Implementation of High Order QAM Modulation on SDR

Hao Wu, Min Lu, Yan Li and Mengrong Liu

College of Telecommunications & Information Engineering,
Nanjing University of Posts and Telecommunications, 66th Xinmofan Road, Nanjing, China
Email: snidg@foxmail.com
Email: lumin@njupt.edu.cn
Email: 2402948304@qq.com
Email: 1179386201@qq.com

Abstract. Nowadays, SDR (software-defined radio) has increasingly occupied a place in scientific research and teaching with its powerful signal processing capability and custom ability. XSRP is a development platform which uses an SDR architecture. In this paper, we develop a wireless real-time audio transmission system with high order modulation (64QAM) based on XSRP platform. We use LabVIEW and MATLAB to write the program’s overall framework and functions. We also analyse the performance of different modulation modes by comparing the constellations and waveforms of the transmitter and receiver under the real situation. The results show that high order QAM modulation achieves a good balance between efficiency and quality.

1. Introduction
With the development of communication technologies, the diversification of service types and the rapid increase in the number of users, the limitation of bandwidth is becoming more and more obvious. Quadrature Amplitude Modulation (QAM) is a typical representation solution to improve spectrum utilization and achieve higher transmission rate [1]. QAM is a combination of amplitude and phase keying which increases the frequency spectrum’s using efficiency effectively. So, it is meaningful for us to do detailed research about it.

Software-defined radio (SDR) has increasingly occupied a place in scientific research and teaching with its powerful signal processing capability and custom ability. SDR employs definable hardware that we can use different programs to realize different systems. XSRP is a development platform which uses an SDR architecture. We use LabVIEW and MATLAB to build the transmission system and analyse the performance of the high order QAM modulation based on XSRP platform.

2. High Order QAM Modulation
QAM is especially suitable for applications where bandwidth resources are limited. For example, since the bandwidth of a telephone channel is usually limited to the voice band, QAM is very suitable if it is desired to increase the rate at which digital signals are transmitted through a modem in this band.

In the QAM system, the amplitude and phase of the signal are modulated simultaneously as two independent parameters. One symbol of such a signal can be expressed as:

\[ e_k(t) = A_k \cos(\omega_c t + \theta_k) \quad kT_B \leq t \leq (k + 1)T_B \]  

where \( k \) is an integer; \( A_k \) and \( \theta_k \) can both take several discrete values.
High-order modulation utilizes the feature of higher bandwidth utilization by improving the signal-to-noise ratio. In a good environment, by extending the constellation point density of the modulation constellation, each modulation symbol can transmit more information bits. For example, in QPSK modulation, each constellation point can represent 2 bits of information. However, in a channel with better conditions, the transmission efficiency of QPSK obviously cannot meet our requirements. When extended to 16QAM modulation, each sample represents 4 bits of information and then extended to 64QAM modulation, each sample represents 6 bits of information. The constellation diagrams of these modulations can be seen in “Figure 1”.

![Constellation diagrams of QPSK, 16QAM, and 64QAM](image)

**Figure 1.** Constellation diagram of three types of modulation

In this paper, we choose 64QAM as the representative modulation method. In the 64QAM modulation system, after level conversion, there are 8 levels and the modulator I outputs 8 signals while modulator II outputs 8 signals. The two-way modulated signals are added in a total of 64 different combinations, thus forming a 64QAM constellation. The 64QAM modulator has a total of 44 different phases, 64 different amplitudes and 64 states. In the constellation diagram, there is a one-to-one correspondence between the amplitude and phase of each state.

Obviously, in the extension of the modulation method, the efficiency of information transmission has been greatly improved. This makes the use of the scarce spectrum resources more efficiently [3][4]. In our implementation, we use the 64QAM system to transmit audio signals based on XSRP platform.

### 3. XSRP——Software Defined Radio (SDR)

XSRP is a development platform using an SDR architecture that provides a powerful signal processing platform and friendly graphical programming. XSRP seamlessly connects the development software such as MATLAB and LabVIEW to the hardware platform through the high-speed Ethernet interface, and the simulation data can be sent to the hardware platform for algorithm verification in real time. XSRP has strong hardware performance, the detailed information is shown in “Figure 2”.

![Overall structure of XSRP](image)

**Figure 2.** Overall structure of XSRP
Abundant hardware interface and modular design method for software enhance the function expansibility and field adaptability of the system. Detailed parameters of XSRP is shown in “Table 1”. From the application direction, XSRP can achieve different application directions by replacing different interface modules. In our implementation, the interface unit uses the RF interface module, coupled with the corresponding driver and algorithm/protocol package. XSRP can be programmed to implement various standard wireless transmission implementations.

| Parameter                                      | Value          |
|------------------------------------------------|----------------|
| Frequency Range                                | 70MHz-6.0GHz   |
| SW Adjustable TX Frequency Step                | <10Hz          |
| MAX Output Power                               | 16dBm          |
| TX Output Power Gain Range                     | 0-90dB         |
| SW Adjustable Output Power Step Size           | 0.25dB         |
| Instantaneous Real-Time Bandwidth              | 20MHz          |
| DAC (Digital to Analog Conversion)             | 30.72MHz       |
| SW Adjustable RX Frequency Step                | <10Hz          |
| Max Input Power (Pin)                          | -10dBm         |
| Instantaneous Real-Time Bandwidth              | 20MHz          |
| ADC (Analog to Digital Conversion)             | 30.72MHz       |

We use the XSRP SDR platform to create a wireless communication transmission system, since the platform has excellent customizable programming environment. After the signal is processed by the computer, the signal is outputted through the TX1 of the XSRP. At the same time, the RX1 of the XSRP receives the signal and sends it to the computer for further processing and displays the processed signal on the main interface[5][6]. The structure of the whole platform is shown in “Figure 3”.

Figure 3. The Structure of the whole platform

4. System Implementation
The entire system can be divided into several modules, each module corresponds to a Sub-vi. The whole program is in the form of a data stream, which is more intuitive and effective. We complete the
corresponding Sub-vis and MATLAB codes for each module, and finally integrate the parts together [7]-[9].

At the transmitter, after reading the audio file and PCM encoding, a 12bits CRC check code is attached, after convolutional encoding, the data frame is modulated in different modes, a reference signal is added, and then data are up-sampled.

At the receiver, after receiving the signal, the program performs down-sampling and phase correction, demodulation, error correction code verification, and then PCM decoding. Finally, the program decodes the voice information and write it to the target file.

The main block diagram and the picture of the system are shown in “Figure 4” and “Figure 5”.

![Figure 4. The main block diagram of the system](image)

![Figure 5. The whole system when running](image)

In the front panel of the program, the key parameters required for this implementation can be adjusted to observe the operation of the program under different real conditions. In the settings panel, we can change the TX and RX channels of XSRP, carrier frequency, transmit gain and receive gain. “Table 2” shows the initial parameters set at settings panel. In addition, the modulation mode and the type of convolutional code also can be selected. More conclusions can be drawn through comparison of different results.

| Settings          | Value     |
|-------------------|-----------|
| Channel Used      | TxCh1/RxCh1 |
| Carrier Frequency | 900MHz    |
| Gain at Transmitter | 30dB      |
| Gain at Receiver  | 20dB      |
| Frame Size        | 960 bit   |
In the display panel, the waveform diagrams of the input audio and the audio signal obtained by demodulating the real-time signal of the receiving end can be seen, so the real-time constellation diagrams. The bit error rate and the total number of errors are live updated. The front panels of the system are shown in “Figure 6” and “Figure 7”. By comparing the audio waveforms and the two constellation diagrams, the quality of the entire signal transmission process can be seen more intuitively. At the same time, the real-time bit error rate quantifies the channel transmission quality and presents it to the users. The combination of these two display modes allows the users to better understand the quality of the entire transmission process.

5. Analysis
This section shows the results of the program transmitting in real channel using 1/2 convolutional code and 64QAM or 16QAM or QPSK modulation. The running conditions can be seen in “Figure 6” and “Figure 7”. In this session, XSRP completes the transmission of audio signals by self-transmit and self-received (TxCh1 to RxCh1).

As we can see, 64QAM is highly effective in communication systems. In the case of transmission rate, when comparing with QPSK and 16QAM modulation mode, it can significantly reduce the spectrum resource occupation by 66.7% and 33.3%, which is of great significance nowadays when
spectrum resources are very valuable. However, an increase in transmission efficiency also leads to a drop in transmission quality. In comparisons above, we can find that the scheme using 64QAM modulation method has some shortcomings in the quality of transmission compared with 16QAM and QPSK. In the real system, when using 64QAM modulation, the bit error rate is 30 times and 5 times the rate of QPSK and 16QAM respectively.

6. Conclusion

XSRP plays a crucial role in our works. Our main goal is to complete realization on high-order modulation techniques by using advanced software-defined radios——XSRP. In the above project, we used XSRP equipment instead of the traditional hardware platform. The joint programming of LabVIEW and MATLAB also makes the whole process more convenient.

In most cases, 64QAM does well in transmission, for both efficiency and quality, which balances transmission efficiency and quality. However, when the channel quality is not good, the disadvantage of high-order modulation is exposed. Therefore, in some areas, adaptive modulation techniques have been introduced to ensure transmission quality with high reliability. At the same time, it is also possible to improve the transmission quality in a complex channel environment by using an error correction coding method which is more excellent.

7. References

[1] Y. Guan 2018. Application of QAM Technology in OFDM System, The era of think tank, 2096-4609(2018)41-0106-002, pp.106-107,2018.

[2] C. Fan and L. Cao 2012 Principles of Communications The 7th edition, (Beijing: National Defense Industry Press), chapter 8, pp228-249

[3] Theodore. S. Rappaport 2002 Wireless communications: Principles and practice 2nd Edition, (Prentice Hall PTR), pp.255-412.

[4] J. Wu and P. Li 2017. High-order modulation technology and its performance analysis in LTE. Mobile Telecommunications,41(17) pp 34-38.

[5] Hwang, J. K., Chiu, Y. L. and Chung, R. L. 2004. Design of a non-data-aided differential-QAM modem for real-time speech communication: a software-defined-radio PC-based approach. Communications Systems, 2004. ICCS 2004. The Ninth International Conference on. IEEE.

[6] Singh, Supreet 2017. Implementation of OFDM and other Multicarrier Modulations on SDR. International Conference on Signal Processing. IEEE.

[7] Singh, P. and Mahajan, R. 2016 " Dynamic Spectrum Access in Cognitive Radio Networks Using USRP and LabVIEW," in International Journal of Advanced Information Science and Technology (IJAIST)., Vol.44, No.44, pp. 55-60.

[8] Politis, C., Maleki, S., Duncan, J. M., Krivochiza, J., Chatzinotas, S. and Björn Ottesten. 2018. Sdr implementation of a testbed for real-time interference detection with signal cancellation. IEEE Access, 6(99), 20807-20821.

[9] Uyanik, G. S., Cepheli, O., Kurt, G. K. and Oktug, S. 2013. Implementation and performance evaluation of dynamic spectrum access using software defined radios. Communications and Networking (BlackSeaCom), 2013 First International Black Sea Conference on. IEEE.