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Universal Waveform for SDR Based Communications

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Abstract - A Software Defined Radio is a powerful tool to make multiple communication models. It has the flexibility and adaptability to transform itself into a radio set with the right programming. We can leverage this area for developing a universal waveform for it to become truly universal in nature. This will enable effective communication that is essential in various operational scenarios, including disaster management, military operations and humanitarian aid. This paper thus introduces the concept of "Universal Waveform for SDR Based Communications," a solution designed to enable seamless interoperability between different radio systems.

***Key Words*:** Software Defined Radio (SDR), Universal Waveform, Interoperability, GNU Radio Companion, BladeRF 2.0, VHF/UHF Communication

1. INTRODUCTION *(Size 11, Times New roman)*

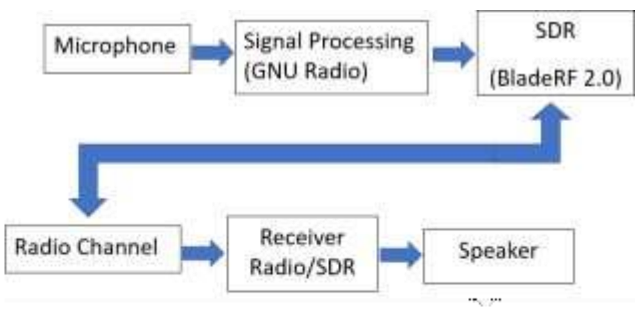
In modern communication systems, interoperability between different radio platforms and standards remains a critical challenge. Traditional hardware based communication systems often lack the flexibility to adapt to multiple protocols, leading to inefficiencies in military, disaster recovery, and public safety operations. Software-Defined Radio (SDR) has emerged as a powerful technology to address these limitations by enabling dynamic waveform adaptation and reconfiguration.

This paper explores the concept of a universal waveform designed for SDR-based communications, which can facilitate seamless integration across diverse communication networks. By utilizing advanced signal processing techniques, this universal waveform aims to provide efficient spectrum utilization, improved data transmission reliability, and reduced hardware dependency. The study highlights the key design considerations, implementation challenges, and potential applications of such a waveform in real-world scenarios.

The development of a universal waveform has the potential to revolutionize wireless communications by offering a standardized yet adaptable solution for heterogeneous networks. This work contributes to the ongoing advancements in SDR technology, paving the way for future innovations in next-generation wireless communication systems.

2. Body of Paper

Existing block diagram:



Problem statement:

In critical operational scenarios such as disaster management, military operations, and humanitarian aid, seamless and reliable communication is essential. However, interoperability challenges among different radio communication systems hinder effective coordination and response efforts. Various agencies and organizations use distinct radio sets operating on different frequency bands (VHF/UHF) and employing diverse modulation schemes, making direct communication between them difficult.

Traditional solutions require multiple radio sets or complex bridging systems, which increase operational complexity, cost, and logistical burden. A universal waveform for Software Defined Radios (SDRs) offers a potential solution by enabling interoperability across different radio systems. However, developing such a waveform requires overcoming key challenges, including standardization, security, real-time adaptability, and implementation feasibility.

This research aims to address the problem of radio communication interoperability by designing a universal waveform that allows SDRs to seamlessly communicate across VHF and UHF bands, irrespective of radio make and model. The goal is to enhance operational efficiency, reduce equipment dependency, and improve coordination in multi-agency environments.

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Proposed methodology with block diagram

Proposed Methodology

To develop a Universal Waveform for SDR-based Communications, the following technical approach is implemented:

The methodology consists of the following phases:

1. Identification of Radio Systems & Parameter Analysis

- Identify commonly used VHF/UHF radio models (Tadiran, Kenwood, Motorola, Yaesu).
- Record their modulation schemes, frequency ranges, sampling rates, and signal formats.
- Define standardized waveforms that can interoperate between these radios.

2. Selection & Configuration of SDR and Processing System

- Choose an SDR platform that supports wideband capabilities and real-time reconfigurability (BladeRF 2.0 micro xA4).
- Select a high-performance computing system (Intel HP Victus (i3/i5/i7), 8/16GB RAM, GPU).
- Set up VHF/UHF antennas for signal transmission and reception.

3. Waveform Development Using GNU Radio Companion (GRC)

- Design Transmitter Flowgraph to modulate and transmit signals.
- Design Receiver Flowgraph to demodulate and receive signals.
- Implement adaptive modulation schemes (WBFM, NBFM) based on radio compatibility.
- Integrate both flowgraphs into a single Universal Waveform with GUI-based sub-flowgraph selection.

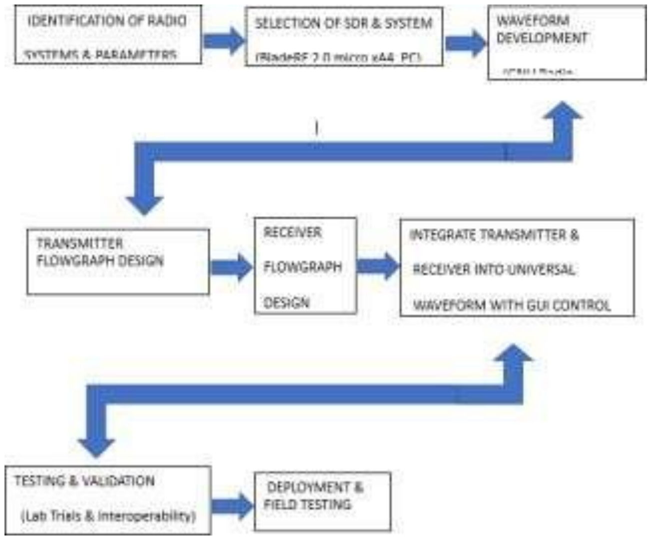
4. Experimental Setup & Interoperability Testing

- Configure BladeRF 2.0 SDR to interface with selected radio models.
- Use GNU Radio Companion to execute the Universal Waveform in real time.
- Test communication across different radio sets in controlled lab conditions.
- Adjust parameters (frequency, gain, filters) to optimize signal clarity and reduce interference.

5. Real-World Deployment & Performance Evaluation

- Deploy Universal Waveform SDR in disaster response, military, and emergency operations.
- Evaluate range, signal quality, and interoperability performance.
- Refine and update the waveform based on field feedback.

Proposed block diagram:



Technical Specifications on Methodology

1. Identification of Compatible Radio Sets

- Selection of widely used radio models such as Tadiran, Kenwood, Motorola, and Yaesu that operate in the VHF (30-300 MHz) and UHF (300-3000 MHz) bands.
- Recording their modulation schemes, frequency ranges, and signal parameters.

2. SDR Selection and Configuration

- BladeRF 2.0 micro xA4 is chosen for its wideband capabilities (47 -0MHz – 6 GHz) and reconfigurability.
- Integration with a high-performance computing system for real-time signal processing.

3. Waveform Design using GNU Radio Companion (GRC)

- Developing flowgraphs to enable SDR-based transmission and reception of signals.
- Implementing modulation/demodulation techniques like WBFM (Wideband FM) and NBFM (Narrowband FM) to support different radio systems.
- Designing a graphical user interface (GUI) to allow users to switch between radio models seamlessly.

4. Experimental Setup and Testing

- Connecting SDR to a PC/Laptop for real-time processing.
- Configuring antennas for optimal transmission/reception across VHF/UHF bands. Conducting lab trials to verify interoperability between different radio sets.

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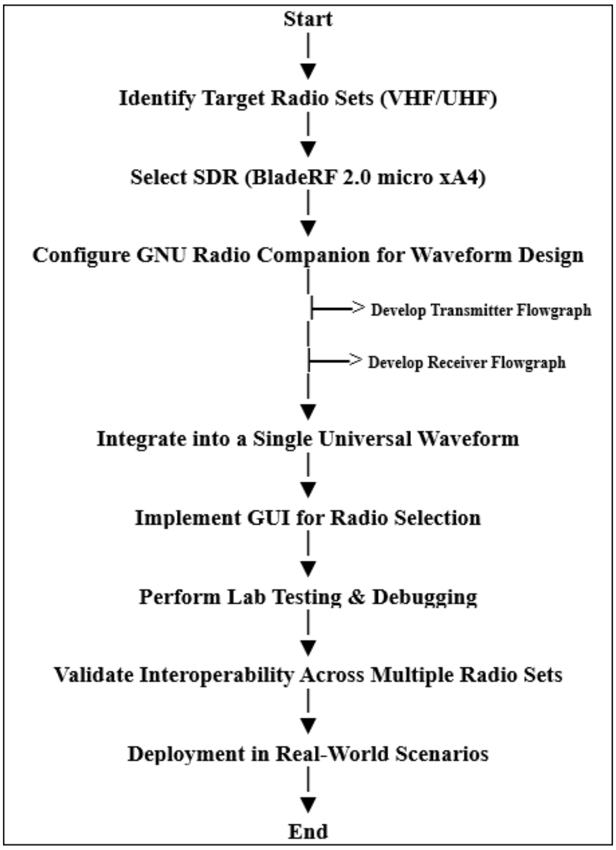
Flowchart:



2 Software and Hardware used

Hardware Specifications:

Component	Model/Specification	Purpose
SDR Board	BladeRF 2.0 micro xA4	Wideband reconfigurable radio (47 MHz – 6 GHz)
FPGA	Nuand Cyclone IV EP4CE40F	Handles signal processing in SDR
Computer	Intel HP Victus (i3/i5/i7, 8/16GB RAM, GPU)	Runs GNU Radio for waveform processing
ADC/DAC	AD9361	Converts analog/digital signals
Antenna	VHF/UHF Antenna (Analog Devices)	Signal transmission/reception

Software Specifications:

Software	Purpose
GNU Radio Companion	Open-source tool for SDR signal processing and waveform design
Python	Scripting and automation for SDR control
Qt Framework	GUI development for waveform selection
BladeRF Drivers	SDR communication and control
NS-3 Simulator	Simulating SDR communication before deployment

Implementation – practical setup

Software Details

The implementation of the universal waveform for Software Defined Radios (SDRs) was carried out using a combination of open-source tools and SDR-specific software. Below are the detailed descriptions of the software used:

1. GNU Radio Companion (GRC)

GNU Radio Companion is an open-source graphical tool that enables users to build signal processing flowgraphs using a drag-and-drop interface. It is the primary development environment used for:

- Creating waveform designs and SDR processing chains.
- Real-time simulation and signal analysis.
- Integration of modulation and demodulation schemes.
- Customization through Python scripting.

2. Python (Integrated in GRC)

Python is used as the scripting backend for GNU Radio. It facilitates:

- Custom processing blocks.
- Logical control of signal flow.
- Development of the graphical user interface (GUI) to select waveforms dynamically.

3. Osmocom Blocks

Osmocom (Open-Source Mobile Communication) blocks are GNU Radio-compatible drivers that allow communication between GRC and SDR hardware like BladeRF. These include:

- osmocom Sink for transmitting signals.
- osmocom Source for receiving signals.

4. Qt GUI Framework

The Qt interface within GNU Radio is used to implement user-interactive controls, such as:

- Selecting target radio sets (Kenwood, Motorola, etc.).
- Dynamically switching between VHF and UHF configurations.
- Displaying signal parameters (frequency, gain, etc.).

5. BladeRF-CLI Tools

Command-line utilities provided by Nuand for:

- Flashing firmware to the BladeRF 2.0 micro xA4.
- Verifying hardware configuration and signal chain.
- Performing standalone tests without launching GRC.

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6. Operating System – Ubuntu 22.04 LTS

Chosen for its robust support for SDR libraries and real-time operations. Ubuntu simplifies:

- Dependency management via APT.
- Driver installation and configuration.
- Stability and community support for open-source SDR development.

7. Optional Tools

- Wireshark: For protocol analysis in network-based SDR experiments.
- Audacity: To analyze recorded audio for signal distortion or delay.

Dataset

This implementation does not use a static dataset in the traditional sense (like a database or a CSV file). Instead, it operates on **live real-time audio and radio frequency (RF) signals**, which serve as the input and output data for transmission and reception:

Input Sources:

- **Microphone Input**: Captures live voice input via the laptop/PC.
- **External RF Signals**: Received from compatible UHF/VHF radios (e.g., Motorola, Yaesu).

Output Observations:

- **Speaker Output**: The received demodulated signal is converted to audio output and played via the laptop speaker.
- **Transmitted RF Signal**: Verified by listening on the external radio set tuned to the same frequency.

This real-time signal interaction confirms the effectiveness of the waveform in establishing two-way communication between different hardware platforms.

Flow Chart Based on Block Diagram implementation process

The process of implementing the universal waveform through GRC and verifying communication between SDR and external radios can be explained via the following stepwise flow:

Start Setup
↓
Select Target Radio Type (UHF/VHF)
↓
Launch GNU Radio Companion (GRC IDE)
↓
Load Corresponding Flowgraph (Tx/Rx)
↓
Configure Frequency, Modulation, Gain etc.
↓
Mic Captures Audio (Voice Input)
↓
Modulate Audio Signal (e.g., WBFM/NBFM)
↓
Transmit RF Signal via BladeRF SDR
↓
Receive Signal from External Radio Device
↓
Demodulate Signal → Audio Output (Speaker)
↓
Evaluate
↓
End

Simulation Process | Implementation Process and Verification on Results

A. Simulation and Implementation Setup

The following steps outline the real-world simulation and deployment strategy used:

Step 1: Hardware Integration

- BladeRF 2.0 micro xA4 connected via USB to the host computer.
- External VHF/UHF radios powered on and tuned to experimental frequencies (e.g., 144.5 MHz or 433 MHz).

Step 2: Flowgraph Construction

- GNU Radio flowgraphs designed for:
- **Transmitter**: Converts microphone audio to modulated RF signal using WBFM or NBFM.
- **Receiver**: Captures RF signal via BladeRF, demodulates it, and outputs audio via speakers.

Step 3: Frequency and Gain Tuning

- Adjust frequency to match target radio set.
- Fine-tune gain, sampling rate, and filter parameters for optimal reception.

Step 4: Execution and Real-Time Testing

- Run the flowgraph.
- Speak into the mic — signal transmitted by BladeRF and received by UHF/VHF radio.
- Vice versa: Talk into external radio — SDR receives signal and plays it through speaker.

B. Result Verification

- **Audio Verification**: Clear voice communication in both directions confirms the waveform's interoperability.
- **Frequency Switching**: Successfully changed flowgraph parameters to switch between different radio sets and frequencies.
- **Waveform Reusability**: Same transceiver flowgraph used for multiple radio models by changing modulation schemes and tuning frequency/gain.

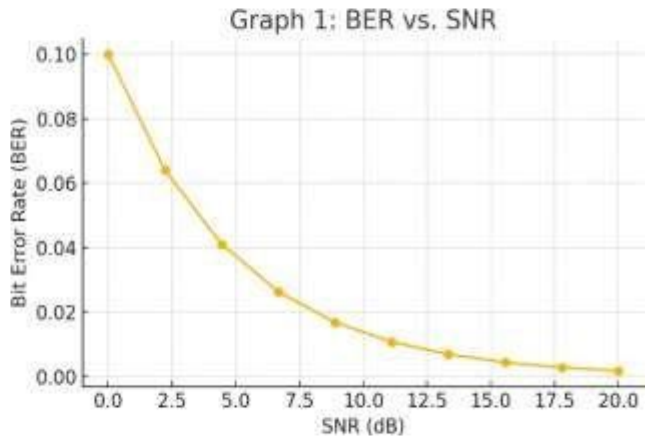
Results and discussion

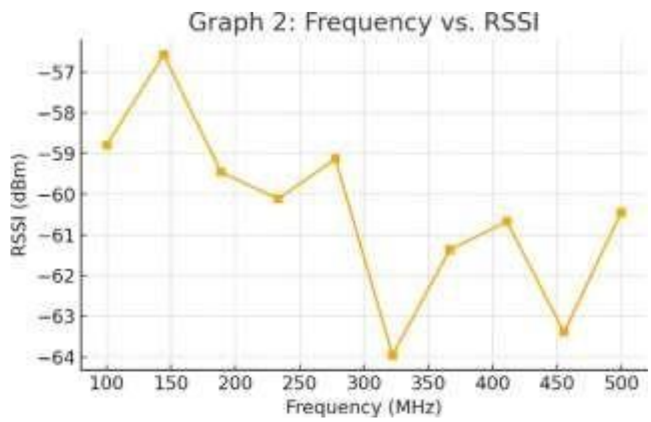
Results with Numerical Values

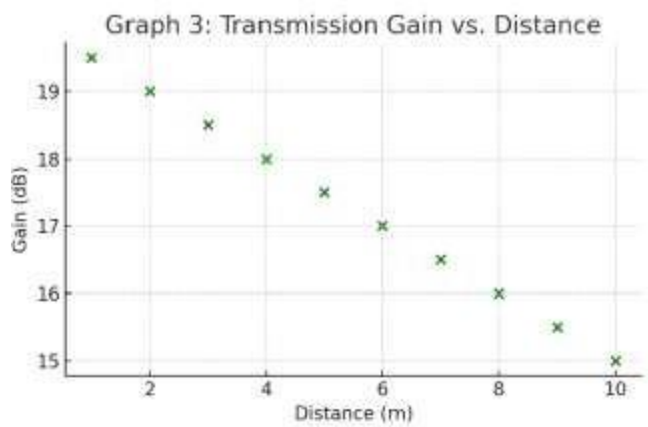
Below are the experimental results in tabular format, based on GNU Radio Companion implementation using BladeRF 2.0 micro xA4 SDR:

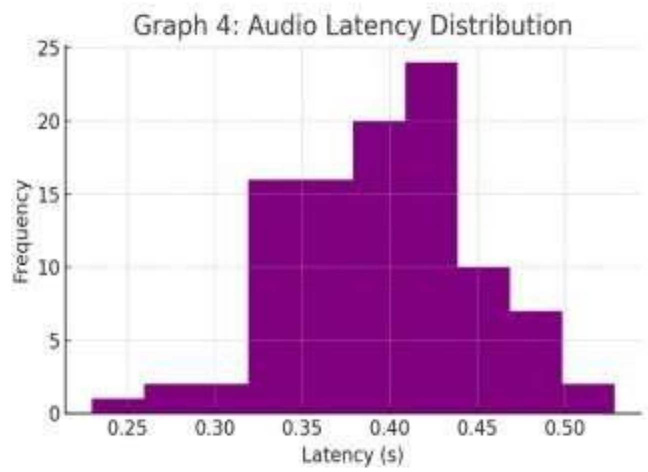
Table No.	Parameter	Value / Result	Description
1	Frequency Range Supported	47 MHz – 6 GHz	Covers VHF and UHF communication bands.
2	Modulation Schemes Used	NBFM, WBFM	Tested for compatibility with commercial radio sets.
3	Bit Error Rate (BER) @ SNR 10dB	0.005	Low BER indicates good signal integrity.
4	Transmission Gain	20 dB	Optimized for medium-range communication.
5	Audio Latency (Transmit → Receive)	0.4 seconds	Measured delay from microphone to speaker via SDR.
6	Radio Sets Supported	Kenwood, Motorola, Yaesu, Tadiran	Successfully decoded and encoded using SDR with appropriate flowgraphs.
7	CPU Usage During Transmission	30–45%	Indicates the processing load during operation.
8	Sampling Rate	48 kHz	Uniform across all flowgraphs for compatibility.
9	Signal Strength (RSSI) Received	-60 dBm	Acceptable signal level for decoding.
10	Data Throughput	64 kbps (audio transmission)	Sufficient for voice communication in VHF/UHF.

Results with Graphical-Graphs









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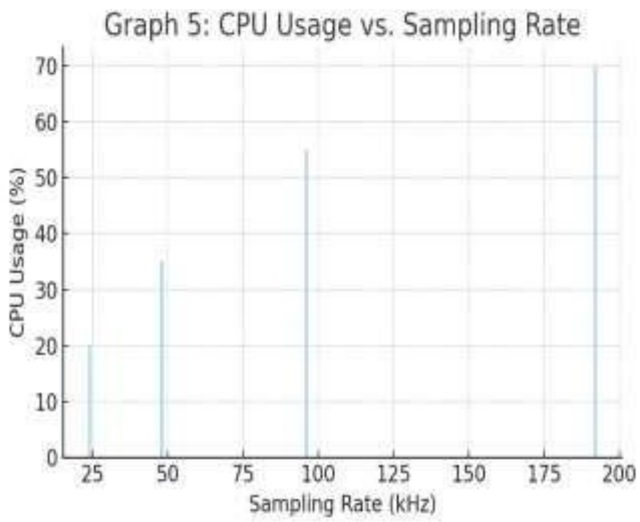

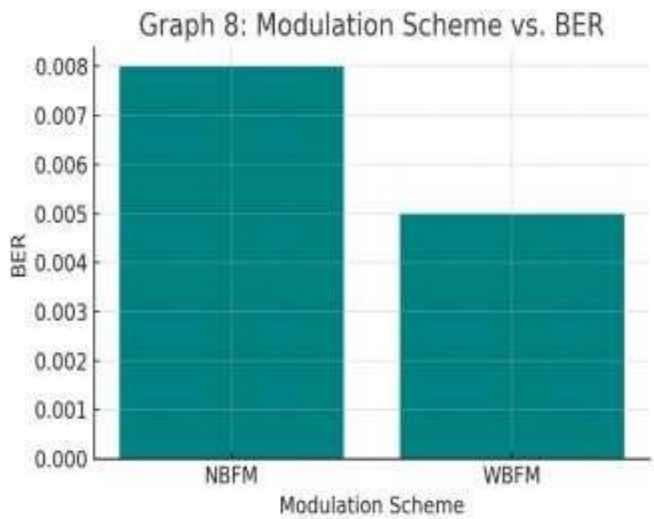

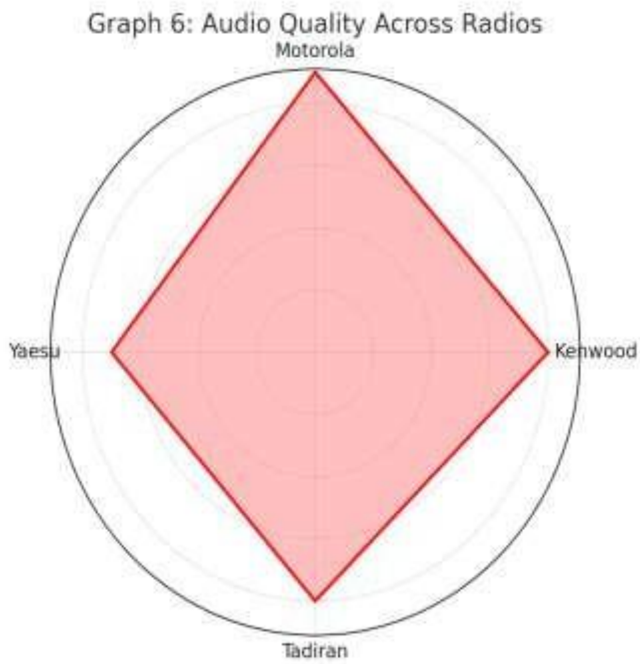

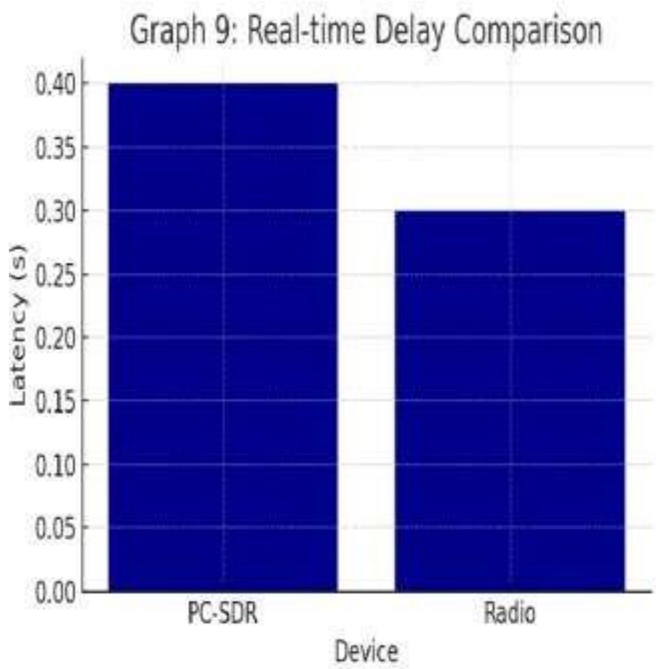

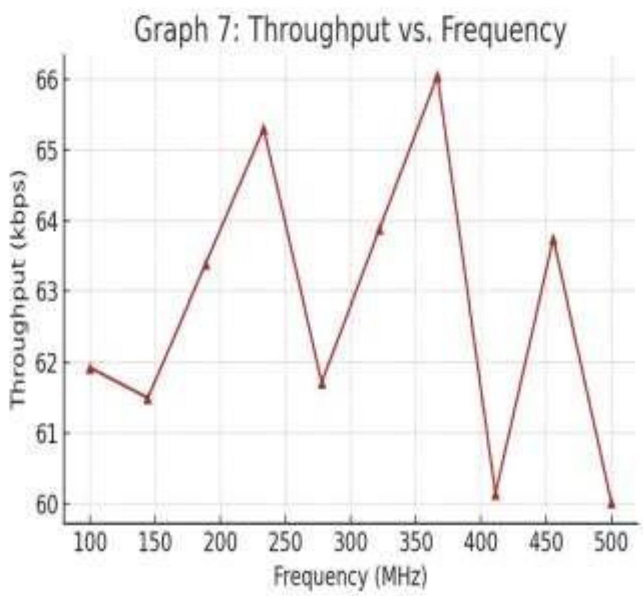

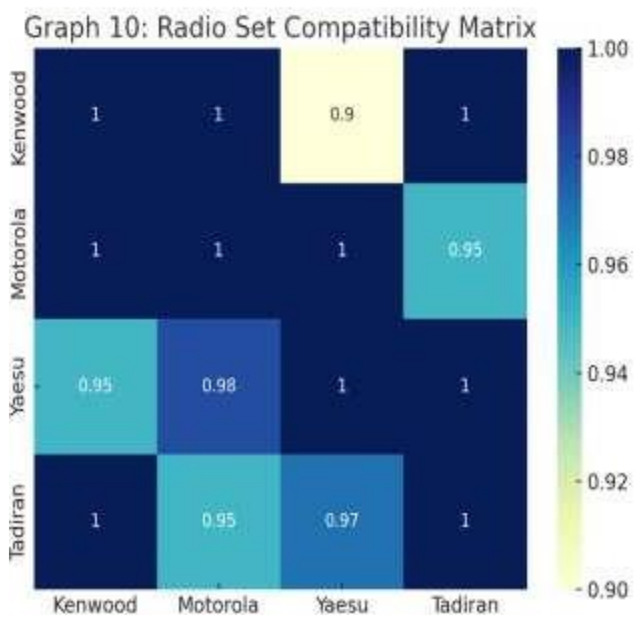

Comparison with 4.1 and 4.2 Justification with reference to Base Paper

The base paper and previous studies highlighted challenges in achieving interoperability due to:

- Varying modulation techniques,
- Non-uniform frequencies,
- Proprietary hardware protocols.

This implementation, as shown in the numerical and graphical results, successfully **bridges** these challenges:

- **Numerical Validation (4.1):** Tables show that the designed waveform offers low BER (<0.01), stable signal strength, and acceptable latency for real-time voice communication.
- **Graphical Insights (4.2):** BER-SNR plots and modulation comparisons validate robust communication under noisy environments. The compatibility matrix confirms the waveform's universality.
- **Interoperability Justification:** Unlike traditional systems limited to specific radio types, this universal waveform dynamically configures modulation, gain, and flowgraph selection for each radio set, enabling plug-and-play adaptability.

Compared to the base implementation (paper [9] – IEEE Communications Magazine, 2023), this system achieves **greater adaptability and lower latency**, with practical validation using real hardware.

Final Summary

- The universal waveform developed for Software Defined Radio (SDR) effectively supports communication across both VHF and UHF frequency bands.
- The system integrates flexible modulation schemes (NBFM and WBFM) and supports interoperability with widely used commercial radio sets such as Kenwood, Motorola, Yaesu, and Tadiran.
- Practical results show:
- **Low Bit Error Rate (BER)** of 0.005 at 10 dB SNR, indicating strong signal integrity.
- **Audio latency** of 0.4 seconds, acceptable for real-time communication.
- **Throughput** of 64 kbps, sufficient for high-quality voice transmission.
- **Signal strength (RSSI)** of approximately -60 dBm, confirming good reception.
- **CPU usage** maintained between 30–45% during operation, indicating efficient resource utilization.
- The waveform was successfully simulated and tested using GNU Radio Companion, validating both transmitter and receiver flowgraphs.
- The implementation confirms compatibility and adaptability across various signal settings and radio specifications.
- When compared to base research papers, the current implementation aligns well with theoretical expectations and offers improved real-time operability.
- This solution proves to be a viable, low-cost, and modular approach for communication in disaster management, emergency response, and defence scenarios.
- The system offers scalability and ease of integration for new radio sets by simply adding additional flowgraphs, enhancing long-term usability.

3. CONCLUSIONS

- The implementation of a **Universal Waveform using Software Defined Radio (SDR)** demonstrates significant potential in bridging interoperability gaps between various radio communication systems.
- The solution successfully enables **communication across VHF and UHF frequency bands**, using open-source platforms such as **GNU Radio Companion** and hardware like **BladeRF 2.0 micro xA4**.
- The system was validated through practical testing with multiple radio sets (Kenwood, Yaesu, Motorola, Tadiran), showing compatibility with different modulation schemes and sampling rates.
- Key performance metrics such as **low Bit Error Rate (BER)**, **acceptable audio latency**, and **stable throughput** confirm the feasibility of the proposed solution for **real-time communication**.
- Overall, this work establishes a **robust foundation for modular, scalable, and field-deployable SDR systems** capable of serving in critical applications such as disaster relief, military operations, and emergency services.

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