Multi-radio Relay Frequency Hopping Based on USRP Platforms

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Abstract. The wireless relay communication system can realize space diversity, expand the communication range, and increase capacity. The technology of frequency hopping communication helps the relay system randomly hop on multiple channels, which can improve system reliability. At present, most of the research related to relay communication and frequency hopping is based on theoretical analysis and numerical simulations, which can not precisely simulate the channel characteristics of the actual wireless communication environment. According to the decoding and forwarding (DF) relay transmission technology, this paper designs and implements the wireless multi-radio relay frequency hopping transmission system based on the software radio hardware platform USRP. The results show that the system realizes multimedia wireless data communication with a low packet loss rate through relay frequency hopping transmission.

Keywords: Relay communication · Frequency hopping · USRP · LabVIEW

1 Introduction

Complex wireless channel environment seriously affects the reliability and coverage of the signal transmission. Relay communication technologies can effectively increase the coverage, enhance reliability and availability of the communication system, which are widely used in wireless communication systems [1]. After Erlang put forward the basic principles of relay theory, relay technologies have been studied more and more extensively [2]. That is, the received wireless signal from the base station is processed through a series of relay stations and then forwarded. Microwave relay communication is the earliest communication system using relay technology. Its carrier wave is microwave, and long-distance radio communication is realized by relay on the ground. If node A and node B are far apart, to achieve communication between them, several relay stations need to be added. After receiving the signal, the relay node amplifies and forwards it to the

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next relay, and finally realizes the communication between the two places [3]. The forwarding protocols of relay communication mainly include the amplify-and-forward (AF), compress-and-forward (CF) and decode-and-forward (DF) in [4]. The sending node sends the signal to the RN, and the RN simply amplifies the received signal and then forwards it, which is called amplified forwarding [5,6]. Differently, the RN in DF mode will decode and restore the original signal after receiving the signal from the previous node, and then encodes and modulates the signal and forwards it to the next node [7,8]. When the channel quality is poor, the RN with the AF protocol not only amplifies the received signal, but also accumulates noise, which ultimately affects the probability of correct decoding by the destination node. If DF protocol is used, the noise can be well controlled, ensuring the performance of the communication system. Therefore, the DF mode is employed in this paper.

The quality of information transmission is subject to harmful interference. To ensure the unimpeded transmission of information, the communication system needs to have a certain anti-interference ability. Frequency-hopping communication is a type of spread-spectrum communication [9], which is characterized by pseudo-random hopping of the carrier frequency at multiple frequencies and has a certain ability to resist interference.

Universal Software Radio Peripheral (USRP) [10–12] is a very nimble open source hardware device developed by Matt Ettus et al. The USRP works as a digital baseband, RF front-end, and digital intermediate frequency, and the remaining of the signal processing is done by software programming on the computer [13]. LabVIEW is a virtual instrument development software which can be used with USRP, with a flexible user interface and powerful interactivity. Combining USRP with LabVIEW can overcome the limitations of traditional communication experiment simulation methods, such as poor scalability of the curing test chamber and non-objective software simulation results.

In this paper, combining relay cooperative communication and frequency hopping communication, a wireless relay frequency hopping communication system based on USRP platform and LabVIEW software simulation is built. The main contribution of this paper is to achieve fixed sequence frequency hopping transmission from source node (SN) to relay node (RN) and relay node (RN) to destination node (DN), in addition, SN-RN link and R-D link do not interfere with each other. Through relay frequency hopping transmission, wireless communication can resist the attack of traditional interference, expand the scope of communication.

The remaining of the paper is arranged as follows. In Sect. 2, physical layer and data frame structure design are investigated. Section 3 is the system construction and the introduction of related functional modules. Section 4 introduces the design principles and system implementation of relay frequency hopping transmission. In Sect. 5, the experimental results are given. Finally, the paper is concluded in Sect. 6.

2 Related Works

The authors in [14] implemented a single relay wireless transmission system based on USRP and GNU Radio. The authors in [15] implemented a multi-relay wireless transmission system based on USRP and GNU Radio. However, the existing work [14,15] mainly focused on the construction of relay system, while communication protocol was not discussed, as well as the multi-channel model. In [18], a concept proof of LTE DF RN using two SDRs was proposed. In [19], a cooperative communication system experimental platform based on NI USRP2920 was proposed. The implemented experiments included voice communications and video streaming by GMSK modulation transmission to develop the cooperative advantages of multimedia communication. In [20], the authors used LabVIEW and USRP as the experimental platform. The three nodes cooperative communication based on amplifying and forwarding was simulated, and the system performance was analyzed by turning the system time slot settings by software.

Different from them, this paper combines wireless relay technology and frequency hopping technology to achieve picture transmission, based on the software radio platform USRP and software platform LabVIEW. The results show that the system can realize relay frequency hopping transmission with low packet loss rate.

3 General Design of Relay System

The designed wireless relay frequency hopping communication system is shown in Fig. 1. The system is mainly composed of one SN, one RN and one DN. The SN and DN are composed of a PC and a NI USRP2920, respectively. The RN is simulated by one PC, one switch and two NI USRP2920. The system consists of four transmission links, which are two data links and two ACK transmission links. Two data links include the data link f_{sr} from SN to RN, and the data link f_{rd} from RN to DN. Two ACK transmission links include an ACK link f_{ack}^{rs} from RN to SN and an ACK link f_{ack}^{dr} from DN to RN.

Before the experiment, the system framework of the experiment is introduced. The hardware of the experimental system in this paper mainly includes NI USRP 2920, supporting antenna, switch and computers. The software platform adopts LabVIEW visual simulation programming environment. LabVIEW is a virtual instrument development software that can be used with USRP, with flexible user interface and strong interactivity.

3.1 System Physical Layer Design

In the LabVIEW software platform, most modulation methods, such as FSK, BPSK, QAM, GMSK, etc., have corresponding modules and corresponding demodulation module. This experiment uses QPSK for modulation and demodulation to ensure transmission reliability.

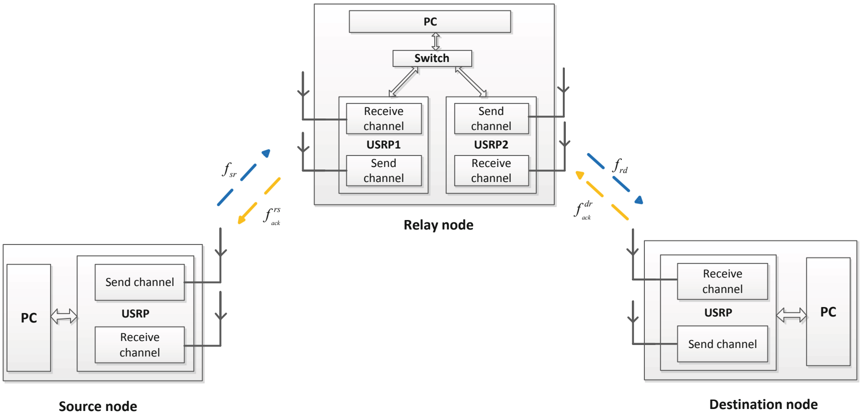

Fig. 1. USRP-based wireless relay frequency hopping system framework.

3.2 Data Frame Structure Design

In order to make sure the accuracy of the received data, we need to design the frame format of the data. In this system, the sender performs equal-length splitting, framing, and encapsulation of the data bit stream to form a data bit packet for modulation transmission. The encapsulation frame format is shown in Table 1. The definition of each data field function is shown in Table 2.

Frame synchronization is extremely important for the receiver correctly receiving data. Only when the sender and the receiver have achieved frame synchronization can they correctly distinguish the starting position of the data frame during reception and receive valid data. In a wireless communication system, data is inevitably subject to errors during transmission due to various adverse factors. Hence, data are detected and corrected, then the upper layers can transmit more reliably. Error detection codes do not correct transmission errors, but can increase transmission reliability and effectiveness. CRC (Cyclic Redundancy Check) is an error check code that is often used in the field of data communications to detect or verify data transmission. The verification method used in this experiment is CRC-16 [16].

Table 1. Encapsulated frame format.

Protection bit	Sync bit	Message type	Data frequency	ACK frequency	Package number	Data bit	Check bit	Padding

Table 2. Frame format function.

Data field	Number of bits	Function
Protection bit	30	Allows the automatic gain control module to reach a steady state quickly before processing useful data
Sync bit	30	Generate a 30-bit random sequence using a PN sequence generator for easy frame synchronization
Message type	8	0000 0000 represents data; 0000 0001 represents ACK
Data frequency	32	Data transmission channel
ACK frequency	32	ACK transmission channel
Package number	32	Received packet sequence number
Data bit	1024	Service data bit length in each frame, which can be set by the user
Check bit	16	CRC check the data
Padding	30	Used to eliminate filter effects

4 System Construction and Function Modules

4.1 System Construction

The NI USRP2920 has two antennas, TX/RX1 and RX2. TX/RX1 can be used to send and receive signals, and RX2 can only be used to receive signals. In the wireless relay frequency hopping transmission communication system, because the SN and the DN both need to send and receive information, the SN and the DN are composed of one PC and one NI USRP2920, respectively. The RN is relatively complicated which needs to receive the data information of the SN and forwards the data processing to the DN, at the same time initiates a frequency change request to the SN and receive the frequency change request initiated by the DN. It can be seen that the RN needs two transmissions and two receptions, so the RN needs to be composed of a PC, a switch, and two NI USRP2920. Figure 2 shows a schematic diagram of the experimental system in this paper.

4.2 Function Modules

The experimental system in this paper is composed of three nodes. In general, the design of RN is relatively complicated, and two receptions and two transmissions are required. To improve the development efficiency of the system, the SN and the DN can be selected to implement the corresponding functions of the RN.

The RN can be divided into two major blocks, the receiving module and the sending module. Among them, the receiving module is further divided into data receiving and ACK receiving, the sending module is further divided into sending data module and sending ACK module. The design of sending and receiving data and ACK are different except for the frame structure design, the other designs are the same, hence the processing flow of the transmitting module and receiving module of the node are introduced here.

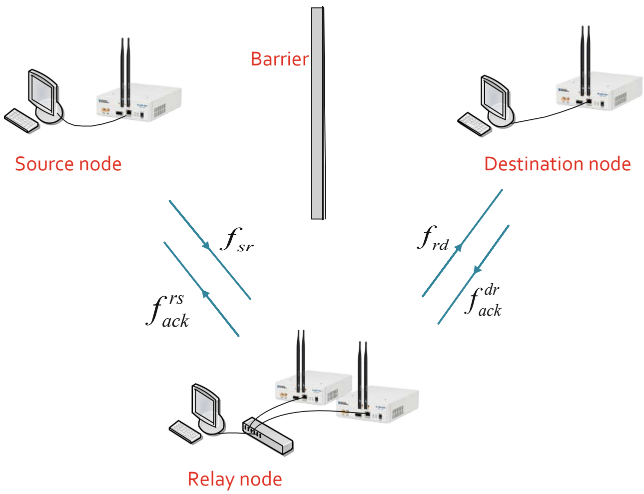

Fig. 2. Experimental system diagram.

At the transmitting end of the node, the service to be transmitted is first converted into a binary bit stream. According to the designed data frame format, the binary data bit stream is grouped into several data packets of the same length. The digital baseband signals are obtained through raised cosine filtering and QPSK modulation, and finally written into USRP through the Ethernet port and transmitted through the antenna.

On the receiving end of the node, the USRP obtains the baseband signal through the receiving antenna and reads it into the PC. The data processing process is completed with LabVIEW program. First, the received baseband signal is separated according to the packet (remove DC component, the corresponding position of each packet is detected by correlation operation, and the data packet is separated), then the extracted data packet is resampled and QPSK demodulated to obtain a binary bit stream. After the serial validity check (CRC check and frame synchronization check), the correctly received data packets are reconstructed and converted into a format to restore the original data information [17].

5 Principle and Implementation of Relay Frequency Hopping Transmission System

5.1 Design Principles of Relay Frequency Hopping

In actual wireless communication, comprehensive coverage is sought. For remote areas, the coverage of the cell is limited and severely affected by shadow fading. Relay communication technology can effectively conquer the fading of wireless channels and increase spectrum efficiency and communication range. The basic concept of wireless relay technology is to add a RN between a SN and a DN. The RN receives the signal from the SN and forwards it to the DN after a certain processing. Generally, in a wireless single-relay network, there are three communication links, namely SN-DN, SN-RN, and RN-DN. In this experimental system, the SN-DN link is not considered.

The handling of the received signal by the RN is diverse. Wireless repeater technology is divided into two categories, AF and DF. AF: After receiving the signal from the SN, the RN simply amplifies the signal and forwards it. DF: The RN decodes and demodulates the received signal to recover the original signal, then encodes and modulates the recovered signal to the DN. In this experiment, the RN uses DF.

The interaction procedure among SN, RN and DN in wireless relay frequency hopping transmission communication system is shown in the Fig. 3. The steps of wireless relay frequency hopping transmission are analyzed as follows:

Step 1: The SN sends data to the RN on the channel f_{sr} and receives ACK signal sent by the RN on the channel f_{ack}^{rs}, and reconfigures the transmission carrier frequency f_{sr} after receipting the ACK signal.

Step 2: The RN receives data on the channel f_{sr}, decodes and forwards it, and sends the data to the DN on the channel f_{rd}; after a time interval Tr, initiates a frequency change request, sends an ACK to the SN on the channel f_{ack}^{rs}, and reconfigures the RN receive the carrier frequency f_{sr}. At the same time receive the ACK signal sent by the DN on the channel f_{ack}^{dr}, and reconfigure the transmit carrier frequency f_{rd} after receiving the ACK signal.

Step 3: The DN receives data information on the channel f_{rd}. After a time interval Td, initiates a frequency change request, sends an ACK to the RN on the channel f_{ack}^{dr}, and reconfigure the receive carrier frequency f_{rd} of the DN.

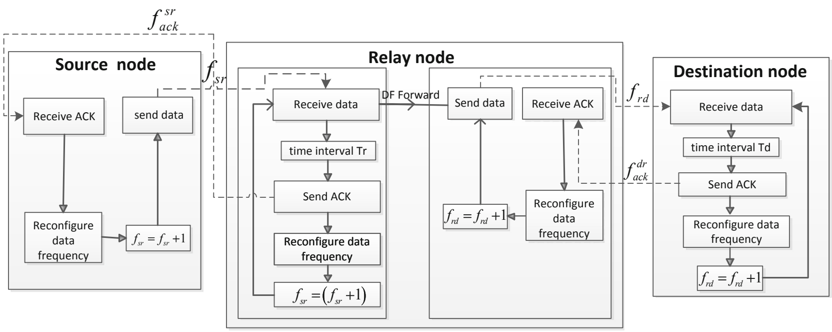

Fig. 3. Experimental flow chart.

5.2 System Implementation

Based on the above design analysis, a physical simulation system was built based on the USRP software radio platform and LabVIEW software. The system consists of 3 computers, 4 NI USRP2920, and 1 switch. The computer and USRP are connected through a Gigabit Ethernet port, which simulates the SN, RN, and DN.

The test steps of the system are as follows:

(1) Connect the USRP and the computer;
(2) Configure system related parameters (such as I/Q rate, carrier frequency, antenna, gain, modulation method, frequency hopping interval, frequency hopping range, frequency hopping time interval, etc.) on the front panel of the program, as shown in the Table 3;
(3) Power on the USRP and run the SN, RN, and DN programs at the same time for data transmission.

Table 3. Related parameter configuration.

Related parameters	Value
S-R frequency range	800 MHz–845 MHz
R-D frequency range	915 MHz–960 MHz
Frequency interval	5 MHz
S-R frequency hopping interval	3 s
R-D frequency hopping interval	3 s
Number of channels	10
Antenna gain	10 dB
S-R data I/Q rate	1M Sample/s
R-D data I/Q rate	800K Sample/s
I/Q rate of R-S ACK	400K Sample/s
I/Q rate of D-R ACK	400K Sample/s
Modulation	QPSK
R-S ACK frequency	750 MHz
D-R ACK frequency	500 MHz

6 Physical Test Results

During the system test, the SN selects a 400k image and sends it to the RN. The front panel operation interface of the SN is shown in Fig. 4, where module 1 is a modulation transmission constellation diagram, module 2 is a time domain waveform diagram of a transmission signal; module 3 is an access frequency point of each time slot, and module 4 is a picture to be transmitted. The access frequency sequence is obtained by the ACK of the RN. The set of available frequencies is {800 MHz, 805 MHz, 810 MHz, 815 MHz, 820 MHz, 825 MHz, 830 MHz, 835 MHz, 840 MHz, 845 MHz}. It can be seen from the Fig. 4. That the modulation method is QPSK.

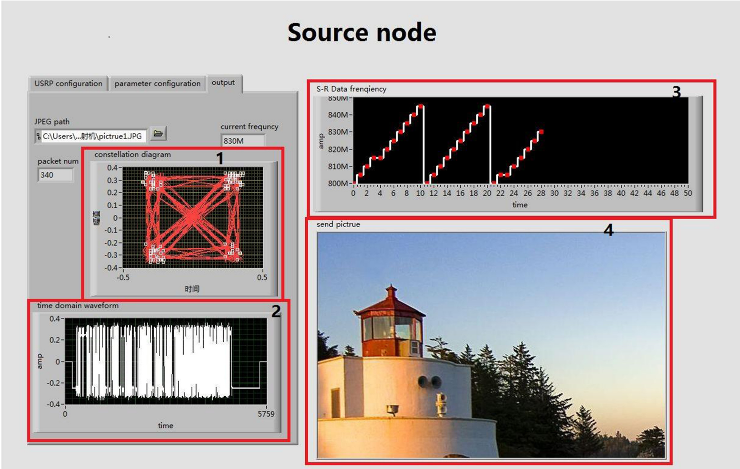

Fig. 4. User operation interface of source node.

The system RN uses the decoding and forwarding (DF) method to re-encode the received data information and send it to the DN. The RN is divided into four parts in terms of function realization, data reception and transmission, and ACK transmission and reception. The front panel operation interface of the RN is displayed in Fig. 5. In Fig. 5, module 1 is the frequency hopping sequence from the SN to the RN, module 2 is the packet loss rate of the RN receiving data, module 7 is the constellation diagram of the RN receiving data, module 8 is the time-domain waveform diagram of the RN receiving data, module 3 is the frequency hopping sequence from the RN to the DN, available frequency points are {915 MHz, 920 MHz, 925 MHz, 930 MHz, 935 MHz, 940 MHz, 945 MHz, 950 MHz, 955 MHz, 960 MHz}, module 5 is the constellation diagram and time domain waveform diagram of the RN sending data to the DN, module 6 is a constellation diagram for sending ACK to the SN and a time-domain waveform diagram for sending ACK information, module 4 is the original picture recovered by the RN. It can be seen from the picture that there is a packet loss phenomenon. There is a time lag between the SN and the RN during each frequency change, resulting in a small amount of packet loss during the frequency change, the packet loss rate floating around 0.1.

The DN is divided into two parts in terms of function implementation, which are divided into data reception and ACK transmission. As shown in the Fig. 6, module 3 is the DN to restore the received data information to the original image, module 1 is the access frequency point sequence, module 2 is the packet loss rate of the DN, the packet loss rate fluctuates around 0.2, module 4 is the constellation diagram of the DN receiving data, module 5 is the time domain waveform diagram of the received data.

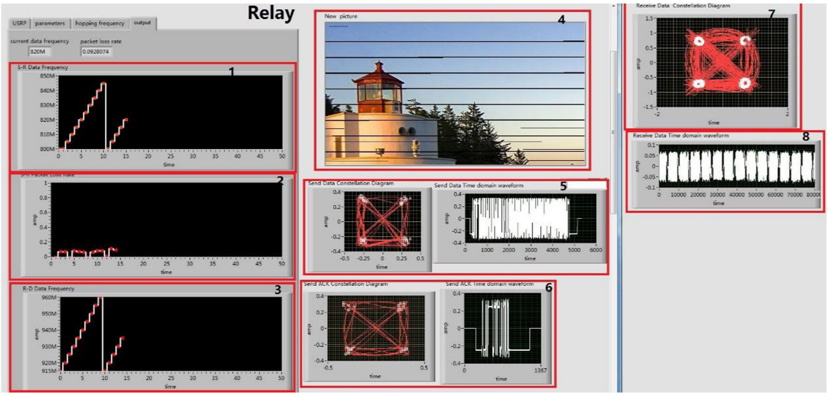

Fig. 5. User operation interface of relay node.

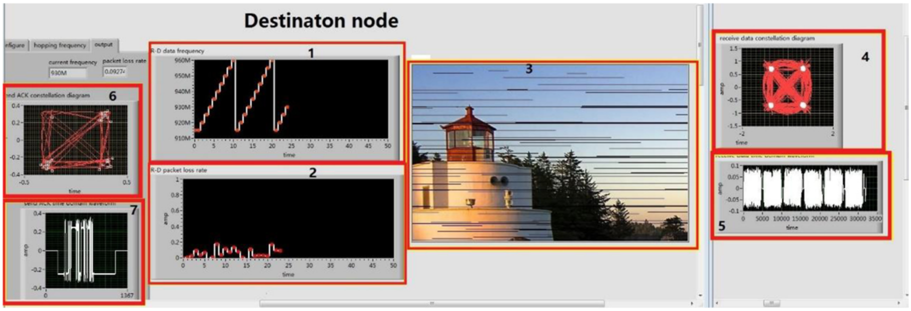

Fig. 6. User operation interface of destination node.

7 Conclusions

This paper makes full use of the reconfigurable, flexible and easy to operate characteristics of the NI USRP software radio platform to build a wireless relay frequency hopping communication transmission system. After many experiments, the system runs stably reliable, and packet loss rate is also within a certain range. On the basis of this article, the next step is to consider the existence of interference, and implement intelligent relay frequency hopping anti-interference combined with reinforcement learning.

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