ISSN: 2664-9640

Review of Design and Implementation of New Software Radio System based on GNU Radio and USRP

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Abstract

This paper provides a comprehensive review of the design and implementation of software-defined radio (SDR) systems based on the GNU Radio platform and Universal Software Radio Peripheral (USRP) hardware in China. The study highlights the evolution of wireless communication technologies, emphasizing the technical advantages of SDR, including flexibility, scalability, interference resistance, and cost-effectiveness. The analysis explores widely used software platforms (GNU Radio and LabVIEW) and hardware peripherals (USRP and HackRF One), comparing their specifications, functionality, and suitability for diverse communication scenarios.A detailed examination of recent Chinese academic research reveals numerous practical implementations, such as adaptive interference cancellation systems, dual-protocol transceivers, spectrum monitoring platforms, visible light communication (VLC) systems, and MIMO-OFDM architectures. These systems leverage the modularity of GNU Radio and the high performance of USRP to address challenges in real-time data processing, spectrum efficiency, and channel interference. Experimental results from case studies demonstrate advancements in packet error rate (PER) reduction, spectral efficiency (up to 10 bit/s/Hz), and interference suppression (e.g., 20 dB self-interference cancellation for full-duplex systems). Challenges such as hardware limitations, environmental interference, and synchronization issues are discussed, alongside proposals for future enhancements, including hardware upgrades, multi-platform integration, and algorithm optimization. The paper underscores the role of open-source SDR frameworks in democratizing wireless innovation while providing critical insights into emerging trends and practical constraints in software radio research.

Keywords

Software-Defined Radio (SDR); GNU Radio; USRP; Wireless Communication Systems; Adaptive Interference Cancellation.

1. Research Background

1.1. A Brief History of Wireless Communication

In recent years, the rapid development of technologies such as the Internet, mobile communications, and the Internet of Things (IoT) has led to an exponential increase in the demand for wireless communication. The history of wireless communication technology traces back to the 19th century. In 1865, British scientist James Clerk Maxwell established the theory of electromagnetic waves based on previous research, theoretically predicting the existence of electromagnetic waves. In 1887, German physicist Heinrich Hertz experimentally confirmed the existence of electromagnetic waves, earning him recognition as a pioneer of radio communication; the unit of frequency is named after him. From the late 19th century to the early 20th century, Italian inventor Guglielmo Marconi and Russian physicist Alexander Popov

ISSN: 2664-9640

successfully transmitted radio signals, marking the official birth of radio communication technology.

As we moved into the 20th century, radio communication technology entered a phase of rapid development, with countries establishing their own radio communication networks and radio broadcasting becoming widespread among the public. This significantly changed how people accessed information. During World War II, radio communication played an extremely important role in military operations; compared to World War I, it greatly transformed combat strategies and improved information dissemination efficiency. Radio communication provided real-time and long-distance connectivity, enhancing coordination between commanders and troops and playing a decisive role in critical aspects such as operational command and intelligence transmission.

From the late 20th century to the present day, radio communication technology has experienced explosive growth, with various new technologies emerging that have profoundly altered human communication methods. The evolution of mobile communication, has deeply impacted all aspects of human life. In 1983, Motorola introduced the world's first commercial mobile phone, officially marking the advent of 1G mobile communication. Subsequently, with the continuous introduction of 2G, 3G, 4G, and now developing 6G technologies, each generation has made significant advancements over its predecessor. The transition from voice to text, images, videos, and ultimately to ubiquitous connectivity exemplifies the critical importance of wireless communication technology.

1.2. Software Defined Radio (SDR)

Software Defined Radio (SDR) is a wireless communication technology that utilizes software to control traditional hardware circuits. By converting electromagnetic wave signals into digital signals, SDR allows users to process signals-such as modulation and demodulation-through software without requiring extensive modifications to hardware. This approach breaks away from traditional reliance on hardware for communication functions.

SDR offers several notable technical advantages:

1.2.1. High Flexibility and Scalability

The SDR platform is capable of configuring and adjusting multiple communication protocols through software programming, enabling reception, demodulation and decoding in different frequency ranges without the need to modify or even replace hardware. This high degree of flexibility enables SDRs to quickly adapt to different communication requirements.

1.2.2. Strong Interference Resistance

SDR supports various modulation and demodulation techniques that can be selected based on specific channel characteristics and interference conditions. For example, it can employ robust spread spectrum or Orthogonal Frequency Division Multiplexing (OFDM) techniques to enhance system stability and reliability against interference. Additionally, it can utilize multi-antenna technologies like Multiple Input Multiple Output (MIMO), combined with OFDM methods to optimize channel conditions and minimize interference impacts as much as possible.

1.2.3. Cost-Effectiveness

SDR is based on relatively generic hardware platforms and implements most radio functions through software, simplifying complex hardware circuits and reducing components typically required for traditional hardware radios. Furthermore, because SDR development environments are relatively open with many available open-source tools and libraries, these factors collectively contribute to significantly lower development costs for users.

ISSN: 2664-9640

2. Software Radio Platforms and Hardware Peripherals

2.1. Software Radio Platforms

To design and implement a radio communication system, collaboration between software and hardware platforms is essential. Commonly used software platforms include GNU Radio and LabVIEW.

2.1.1. GNU Radio

GNU Radio is a free and open-source software radio platform that allows users to define the transmission and reception of radio signals through software, enabling the construction of radio communication systems. The primary motivation behind the creation of GNU Radio was to address the high costs and limited development options associated with traditional radio equipment, aiming to inspire enthusiasts and developers to explore and innovate in the field of radio signals by providing free software resources.

The core feature of GNU Radio is its high modularity. Users can combine different signal processing modules, such as signal waveform generator, modulator and filter, to form a signal processing system, and flexibly customize the configurations between the modules in the form of an image flowchart, so as to realize the transmission and reception of wireless signals. Users can use the signal processing modules provided by GNU Radio, or customize the modules according to their own needs and compile them into the platform for direct calling.

GNU Radio's software programming is based on C++ and Python languages. By combining the advantages of both programming languages, it provides a flexible and powerful platform to meet the practical requirements of different radio systems. Applications in GNU Radio are typically written in Python, which has a relatively simple syntax that allows for rapid construction of signal processing flowcharts; meanwhile, C++ is commonly used for writing various core signal processing modules known as blocks. Although applications are written in Python, the actual information processing is performed by C++ floating-point extension libraries. The collaboration between C++ and Python within GNU Radio offers software radio developers a robust platform that ensures both development efficiency and high performance.

2.1.2. LabVIEW

LabVIEW, which is the abbreviation of Laboratory Virtual Instrument Engineering Workbench. It is a graphical programming development environment created by National Instruments (NI) in the United States. It enables users to create virtual instruments graphically, using icons and wiring to represent program logic. Its intuitive programming approach makes the overall program structure very clear.

One significant advantage of LabVIEW is its support for multi-platform development across environments such as Windows, Linux, and macOS. If multi-platform development is required, LabVIEW may be a better choice. However, when choosing between GNU Radio and LabVIEW, it is crucial to consider the specific requirements of the designed system. Generally speaking, GNU Radio tends to be more compatible with USRP devices; thus, many researchers opt for this combination when designing specific radio systems.

2.2. Software Defined Radio Hardware Platforms

Software platforms like GNU Radio and LabVIEW provide tools for simulating wireless systems; however, we also need to consider how to map these software functionalities into the real world. Hardware platforms such as USRP (Universal Software Radio Peripheral) and HackRF One provide matching hardware support.

There are many SDR hardware platforms available, among which USRP and HackRF One are commonly used due to their respective application scenarios. The following table 1 presents basic information about these two hardware platforms:

ISSN: 2664-9640

Table 1. USRP and HackRF One parameters

	USRP	HackRF One
Cost	Higher	Lower
Size	Larger	Smaller, portable
Functionality	Comprehensive	Slightly limited
Operating Mode	Full duplex; supports MIMO	Half duplex
Maximum Real-Time Bandwidth	56MHz	20MHz
RF Front-End ADC/DAC Bit Depth	12 bits	8 bits
RF Frequency Range	70MHz-6GHz	1MHz-6GHz

2.2.1. USRP

USRP, which stands for Universal Software Radio Peripheral, is a product line developed by the Ettus Research team. Its primary design goal is to provide a flexible and user-friendly hardware platform for radio applications. A typical USRP product consists of two main components: a motherboard equipped with a high-speed signal processing FPGA and one or more interchangeable daughterboards that cover different frequency ranges.

USRP is equipped with high-performance hardware components, including a radio frequency (RF) front end, analog-to-digital converters (ADC), digital-to-analog converters (DAC), digital signal processors (DSP), and communication interfaces. These components enable the USRP to effectively receive and transmit signals while converting them into digital format for subsequent processing on a computer.

The software component of the USRP operates through software-defined radio (SDR) programs running on a computer. Users can control the USRP by writing code, allowing the program to communicate with external devices via the hardware component of the USRP. The integration of USRP with software platforms like GNU Radio makes the design and implementation of software radio systems more convenient and efficient.

2.2.2. HackRF One

HackRF One is an open-source software-defined radio (SDR) device developed by Great Scott Gadgets, capable of transmitting or receiving radio signals within the frequency range of 1 MHz to 6 GHz.

Since HackRF One does not support full-duplex communication, it cannot send and receive signals simultaneously. Therefore, in practical applications, it is common to use two or more HackRF One devices to ensure that the system can achieve full-duplex functionality. Additionally, due to its more affordable price point, HackRF One is accessible to many enthusiasts and developers, facilitating the promotion and popularization of software-defined radio technology.

However, this lower cost characteristic also means that HackRF One's functionality is relatively less powerful compared to USRP. In some high-performance wireless communication systems, it may still be necessary to choose USRP for designing and implementing more complex functionalities within the system.

3. Current Research Status in China

Many scholars in China have designed and implemented specific radio communication systems based on combinations of the aforementioned software radio platforms and hardware peripherals. These systems have been validated for feasibility through simulations and tests. The following sections provide an analysis of these systems' designs and characteristics.

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3.1. Journal Articles

3.1.1. Software Radio System based on GNU Radio and USRP

Researchers Qu Jiajun, Wang Ming, and others from the School of Electronic Information at Soochow University developed a dual-protocol wireless communication system in their paper titled “An IEEE802.15.4/6 Dual-protocol Transceiver System Based on GNU Radio&USRP” [1]. This system was designed to address the limitations of traditional single-protocol communication systems, which are increasingly unable to meet more complex application scenarios. The researchers explored how to combine different communication protocol standards to achieve higher performance in wireless communication. The system integrates the long-range transmission capabilities of the IEEE802.15.4 standard with the high-speed characteristics of the IEEE802.15.6 standard, enabling complementary wireless communication functions for both protocols. Testing involved transmitting 1000 frames of data under varying Signal-to-Noise Ratio (SNR) conditions, followed by an analysis of Packet Error Rate (PER). Experimental results indicated that as SNR increased, the PER for both protocols significantly decreased, achieving the expected system performance.

Scholars Sun Lingge and others from Air Force Engineering University published a paper titled “Design and Implementation of an Adaptive Interference Cancellation System Based on GNU Radio and USRP” [2]. They constructed a semi-physical simulation system using GNU Radio and USRP platforms, effectively suppressing interference signals entering from antenna side lobes through adaptive interference cancellation technology based on a normalized least mean square error algorithm.

Experimental results showed that when the order of the adaptive filter was set to 2, 3, or 5, approximately 40 dB of interference suppression was achieved. Furthermore, the authors suggested that system performance could be enhanced by increasing the sampling bit depth of USRP devices to expand the signal dynamic range.

Chen Ying, Dou Gaoqi, Wang Qingbo, Deng Ran and other scholars in the article ‘Design and Implementation of Multicode Combined Spread Spectrum Communication Based on GNU-Radio+USRP’ [3], based on GNU Radio and USRP, in the SDR software radio universal platform to build multi-code combined spread spectrum (MCSS) communication transceiver system, and verified the system communication performance by data.

This research paper details the design and implementation of a multi-code combined spread spectrum communication system based on GNU-Radio and USRP. As a novel spread spectrum technology improved from multi-rate spreading techniques, MCSS offers higher bandwidth utilization efficiency. The research team utilized SDR's flexibility to adjust key communication parameters such as spreading code period, constellation mapping method, transmission rate, and carrier frequency according to various parameters while observing sequences, bit information, and signal waveforms before and after spreading to validate system feasibility.

At the Beijing Aerospace Flight Control Center, researchers Feng Zhan, Chen Wenqiang, Chen Lei, and Chen Shuai designed and implemented a spectrum monitoring system in their work titled “Design and implementation of real-time spectrum monitoring system in TT&C station based on USRP” [4]. This system employs USRP N210 hardware peripherals combined with the GNU Radio open-source software platform. As illustrated in Figure 7 of their paper, this system can perform multi-channel monitoring while simultaneously tracking multiple control signals in real-time. Additionally, it can store replay spectrum data for subsequent analysis and processing. The low cost, high flexibility, and portability of this system enable it to meet diverse spectrum monitoring needs across various scenarios.

From Army Engineering University, researchers Lu Chaofeng and Xu Zhiyong analyzed the design and implementation of an indoor Visible Light Communication (VLC) system based on GNU Radio software platform and USRP peripherals in their paper titled “Design and

ISSN: 2664-9640

implementation of visible light communication system based on software defined radio" [5]. The system consists of a transmitter and receiver with signal transmission accomplished via visible light links. It also employs Orthogonal Frequency Division Multiplexing (OFDM) modulation technology to effectively reduce inter-symbol interference. The experiment successfully transmitted 720P video at 30 frames per second in real-time, validating the feasibility of the designed system; however, VLC still faces challenges such as limited transmission distance and susceptibility to ambient light interference. Future research could explore further enhancements in reception methods to improve transmission distance and anti-interference capabilities.

In their article "Design of Pseudo-Satellite Signal Software Transmitter Based on GNU Radio," researchers Guo Jing and Wu Xiaoming implemented a pseudo-satellite software signal transmitter using GNU Radio and USRP platforms [6]. Experimental validation confirmed that emitted signals could be utilized in satellite positioning systems. Pseudo-satellites can supplement Global Navigation Satellite Systems (GNSS), particularly in areas where GNSS signals cannot effectively cover.

GNU Radio was employed to implement pseudo-satellite baseband signals encompassing modulation, demodulation, spreading, encoding processes; while USRP was responsible for converting digital baseband signals into desired frequencies for transmitting pseudo-satellite signals. Finally, receivers were used to verify signals emitted by the designed transmitter; effective reception enabled recognition and observation of data. However, this study did not provide detailed information about specific experimental environments or conditions that might affect its generalizability or reproducibility.

In his article "USRP RIO Communication Jamming System Based on Machine Learning," Lyv Guanghui focused on enhancing security and reliability within communication systems [7]. This system developed an intelligent wireless communication interference mechanism using machine learning concepts alongside USRP hardware peripherals; reinforcement learning was employed to predict interference for optimal disruption effects during signal transmission experiments. The results indicated that when no interference occurred during signal transmission, constellation diagrams appeared clear; conversely, under interference conditions they became disordered and dispersed without achieving optimal outcomes. Although experimental results did not reach peak effectiveness yet provided new ideas for research related to communication interference; future studies may further optimize algorithms to enhance interference effects within such systems.

3.1.2. Software Radio System based on GNU Radio and HackRF

Additionally, some researchers have utilized the more affordable HackRF hardware development boards as an alternative to the higher-cost USRP for the design of software radio systems, aiming to promote the widespread use of radio systems.

In their paper titled "Spectrum Sensing and Communication System Design Based on GNU Radio and HackRF" [8], Xia Qiu, Shi Shouhan, and others designed a system capable of spectrum sensing within specific frequency bands, with the goal of efficiently utilizing precious spectrum resources and minimizing waste. This system employs four half-duplex HackRF development boards to form nodes A, B, C, and D, which are responsible for signal capture, transmission, reception, and spectrum sensing. Nodes C and D serve as normal communication nodes and interference sources, while node A performs spectrum sensing and transmits data to node B when it detects that the channel is idle.

Experimental validation demonstrated that node A successfully captured a 433 MHz signal that was not occupied by nodes C or D, indicating that the channel was free; thus, it successfully transmitted information to node B. Node B also successfully decoded the data transmitted by node A, confirming the reliability of the designed system.

Xia Qiu, Shi Shouhan, and others also developed a system based on GNU Radio and HackRF, which was published in their paper "Signal Capture and Communication System Design Based on GNU Radio and HackRF" [9]. This system is primarily divided into two main components: an FM signal capture system and a signal amplification relay system.

The FM signal capture system is designed to capture, process, and play FM signals within the 99 MHz frequency band. The system uses a low-pass filter to eliminate low-frequency signals before adjusting the sampling rate and performing FM demodulation to receive and play FM signals. This can be applied in scenarios such as broadcasting reception and signal monitoring. The signal amplification relay system consists of three subsystems: signal capture and storage, signal amplification and transmission, and signal reception and decoding. Three HackRF development boards are required for capturing, transmitting, and receiving signals respectively. This system can be practically used for relaying and forwarding signals in wireless communication to enhance signal coverage.

In summary, this system's design effectively captures and processes wireless signals using low-cost hardware and open-source software to meet communication needs in specific scenarios.

Hao Jingtang, Su Zhigang et al., in their paper "Design of ADS-B Signal Transceiver System Based on GNU Radio" [10], implemented an ADS-B (Automatic Dependent Surveillance - Broadcast) signal transceiver system based on GNU Radio and HackRF. ADS-B is a technology used for air traffic monitoring that enables aircraft to automatically broadcast information such as position, speed, and direction for air traffic regulation.

Due to the high costs associated with real-world airborne monitoring research and development, this system serves as a low-cost and highly extensible ADS-B signal transceiver capable of simulating real-time aircraft signal transmission and reception processes. The system is divided into two main parts: the transmitter acquires historical state information from aircraft; encodes it into baseband signals; upconverts it for power amplification; then transmits it via an antenna; while the receiver captures ADS-B signals through an antenna; down converts the received high-frequency signals into baseband signals; detects demodulates them; then analyzes to extract information regarding aircraft position, speed, direction etc., thus completing the operation of the entire system.

However, if this system is put into practical use, considerations regarding actual weather conditions must also be taken into account. For example, during overcast or rainy/snowy weather conditions, measures may need to be adopted to improve signal quality and enhance the system's resistance to interference. This could involve increasing transmission power to enhance signal penetration capability; however, this may interfere with other electronic devices requiring careful consideration. Additionally, antenna diversity techniques could be employed to increase both the probability of receiving signals as well as their quality; though this may incur additional costs.

3.1.3. Software Radio System based on LabVIEW and USRP

In addition to using the GNU Radio platform, some researchers have also designed and implemented software radio systems based on LabVIEW in combination with USRP.

Scholars Hu Wenbo, Li Haoyang, and Liu Haitao developed a broadband aviation communication system called L-DACS1 in their paper "Design and Implementation of L-DACS1 Forward Link Based on USRP" [11]. This system employs Orthogonal Frequency Division Multiplexing (OFDM) technology, aiming to provide high transmission capacity and data throughput for communication services.

In their design, the authors utilized the USRP N210 along with the LabVIEW graphical programming environment to construct both the transmitter and receiver for the L-DACS1 forward link. Transmission tests were conducted in a laboratory setting. Based on the power

ISSN: 2664-9640

spectrum and time-domain waveform obtained from the test results, the received signals were found to be consistent with the transmitted signals.

The paper also discusses the Bit Error Rate (BER) performance of the L-DACS1 system under different channel conditions, such as Additive White Gaussian Noise (AWGN) channels and multipath channels. Simulation results indicated that the measured and simulated BER curves were essentially parallel, demonstrating that the designed system achieved its expected performance.

Li Haoyang, Liu Haitao, Li Dongxia, and others from Civil Aviation University of China detailed their work on an 802.11a OFDM transceiver system in "Design and Implementation of 802.11a OFDM Transceiver Based on USRP" [12]. This study elaborates on how they implemented an 802.11a OFDM transceiver system using USRP and LabVIEW. The OFDM technology segments the channel into multiple mutually orthogonal sub-channels, converting high-speed transmitted signals into low-speed parallel data streams that are modulated onto sub-channels for data transmission. In accordance with the IEEE 802.11a standard, OFDM is applied at the physical layer of wireless local area networks (WLANs) to achieve high-speed and reliable wireless data transmission by controlling modulation and coding for each sub-channel.

Figures 9(a) and 9(b) in their paper illustrate constellation diagrams of received signals affected by noise and frequency offset, respectively. The constellation points in Figure 9(a) are dispersed, indicating that Additive White Gaussian Noise (AWGN) impacts these points as they traverse through the channel, leading to increased error rates during receiver decision-making processes. The Bit Error Rate (BER) is a critical metric for assessing system performance; excessively high BER can compromise reliability. By observing the degree of dispersion in constellation points, one can effectively evaluate signal quality. The cleaner the constellation diagram, the better the signal quality; conversely, a more cluttered diagram indicates poorer signal quality.

Frequency offset refers to a deviation between the carrier frequencies of transmitted and received signals, which affects signal phase and causes constellation points to rotate around an origin point-potentially leading to symbol interference that impacts signal reception and overall system performance. Therefore, when designing and implementing practical communication systems, it is essential to consider noise and frequency offset effects while adopting corresponding measures such as modulation techniques, coding strategies, and frequency offset correction algorithms to minimize their impact on system performance.

In their paper "Design of MIMO communication systems based on USRP platform," Feng Jiao, Liu Wen, and Li Peng constructed a communication system based on Multiple Input Multiple Output (MIMO) technology [13]. This system operates as a semi-physical semi-experimental setup utilizing USRP software-defined radio peripherals alongside LabVIEW graphical software development integrated environments.

The system employs two transmitting antennas and two receiving antennas while utilizing Alamouti space-time coding to split a single-input single-output (SISO) data stream into two separate streams. Alamouti coding is a space-time coding technique proposed in 1998 that allows two data symbols s1 and s2 to be transmitted from two antennas simultaneously while orthogonalizing the channel matrix-helping reduce interference between signals. Additionally, OFDM is introduced at the transmitter end to further mitigate inter-symbol interference. The receiver side of the system uses the frequency domain least squares algorithm LS for channel estimation and the maximum likelihood detection algorithm ML to detect the received signal.

Finally, experimental validation confirmed the feasibility of this system; it successfully transmitted and received signals while combining LS channel estimation with maximum likelihood detection algorithms to enhance overall transmission performance.

3.2. Dissertation

Shen Mengmeng from China University of Mining and Technology developed a MIMO-OFDM wireless communication system in her thesis titled “Design of MIMO-OFDM System Based on GNU Radio and USRP” [14]. This section represents the core content of her research, transforming theoretical studies into practical system implementations while validating the improved algorithms. At the receiver end of the communication system, the author designed modules for signal demodulation and channel estimation. The channel estimation module was custom-built by the author, applying an enhanced channel estimation algorithm to the MIMO-OFDM system.

The author also conducted experimental tests involving the transmission of images, videos, and text data to validate the performance of the improved algorithms and system. By comparing data from both the receiver and transmitter, it was shown that the enhanced channel estimation and synchronization algorithms effectively reduced error rates in signal reception and transmission. In practical communication channels, the performance of these improved algorithms significantly outperformed traditional methods. However, due to hardware limitations, the system's performance did not reach its optimal level. Future work could involve additional hardware support to construct a higher transmission rate MIMO-OFDM system.

In the paper “Research on Self-Interference Cancellation Technology for Full-Duplex Wireless Communication System Based on USRP and GNU Radio” [15], published in 2019 under the guidance of Prof. Nan Jing, Peng Dong of Yanshan University focused his research on how to effectively eliminate self-interference signals from a full-duplex communication system to improve the performance of the system. Full-duplex communication allows simultaneous data transmission in both directions and simultaneous signal transmission and reception. Therefore, this technology can theoretically save valuable spectrum resources and double the spectrum utilization, which is of great significance to modern communications where spectrum resources are increasingly tight. However, a big problem faced by full-duplex communication is the problem of self-interference. Self-interference refers to the interference caused by the device's own transmitting signal to the receiving signal in wireless communication, which will seriously affect the communication quality.

In this paper, Dong Peng designed and implemented a self-interference cancellation system for full-duplex communication based on GNU Radio software radio platform and USRP hardware peripherals. This system operates within the digital domain of radio communications; it employs a self-interference cancellation algorithm based on training sequences within a proposed full-duplex OFDM baseband model. The algorithm reconstructs self-interference signals in both frequency and time domains using known transmitted signals and estimated values from self-interference channels. Ultimately, it subtracts the estimated self-interference signal from the received signal to achieve cancellation.

Experimental validation involved testing under different bandwidth conditions to assess actual self-interference cancellation levels. The final results indicated that the digital domain self-interference cancellation algorithm could effectively suppress self-interference signals by 20 dB, confirming the feasibility of the designed cancellation system. However, it should be noted that self-interference cancellation was addressed independently in both analog and digital domains; future research could consider integrating these two domains for more effective cancellation methods. Additionally, while experiments were conducted with bandwidths ranging from 1 MHz to 10 MHz, exploring wider bandwidths could yield insights into achieving effective self-interference cancellation.

Li Yang from Hunan University developed a physical layer data transmission system suitable for vehicle-to-vehicle (V2V) communication in his master's thesis titled “Physical Layer Design and Implementation of Vehicle-to-Vehicle Communication Based on GNU Radio and USRP” [16].

ISSN: 2664-9640

V2V communication is a technology that enables vehicles to share speed, position, and other driving information through radio signals. Key performance indicators include real-time capabilities and reliability to ensure rapid and accurate transmission of critical information. Therefore, Li Yang meticulously designed and comprehensively validated various modules at both transmitter and receiver ends for V2V communication's physical layer, including signal synchronization, channel estimation, OFDM demodulation techniques, convolution coding, among others. A semi-physical simulation testing platform was established to evaluate system performance under scenarios with unobstructed direct paths as well as obstructed paths-focusing primarily on key metrics such as latency and Bit Error Rate (BER). Experimental data ultimately demonstrated that the implemented system met design requirements. While testing was conducted in a semi-physical simulation environment, conducting performance evaluations under real vehicle and road conditions would likely yield more accurate data.

Zhang Hao from Xi'an University of Technology designed an anti-fading MIMO-OFDM system combining advantages from MIMO technology and OFDM technology in his master's thesis titled “Design of Multipath Channel Measurement and Anti-Fading System Based on USRP” [17]. MIMO (Multiple Input Multiple Output) is an antenna spatial diversity technique that enhances signal strength by utilizing multiple antennas at both transmitting and receiving ends through multipath propagation—thereby improving transmission rates in wireless communication systems. Zhang first identified shortcomings in traditional algorithms before proposing an improved synchronization algorithm; simulation experiments confirmed that this enhanced algorithm maintained high synchronization even at low SNR conditions.

Following improvements to synchronization algorithms, Zhang designed an SISO-OFDM (Single Input Single Output Orthogonal Frequency Division Multiplexing) system where key components included transmitter design responsible for modulating data into OFDM signals sent via USRP while receivers demodulated incoming signals post-reception. Building upon SISO principles further led to designing a 2x2 MIMO-OFDM system with additional enhancements made to synchronization algorithms tailored for multi-antenna MIMO systems' requirements.

Final tests verified actual send-and-receive results for their designed MIMO-OFDM system through image file transmissions among other data types-demonstrating successful data transmission with low BER values confirming feasibility of their design approach. However, due to hardware limitations imposed upon bandwidth constraints affecting transmission rates alongside restricted numbers of transmitting/receiving antennas within their MIMO-OFDM setup; future endeavors may involve employing more advanced equipment enabling configurations such as four-transmitter-four-receiver or greater multi-antenna systems if conditions permit.

Under Professor Qingyi Quan's supervision at Beijing University of Posts and Telecommunications (BUPT), Xie Fuxin explored high spectral efficiency wireless communication systems based on software-defined radio in her master's thesis titled “Research and Implementation of High Spectral Efficiency Communication Systems Based on Software Defined Radio” [18]. Utilizing LabVIEW alongside USRP-N200 software-defined radio platforms allowed Xie Fuxin's research focus on overlapping multiplexing techniques-creating artificial overlaps between adjacent symbols during data transmission which can be applied across frequency domains as overlapping frequency division multiplexing (OvFDM) or time domains as overlapping time division multiplexing (OvTDM).

In addition, the paper discusses the use of several key algorithms, such as the maximum energy detection algorithm in symbol synchronization, the L&R algorithm in carrier synchronization, and decoding algorithms. Finally, tests conducted under actual channel conditions validate that this overlapping multiplexing system has a high spectral efficiency, reaching up to 10bit/s/Hz. Future improvement directions include seeking more suitable algorithms to enhance computational capacity and using GNU Radio to replace LabVIEW software, along with adding some extra hardware to achieve a higher overlapping system.

4. Conclusion

This review synthesizes the advancements and practical implementations of software-defined radio (SDR) systems in China, particularly those integrating the GNU Radio platform with USRP hardware peripherals. Through extensive experimentation and case studies, researchers have demonstrated the transformative potential of SDR in addressing critical challenges in wireless communication, including adaptive interference cancellation, multi-protocol coexistence, real-time spectrum monitoring, and high spectral efficiency transmission. Key innovations, such as MIMO-OFDM architectures, full-duplex systems with digital-domain self-interference suppression, and low-cost ADS-B signal transceivers, highlight the versatility of SDR frameworks in bridging theoretical models with real-world applications.

The modularity of GNU Radio, combined with the computational power of USRP, has enabled rapid prototyping of systems exhibiting reduced packet error rates (PER), enhanced spectral efficiency (up to 10 bit/s/Hz), and robust interference mitigation (e.g., 40 dB suppression via adaptive algorithms). However, limitations in hardware capabilities, such as bandwidth constraints and antenna configurability, underscore the need for advanced hardware integration to unlock the full potential of designs like large-scale MIMO-OFDM or ultra-wideband systems. Additionally, environmental factors (e.g., weather impacts on VLC) and synchronization challenges in dynamic scenarios (e.g., vehicular networks) highlight the importance of algorithm optimization and multi-domain interference management.

Future research should prioritize cross-platform compatibility (e.g., merging GNU Radio with LabVIEW), algorithm refinement for real-time signal processing, and the incorporation of emerging technologies like AI-driven interference prediction. By addressing these challenges, SDR-based systems will continue to drive innovation in next-generation wireless networks, offering scalable, cost-effective solutions for diverse applications-from intelligent transportation to aerospace communications-while reinforcing China's leadership in advancing open-source, software-driven radio technologies.

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