Optimizing Wireless Communication Performance using Hybrid Modulation: A Comparative Study

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Abstract: Modulation and demodulation techniques for signals are receiving more attention with the development of wireless communication technologies. This paper presents a comprehensive analysis of single and hybrid modulation techniques in wireless communications. The definition and theory of four types of classical single modulation Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), Phase Shift Keying (PSK) and Quadrature Amplitude Modulation (QAM) are first analyzed. Secondly, through the simulation study of the adaptive strategy, it is found that adaptive hybrid modulation selects a more appropriate modulation type under different signal-to-noise (SNR), demonstrating the potential of hybrid modulation to enhance the robustness and adaptability of wireless systems in such situations. This study demonstrates the effectiveness of hybrid modulation, especially QAM-PSK combinations, in utilizing the advantages of both strategies to improve bandwidth and power efficiency. The results of this study exemplify the importance of hybrid modulation in the development of wireless communications and the value of its research.

Keywords: wireless communication technology, single modulation, hybrid modulation, Quadrature Amplitude Modulation, Phase Shift Keying

1 Introduction

With the continuous development of wireless communication technology, the modulation and demodulation techniques of wireless communication technology are also attracting more and more attention from the public. The main parameters used to evaluate such technologies are bandwidth efficiency and power efficiency. Bandwidth efficiency refers to the ability of a modulation method to accommodate messages within the allocated finite frequency band. Power efficiency is the ability of a communication system to send messages using low power without affecting channel allocation [1]. Chaos communication, due to its low power consumption, low complexity, high efficiency, and excellent anti-fading capabilities, can be widely used in spread spectrum communication systems, and is therefore receiving increasing attention [2].

This paper first analyzes the common single modulation techniques in wireless communication, including ASK, FSK, PSK, and QAM. Next, it selects several classical

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hybrid modulation methods, mainly focusing on the combination of different hybrid modulation methods of single modulation. In the field of wireless communication today, these methods have made significant contributions and are worth learning from and further researching by future generations. Finally, this paper conducts simulation studies on the hybrid modulation of QAM and PSK, designs adaptive strategies to simulate and demonstrate the advantages of hybrid modulation, and compares the performance and efficiency of single modulation and hybrid modulation. The simulation results indicate that hybrid modulation technology, combining the advantages of the two single modulation techniques being mixed, is of research value.

2 Theoretical Basis

2.1 Single Modulation Technique

2.1.1 Amplitude Shift Keying/On-Off Keying (ASK/OOK)

Amplitude Shift Keying, or ASK for short, is a basic but very important digital modulation technique. In ASK modulation, the digital signal needs to change the amplitude of the carrier in order to transmit information. One of these, On-Off Keying or OOK, is a special form of ASK, also known as 2ASK or Binary ASK, where the digital signal achieves the ultimate goal of transmitting information by determining whether or not a carrier is present [3].

ASK modulation uses signal waveforms of different amplitude (usually cosine waves) to represent different states of digital information, but there must be a correspondence between that amplitude and the logic that was originally input. There are usually two input logics, "Logic 1" and "Logic 0", taking OOK as an example. If the input signal is "logic 1", the amplitude of the carrier is set to a certain value; And on the flip way, if the input signal is "logic 0", a new amplitude value of the carrier is modulated, i.e. the amplitude is zero in the simplest case. In contrast, in the generalised form Multilevel Amplitude Shift Keying, M-ary ASK, the carrier amplitude can be one of M discrete levels, each corresponding to an M-ary symbol, where M is k binary symbols.

The advantages of OOK are that it is simple to build and the results of modulation and demodulation are obvious and easy to observe. This is due to the binary nature of OOK - if the input is a logic "0", the amplitude of the output waveform can be reduced to zero in the simplest case.

$$s_{MASK}(t) = A_i * \cos(2\pi f_c t + \phi) \tag{1}$$

where A_i is one of the frequencies selected on the basis of the input data. $s_{MASK}(t)$ is the output MASK signal. f_c is the carrier frequency. $\cos$ is the cosine function. ϕ is the phase. $s_{OOK}(t)$ is the output of OOK signal.

$$\begin{aligned} s_{OOK}(t) &= s_1(t) = A\cos 2\pi f_c t -- \text{"logic1"} \\ or &= s_2(t) = 0 -- \text{"logic0"} \end{aligned} \tag{2}$$

Where M=2, $a_n \in \{0,1\}$

2.1.2 Frequency Shift Keying (FSK)

Another important modulation technique, Frequency Shift Keying (FSK), which uses digital signals to carry different information by changing the frequency of the carrier signal. The multi-level variant of FSK is Multi-frequency Shift Keying, MFSK, where the frequency of the carrier can have multiple discrete values, each corresponding to a different digital state or symbol. Of these, 2FSK is the simplest form. It uses two different frequencies to represent the binary '0' and '1'.

In MFSK, different digital signals correspond to different carrier frequencies to differentiate between different data or symbols, enabling multivariate modulation. This is similar to different symbols or bits in MASK having different amplitudes, but there are differences in the technical reality of the two modulation techniques. Each frequency of MFSK represents a symbol or combination of bits, allowing the transmission system to carry more information at a time [4].

$$s_{MFSK}(t) = A * \cos(2\pi f_{ci} t + \phi) \tag{3}$$

where f_{ci} is one of the frequencies selected on the basis of the input data.

2.1.3 Phase Shift Keying (PSK)

Digital signals transmit information by changing the phase of the carrier signal using phase shift keying (PSK). In PSK, the carrier phase matches the digital signal one-to-one to transmit information efficiently, but strict phase synchronisation is usually required.

PSK changes the phase of the carrier signal (usually a sine wave) according to different digital signals. Digital signals are represented by changing phase, which can be discrete (e.g. 0°, 90°, 180°, 270°) or continuous. Common forms of PSK are mainly BPSK, QPSK, 8PS, which can be considered as typical of M-ary phase shift keying, MPSK. Within an M index symbol interval of MPSK there are M possible symbols corresponding to M possible carrier phases [5]. This can be extended with DPSK, which introduces differential coding to resolve phase ambiguity, and OQPSK, which improves performance by reducing envelope undulation.

$$s_{MPSK}(t) = A * \cos(2\pi f_c t + \phi_i) \tag{4}$$

where ϕ_i is one of the phases selected on the basis of the input data.

2.1.4 Quadrature Amplitude Modulation (QAM)

Quadrature Amplitude Modulation (QAM) is different from all of the previously described modulation methods in that, rather than altering only one attribute of the carrier signal, QAM uses quadrature amplitude modulation to simultaneously change both amplitude and phase to convert a digital signal into an analogue signal for transmission [6].

QAM is the simultaneous use and transmission of two orthogonal carriers, one to carry the real part (I) of the input signal and then the other to carry the imaginary part

(Q) of the input signal. The amplitude on each carrier is modulated according to the digital data to be transmitted, and different digital data is represented by adjusting the magnitude of the amplitude. QAM can modulate both the phase and amplitude of a signal. This makes data transmission very efficient.

$$s_{MQAM}(t) = A_{Ii}(t) \cdot cos(2\pi f_c t) + A_{Qi}(t) \cdot sin(2\pi f_c t) \quad (5)$$

Where A_{I_i} and A_{Q_i} are the amplitudes of the I and Q components respectively, modulated according to the input data, representing different points on the constellation diagram.

2.2 Hybrid Modulation Technique

2.2.1 FSK+QAM

The first type of classical hybrid modulation is a mixture of Frequency Shift Keying and Quadrature Amplitude Modulation to transmit the information. There have been many studies of this type of hybrid modulation, proposing a combination of FSK and QAM and calling it FQAM. The proposed and further research on FQAM is summarized in [7], which also compares the performance of FQAM with OFDM and shows that the hybrid modulation combination, FSK and QAM, can bring greater benefits to hybrid modulation. Because FSK carries different information by changing the frequency of the carrier, it is not as sensitive to channel amplitude disturbances as other modulation techniques, whereas QAM, as an orthogonal modulation, can achieve higher data rates, so combining FSK and QAM for hybrid modulation can increase the rate while improving immunity to interference.

HFQAM as a modulation scheme plays an important role in dealing with interference and achieves significant performance gains. With HFQAM, the ICI distribution is not Gaussian. The channel capacity can therefore be increased [1].

2.2.2 FSK+PSK

Combined hybrid modulation of FSK and PSK is another typical example of hybrid modulation. Hybrid FSK and PSK modulation techniques can improve the robustness of the system and at the same time can cost less in terms of time and money when using the same equipment for modulation, and therefore deserve to be investigated in depth. There are many authors who have explored in depth the various methods of hybrid modulation of FSK and PSK. A study set up a new digital modulation scheme, termed frequency-phase keying (FPK), that combines frequency-shift keying (FSK) and phase-shift keying (PSK), is presented [8,9]. Some experiments have been obtained through research that the equipment used in the hybrid modulation method of FSK and PSK differs very little from that used in FSK, and two different sequences can be transmitted simultaneously in the same bandwidth, with a higher bandwidth utilisation than FSK and PSK [10]. There are also experiments to design pseudo-random FSK/PSK signals in conjunction with national military research projects to observe the spectral information of the target through radar models, and it is concluded that this hybrid modulation has a higher spectral adaptability and better fuzzy signal resolution [11].

2.2.3 PSK+QAM

When PSK and QAM are combined, PSK performs better in terms of BER performance while QAM can achieve high data rates, so it is desirable to investigate hybrid modulation that can combine the advantageous performance of both.

A new hybrid modulation scheme for modulation and identification of hybrid modulation of PSK and QAM was once proposed by a researcher. Based on the hierarchical structure, using K-S test and cumulant test, the classification process includes calculating the ECDF of the decision. Finally, it was concluded that the hybrid modulation classification scheme outperforms the cumulant only scheme in AWGN channels [12].

3 Modeling and Simulation

3.1 Single

To compare the performance of different single modulation techniques, this paper performs MATLAB simulation experiments to investigate the bit error rate (BER) of different modulation techniques under different signal-to-noise ratio (SNR) conditions. In this paper some representative 2ASK, 2FSK, BPSK, 4QAM, 4ASK, 4FSK, QPSK, 16QAM and 64QAM different modulation techniques are selected. The BER of each modulation technique was first calculated for a range of SNR values using MATLAB's 'berawgn' function. The BER versus SNR curves were then plotted using MATLAB's 'semilogy' function to visually compare the differences in performance between the different modulation techniques. The figure 1 shows a comparison of the Bit Error Rate (BER) performance of different modulation techniques at different Signal to Noise Ratios (SNR). The x-axis represents the SNR in dB and the y-axis represents the BER. The BER curves of different modulation techniques are shown in the figure 1. Each curve has a different colour and line shape to distinguish be-tween different modulation techniques.

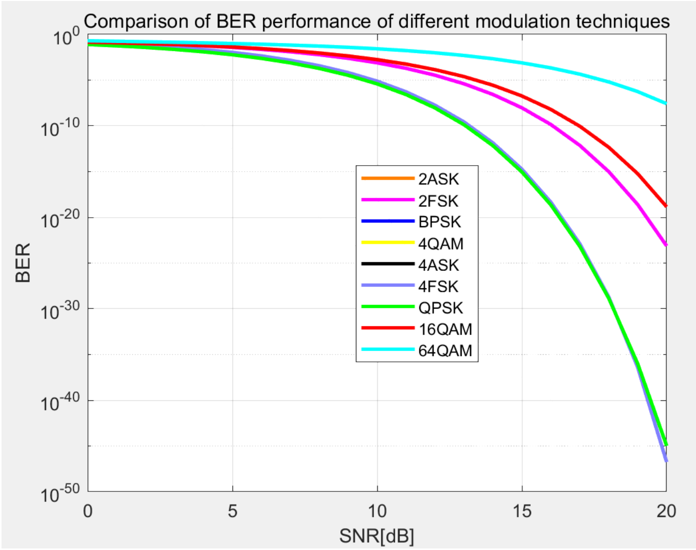

Fig.1. Comparison of BER performance of different modulation techniques (Photo/Picture credit: Original)

It can be seen that at lower SNR values all modulation techniques have a higher BER. As the SNR increases, the BER will gradually decrease for all modulation techniques, i.e. the BER will gradually decrease. The performance of different modulation techniques varies at different SNR values, for example BPSK and QPSK perform better at lower SNR values, while 16QAM and 64QAM perform better at relatively higher SNR values.

3.2 Hybrid—— PSK+QAM adaptive modulation technology

In this study, the performance of different modulation techniques under different SNR conditions is evaluated by calculating the bit error rate (BER) for BPSK, QPSK, 16-QAM, and 64-QAM modulation techniques over a signal to noise ratio (SNR) range of 0 dB to 20 dB. In addition, this study designs an adaptive modulation strategy based on SNR thresholds, which switches modulation modes according to different SNR thresholds, aiming to optimise the communication performance under various channel conditions.

This experiment was carried out using MATLAB simulation software. In MATLAB, this paper first defines the range of SNR and calculates the corresponding BER using the built-in function ‘berawgn’. Next, the BER of the adaptive modulation strategy is defined, which selects the most appropriate modulation technique based on different SNR thresholds. Finally, the experiments generated BER comparison plots using the ‘semilog’ function, clearly demonstrating the performance of different modulation techniques and adaptive modulation strategies over the entire SNR range. The figure 2 shows the BER curves of BPSK, QPSK, 16-QAM and 64-QAM modulation schemes as well as the adaptive modulation scheme for different values of SNR. The curves are differentiated using different colors and line shapes.

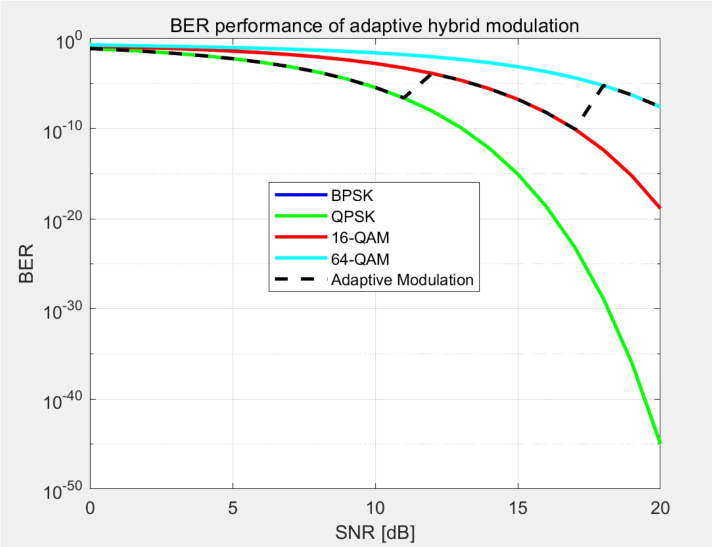

Fig.2. BER performance of adaptive hybrid modulation (Photo/Picture credit: Original)

It can be seen from the figure that the BER for all modulation schemes gradually decreases as the SNR increases, i.e. the BER gradually decreases. For higher SNR values, the adaptive modulation scheme shows the best performance. The adaptive scheme selects the most appropriate modulation technique based on different SNR values, e.g. BPSK and QPSK in the lower SNR range and 16-QAM and 64-QAM in the higher SNR range.

Simulation results show that BPSK performs well under low SNR conditions due to its low bit error rate (BER). However, since BPSK can only carry one bit of information per symbol, its data rate is relatively low--For example, QPSK (4-phase shift keying) can transmit 2 bits of information per symbol, while 16-QAM (16 amplitude modulation) can transmit 4 bits of information and 64-QAM can transmit 6 bits of information. As the SNR increases, higher order modulation techniques can be used, allowing more bits of information to be carried per symbol, resulting in higher data rates. Therefore, where SNR allows, the use of higher order modulation techniques can significantly increase the data rate, although this may also result in a slight increase in BER. The adaptive modulation strategy aims at achieving an optimal balance between BER and data rate by selecting appropriate modulation patterns at different SNR levels.

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4 Conclusion

In this experiment, the simulation of hybrid modulation was conducted in this study. By employing adaptive strategies to investigate the performance of hybrid modulation, it was found that the combination of QAM and PSK in hybrid modulation can to some extent integrate the respective advantageous characteristics of the individual QAM and PSK single modulation techniques. Choosing the most suitable modulation and demodulation scheme based on different signal-to-noise ratios (SNR) can enhance efficiency, robustness, and adaptability to varying SNR levels. Single modulation and hybrid modulation have universality and fundamentality in the field of wireless communication. Therefore, hybrid modulation, as an innovative method that can significantly enhance the value of wireless communication systems, is worth further exploration of its potential. Researching more optimization methods based on hybrid modulation theory holds high applicability value in future 6G communication technology or other wireless communication technologies.

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