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Analysis of channel performance in modern digital communication technology and understanding the enhancement of channel performance

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Abstract. With the rapid development of the information age, the demands on communication technology continue to grow. As a crucial communication method, digital communication systems play a vital role in achieving efficient transmission speeds and reliability. This paper centers around modulation techniques within digital communication systems, with a specific emphasis on the analysis of reducing bit error rates and enhancing transmission speeds. Consequently, this study delves into the current methods employed for achieving an all-encompassing optimization of both transmission speed and reliability, while also proposing novel insights. The paper will detail the benefits and drawbacks of contemporary noise processing techniques that aim to enhance channel performance and explore methods for their improvement.

Keywords: peak to average power ratio, average percent of zero, bit error rate, neural network encode.

1. Introduction

With the advancement of the information age, the demand for communication technology is increasing significantly. To meet the evolving requirements of this era, higher-performing communication methods have emerged [1-5]. In our daily lives, two major communication systems exist: analog communication systems and digital communication systems. This paper specifically focuses on analyzing methods for reducing bit error rates and achieving efficient transmission speeds within the modulation of digital communication systems.

In digital communication systems, widely used modulation methods include M-QAM, M-PSK, and other variants. Different modulation methods exhibit varying levels of anti-interference capability and transmission speed performance [6]. For instance, under high Signal-to-Noise Ratio (SNR) conditions, QAM demonstrates higher transmission speeds than 16-QAM [7]. However, at low SNR conditions, QAM tends to be more reliable than 16-QAM. Thus, it becomes evident that optimal transmission speed and reliability cannot always be simultaneously achieved under specific SNR conditions. The performance of modulation methods like M-QAM and M-PSK differs across varying SNR ranges, making it challenging to achieve optimal transmission speed and reliability simultaneously.

This paper delves into existing methods and introduces fresh insights, including noise processing, signal correction, and algorithm optimization. Noise generation arises from sources such as

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environmental factors (obstacles, rain, wind) and internal system elements (electronic devices), impacting signal propagation. White noise and colored noise result from thermal noise and nonlinear device characteristics, respectively. Crosstalk between signals, particularly Rayleigh fading, significantly influences bit error rates. Rayleigh fading emerges due to multipath propagation, leading the receiver to capture multiple signal components with distinct phases and amplitudes.

Furthermore, to mitigate noise effects and decrease bit error rates, this paper explores coding methods like Hamming code and convolutional code, as well as the integration of spectrum clipping and coding. The technology of Orthogonal Frequency Division Multiplexing (OFDM) and Time Division Multiplexing (TDM) combination is introduced to enhance spectrum utilization efficiency. The paper highlights the issue of Peak-to-Average Power Ratio (PAPR) caused by power amplifiers, proposing methods to alleviate PAPR, such as Partial Transmit Sequence (PTS) and amplitude modulation.

From an energy consumption standpoint, the paper discusses methods to increase SNR and transmission power, particularly focusing on transmission power optimization of Phase-Shift Keying (PSK). Additionally, the paper explores the application of neural networks, adaptive modulation and demodulation through channel characteristic learning, dynamic power allocation, and techniques to enhance neural network efficiency, such as Average Percentage of Zeros (APoZ).

Noise originates from various sources in daily life, including obstacles such as high-rise buildings, environmental factors like rain and wind, and issues intrinsic to electronic devices. The interaction between information signals can also be considered noise. These various types of noise interfere with signal propagation. Noise can be broadly categorized into noise power spectral density, characterized as average noise or white noise. Thermal noise in electronic devices, molecular thermal motion, and atmospheric and electromagnetic interferences contribute to white noise. Colored noise, characterized by uneven power spectral density, stems from system nonlinearities, filtering effects, and periodic interferences.

Average power spectral density noise can be simulated using MATLAB's Additive White Gaussian Noise (AWGN) channel. Generally, its impact on signals is manageable and can be corrected by incorporating redundant coding techniques. However, the influence of noise with fluctuating power spectral density on signal reliability is more significant. Apart from these two types of noise, crosstalk between signals, notably Rayleigh fading, poses challenges. Rayleigh fading results from multiple reflection, scattering, or refraction paths in addition to the direct signal path. These various paths introduce differences in propagation environments, path lengths, and time and phase characteristics upon reaching the receiver, generating signal components with varying phases and amplitudes at the receiving end.

2. Signal correction

Commonly, people employ various coding methods such as Hamming code, repeated code, and convolutional code to enhance the performance of the bit error rate. Encoding information using these codes can effectively improve the bit error rate, but it might impact the transmission speed of the information. This is because the error detection code introduced after encoding adds redundancy, potentially affecting transmission efficiency.

Figures 1 and 2 depict the bit error rate of BPSK with Hamming code, convolutional code, and without any coding. Hamming codes are well-suited for short-length information codes, while convolutional codes are more appropriate for longer-length information codes.

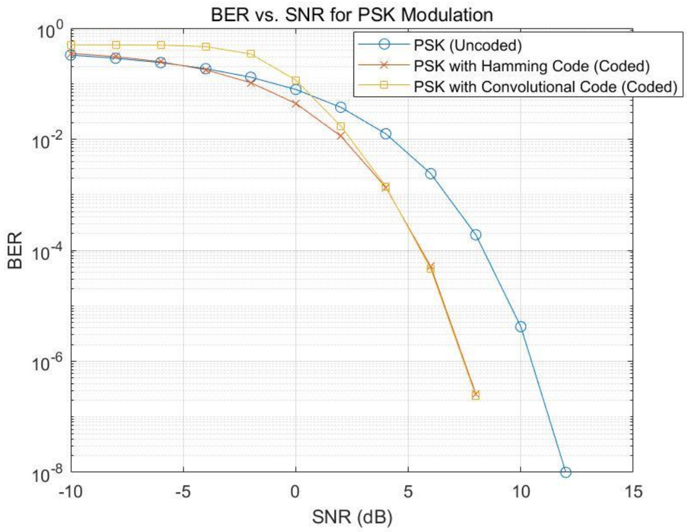

Figure 1. Long bit-length information codes.

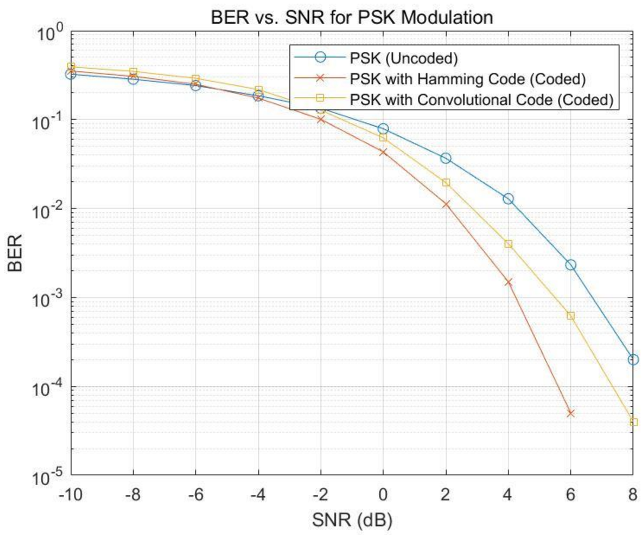

Figure 2. Short bit-length information codes.

Presently, in efforts to reduce the bit error rate, adjustments are primarily made through methods such as spectrum shifting, spectrum clipping, or coding. In the case of spectrum clipping, a common approach involves filtering modulation to remove a portion of the signal affected by noise interference [8]. However, it's evident that this method doesn't lead to a reduction in bit error rate after clipping and demodulation of the spectrum amplitude. Paradoxically, the bit error rate observed in the clipped spectrum tends to be higher compared to the bit error rate after demodulation of the unprocessed signal. Clearly, this approach is flawed. Therefore, by identifying the appropriate threshold, effective improvement in bit error rate performance can be achieved without the need for counterproductive processing.

For instance, in the context of bipolar binary signals, setting the threshold at 0 or using the average value as the threshold can significantly enhance performance, as shown in Figure 3.

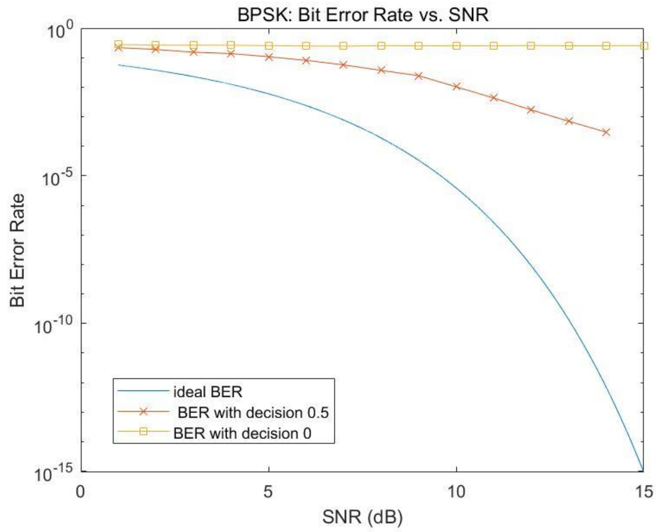

Figure 3. The BER with different threshold.

Furthermore, a significant portion of spectrum shifting technologies employs OFDM, often combined with TDM to effectively mitigate information cross-talk. OFDM involves the modulation of a signal by dividing it into N equally sized sub-signals, each modulating a carrier that is orthogonal and situated at different frequencies. TDM, on the other hand, centers on time multiplexing. It arranges signals from various users into distinct time intervals, thereby preventing collisions and interference between users. This approach is well-suited for scenarios with limited bandwidth, as it segregates signals from different users based on time, allowing each user to transmit data within a designated time interval.

3. Multiple modulation

When combining OFDM and TDM, the advantages of both can be fully harnessed. OFDM partitions the signal into multiple subcarriers, while TDM technology is applied to each subcarrier, effectively segregating signals from different users based on time. This approach capitalizes on the extensive frequency domain bandwidth and maximizes the utilization of time slices among users, resulting in heightened transmission efficiency.

However, OFDM is not without drawbacks. Imperfect phase alignment or lack of phase synchronization can lead to mutual influence among different subcarriers in terms of amplitude and phase disparities during combination. The summation of peaks from different subcarriers can cause an increase in the instantaneous signal amplitude, giving rise to the PAPR problem [9]. Elevated PAPR levels can trigger signal nonlinearities, particularly in power amplifiers, leading to additional distortion and errors in transmission processes. These effects ultimately compromise signal quality and system performance [9].

To address this challenge, certain technologies must be adopted. PTS, a selective mapping technique, controls signal peak amplitudes by adding different signal segments with assigned weights at the transmitting end, effectively diminishing PAPR. Clipping and Filtering technology intercepts signal peaks, reducing them to levels near the surrounding troughs, where the amplitude is lower than the peak, thus mitigating instantaneous amplitude disparities. Another approach involves amplitude modulation, which curbs PAPR by introducing diverse subcarrier amplitude-to-amplitude ratios.

Reducing intercarrier crosstalk stems from the influence of the previous pulse tail on subsequent pulse sampling, thereby affecting the bit error rate. Adjusting the sampling frequency can neutralize Inter-Symbol Interference (ISI), or incorporating a raised cosine filter can minimize the impact of ISI [10].

4. Energy-wise

To mitigate the bit error rate, the technique of gain adjustment can be employed, which involves increasing the SNR and subsequently decreasing the BER. Elevating transmission power is an effective method to enhance SNR. In the case of PSK, improving its transmission power presents a unique challenge. As PSK is modulated within the framework of a constellation diagram, direct energy amplification of the source isn't feasible. Instead, the approach involves amplifying the average power of the carrier signal to boost the power unaffected by noise post-modulation.

As illustrated in Figure 4, maintaining a consistent SNR across the same AWGN channel entails using a threshold of 0. The decision process assigns a value of 1 for results greater than 0, and a value of 0 for results less than or equal to 0. It's important to note that Hamming code is not integrated into the system. By manipulating the carrier coefficient, observations indicate that as the coefficient increases, the bit error rate initially experiences a rapid decline, reaching its lowest point at 0.063, before stabilizing.

This behavior can be attributed to the influence of signal power increment within the constraints of upper and lower bandwidth limits. As signal power gradually increases, the excessive amplitude becomes restricted due to bandwidth limitations, leading to distortion. This phenomenon maintains the bit error rate at a consistent level. To optimize bit error rate performance, pre-distortion processing can be employed. This approach involves adjusting the source coefficient before signal modulation, factoring in amplification power multiples to prevent distortion [11]. Alternatively, negative feedback regulation can be employed. This technique entails pre-amplifying the initial signal to ascertain the maximum amplitude the channel can accommodate. Subsequently, an amplifier is utilized to apply the corresponding amplification factor, achieving the desired amplification power.

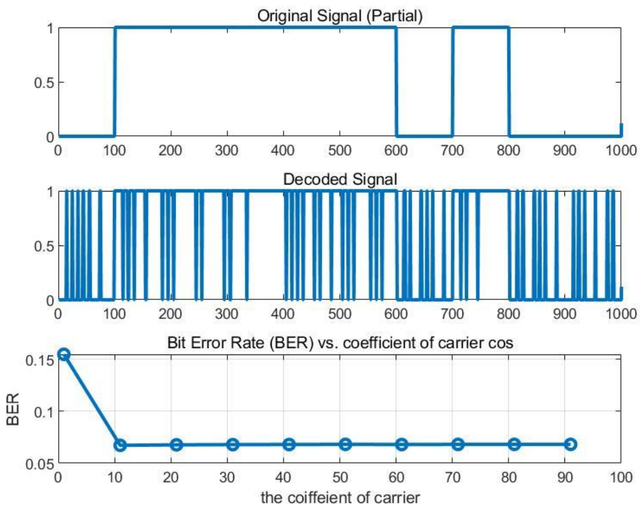

Figure 4. BER vs coefficient of carrier cos.

5. Algorithmically

In order to make the channel more intelligent, the neural network can use the above methods to reduce BER. The neural network can help to identify the pattern and structure information of the signal by means of special extraction, so as to reduce redundancy and noise. Therefore, it can realize adaptive modulation and demodulation by learning the changes and characteristics of the channel, and the corresponding demodulation according to the characteristics of the corresponding channel will help the information run more efficiently. Moreover, the neural network can dynamically allocate power according to channel quality and network load to increase power in harsh channel environment to ensure reliability. Reduce power to save energy under good channel conditions [3].

The author also used APoZ to improve the efficiency of neural networks. APoZ is a metric used to measure the activity of each convolutional channel by calculating the percentage of the output average

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zero value in each convolutional channel to determine that those channels are inactive for most of the cases on the sample. Below a certain threshold, inactive channels are clipped to reduce the redundancy parameters of the neural network itself. So that the Bible network can maintain fewer parameters and computational burden while still having a high performance guarantee. The tailored neural network consumes less storage space and computing resources, which improves transmission efficiency in embedded devices or resource-constrained environments.

Of course, neural networks also have certain limitations. When in digital signal transmission, due to the complexity of information in different channels, which may need a large amount of data to train the neural network. If the data involved in training is insufficient, it is likely to lead to over-fitting of the training model, resulting in poor performance on the new signal data, resulting in degraded channel performance. In addition, the subjectivity of data may arise in the process of data processing due to data imbalance, which will have a negative impact on the training of neural network. Because the neural network is a black box model, it is difficult to explain its internal decision-making process and feature extraction method. What is more dangerous is that the black box model is vulnerable to adversarial attacks, and only a small modification of the input can be used to deceive the network and it is almost impossible to be detected by human vision, which will make the output result of the digital signal difficult to be understood and trusted.

In order to solve the black box problem, it may be possible to test the neural network several times through the signal model with known results after the training of the neural network, so as to judge the reliability of the neural network according to the results. It may also be possible to further learn the decision-making process and feature extraction mode of the internal operation of the neural network through the analysis of the results, so as to gain a deeper understanding of the neural network.

6. Conclusion

This paper summarizes the methods of reducing bit error rate and improving transmission speed in digital communication system. In the face of problems such as noise, signal correction, energy consumption and algorithms, various techniques and methods are proposed and explored. Although neural networks have a significant effect in optimizing transmission performance, there are some limitations, such as insufficient data leading to overfitting, adversarial attacks, and the opacity of black-box models. These problems can be solved through more training data, signal model testing, and in-depth study of the inner workings of neural networks. Combining various methods can achieve higher reliability and efficiency in digital signal transmission figures. Each figure should have a brief caption describing it and, if necessary, a key to interpret the various lines and symbols on the figure.

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