A Research on Modulation in Digital Communication System

Xinyu Niu\textsuperscript{1,*,†}, Jingdong Wu\textsuperscript{2,†} and Linen Zhang\textsuperscript{1,†}

\textsuperscript{1} Nanjing University of Posts and Telecommunications, Nanjing, Jiangsu, China
\textsuperscript{2} Tianjin University, Tianjin, China
\textsuperscript{3} Beijing University of Posts and Telecommunications, Beijing, China

*Corresponding author’s e-mail: niuxinyu990815@bupt.edu.cn
†These authors contributed equally.

Abstract. With the development of network and communication technology in modern society, WiFi technology has become an indispensable part of people’s lives. WiFi shows its future application prospects with its wireless portability and multi-user access. This paper briefly introduces the meaning and development of WiFi technology and predicts its future development trend. The communication modulation technology QPSK, 16QAM in WiFi is described in detail, and its characteristics are compared by systemview and MATLAB software. Finally, we summarize the common techniques in WiFi.

1. Introduction

In recent years, with the development of communication technology, WiFi technology, as the key access mode of Wireless Local Area Network (WLAN), has been widely recognized for its importance and commercial value since its birth for more than 20 years ago. As WiFi technology becomes more widely used, users have higher requirements for data transmission rates. But in the indoor, this is a more complex electromagnetic environment. The existence of multiple effects, frequency selective fading, and other interference sources make it more difficult to achieve high-speed data transmission in the wireless channel than in the wired channel. WLAN needs to adopt appropriate modulation technology to improve the efficiency of WiFi signal transmission and save frequency resources. In the evolution and upgrading of WiFi, QPSK and QAM have been successfully applied as digital modulation technologies of WiFi. Digital modulation is the basis of digital transmission. Through the carrier modulation to transmit digital signals in the channel, carrier expression has three variables, so digital signal modulation technology is divided into amplitude keying ASK, frequency shift keying FSK, and phase shift keying PSK three ways, among which QPSK is one of the most commonly used digital signal modulation methods. The advantages of QPSK modulation are high-frequency spectrum utilization, strong anti-interference, and a good trade-off between frequency band utilization and acceptance of SNR [1]. In 2001, Tarokh et al. made significant progress in constructing complementary sequences with amplitude and phase modulation. They propose a 16-QAM sequence based on the QPSK complementary sequence in the XY plane by using two encoding schemes on QPSK. The relationship between sequence on QPSK and sequence on QAM is found. Thus, the study of complementary sequences is extended to QAM modulation [2]. QAM modulation also has the characteristics of high spectrum utilization and strong noise resistance and can balance the two technical indexes of information transmission and limited bandwidth [3].
Wireless LAN based on IEEE802.11 standard [4] IEEE802.11 wireless LAN (WLAN) is a self-managed computer LAN (LAN) which can support a high data transmission rate (1-54Mbit/s) and adopts micro-cell and micro-cell structure. There are three key technologies: DSSS, CCK and PBCC, and OFDM. As the spread spectrum signal rate of the DSSS system is much higher than the information rate, the signal transmission bandwidth is much higher than the information bit bandwidth, thus limiting the system frequency band utilization and information transmission rate [5]. At present, spread spectrum modulation technology is becoming mainstream. The orthogonal frequency division multiplexing (OFDM) system is widely used in various wireless communication systems due to its advantages of high transmission rate and high spectrum efficiency [6]. DSSS direct sequence spread spectrum and OFDM orthogonal multi-carrier modulation, the two technologies have their own advantages and disadvantages and play different roles in different situations. There are various modulation technologies in OFDM, including orthogonal amplitude modulation (QAM), a modulation mode of amplitude modulation on two orthogonal carriers. Frequency modulation FSK, frequency shift keying is the use of carrier frequency changes to transmit digital information; Phase modulation PSK, and other technologies.

This paper first introduces and compares OFDM and DSSS technologies and then focuses on the simulation, analysis, and comparison of the 16QAM in OFDM [7]. (refers to the superposition of two independent orthogonal 4ASK signals in the QAM modulation mode containing 16 symbols. 4ASK is the signal obtained by using a multilevel signal to diskey the carrier wave. Which is a generalization of the 2 ask system, compared with 2 ask. The advantages of this system lie in the high speed of information transmission) and the technology of QPSK [8]. (quaternary phase modulation is a kind of high spectrum efficiency, strong anti-jamming of the number of modulation mode, QPSK signal of the sine carrier has four possible discrete phase states, each carrier phase carries two binary notation). Their advantages and disadvantages are summarized through simulation, and their application scenarios are summarized.

IEEE802.11 series standard is the most widely used standard in wireless LAN [9]. After decades of development since its launch, it has become more and more mature and widely used. It has become the favorite wireless network. From the development perspective, this paper introduces the IEEE 802.11 series of standards and compares several common standards, IEEE 802.11 and IEEE 802.2.1 LA /b/ G/N. Finally, we will briefly introduce the development of the 802.11 series of WiFi protocols and make predictions for future development [10].

2. Method
This section describes the principles of the three modulation modes in detail

2.1. QPSK

2.1.1 Definition of QPSK

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Definition of QPSK:

Four-phase phase shift modulation uses four different phase differences of the carrier to represent the digital input information, which is a quad phase shift keying. QPSK is a phase modulation technology when M=4, which defines four carrier phases, which are respectively 45°, 135°, 225° and 315°. The data input by the modulator is a binary number sequence. To cooperate with the quad carrier phase, the binary data needs to be transformed into quad data. This means that you need to divide every two bits of the binary number sequence into four combinations, namely 00,01,10,11, each called a double bit. Each double-bit symbol is composed of two bits of binary information, each representing one of the four symbols in the quaternary system. Each modulation is QPSK can transmit 2 information bits, which are transmitted through the four phases of the carrier wave. The demodulator determines the information bits sent by the sender according to the constellation and the phase of the received carrier signal.
To analyze the $\pi/4$ QPSK signal, it can be seen from the phase diagram:

When the input digital information is "11" symbol, the modulated carrier is output $A \cos(2\pi f_c t + \frac{\pi}{4})$

When the input digital information is "01" symbol, the modulated carrier is output $A \cos(2\pi f_c t + \frac{3\pi}{4})$

When the input digital information is "00" symbol, the modulated carrier is output $A \cos(2\pi f_c t + \frac{5\pi}{4})$

When the input digital information is "10" symbol, the modulated carrier is output $A \cos(2\pi f_c t + \frac{7\pi}{4})$

QPSK modulation block diagram is as follows:

The serial-to-parallel conversion module separates the symbol sequence by I/Q, and the conversion rule can set the odd digit to I and the even digit to Q.

Example: 1011001001:
Route I: 11010;
Q: 01001

The level conversion module converts 1 to A level with amplitude A and 0 to A level with amplitude -A.
00 input $QPSK = -A \cos(2\pi f_c t) + A \sin(2\pi f_c t) = \sqrt{2}A \cos(2\pi f_c t + \frac{\pi}{4})$

11 input $QPSK = A \cos(2\pi f_c t) - A \sin(2\pi f_c t) = \sqrt{2}A \cos(2\pi f_c t + \frac{\pi}{4})$

2.1.2 QPSK demodulation:
The QPSK signal received by the receiver for a certain symbol can be expressed as:

$$y_i(t) = a \cos(2\pi f_c t + \phi_n)$$

$$\phi_n = \frac{\pi}{4}, \frac{3\pi}{4}, \frac{5\pi}{4}, \frac{7\pi}{4}$$

Demodulation block diagram:

According to the demodulation block diagram:

$$y_A(t) = y_B(t) = y_i(t) = a \cos(2\pi f_c t + \phi_n)$$

$$z_A(t) = a \cos(2\pi f_c t + \phi_n) \cos 2\pi f_c t = \frac{a}{2} \cos(4\pi f_c t + \phi_n) + \frac{a}{2} \cos \phi_n$$

$$z_B(t) = a \cos(2\pi f_c t + \phi_n) \cos(2\pi f_c t + \frac{\pi}{2}) = -\frac{a}{2} \sin(4\pi f_c t + \phi_n) + \frac{a}{2} \sin \phi_n$$

$$x_A(t) = \frac{a}{2} \cos \phi_n, x_B(t) = \frac{a}{2} \sin \phi_n$$

2.1.3 Output table:

| Symbol phase $\phi_n$ | The polarity of $\cos \phi_n$ | The polarity of $\sin \phi_n$ | Adjudicator output |
|----------------------|-------------------------------|-------------------------------|--------------------|
| $\pi/4$              | +                             | +                             | 1                  |
| $3\pi/4$             | -                             | +                             | 0                  |
| $5\pi/4$             | -                             | -                             | 0                  |
| $7\pi/4$             | +                             | -                             | 1                  |
2.2. OFDM

2.2.1. Orthogonality and baseband signals

Orthogonal frequency division multiplexing (OFDM) is a kind of multi-carrier modulation (MCM), which uses quadrature subcarrier modulating multichannel signals. Under normal circumstances, the channel bandwidth of a communication system is far greater than the bandwidth required for transmitting one signal, so transmitting only one signal in a channel will cause serious waste of channel resources, and OFDM arises as The Times require.

The principle of OFDM is to divide the channel into multiple sub-channels for data transmission, convert the high-speed sub-carriers into low-speed sub-carriers, and then modulate to each different sub-channel for transmission. This transmission method converts the non-flat fading channel into multiple orthogonal flat fading sub-channels, thus eliminating the interference between the channel waveforms.

The core of OFDM is to use the orthogonal property of the subcarrier. No matter how the amplitude of the subcarrier signal (function) changes, when multiplied in a fixed period, the integral is equal to 0. For example, suppose that the function f(t) is orthogonal to g(t) from 0 to t, i.e.

\[ \int_0^T f(t) \cdot g(t) dt = 0 \]

A pair of very simple examples of orthogonal functions, sine (t) and sine (2t), to transmit information, let a modulate in sin(t) and b modulate in sin(2t), and let f(t)=a*sin(t), g(t)=b*sin(2t), and \( t = 2\pi \).

At the receiving end, to obtain the original information A and B, we need to integrate the two subcarriers, respectively, in the form of:

\[ \int_0^{2\pi} (a \sin(t) \cdot b \sin(2t)) \cdot \sin(t) dt = a \int_0^{2\pi} \sin^2(t) dt 
\]

\[ \int_0^{2\pi} (a \sin(t) \cdot b \sin(2t)) \cdot \sin(2t) dt = b \int_0^{2\pi} \sin^2(2t) dt 
\]

Because of the orthogonality of the subcarrier, OFDM modulation can transmit multiple subchannels and multiple subcarriers. Because the frequency interval is very small, the utilization of the channel is improved.

Assuming that there are N frequencies \( f_0 \sim f_{N-1} \), where \( \Delta f \) is the frequency interval that makes each subcarrier orthogonal to each other, there are

\[ s(t) = a_0 \sin(2\pi f_0 t) + a_1 \sin(2\pi f_1 t) + \cdots + a_{N-1} \sin(2\pi f_{N-1} t) \]

Based on the above example, we can also get the baseband signal expression of OFDM:

\[ s(t) = -a_0 \sin(2\pi f_0 t) - a_1 \sin(2\pi f_1 t) - \cdots - a_{N-1} \sin(2\pi f_{N-1} t) + b_0 \cos(2\pi f_0 t) + b_1 \cos(2\pi f_1 t) + \cdots + b_{N-1} \cos(2\pi f_{N-1} t) \]

(The minus sign here is for the sake of subsequent derivation of signals in the complex frequency domain)

2.2.2. Frequency interval \( \Delta f \)

Suppose that the period of a symbol of S (t) is \( T_s \), and all subcarriers within the period of the symbol are orthogonal. Because the amplitude is not related to the conclusion, it is not listed. There are:

\[ \int_0^{T_s} \cos(2\pi f_m t) \cos(2\pi f_n t) dt = \frac{1}{2} \left\{ \int_0^{T_s} \cos[2\pi(f_m - f_n)t] dt + \int_0^{T_s} \cos[2\pi(f_m + f_n)t] dt \right\} 
\]

\[ = \frac{\sin[2\pi(f_m - f_n)T_s]}{2\pi(f_m - f_n)} + \frac{\sin[2\pi(f_m + f_n)T_s]}{2\pi(f_m + f_n)} 
\]

\[ = \frac{2\pi(f_m - f_n)T_s}{2\pi(f_m - f_n)} = i; \frac{2\pi(f_m + f_n)T_s}{2\pi(f_m + f_n)} = j 
\]

i and j are integers, so the subcarrier frequency:
\[ f_m = \frac{(i+j)}{2T_s}, \quad f_n = \frac{(i-j)}{2T_s} \]

Therefore, the subcarrier must meet the following requirements:

\[ f_k = \frac{k}{2T_s} \]

The minimum sub-carrier frequency interval is:

\[ \min(f_m - f_n) = \min\left(\frac{j}{T_s}\right) = \Delta f_{\text{min}} = \frac{1}{T_s} \]

### 2.2.3 Baseband signal modulation block diagram

![Baseband signal modulation block diagram](image)

In the above OFDM, there are N subchannels, where the formula of the KTH subcarrier is:

\[ x_k(t) = -a_k \sin(2\pi f_k t) + b_k \cos(2\pi f_k t), \quad k = 0, 1, \cdots, N-1. \]

A subcarrier consists of two orthogonal signals (the orthogonality of sine and cosine waves is independent of frequency), which can be regarded as an i-Q signal I multiplied by signal \( \cos(\omega t) \), and Q multiplied by signal \( \sin(\omega t) \) (\( \omega = 2\pi f \)).

By superimposing each subcarrier, the signal form of OFDM can be obtained:

\[ s(t) = \sum_{k=0}^{N-1} [-a_k \sin(2\pi f_k t) + b_k \cos(2\pi f_k t)] \]

And since we're getting a baseband signal here, so

\[ f_0 = 0, \Delta f = \frac{1}{T_s}, f_k = k/T_s, k = 0, 1, \cdots, N-1 \]

Then according to the formula of \( S(t) \), each subcarrier is modulated by IQ, and the output result of the baseband signal is two IQ signals (one is cos and the other is sin). The modulation mode can be QPSK or QAM.
2.2. 4QAM

(Quadrature Amplitude Modulation) is formed by superimposing two independent quadrature 4ASK signals. 4ASK is a signal obtained by de-keying the carrier with a multi-level signal. It is the promotion of the 2ASK system. Compared with 2ASK, the advantage of this system lies in the high information transmission rate.

16QAM is produced by a combination of multi-ary amplitude keying (MASK) and quadrature carrier modulation. There are two ways to generate 16QAM: (1) Quadrature amplitude modulation method, which is composed of two orthogonal four-level amplitude keying signals superimposed; (2) Composite phase shift method: it uses two independent channels. The four-phase shift phase keying signal is superimposed. The quadrature amplitude modulation method is used here. The modulation principle is shown in Figure

![Figure 5. 16QAM modulation diagram](image)

In the figure, the serial/parallel converter divides the binary symbol sequence with Rb rate into two channels, and the rate is Rb/2. 2-4

The binary symbol sequence converted to Rb/2 becomes a 4-level signal with a rate of RS=Rb/log216. The 4-level signal is multiplied by the quadrature carrier to complete the quadrature modulation, and the two signals are superimposed to produce a 16QAM signal.

The 16QAM signal is demodulated by the quadrature coherent demodulation method. The demodulator first performs quadrature coherent demodulation on the received 16QAM signal, multiplying one by cosωct and the other by sinωct. Then the high-frequency component generated by the multiplier is filtered through a low-pass filter to obtain a useful signal. The output of the low-pass filter can be sampled and judged to recover a level signal. The demodulation block diagram is shown in Figure

![Figure 6. 16QAM demodulation block diagram](image)
3. Emulation and Result
Firstly, we use Systemview to simulate the QPSK process to better help us understand the signal modulation and demodulation process in QPSK. The module connection diagram is shown in the figure. Firstly, a random sequence is divided into two channels through serial-parallel conversion. Two-phase modulation is carried out on the in-phase carrier and orthogonal carrier, respectively. The two outputs are superimposed to form a modulation signal. After the modulated signal is transmitted through the channel, it is demodulated in the receiving part. The received signal is multiplied by the orthogonal coherent carrier, sampled, and determined by the low-pass filter to form two PSK signals. One 4PSK signal is synthesized by parallel series conversion. During demodulation, it is multiplied by two orthogonal coherent carriers to form two PSK signals through low-pass filter sampling decision (sampler holder equalizes the waveform amplitude), and one 4PSK signal is synthesized through parallel series conversion (input a series of 01 pulse sequence to select the symbols of the upper and lower branches).

Simulation results and analysis:
1) Input signal and final demodulation output sequence: 11011001110011100100

![Figure 7. Input signal and final demodulation](image)

1) The input sequence is completely consistent with the output sequence, which shows that modulation and demodulation are realized.
2) After serial-parallel conversion, the input signal is divided into upper and lower branches.
   Upper branch signal sequence: 011010101
   Lower branch signal sequence: 101010110
3) Multiply and add with the modulation carrier, respectively.
4) Modulated signal with noise interference.
5) Waveform multiplied by the carrier during demodulation.

6) Signal after passing through the low-pass filter
7) Add sample and holder to smooth the waveform

The experimental simulation results show that software simulation can determine the feasibility of the theoretical modulation and demodulation scheme. By comparison, the two waveforms are completely consistent with the upper and lower branch waveforms after serial, parallel conversion of the input signal, and the input and output signals are also completely consistent. Under the condition of the same bandwidth, QPSK can carry twice the amount of information of traditional PSK modulation. QPSK is used for satellite communication, cable modulation and demodulation, video conference system, cellular telephone, and other digital communication for transmitting the MPEG2 video signal.
The following is the simulation run of 16QAM on Systemview. The module connection diagram is shown in the figure. 16QAM (quadrature amplitude modulation) is formed by the superposition of two independent quadrature 4ask signals. 4ask is the signal obtained by keying the carrier with multi-level signals. During demodulation, quadrature coherent demodulation is performed on the received 16QAM signal. Then the high-frequency component generated by the multiplier is filtered through the low-pass filter to obtain the useful signal. The low-pass filter output can recover the level signal through sampling decisions.

Input signal

![Input signal](#)

Modulated signal:

![Modulated signal](#)
Output signal:

Next, we simulate 16QAM and QPSK on MATLAB and compare the bit error rates of 16QAM and QPSK.

QPSK modulates the digital signal by changing the phase information of the modulated signal. Set different initial phase is used to distinguish different digital symbols, and its demodulation process needs to be carried out through phase information. first A series of random 01 code sequences are generated, and then every two codewords are divided into a group for discrimination, mapping, and drawing

Constellation, make the sequence demodulate through Gaussian noise, draw the constellation, and observe the signal-to-noise ratio

Impact on symbol transmission. The following is the constellation diagram and bit error rate curve of QPSK.
It can be seen from the figure that the signal-to-noise ratio has an impact on the bit error rate. The higher the signal-to-noise ratio, the lower the bit error rate. Therefore, properly improving the signal-to-noise ratio in noisy channels can effectively improve the quality of communication. In addition, it can be seen from the constellation diagram of QPSK that its noise tolerance is also large, so the error rate of information in the process of demodulation will be very low. Still, the utilization of its spectrum is relatively low.

Similarly, we get the constellation and bit error rate curve of 16QAM.
As can be seen from the constellation diagram, 16QAM modulates more constellation points, so it has more information capacity. When the bandwidth resources are the same, it will contain more
information, and its transmitted information bit rate will be higher, but the cost is easy to see. By comparing the bit error rate curves of the two in one diagram, the bit error rate of 16QAM demodulation will be higher. The complexity of the equipment will be correspondingly higher.

Therefore, QAM and QPSK need to be determined according to specific conditions in practical applications. When the channel is highly reliable, we use 16QAM to improve the transmission rate. If the channel environment is poor, we use QPSK to ensure effectiveness. In addition, when there is only voice service in the transmission, the most traditional modulation and demodulation can be used.

However, with the rapid expansion of social data, people demand multimedia and data services. Therefore, it is necessary to adopt higher QAM modulation technology. With the increasing number of users, today's spectrum resources are extremely limited. Making better use of the spectrum and improving the spectrum utilization rate is a difficult problem that all businesses are considering.

This is why QAM modulation is widely used in LTE.

4. Conclusion
In this research, we search information from the internet and use specific software to conduct the research. Through the research, we figure out what is Wi-Fi and its' basic technologies and protocols. Plus, we pay a lot of attention on comparing 16QAM and QPSK by simulation and we draw the conclusion. Finally, we achieve the goal that be more familiar with Wi-Fi and we also predict future’s development of Wi-Fi.

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