Exploration of Experimental Teaching for OFDM Simulation Based on GNU Radio

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Abstract: With the rapid development of wireless communication technology, the existing hardware experimental platform has been difficult to meet the needs of experimental teaching. Aiming at the problems in traditional wireless communication experiments, this paper proposes a wireless communication simulation experiment system based on GNU Radio, to replace the out-of-date hardware experimental cases. Taking OFDM experiment as an example, the module selection, parameter settings and experimental results of the simulation experiment system are described. The simulation experiment system has wider applicability. There are a large number of functional modules to choose from in the design kit, which can be used for further development according to requirements of incoming technologies. The system can realize the simulation of wireless communication, so as to further develop more experimental projects that keep pace with the times. As a beneficial supplement to theory teaching in class, it can provide students with more practical chances.

1. Introduction

With the rapid development of wireless network and mobile communication technology, the demand for communication professionals in various industries is quickly growing. Professional course of communication specialty, such as Communication Electronic Circuit, Principles of communications and Wireless Communications, mainly teach the basic theory and methods of information communication and wireless communication. Because there are many knowledge nodes in these courses, most students cannot really understand the knowledge just by listening in class. It is very necessary to master the technologies with the help of the corresponding experiments. With the continuous emergence of new communication technologies, it is also urgent to provide students with more flexible experimental projects, by means of new experimental methods and apparatus, such as configurable simulation system. The students can then demonstrate their knowledge through the simulations and experiments in their spare time.

After years of practice, we found that the existing experiments based on the hardware instruments or experimental cases still have many weaknesses which be improved. First of all, once the hardware of experimental cases fails, it is difficult for students to distinguish whether it’s a mistake during the experimental process or just a hardware problem in the equipment itself. This situation always results in invalid experimental results or waste of time. Secondly, with the rapid development of wireless communication technology, it is difficult to carry out experiments on newer technologies with the out-of-date existing hardware. Thirdly, if the students are unable to attend the course in school due to the COVID-19, although the theoretical courses can be taught online, all experiments based on hardware apparatus cannot be performed.

To solve the above problems, we think that it is urgent to design and develop simulation experiments of wireless communication based on GNU Radio. First of all, the experiments may use software simulation as the main experimental method. Once the simulation system fails, it is easy to be recovered to the initial status by restarting the software. Secondly, GNU Radio is the most perfect open-source development kit of software defined radio at present. It not only supports a

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various of RF front-end, but also provides a wide range of parameter adjustment and plenty of optional modules, which greatly improves the practicability and scalability of the experiment and facilitates the development of new experimental projects. Thirdly, by deploying the simulation system to the server, students can log in online and run the simulation remotely, regardless of time and location, which is particularly important nowadays due to the threaten of COVID-19. Finally, we can further build a virtual simulation experiment system on the basis of the simulation experiments in the future, to provide students with a better and more realistic experimental experience.

In the rest of this paper, we will take OFDM experiment as an example to describe the simulation experiment of wireless communication based on GNU Radio.

2. Background of Software Defined Radio and GNU Radio

Software defined radio (SDR) is a radio broadcasting communication technology, which is based on software defined wireless communication protocols rather than hardware by hard-wired[1]. The basic idea of SDR is: based on a general (open), standard (unified), modular (extensible) hardware platform, use software programming as much as possible to implement various functions of the radio, and then get rid of the traditional hardware of wireless system. With the rapid development of software and hardware in the electronic and information field, it increasingly shows great advantages for the use of software defined radio system to build new generations of communication, broadcasting and even radar systems.

2.1. Software Defined Radio

SDR is a highly digitized platform. It is an important basis for implementing SDR platform to digitizing the baseband signal of the communication system, up to the IF and RF bands. Since SDR is based on a general hardware platform, such as CPU or DSP, where run the software program codes, it may implement various functions of the communication system completely by software programming. By adding software modules, it is easy to implement new functions, such as programmable channel modulation and demodulation in wide band, programmable RF and IF bands, and source coding and decoding methods.

Further, with the help of software programming, the SDR platform can be upgraded only by updating the software module or modifying the configuration parameters, which is far more convenient than redesigning the hardware circuits or systems. At the same time, taking the advantage of flexibility of software programming, the developer may expend the system framework and functions of SDR platform much easier.

Due to the standardized and modular structure, SDR platform can be updated or expanded with the development of general-purpose processers and programming technologies. Software program can be upgraded at any time if necessary. SDR can not only communicate with new RF front-end devices, but also be compatible with old ones[2,3]. This extends the working life of the old devices, as well as ensures the SDR itself a longer working life.

2.2. GNU Radio

Open-source software defined radio (GNU Radio) is a free software toolkit for study and deploying Software Defined Radio systems[4]. With two decades developing, GNU Radio is now one of the most popular projects of GNU. It provides signal operation and processing modules, with which SDR can be implemented on low-cost RF hardware and general-purpose microprocessors. This suite is widely used by amateurs, academic and industry to research and build wireless communication systems[5].

The application programs of GNU Radio platform are mainly coded in Python, while its core signal processing module is built on the microprocessor with floating point operation by coded in C++. Developers can simply and quickly build a real-time, high-capacity wireless communication system, mainly using Python. Although the main purpose of SDR platform is not a simulator, it also supports the way of signal processing algorithms research, by using pre-set digital signals or the signal data generated by software signal generator, without RF hardware components. This attribution provides the possibility for us to design simulation experiments of wireless communication.

3. The experiment of OFDM simulation based on GNU Radio

3.1. Principle of OFDM

OFDM (Orthogonal Frequency Division Multiplexing) is one kind of the multi-carrier modulation. As it is named, OFDM is an orthogonal frequency division multiplexing technology. The parallel transmission of high-speed serial data is realized through frequency division multiplexing. It also has a good ability to resist multipath fading and can support multi-user access. OFDM system may use FFT to realize modulation and demodulation, which can greatly simplify the complexity of the system. Its principle will be briefly described below.

An OFDM symbol includes a composite signal of multiple modulated subcarriers, and each of them can be modulated by a phase shift keying (PSK) or quadrature amplitude modulation (QAM) symbol[6,7]. Every subcarrier contains an integer period in an OFDM symbol, and every adjacent subcarrier has a period difference. This feature guarantees the orthogonality between subcarriers. In the frequency domain, each OFDM symbol contains multiple non-zero subcarriers in its period[8]. Therefore, its frequency spectrum can be regarded as a function of the rectangular pulse with period and a group of sub carrier frequencies δ Convolution. At the maximum value of each subcarrier frequency, the spectrum value of other subchannels is exactly zero.

Since the maximum value of each subcarrier frequency corresponding to these points needs to be calculated during the demodulation of OFDM symbols, the symbols of each subchannel can be extracted from multiple overlapping subchannel symbol spectrums without interference from other subchannels. In fact, the OFDM symbol spectrum can meet the Nyquist criterion, that is, there is no mutual interference between multiple subchannel spectrums. Therefore, the maximum of the spectrum of one subchannel corresponds to the zeros of other subchannels, which can avoid the occurrence of interference (ICI) between subchannels[9].

OFDM modulation and demodulation can be replaced by IDFT and DFT respectively. By N-point IDFT operation, frequency domain data can be converted to time domain. After RF carrier modulation, it is sent to the wireless channel. Each IDFT output data symbol is generated by the superposition of all subcarrier signals. That is, it is obtained by sampling the superposition signal of a continuous number of modulated subcarriers.

One of the main reasons for using OFDM is that it can effectively relieve the problem of multipath delay spread. By converting the input data stream into N parallel channels in series and parallel, the data symbol period of each subcarrier used for modulation can be expanded to N times of the original data symbol period. Then the ratio of delay expansion to symbol period is also reduced by N times. In order to eliminate inter symbol interference to the greatest extent, protection intervals can also be inserted between each OFDM symbol. The length of the protection interval should be greater than the delay spread of the infinite channel, so that the multipath component of one symbol will not interfere with the next symbol. In this protection interval, no signal can be inserted. That means an idle transmission period. However, in this case, due to the impact of multi-path propagation, ICI will occur, and the orthogonality of sub carriers will be damaged. In order to eliminate ICI caused by multipath, OFDM symbols need to fill in cyclic prefix signals in their protection intervals. In this way, the period of the waveform contained in the delay copy of the OFDM symbol is also an integer within the FFT period. As a result, delay signals with time delay less than the protection interval will not generate ICI during demodulation.

3.2. Structure of the Simulation Platform

In this simulation system, we use the built-in OFDM module of GNU Radio to build the transceiver system. The selected modules and brief diagrams of modulation and demodulation are shown in Figure 1 and Figure 2, respectively.

3.2.1. OFDM Transmitter

We use the File Source module as the data source, manually create a file and write some characters as the sending content. Since the OFDM Transmitter will add CRC cyclic redundancy check to the input data, the 'Stream to Tagged Stream' module is used to subcontract the input data.

When setting RF parameters, the OFDM system requires high computer performance due to its high-performance requirement and computational overhead. Therefore, in this experiment, the actual sampling rate of the OFDM system is set to 100KHz, and the signal is upsampled through the 'Rational Resampler' module to match the possible working sampling rate of the hardware. IN 'Rational Responder' module, we set the variable 'Interpolation' to 384, the variable 'Decision' to 10, and the output signal sampling rate to 100KHz * 384/10=3.84MHz.

Next, we set the OFDM Transmitter module with the following parameters: 'Length Tag Name', 'Header Modulation' and 'Payload Modulation'. The 'Length Tag Name' should be consistent with the 'Stream to Tagged Stream' module. The 'Header Modulation' is set to BPSK for header data and the 'Payload Modulation' is set to QPSK for payload data.

'FFT length' is determined according to the bandwidth occupied by OFDM and the set subcarrier width. In order to use the FFT algorithm under radix-2, the size of OFDM symbols in actual systems is generally taken as the n-th power of 2. In this experiment, the OFDM symbol size is 64, and the effective sampling rate is 100KHz. It can be calculated that the actual transmission subcarrier spacing is 100/64=1.5625KHz. The longer the cyclic prefix is set, the smaller the inter symbol interference and inter channel interference are, but the lower the efficiency is. Therefore, it is necessary to select an appropriate intermediate value, which is neither too large nor too small. Here we set the length of the cyclic prefix to one fourth of the 'FFT length'.

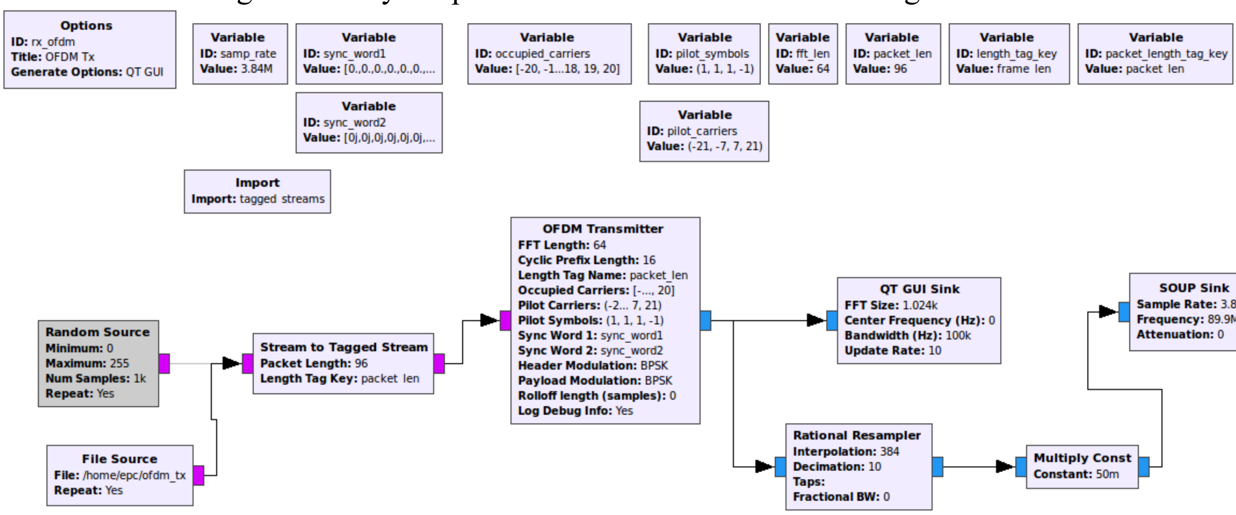

Figure 1 The block diagram and connection of OFDM modulation based on GNU Radio.

There is something should be paid attention to when setting the subcarrier range. First, it cannot be set too large. Otherwise, the system function of the band-pass filter at the receiving end will decline at both ends, which will result in that the OFDM symbols at both ends cannot be used as transmission information. Therefore, the subcarriers cannot occupy all 64 locations. To avoid this problem, we use a total of 42 subcarriers from - 21 to 21.

In OFDM systems, pilot signals are also needed, which can be used for channel estimation and symbol timing reception. In this case, four subcarriers are selected as pilots among the 42 subcarriers, and the pilot positions are distributed among the subcarriers as widely as possible. To prevent boundary effects, pilot symbols should be set on the first and last subcarriers of the OFDM symbol. Here we use four symbols - 21, - 7, 7 and 21 as pilots. Noted that there is no other information on the pilot position, so it is necessary to remove the subcarriers from the pilot position when setting the captured carriers.

Finally, a fixed synchronization sequence is adopted, and the settings are as follows:

Synchronization sequence 1: [0., 0., 0., 0., 0., 0., 0., 1.41421356, 0., -1.41421356, 0., 1.41421356, 0., -1.41421356, 0., -1.41421356, 0., -1.41421356, 0., 1.41421356, 0., -1.41421356, 0., 1.41421356, 0., -1.41421356, 0., -1.41421356, 0., -1.41421356, 0., -1.41421356, 0., 1.41421356, 0., -1.41421356, 0., 1.41421356, 0., 1.41421356, 0., 1.41421356, 0., -1.41421356, 0., 1.41421356, 0., 1.41421356, 0., 1.41421356, 0., -1.4142 1356, 0., 1.41421356, 0., 1.41421356, 0., 1.41421356, 0., 0., 0., 0., 0., 0.];

Synchronous sequence 2: [0j, 0j, 0j, 0j, 0j, 0j, (- 1+0j), (- 1+0j), (- 1+0j), (- 1+0j), (1+0j), (1+0j), (- 1+0j), (- 1+0j), (- 1+0j), (1+0j), (1+0j), (1+0j), (1+0j), (1+0j), (- 1+0j), (- 1+0j), (- 1+0j), (- 1+0j),+0j), (- 1+0j), (- 1+0j), (1+0j), (- 1+0j), 0j, (1+0j), (- 1+0j), (1+0j), (1+0j), (1+0j), (1+0j), (1+0j), (1+0j), (1+0j), (1+0j), (1+0j), (1+0j), (1+0j), (1+0j), (-1+0j), (-1+0j), (-1+0j), (1+0j), (-1+0j), (1+0j), (-1+0j), (-1+0j), (-1+0j), (-1+0j), 0j, 0j, 0j, 0j, 0j].

3.2.2. OFDM Receiver and Results of simulation

Contrary to the transmitter, the 'Rational Resampler' module is used to down sample the input signal during demodulation in the receiver. The effective signal sampling rate of the input OFDM receiver is 3.84MHz * 384/10=100KHz. The parameter settings of the OFDM receiver are similar to those of the OFDM transmitter, as shown in Figure 3. Moreover, we use the 'File sink' module in the receiver, and choose the corresponding file path to store the received data for further study.

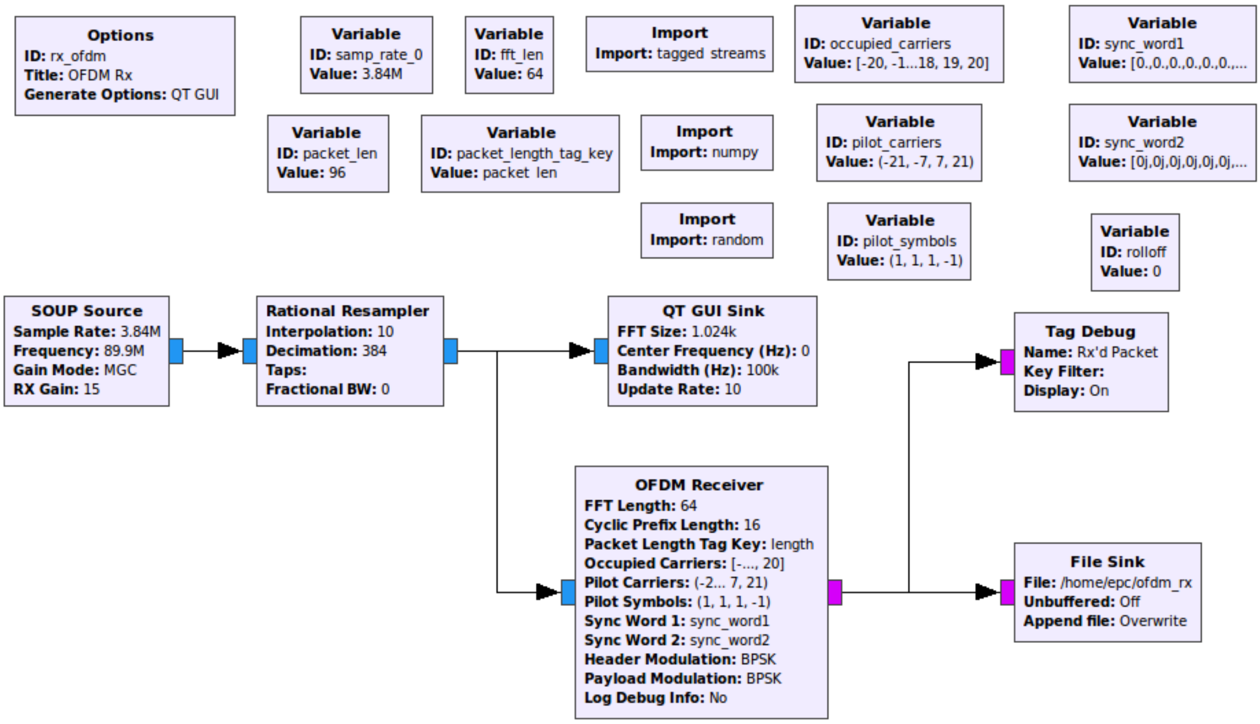

Figure 2 The block diagram and connection of OFDM demodulation based on GNU Radio.

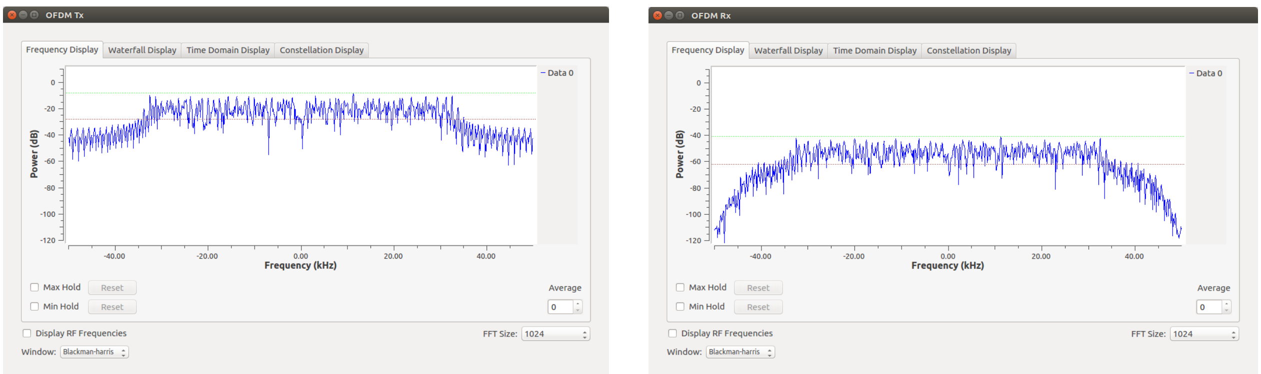

Figure 3 The spectrums of OFDM transmission signal and received signal.

In the experiment, students may execute the OFDM transmission program to observe the spectrum of the transmission signal, as shown in Figure 3 (left side). At the same time, the OFDM receiving program may be launched in the meanwhile to show the spectrum of the received signal, as shown in Figure 3 (right side). If the OFDM signal is received successfully, the statistical information of the received signal will be printed on the terminal below GNU Radio as shown in Figure 4. Students can also determine whether the received data is correct by checking the receiver output file.

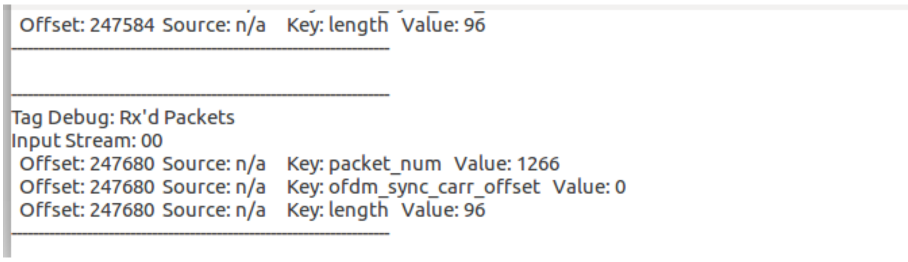

Figure 4 The statistical information of the received signal.

4. Conclusion

The main component of the proposed wireless communication simulation system is the GNU Radio design kit on the PC, which has plenty of functional modules to choose from, and can be modified or re-designed according to the demands. New experiments can then be easily developed. The simulation system can emulate wireless communication behaviour through data interaction with MATLAB or Python. If the system is deployed on the server, it can be remote accessed, so that students can participate in the experiment without the restrictions of time and location. It can also provide more experimental chances for the students who have spare time, without adding class hours.

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