users: This decrease is a result of the decrease in the quality of the service provided Increased Energy Consumption: When devices attempt to overcome interference, they consume more energy searching for stronger signals or retransmitting data, negatively impacting battery life [19].

From the above, it is evident that interference can have significant negative effects on user experience and satisfaction with the service provided. Therefore, it is essential to explore new strategies to mitigate the problem of interference [20].

C. Techniques and Strategies For Interference Management Wireless Networks

Interference is a big challenge in wireless communication systems. It affects signal quality and lowers network performance. To combat this, various advanced techniques and strategies have been created. These focus on improving transmission coordination, using smart devices, and accessing higher frequency bands to enhance spectral efficiency. The following subsections highlight important methods for reducing interference in wireless networks.

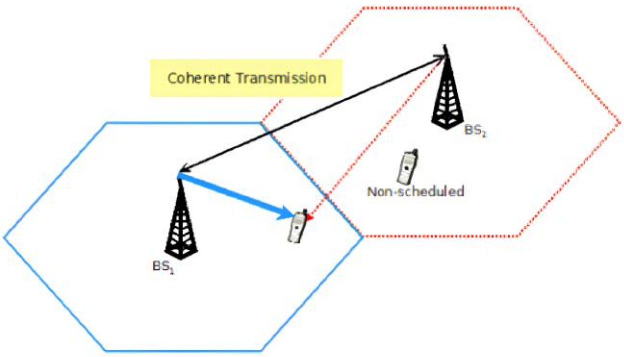
i. Cooperative Multi-Point Systems (CoMP)

Cooperative Multi-Point Systems (CoMP) are designed to enhance the quality of wireless networks in areas where interference occurs. Although one of its drawbacks is that it increases the complexity of system operations, it expands coverage area and maximizes network capacity, thereby improving performance at both the cell edges and the center [21].

This system is based on coordinating transmissions among base stations, and there are two main types:

ii. Joint Processing and Transmission (CoMP-JP):

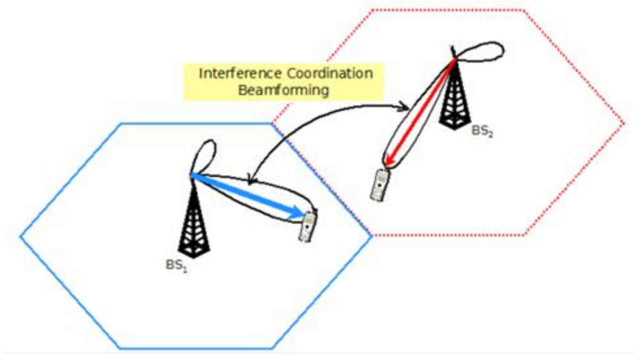
- Data is sent simultaneously from multiple transmission points to several users located at the cell edges.
- The goal of this process is to improve network performance and mitigate interference [22].



[Fig.1: Joint Transmission in Cooperative Multi-Point Systems (CoMP)]

iii. Beamforming:

- Weights are assigned to reduce interference between users located in different cells.
- This system aims to improve the signal-to-noise ratio for each user [23].



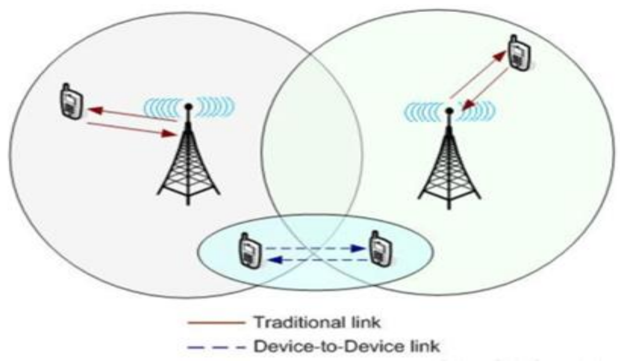
[Fig.2: Coordinated Transmission Using Beamforming Techniques]

Difference between the two types:

- The first relies on coordination to provide synchronized signals, while the second focuses on reducing interference.
- The first is more complex but delivers higher signal quality [24].

iv. Smart Terminal Devices

These devices utilize technologies, methods, and applications of artificial intelligence. With the significant advancements we are witnessing, these devices play a crucial role in reducing interference and improving performance quality. By employing methods such as direct communication between devices, nearby devices can communicate directly without needing to go through the network. This helps reduce network congestion and increases its efficiency [25].



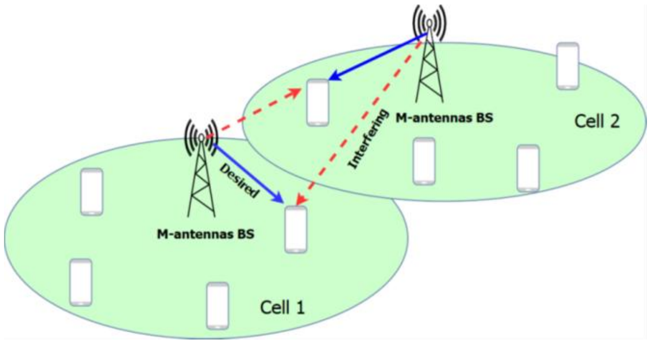
[Fig.3: Device-to-Device Communication]

v. Millimetre Wave Communications

This system is used to alleviate pressure on traditional frequency bands, allowing for extremely high-speed data transmission even in densely populated environments. Despite challenges such as attenuation from barriers and rain, integrating it with multi-antenna systems like Massive MIMO significantly enhances performance, making it suitable for use in fifth-generation (5G) networks and beyond [26].

vi. Massive MIMO (Multiple Input Multiple Output) Systems

This system uses many antennas at base stations [27]. This allows for the simultaneous transmission and reception of many signals [28]. As a result, spectral efficiency and signal quality improve [29], while interference effects decrease [30]. Also, massive MIMO systems are more energy efficient [31]. They can use low-cost, efficient amplifiers instead of those found in traditional systems [32].



[Fig.4: Multi-Cell Massive MIMO Network System Model]

IV. EXPERIMENTAL ANALYSIS AND DISCUSSION

We performed a test to evaluate the impact of interference on wireless communication. We proposed a smart strategy to fix this issue with Python. The experiment involved sending a signal to represent a communication channel. It also introduced a noise signal to simulate interference. The study used signal processing techniques to separate the interfering signals. This helped retrieve the desired signal with precision.

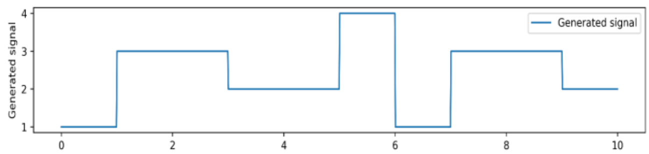
A. Required Tools

The research used the Python programming environment and libraries, including NumPy, Pandas, and Matplotlib.

B. Work Procedures

Phase 1: Signal Generation

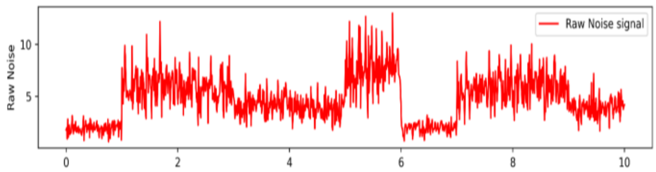
In this phase, the required communication signal was generated. As illustrated in Figure (5), the initial communication channel signal is a square wave signal, which serves as the base signal for the transmission process.



[Fig.5: Illustrates a Signal Representing the First Communication Channel]

Phase 2: Noise Signal Generation

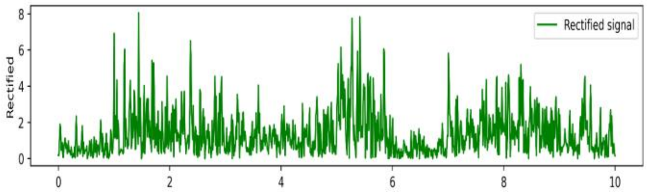
In this phase, a noise signal was generated to represent the second communication channel. This signal overlaps with the first one and was intentionally designed to interfere with the primary communication signal, as illustrated in Figure (6).



[Fig.6: Noise Signal Generated for Channel Interference]

Phase 3: Signal Overlapping and Interference

In this phase, both signals were transmitted simultaneously in an overlapping manner. This was done to create an interference effect, as illustrated in Figure (7).



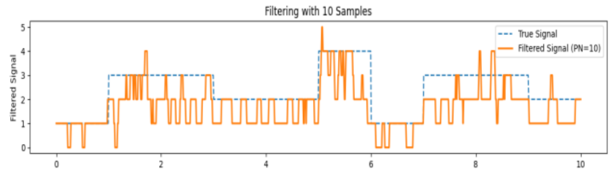
[Fig.7: Interference Process of the Two Signals]

As observed in the figure, the two signals overlap during transmission, leading to a significant degradation in communication quality, as previously mentioned. Therefore, to mitigate this interference, it is essential to extract the original signal while eliminating the interfering signal. This objective is addressed in Phase Four.

Phase 4: Signal Reception and Interference Cancellation

In this phase, the goal is to recover the original signal without interference. A high-pass filter was utilized to eliminate unwanted noise. The filtering mechanism relies on sampling points to detect interference within each pulse of the original signal. Experimental results indicate that increasing the number of samples per pulse enhances the accuracy of the received signal, ensuring better alignment with the transmitted signal.

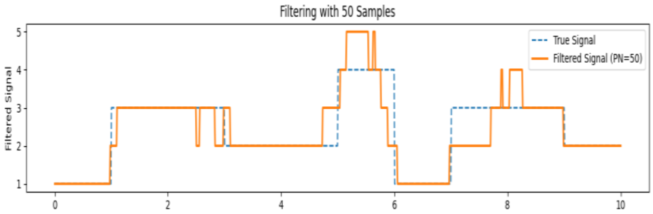
In the first scenario**,** 10 samples were used to detect interference in each pulse of the transmitted signal. The resulting response is shown in Figure (8).



[Fig.8: Comparison of Transmitted and Received Signals After Interference Removal (10 Samples)]

Figure (8) illustrates the comparison between the original transmitted signal (blue) and the filtered received signal (purple) after interference removal. The figure demonstrates a noticeable alignment between the two signals.

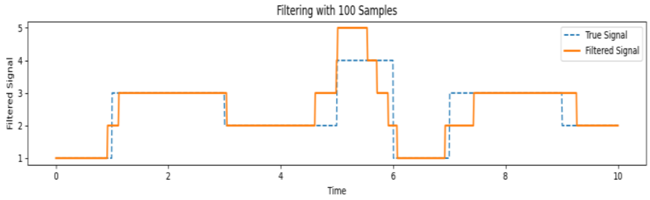
In the second scenario, 50 samples were used for interference detection in each pulse, producing the response shown in Figure (9).



[Fig.9: Comparison of Transmitted and Received Signals After Interference Removal (50 Samples)]

Figure (9) presents the comparison when 50 samples were utilized for interference detection per pulse. The results indicate a higher degree of matching compared to the previous case.

In the third scenario, 100 samples were used for interference detection per pulse, yielding the response depicted in Figure (10).



[Fig.10: Comparison of Transmitted and Received Signals After Interference Removal (100 Samples)]

Figure (10) shows the comparison after applying 100 detection samples per pulse. The received signal (orange) exhibits an almost perfect match with the original transmitted signal (blue), indicating a highly effective interference cancellation process.

When analyzing the three previous cases, we observed an improvement in the results and an increase in the matching between the received and transmitted signals as the number of detection samples for interference per pulse of the transmitted signal increased. The results are summarized in Table (II).

Table–II: Matching Percentages Comparison Across the Three Detection Cases

Matching Percentage (%)	Number of Samples per Pulse	Case
%40	10	1
%70	50	2
%90	100	3

To further improve the accuracy of matching between the transmitted and received signals, the following points are recommended:

- Increase the number of detection samples for interference to further enhance signal alignment.
- Explore alternative filter types to optimize interference cancellation.
- Leverage advanced machine learning techniques for selecting the most effective detection samples for interference.

V. CONCLUSION

Throughout the research process, the crucial role of the programming language in enhancing the quality and efficiency of communication through signal processing techniques was highlighted. The findings showed that increasing the number of samples significantly improved signal alignment, with the matching rate approaching 100% when 100 samples were used. This encourages ongoing efforts to explore new strategies for enhancing wireless communication performance. Future work could include utilizing artificial intelligence and machine learning to improve the accuracy and scientific approach to sample selection, expanding experiments to a

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larger sample size to validate and refine results, exploring advanced filters for more precise signal matching, investigating new signal processing techniques to further optimize performance, and applying the study to a wider range of communication methods to test its broader applicability.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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