Proceedings of the 2023 International Conference on Machine Learning and Automation
DOI: 10.54254/2755-2721/34/20230312

Adaptive simulation of digital signal transmission

Diwen Ye

Physical and Electronic Engineering College, Hengyang Normal University, HengYang, 421000, China

1910741134@mail.sit.edu.cn

Abstract. High-order modulated signals have lower anti-interference ability than low-order modulated signals with the same modulation method and conditions. In situations with low signal-to-noise ratios, the quality of high-order signals can degrade significantly. An algorithm capable of intelligently switching the modulation order based on the current signal-to-noise ratio can effectively address this issue. This paper presents an adaptive signal transmission algorithm that intelligently selects different orders of Phase shift keying (PSK) modulation depending on varying signal noise ratio (SNR) conditions, while ensuring the user-specified upper limit of bit error rate (BER). This approach guarantees signal transmission quality. The algorithm is implemented in Python and involves simulating the relationship curve between SNR and BER for different PSK orders. This simulation is combined with theoretical transmission rate analysis, resulting in an adaptive algorithm that intelligently switches modulation methods under complex conditions to meet transmission requirements. The proposed algorithm dynamically adapts to diverse user requirements for signal-to-noise ratios in various environments. It achieves this by adjusting the modulation order, calculating theoretical transmission times based on the given signal frequency, and ultimately verifying the actual bit error rate through transmission and testing. Upon testing, this design successfully achieved its intended goals.

Keywords: digital transmission, phase shift keying, adaptive algorithms.

1. Introduction

In the present day, digital communication has become one of the foremost research areas within the realm of electronic information engineering. As pivotal technologies for 5G and forthcoming communication [1], the methods represented by Phase shift keying (PSK) and Quadrature Amplitude Modulation (QAM) hold substantial research significance. When juxtaposed with traditional modulation techniques such as 2PSK, higher-order QAM, like 16-QAM, 64-QAM, and 256-QAM, exhibit elevated transmission rates [2] and are experiencing escalated adoption. The burgeoning need for augmented velocity, heightened stability, and more dependable communication across diverse industries has spurred the emergence of progressively advanced algorithms. For instance, a novel approach grounded in constellation structure has been introduced to discern distinct orders of PSK and QAM modulation within sluggish and flat fading channels [3], or to employ equipment like adaptive equalizers for interference-immune communication [4]. Moreover, assorted channel estimation techniques are harnessed to enhance anti-jamming performance, including interpolation techniques such as Linear, Cubic Spline, and Discrete Fourier Transform (DFT) [5], or the implementation of anti-jamming coding like Hamming code, Convolutional code, Turbo code, Low Density Parity Check (LDPC) code, and the

DOI: 10.54254/2755-2721/34/20230312

like [6]. These algorithms exert a noteworthy influence on enhancing anti-interference capabilities, diminishing Bit Error Rate (BER), and augmenting transmission rates.

However, more advanced algorithms also introduce additional challenges. When compared to traditional medium and low-frequency base stations, the propagation characteristics of millimeter waves have engendered issues of link instability and interference in expansive networks [7]. For instance, the transition from 8QAM to 16QAM, 64QAM, or even higher coding introduces enhanced transmission rates but concurrently jeopardizes signal stability. Within the same Signal-to-Noise Ratio (SNR) parameters, the stability of 8PSK lags behind Quadrature Phase Shift Keying (QPSK) and notably trails the most traditional and gradual Binary Phase Shift Keying (BPSK) signal transmission technique. Consequently, within intricate electromagnetic landscapes, the reduction of SNR has a substantial impact on signal quality as higher-speed communication methods experience diminishing stability. In select extreme scenarios, low-efficiency coding techniques might permit gradual yet reliable signal transmission, while signals encoded using high-speed methods might encounter complete degradation in quality, rendering them impractical for use.

In reality, within the majority of application scenarios, the requirements of various industries lean more towards stable and dependable signals than an emphasis on high-speed transmission. In intricate electromagnetic landscapes, it is often a wiser decision to relinquish some transmission speed in favor of adopting the most stable and reliable signal transmission approach. Unfortunately, current prevailing signal transmission systems fall short in delivering this functionality. Consequently, this paper introduces a fresh PSK digital signal communication design, developed using Python. This design centers around distinct orders of PSK modulation and integrates the capability to adaptively select suitable signal modulation and demodulation techniques. The selection is based on the prevailing SNR of the environment and the maximum BER deemed acceptable by the user, thereby striking a balance between transmission speed and stability.

2. PSK technology and analysis

PSK technology is a prevalent form of digital modulation. It encodes binary information by altering the phase of the carrier wave. Among its variants, BPSK, where each symbol corresponds to 1 bit, and two distinct phases signify "0" and "1" respectively. In the case of QPSK, one symbol corresponds to 2 bits, and its four phases represent "00," "01," "10," and "11" respectively. Higher-order PSK technologies follow a similar pattern, segmenting a period into more phases to transmit a greater number of bits within that interval.

Within low-order modulation and demodulation systems, PSK exhibits superior performance. For instance, in binary modulation systems, 2PSK demonstrates the highest resistance to noise. When employing the same demodulation technique, 2PSK necessitates 6dB less SNR than 2ASK [8]. In contrast to QAM technology, where the modulation constellation points are distributed within a defined range on the complex plane, PSK modulation places its constellation points along a unit circle with consistent magnitude but varying phases. Clearly, an increased number of constellation points translates to higher spectrum utilization rates, enabling greater data transmission per unit of time. The order of QAM or PSK directly impacts the density of constellation points, thereby influencing error rates. Under comparable channel conditions, QAM of the same order outperforms PSK [9]. This performance disparity becomes more pronounced as the order rises in QAM, due to the unchanging distance between each combination within the QAM constellation diagram. Conversely, the distance between constellation points in PSK is smaller [10]. In comparison to QAM technology, high-order PSK technology exhibits greater sensitivity to phase deviations. In other words, high-order PSK technology lacks the stability seen in QAM technology of the same order. QAM demonstrates considerably superior resistance to noise-induced interference than PSK [11]. Consequently, as the order increases, PSK experiences a swift deterioration in anti-interference performance; these shifts are substantial and easily discernible. The present study delves into the examination of BER changes in QPSK concerning alterations in SNR for 16PSK, 64PSK, and 256PSK. Furthermore, it proposes an adaptive algorithm design based on this analysis.

Initially, the study employs Python's random function to generate a random bit sequence. For this investigation, a dataset of $6*10^6$ bits was chosen. Subsequently, the original data is subjected to modulation using QPSK, 16PSK, 64PSK, and 256PSK methods individually. Following the modulation process, Gaussian additive white noise is introduced within a SNR range spanning from -30 to 50. The intensity of the added noise is determined according to the corresponding SNR levels. This specific SNR range was selected due to its pronounced impact on the BERs of the four modulation techniques.

Once the noise is incorporated, the signals containing noise are decoded separately. A bit-by-bit comparison is then performed between the decoded signals and the original signals. By calculating the ratio between the number of erroneous code elements and the total count of code elements, the relationship between SNR and BER under various SNR conditions is obtained for the four modulation methods, as illustrated in Figure 1.

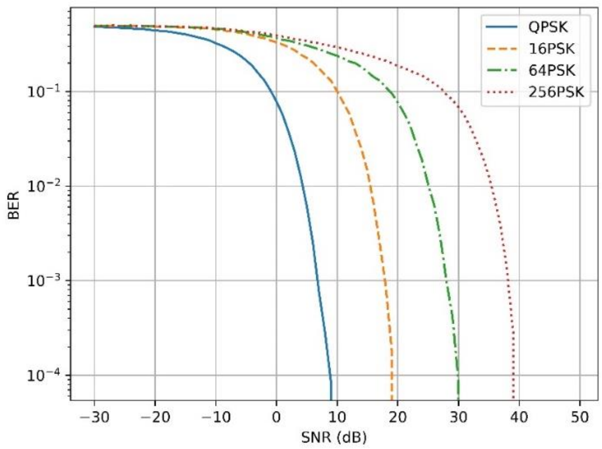

Figure 1. BER variation with SNR for different orders of PSK.

Upon observation, it becomes apparent that when the SNR is at 1, the BER of QPSK has already dropped below 10^{-1}. In contrast, it takes an SNR of 10 for the BER of 16PSK to reach the same level. Furthermore, in the case of 256PSK, the SNR must approach 30 before its BER can be brought below 10^{-1}. For a more stringent requirement of a BER at 10^{-4}, QPSK suffices at an SNR of 10, while 256PSK necessitates an SNR of 40 to achieve the same.

In essence, under identical noise intensities, as the modulation order escalates, the BER experiences a significant rise, consequently impacting the signal's quality and diminishing its practicality. As a result, despite the theoretically heightened transmission rates of high-order signal coding compared to low-order coding, as illustrated in Figure 2—where Shannon's formula calculates the theoretical transmission rate—such data holds limited practical relevance.

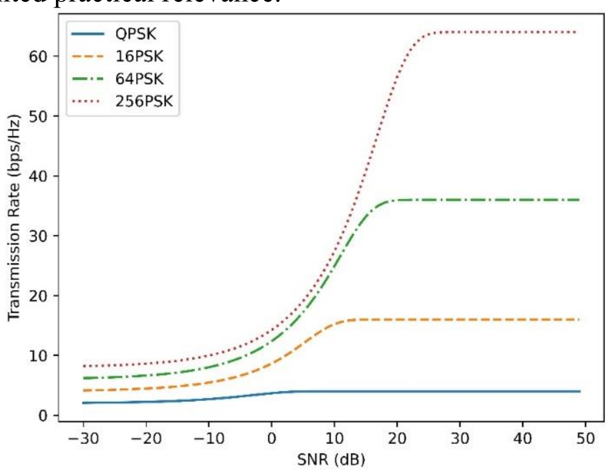

Figure 2. Theoretical transmission rate for PSK modulation.

From Figure 2, it becomes evident that at an SNR of 10, the transmission rate of 256PSK outperforms QPSK by a substantial margin. However, referring to Figure 1, it becomes apparent that when the SNR is 10, the BER of 256PSK nears 0.5. This implies that the signal is nearly indistinguishable from a randomly generated, unordered sequence, rendering it practically useless.

Based on the above analysis, the following conclusions can be drawn. On one hand, in environments with high SNRs, high-order coding does yield a notable enhancement in transmission speed. However, on the other hand, high-order coding, despite boasting high theoretical transmission rates, struggles to operate effectively in low SNR scenarios. The demands for BERs vary across different application contexts. Hence, it is imperative to devise an algorithm capable of adaptively selecting suitable coding methods in accordance with prevailing SNR conditions and users' maximum acceptable BERs.

The proposed adaptive algorithm in this paper adeptly addresses this challenge. This algorithm demonstrates intelligent modulation method selection by incorporating the SNR and capturing the maximum acceptable BER for current requirements. The algorithm masterfully attains equilibrium between transmission speed and stability, effectively catering to a spectrum of needs.

3. Design of the adaptive algorithm

In our devised algorithm, we begin by acquiring the prevailing SNR of the current environment and determining the maximum acceptable BER. Next, we systematically explore the various PSK methods that satisfy these requirements under distinct SNR levels. This exploration is conducted through reference to stored relationship curves, which depict the connection between SNR and BER for differing orders of PSK. Subsequently, we select the modulation method that boasts the highest SNR among those that meet the specified conditions.

Within the simulation process, we initially input these two values manually. Subsequently, the length and frequency of the signal are entered, with the frequency assuming the role of simulation calculation time. For instance, considering a BER of 10 to the power of negative three, an SNR of 12, a code element count of 1 million, and a bandwidth of 10K, the input's influence is illustrated in Figure 3.

```
Please enter the maximum acceptable BER: 0.001
Please enter the SNR value (between -5 and 60): 12
Please enter the data size (in bytes): 1000000
Please enter the bandwidth (in Hz): 10000
```

Figure 3. Receive user input values.

After inputting the corresponding values, the algorithm undertakes a data comparison between the input and the library's stored data to ensure data remains within bounds. In this simulation system, the minimum attainable BER is ten to the power of negative twenty, while the acceptable SNR range spans from -5 to 60. Situations falling below -5 encounter no coding method capable of guaranteeing effective signal transmission, while scenarios surpassing 60 witness all codings achieving highly usable low BERs. Consequently, this algorithm's SNR range zeroes in on this interval, where differences between distinct codings become pronounced.

Following the reception of pertinent values, the algorithm proceeds to generate a visual representation to showcase available codings. Upon obtaining the SNR, data volume, signal transmission frequency, and the user's maximum acceptable BER within the present environment, the algorithm adroitly selects the most fitting modulation method for the signal transmission. This selection occurs by juxtaposing the input values with previously computed BER variation curves across various PSK modulations in relation to SNR, which is subsequently visually displayed through imagery. For instance, if the maximum acceptable BER is $1*10^{-3}$, the SNR is 12, the total data volume is $1*10^{6}$, and the signal frequency is $1*10^{4}$, the displayed visual representation is depicted in Figure 4.

DOI: 10.54254/2755-2721/34/20230312

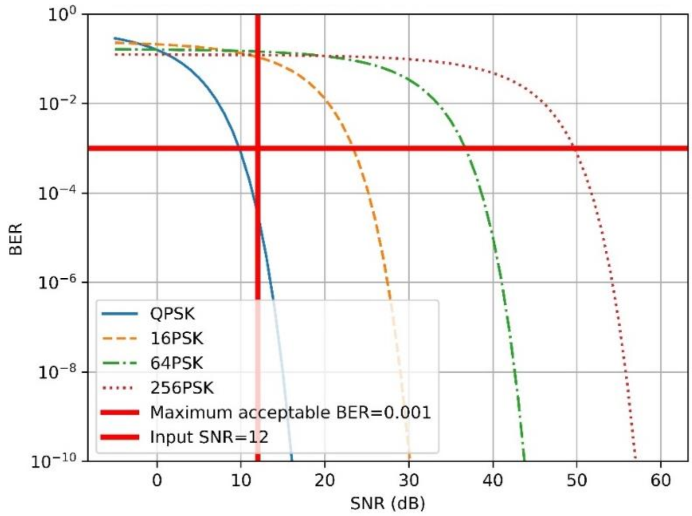

Figure 4. BER vs. SNR for M-PSK modulation schemes.

Figure 4 provides an intuitive visualization, demonstrating that curves positioned within the third quadrant—formed by the intersection of the Maximum Acceptable BER and Input SNR—fulfill the stipulated criteria. In this particular instance, only QPSK aligns with the specified demands.

Simultaneously with the visual representation, coding methods that meet requirements for varying SNRs given a particular maximum BER are displayed in textual form, as depicted in Figure 5. Notably, solely QPSK meets the requisites for an SNR of 12dB. Upon calculation, the theoretical BER of QPSK at an SNR of 12 is computed to be $3.43*10^{-5}$, satisfying the user's BER criteria. Furthermore, the algorithm evaluates QPSK's theoretical transmission rate at 4 bits per second per Hertz (bps/Hz). At this rate, for a frequency of 10K and a data volume of 1 million, transmission completion is projected within 200 seconds.

Upon the conclusion of calculations, the algorithm reads the signal and employs the relevant modulation technique, simulating transmission within the corresponding noise-infused environment. After transmission, the signal undergoes demodulation and is compared against the original signal, culminating in the output of the actual BER for user confirmation.

As demonstrated by Figure 5, the verified BER post-testing stands at $3.50*10^{-5}$, successfully adhering to the user's maximum BER prerequisite. This design evidently attains the projected objective.

```
At SNR of 10 dB - 23 dB, the available modulation schemes are: QPSK
At SNR of 24 dB - 36 dB, the available modulation schemes are: QPSK, 16PSK
At SNR of 37 dB - 49 dB, the available modulation schemes are: QPSK, 16PSK, 64PSK
At SNR of 50 dB - 60 dB, the available modulation schemes are: QPSK, 16PSK, 64PSK, 256PSK
At an SNR of 12 dB, the selected modulation scheme is: QPSK
At an SNR of 12 dB, the theoretical transmission rate is: 4.00 bps/Hz
At an SNR of 12 dB, the theoretical BER is: 3.43e-05
With a data size of 1000000.00 bytes and a bandwidth of 10000.00 Hz, the expected transmission time is: 200.00 seconds
The actual BER is: 3.50e-05
```

Figure 5. Output display.

4. Conclusion

This design introduces an adaptive anti-interference algorithm that leverages an analysis of theoretical transmission rates and BERs across various PSK codings within different noise intensity scenarios. This enables the transmission of stable signals at comparatively lower rates in low SNR environments, thereby accommodating diverse user demands. In contrast to conventional designs, this adaptive approach boasts versatility and adaptability, thus holding promise for application across various industries.

Consider mobile phone communication as an example: in areas with minimal electromagnetic interference, such as suburban and rural locales, higher-order coding can be harnessed to ensure optimal transmission rates. Conversely, amidst complex electromagnetic conditions in urban settings, the algorithm can intelligently and adaptively opt for reliable low-order coding. This ensures fundamental communication needs are met, averting instances of complete communication breakdown due to overwhelming signal interference.

Moreover, coding techniques renowned for their resilience and capability to operate proficiently within low SNR environments could be deployed in sparsely populated regions, such as deserts or polar areas, where weak signals prevail. This can, to some extent, substitute the role of satellite phones, trading a lower transmission rate for signal stability, thus satisfying elementary communication requisites.

However, it's important to acknowledge certain limitations of this design. For instance, to effectively present simulation outcomes, the design chose to compare diverse PSK coding orders. Yet, in everyday scenarios, higher-order coding, such as QAM, is more prevalent. The design omits a comparison between high-order QAM and high-order PSK, thereby imposing certain constraints. Additionally, the noise incorporated within this design solely accounts for Gaussian additive white noise. In actual electromagnetic environments, electromagnetic interference is a composite of varied noises, exhibiting different interference dynamics compared to single Gaussian additive white noise. Consequently, the design fails to fully replicate complex electromagnetic interference in real-world scenarios, resulting in a discrepancy between simulation and reality.

In forthcoming research, the author aims to refine the relevant content and diligently work towards enhancing the algorithm, striving to align it more closely with reality and expanding its applicability.

References

[1] Chen H, Ran N, Yuan L. Ber research of OFDM systems under qpsk and 16-qam modulation 2022 IEEE International Conference on Advances in Electrical Engineering and Computer Applications (AEECA). IEEE, 2022: 14-19.
[2] Kumar A, Gour N, Sharma H. Analysis of throughput and error rate of 16-QAM, 64-QAM, and 256-QAM O-NOMA waveforms. Journal of Optical Communications, 2023 (0).
[3] G. Jajoo, Y. Kumar and S. K. Yadav, Oct. 2019, Blind Signal PSK/QAM Recognition Using Clustering Analysis of Constellation Signature in Flat Fading Channel IEEE CommunicationsLetters, vol. 23, no. 10, pp. 1853-1856.
[4] Lee J, Ha I, Park J, et al. Optical Intensity Predistortion for Inter-dimensional Interference Mitigation in Multidimensional QAM-PIRFSK-MDPSK Optical Access Transmission Journal of Lightwave Technology, 2023.
[5] Vamsi T S, Terlapu S K, Krishna M V. Investigation of channel Estimation Techniques using OFDM with BPSK QPSK and QAM Modulations 2022 International Conference on Computing, Communication and Power Technology (IC3P). IEEE, 2022: 209-213.
[6] Bai S. BER of different modulation and channel coding methods in different channels International Conference on Intelligent Systems, Communications, and Computer Networks (ISCCN 2022). SPIE, 2022, 12332: 386-393.
[7] Zheng K, Wang D, Han Y, et al. Performance and measurement analysis of a commercial 5G millimeter-wave network IEEE Access, 2020, 8: 163996-164011.
[8] Chen Z, Ding Y, Ruan L. SERs of Different Modulation Systems in 1G-4G Journal of Physics: Conference Series. IOP Publishing, 2022, 2384(1): 012049.
[9] Farzamnia A, Mariappan M, Moung E, 2022, et al. BER performance evaluation of M-PSK and M-QAM schemes in AWGN, Rayleigh and Rician fading channels Control Engineering in Robotics and Industrial Automation: Malaysian Society for Automatic Control Engineers (MACE) Technical Series 2018, 2022: 257-266.
[10] A. Suhartomo and V. Vincent, 2020, Comparison of BER Performance for M-ary QAM and PSK on DWT-based OFDM System with PTS Technique Through AWGN Channel 2020 IEEE

DOI: 10.54254/2755-2721/34/20230312

International Conference on Sustainable Engineering and Creative Computing (ICSECC), Indonesia, pp. 5-10.
[11] Gopinath S, Varshitha G, Akhil M, et al. Performance Comparison of Modulation Technique and Coding Algorithms.