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Implementation of OFDM using GNU Radio with HackRF One and RTL-SDR

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***Abstract*— Modern communication systems frequently employ orthogonal frequency division multiplexing (OFDM) as a modulation technology because of its capacity to reduce the impacts of inter-symbol interference and multipath fading. In this work, the implementation of OFDM using GNU Radio with the HackRF One software-defined radio (SDR) platform has been proposed. The work aims to demonstrate the practical implementation of OFDM, a complex digital communication technique, using readily available hardware and open-source software tools. GNU Radio provides a flexible and powerful framework for signal processing and modulation, while the HackRF One SDR offers the capability to transmit and receive RF signals over a wide frequency range. The implementation involves designing and configuring OFDM transmitter and receiver blocks within the GNU Radio environment, utilizing the HackRF One for RF signal transmission and RTL-SDR for reception.Various aspects such as synchronization, channel estimation, and error correction will be addressed to ensure reliable communication performance. The work not only serves as an educational resource for understanding OFDM principles and GNU Radio usage but also provides a practical platform for experimenting with SDR technology in real-world communication scenarios. OFDM (Orthogonal Frequency Division Multiplexing) signal transmission has been successfully implemented to accommodate three distinct types of input data: textual, audio, and image inputs and their corresponding waveforms and outputs have been obtained.**

Keywords—Orthogonal Frequency Division Multiplexing (OFDM), Software-Defined Radio (SDR), HackRF One, GNU Radio.

I. Introduction

In the ever-evolving landscape of wireless communication, the quest for efficient, robust, and versatile modulation techniques is ceaseless. Among these, Orthogonal Frequency Division Multiplexing (OFDM) stands as a beacon of innovation, offering a potent solution to the challenges of modern communication systems[1]. The project "Implementation of OFDM Using GNU Radio with HackRF One and RTL-SDR" represents a convergence of advanced digital signal processing, software-defined radio (SDR) technology, and practical experimentation. This endeavor seeks to explore, implement, and evaluate OFDM modulation—an integral component of numerous wireless standards—utilizing the powerful capabilities of GNU Radio in tandem with the versatile hardware platforms of HackRF One and RTL-SDR. The primary objective of this project is to realize the implementation of OFDM modulation within the GNU Radio framework, leveraging the flexibility and extensibility it offers for signal processing tasks[6]. By integrating the capabilities of HackRF One and RTL-SDR, two prominent SDR platforms renowned for their wide frequency coverage and programmability, we aim to create a comprehensive platform for OFDM experimentation[5].

Our approach encompasses several key steps:

1. **Understanding OFDM:** Delve into the principles and advantages of OFDM modulation, exploring its application in modern communication systems.
2. **GNU Radio Setup:** Configure the GNU Radio environment, harnessing its vast array of signal processing blocks to design and simulate OFDM modulation and demodulation algorithms.
3. **Hardware Integration:** Interface with the HackRF One and RTL-SDR platforms, configuring them for transmission and reception of OFDM signals.
4. **Implementation:** Develop GNU Radio flowgraphs to generate OFDM signals, transmit them through the hardware platforms, and receive and demodulate them for analysis.

In this work, UHF(Ultra High Frequency) band from 420 to 450 MHz has been used with 435 MHz as the center frequency and a bandwidth of 2 MHz has been used for OFDM data transmissions[8]. HackRF One transreceiver, GNU Radio have been used to transmit and RTL-SDR receiver, GNU Radio have been used to receive OFDM data. HackRF One is a software defined radio (SDR) half-duplex transceiver. It is able to send and receive signals. HackRF One has a maximum output power of 15 dBm and can receive and transmit on frequencies between 1 MHz and 6 GHz. Popular software defined radio programs like SDR# and GNU Radio are compatible with HackRF One. Software-defined radio (SDR) is a type of radio communication system in which computer or embedded system software replaces analog hardware components (such as detectors, modulators/demodulators, amplifiers, filters, mixers, and so on) that were previously implemented[7]. The frequency range that the RTL-SDR could receive is 500 kHz to 1.75 GHz. RTL-SDRs cannot transmit. We hope to gain a thorough understanding of

OFDM modulation and improve our practical knowledge of SDR technology and digital signal processing through this research. By means of practical experimentation, we want to unleash the capabilities of OFDM-based communication systems and clear the path for upcoming advancements in wireless communication[3].

II. SYSTEM DESIGN

A. System Block Diagram

Fig. 1 shows the block diagram of the system design that was employed.

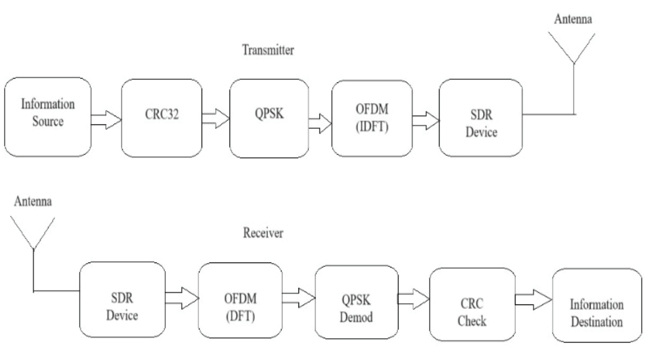

Fig. 1. System Block Diagram

B. System Components

- Information Source: This includes all digital data that has to be sent.
- Cyclic Redundancy Check: This coding is intended to help the receiver find and fix errors.
- Quadrature Phase Shift Keying(QPSK): QPSK is utilized in this work. The entering sequence's every two bits are mapped into a QPSK symbol.
- Software Defined Radio(SDR): This device can send and receive a wide range of waveforms at different frequencies. To specify transmitter settings like frequency, gain, and bandwidth, we utilize GNU Radio.
- Antenna: The length of this dipole antenna is proportionate to the signal's wavelength that we are transmitting.

III. METHODOLOGY

A. Working

On one computer, designated as the transmitter system, GNU Radio Companion (GRC) software is employed to construct a flowgraph that represents the transmission process. This flowgraph incorporates various signal processing blocks to modulate the input audio file into OFDM signals. The output of this flowgraph is then fed into a HackRF One transceiver, which serves as the transmitting hardware. The HackRF One facilitates the conversion of digital signals into radio frequency (RF) waves for transmission over the air. Concurrently, on another computer, designated as the receiver system, a separate flowgraph is crafted within GNU Radio Companion. This flowgraph emulates the reception process and includes signal processing blocks tailored to demodulate and decode the received OFDM signals[10,11]. The input to this flowgraph is the signal captured by an RTL-SDR dongle, equipped with an antenna, which is tuned to the frequency at which the OFDM signal is transmitted. During the experiment, an audio file is provided as input to the transmitter flowgraph, simulating real-world data that needs to be transmitted wirelessly. This audio signal undergoes digital processing within the transmitter flowgraph, where it is modulated onto OFDM subcarriers[9]. Subsequently, the modulated signal is transmitted via the HackRF One transceiver. Simultaneously, the receiver flowgraph is executed on the second computer, capturing the transmitted OFDM signal with the RTL-SDR dongle. The transmitter and receiver setup is shown in Fig. 2. The setup comprises HackRF One and RTL-SDR devices, alongside two laptops dedicated to executing GNU Radio flowgraphs. The GNU Radio Companion has been installed from Windows Radioconda Installer. The RTL-SDR drivers have been installed from Zadig application which can be installed from SDRSharp (SDR#).

Fig. 2. Transmitter and Receiver Setup

The transmitter and receiver flowgraph with Text and Image inputs is shown in Fig. 3. The description of flowgraphs is given below.

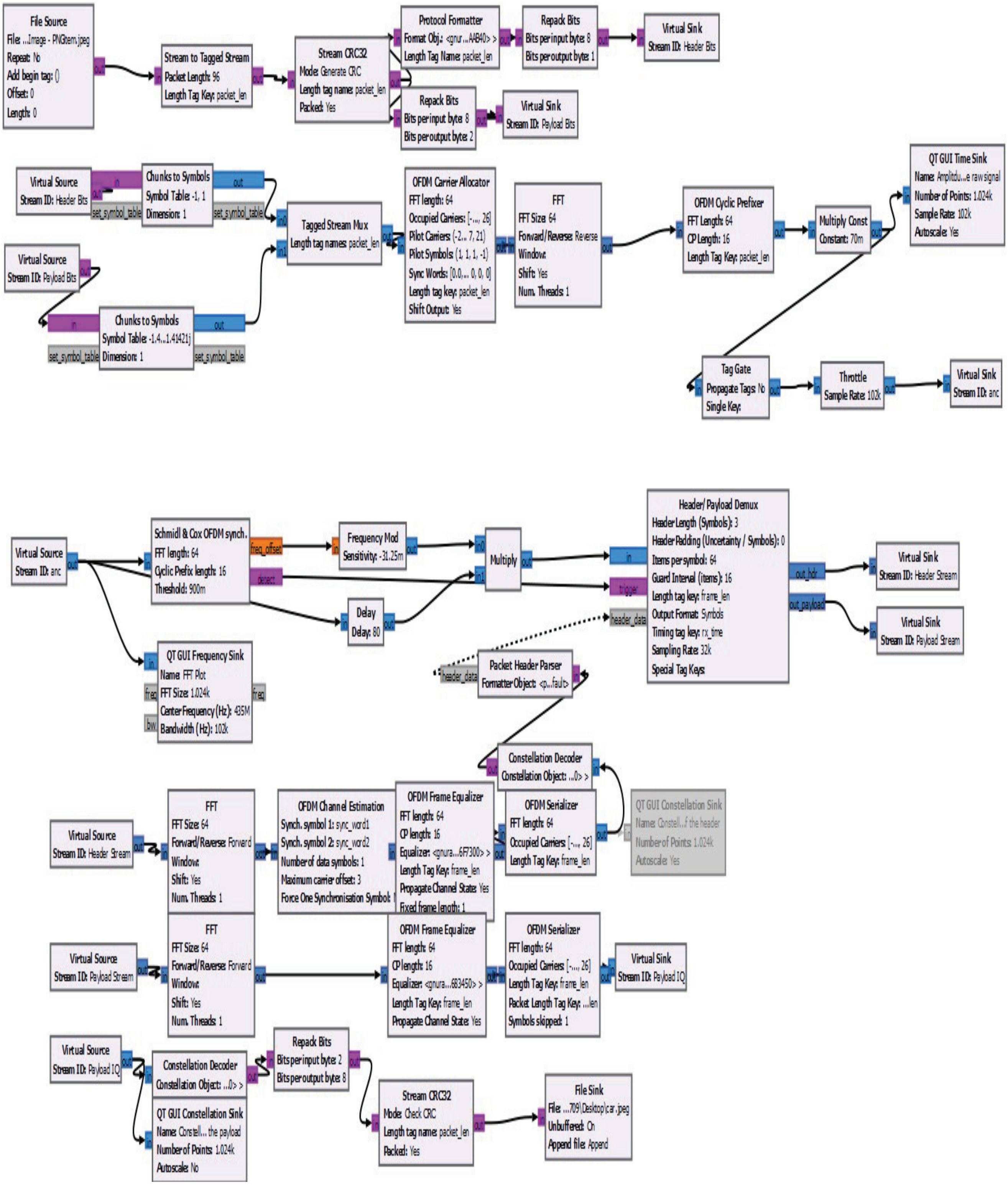

Fig. 3. Transmitter and Receiver Flowgraph with Text and Image Inputs

The transmitter and receiver flowgraphs with audio input are shown in Fig. 4 and Fig. 5 respectively. The description of flowgraphs is given below.

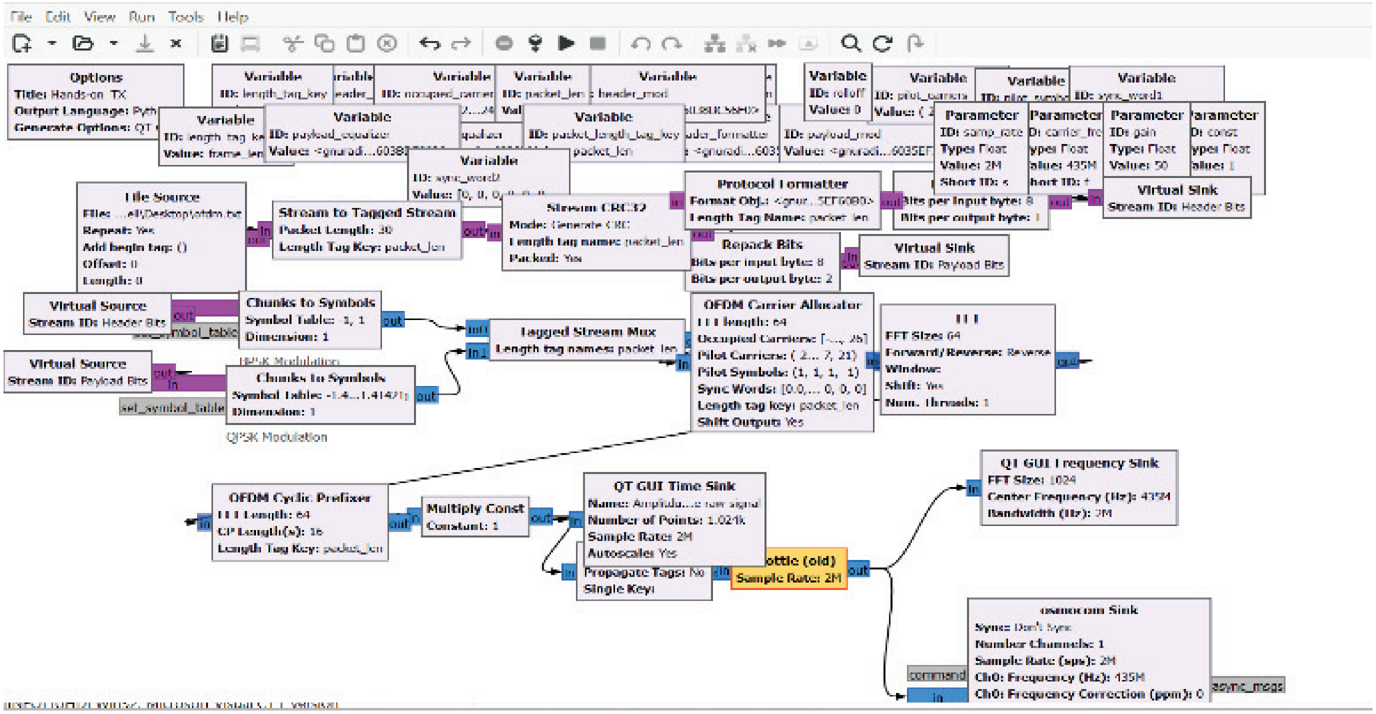

Fig. 4. Transmitter Flowgraph with Audio Input

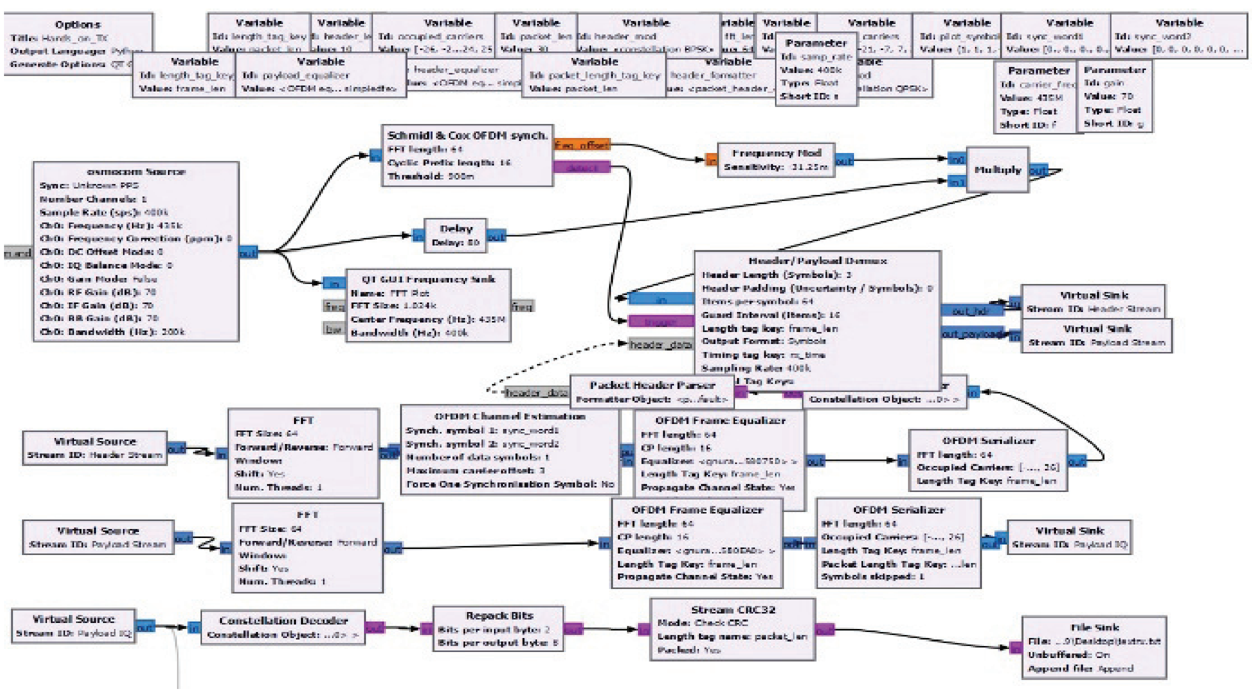

Fig. 5. Receiver Flowgraph with Audio Input

B. Flowgraph Description

- **Stream to tagged stream:** The "Tagged Stream" block in GNU Radio is a specific block designed to handle streams of data with associated tags. Tags are metadata attached to individual samples within the stream. These tags can contain information such as timestamps, identifiers, or any other relevant metadata. The purpose of the Tagged Stream block is to allow users to manipulate and process both the data samples and their associated tags within a GNU Radio flowgraph. This block provides functionalities for adding, modifying, or removing tags, as well as for performing signal processing operations based on the information contained in the tags.

- **Stream CRC32**: The "Stream CRC32" block is a block used for computing the cyclic redundancy check (CRC) of a data stream. CRC is a type of checksum used to detect errors in digital data transmission or storage. It is computed based on the data bits in the stream and appended to the data for error detection purposes.

- **Chunks to symbols**: The Chunks to Symbols block is used in digital communication systems to convert chunks of data into symbols. This block is particularly useful in modulation schemes where data is represented by symbols before transmission over a channel.

- **OFDM Carrier Allocator:** In Orthogonal Frequency Division Multiplexing (OFDM), the Carrier Allocation block plays a crucial role in organizing the subcarriers within the system. The available frequency spectrum is divided into several subcarriers via OFDM, each of which carries a piece of the data. The subcarriers that are used for data transmission and their distribution over the frequency spectrum are decided by the carrier allocation block.

- **Osmocom sink:** The osmocom sink block is specifically designed to interface with SDR hardware supported by Osmocom, such as certain models of Ettus Research USRP devices, LimeSDR, HackRF, and others. It allows GNU Radio users to transmit signals generated within a flowgraph to these SDR devices for transmission over the air.

- **RTL SDR Source:** The RTL-SDR Source block in GNU Radio is used to receive digital signals using RTL-SDR (RTL2832U) dongles.

- **FFT:** In GNU Radio, the FFT (Fast Fourier Transform) block is a fundamental signal processing block used for performing the Fast Fourier Transform on input data streams. The FFT block converts time-domain signals into frequency-domain representations, allowing users to analyze the spectral content of signals. The Fast Fourier Transform and the Inverse Fast Fourier Transform can both be carried out with it.

- **File Source:** The File Source block is used to read data from files and provide it as an input stream to a flowgraph. This block is particularly useful for processing pre-recorded or saved data, allowing users to analyse signals that have been captured and stored in files.

- **File Sink:** Information from a flowgraph can be written to a file using the "File Sink" block. It allows users to save digital samples generated within a flowgraph or processed by other blocks to a file for further analysis, storage, or playback.

- **OFDM Channel Estimation:** Channel estimate is an essential procedure in OFDM (Orthogonal Frequency Division Multiplexing) systems for determining the properties of the communication channel between the transmitter and receiver. Since OFDM divides the available frequency spectrum into multiple subcarriers, each experiencing different channel conditions, channel estimation helps in compensating for the effects of frequency-selective fading and other impairments. In order to accurately demodulate and decode sent signals, the "OFDM Channel Estimation" block in GNU Radio is intended to estimate the channel response or characteristics in an OFDM system.

C. *Equations*

Antenna Length= $\frac{\lambda}{2}$ and λ= $\frac{c(speed\ of\ light)}{f}$.

So, antenna length= $\frac{c}{2\times f} \approx$ 0.345 m or 34.5 cm.

IV. RESULTS AND ANALYSIS

HackRF One was used to transmit OFDM signals with a center frequency of 435MHz and a bandwidth of 2MHz. Fig. 6 and Fig. 7 show the transmitted and received text files in the software simulation, respectively.

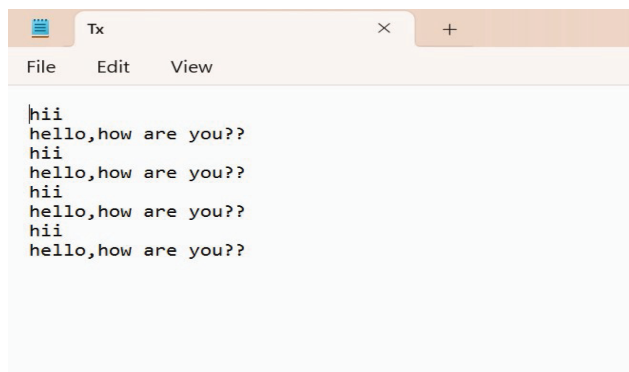

Fig. 6. Transmitted Text File

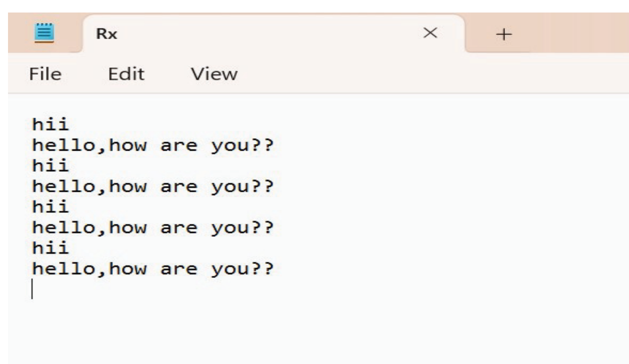

Fig. 7. Received Text File

The time domain transmitted signal waveform and its spectrum for Audio input are shown in Fig. 8.

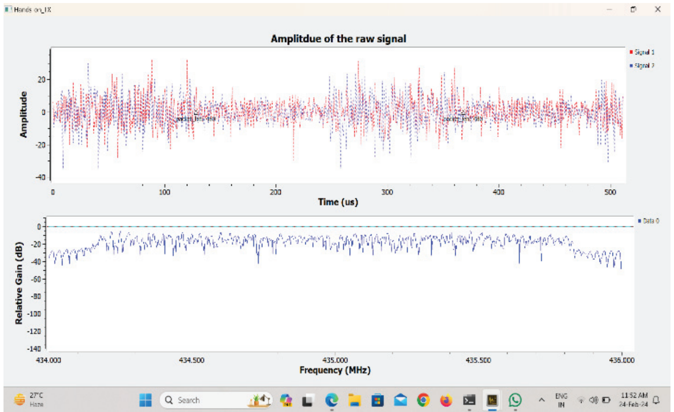

Fig. 8. Transmitted Signal waveform and its Spectrum

At the receiver end, RTL-SDR was used to detect OFDM signals of 435MHz frequency[4]. The spectrum of received signal is shown in Fig. 9. We have also plotted the IQ Constellation and it is shown in Fig. 10. Since QPSK modulation was used, the IQ Constellation has 4 points[2].

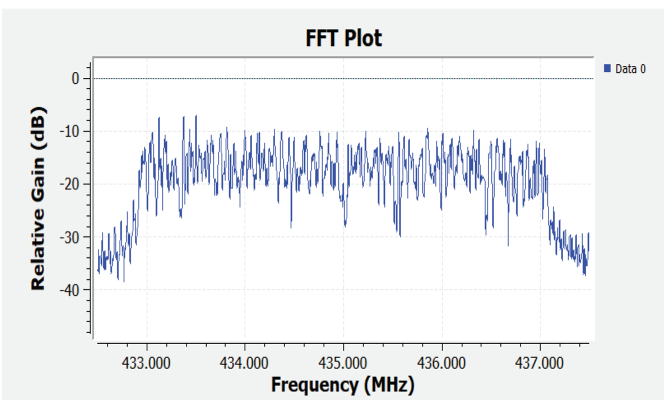

Fig. 9. Received Signal Spectrum

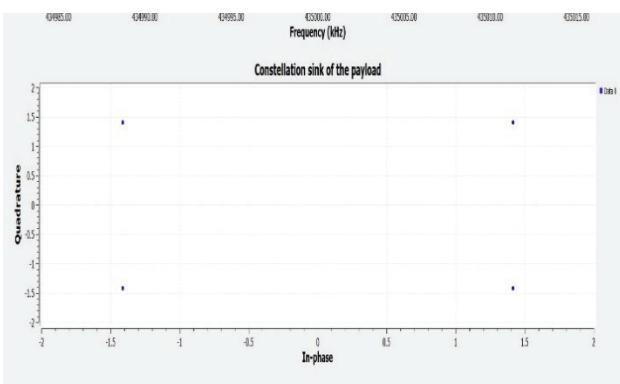

Fig. 10. IQ Constellation of Received Signal

The transmitted and received images in software simulation are shown in Fig. 11 and Fig. 12 respectively.

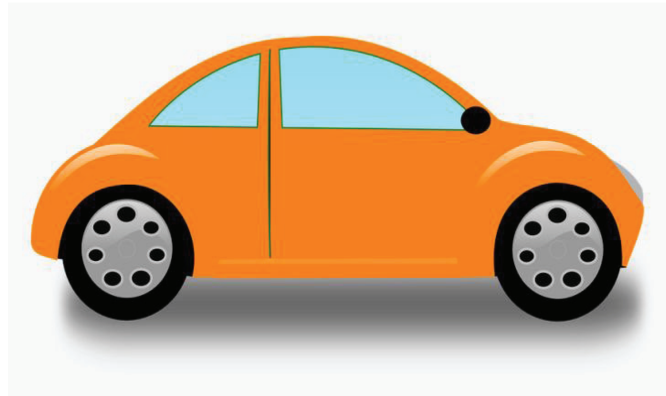

Fig. 11. Transmitted Image

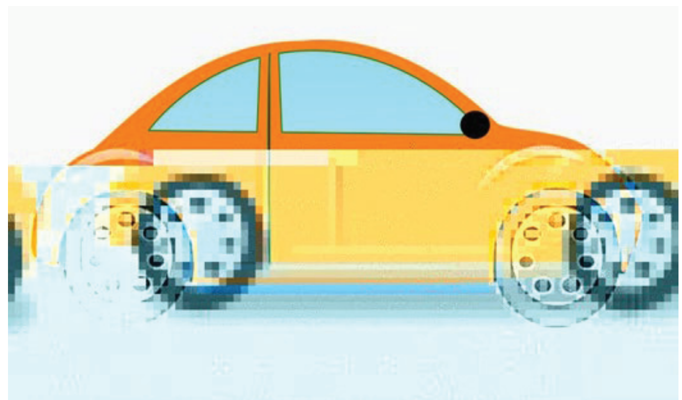

Fig. 12. Received Image

V. CONCLUSION

Throughout the duration of this project, we embarked on a comprehensive exploration of wireless communication, delving into a myriad of modulation techniques, antennas, and Software Defined Radio (SDR) devices. This endeavor aimed to provide a thorough understanding of the intricacies inherent in modern wireless communication systems. Central to our work was the utilization of GNU Radio Companion as our primary tool, leveraging its versatile capabilities to facilitate the transmission and reception of Orthogonal Frequency Division Multiplexing (OFDM) signals. Text, audio and image files have been successfully transmitted while plotting their respective FFT plots and constellation diagrams. This allowed us to delve into the complexities of OFDM modulation and gain practical insights into its application in real-world scenarios. A pivotal aspect of our investigation focused on understanding the effects of shadowing on signal strength. By manipulating the distance between transmitter (TX) and receiver (RX) antennas within our controlled laboratory environment, we observed variations in signal strength, shedding light on the dynamic nature of wireless propagation. This exploration provided valuable insights into the challenges posed by shadowing in practical communication scenarios. Furthermore, we delved into the relationship between antenna length and signal wavelength, a fundamental aspect of antenna design. Through systematic experimentation and analysis, we sought to understand how variations in antenna length impact signal transmission and reception. This investigation allowed us to gain deeper insights into antenna design considerations and their implications for real-world deployment scenarios. By conducting practical experimentation and rigorous analysis, we were able to extract valuable insights into wireless propagation dynamics and the factors influencing signal behavior. This practical method enhances practical skills in wireless communication system design and implementation in addition to solidifying theoretical understanding. The integration of SDR devices with GNU Radio Companion facilitated seamless signal processing and experimentation. This combination provided a powerful platform for designing and implementing wireless communication systems, enabling us to gain practical insights into signal propagation, antenna design, and modulation techniques.

VI. FUTURE SCOPE

The work lays a solid foundation for further exploration and advancement in the realm of Orthogonal Frequency Division Multiplexing (OFDM) and Software Defined Radio (SDR) technology. Here are several avenues for future research and development:

- Future studies can investigate more sophisticated modulation methods, such as Quadrature Amplitude Modulation (QAM) and higher-order constellations, in addition to the fundamental QPSK modulation used in this work. Investigating the performance and complexity trade-offs of different modulation schemes can provide insights into maximizing spectral efficiency and improving data throughput.
- Research can focus on developing adaptive OFDM systems that dynamically adjust modulation parameters, subcarrier spacing, and power allocation based on channel conditions. By integrating machine learning algorithms and cognitive radio techniques, adaptive OFDM systems can optimize performance in varying environments and mitigate interference effectively.
- Extending the project to incorporate MIMO techniques can enhance system capacity and reliability by exploiting spatial diversity. Future research can investigate MIMO-OFDM systems, including space-time coding, beamforming, and precoding techniques, to achieve higher data rates and improved link robustness in wireless communication.
- Further research can focus on optimizing channel coding and error correction techniques for OFDM systems, including forward error correction (FEC) codes, turbo codes, and LDPC codes. Investigating advanced coding schemes and iterative decoding algorithms can improve error resilience and enhance system performance in noisy or fading channels.
- Addressing interference challenges in OFDM-based systems remains a critical area for future research. Techniques such as interference cancellation, spectrum sensing, and dynamic spectrum access can mitigate co-channel and adjacent channel interference, enabling more efficient spectrum utilization and coexistence with other wireless systems.
- Enhancing the security and privacy of OFDM-SDR systems is paramount in ensuring data integrity and confidentiality. Future research can explore encryption techniques, authentication protocols, and secure key exchange mechanisms to protect communication channels from eavesdropping, tampering, and unauthorized access.
- Exploring the integration of OFDM-SDR systems with emerging technologies such as blockchain, edge computing, and Internet of Things (IoT) can unlock new applications and use cases. Research in this area can focus on enabling seamless connectivity, efficient resource management, and decentralized communication in future wireless networks.

By delving into these future research directions, the project can contribute to advancing the state-of-the-art in OFDM and SDR technology, paving the way for innovative solutions and applications in wireless communication systems. Additionally, collaboration with industry partners and academia can facilitate technology transfer and real-world deployment of research outcomes, driving further innovation and impact in the field.

REFERENCES

[1] Zaidoon Y. Hadi, Manal J. Al-Kindi, "Design and Implementation of Software Defined Radio System for OFDM Communications", Department of Electronic and Communications Engineering, Al-Nahrain University Baghdad, Iraq, ISSN: 0974-5823 Vol. 7 No. 2 February, 2022.

[2] Majed M. Albogame and Khaled M. Elleithy, "Enhancement Orthogonal Frequency Division Multiplexing (OFDM) in Wireless Communication Network by Using PTS(Partial Transmit Sequences) Technique", University of Bridgeport, Bridgeport, CT 06604, USA.

[3] Y. Dou and F. Zhang, "Design and Implementation of OFDM Communication System Based on ARM," *2018 10th International Conference on Intelligent Human-Machine Systems and Cybernetics (IHMSC)*, Hangzhou, China, 2018, pp. 362-365, doi: 10.1109/IHMSC.2018.10188.

[4] C. Jing, X. Tang, X. Zhang, L. Xi and W. Zhang, "Time domain synchronous OFDM system for optical fiber communications," in *China Communications*, vol. 16, no. 9, pp. 155-164, Sept. 2019, doi: 10.23919/JCC.2019.09.011.

[5] A. Ghazi, S. Aljunid, S. Z. S. Idrus, A. Fareed, A. Al-dawoodi, Z. Hasan, et al., "Hybrid Dy-NFIS & RLS equalization for ZCC code in optical-CDMA over multi-mode optical fiber," Periodicals of Engineering and Natural Sciences, vol. 9, pp. 253-276, 2021.

[6] A. Y. Reddy, B. L. Reddy, A. S. Naga Veera Sai, A. K and P. S. S, "MSE and BER Analysis of Text, Audio and Image Transmission Using ML Based OFDM," 2020 IEEE International Conference for Innovation in Technology (INOCON), Bengaluru, India, 2020, pp. 1-3.

[7] D. T. Nguyen, F. Safaei, and P. J. Vial, "An experimental study of OFDM in software defined radio systems using GNU platform and USRP2 devices," in 2014 International Conference on Advanced Technologies for Communications (ATC 2014), 2014, pp. 657-662.

[8] de Souza, E. O., Dias, J. T., & Gonçalves, D. N. (2023). Implementation and Performance Analysis of a Low Resolution OFDM System Prototype with Low Cost Hardware. *Journal of Communication and Information Systems*, *38*(1), 149–156.

[9] A. Amphawan, A. Ghazi, and A. Al-dawoodi, "Free-space optics mode-wavelength division multiplexing system using LG modes based on decision feedback equalization," in EPJ Web of Conferences, 2017, p. 01009.

[10] M. Braun, M. Muller, M. Fuhr, and F. K. Jondral, "A USRP-based testbed for OFDM-based radar and communication systems," in Proceedings of 22nd Virginia Tech. Symposium on Wireless Communications, 2012.

[11] Yatagiri, M., & Telagathoti, P.Fast Convergent Unified Richardson Detection Technique for Massive MIMO Systems. In 2022 International Conference on Recent Trends in Microelectronics, Automation,

Computing and Communications Systems (ICMACC) (pp. 200-203),2022.