ECE 457 Final Project Digital Portion
An Analysis of a Quadrature Phase-Shift Keying Mapper and Slicer in Additive White Gaussian Noise Channels

Jacob Honer
College of Electrical and Computer Engineering
Michigan State University
East Lansing, United States of America
honerja1@msu.edu

***Abstract*—This project simulates a quadrature phase-shift keying (QPSK) mapper and slicer with an intermediate additive white Gaussian noise channel. This work stems from a standard transmission system, where an analog signal is digitized, passed, and then converted back to analog through a series of systems. Here, we only focus on the Mapper and Slicer of a typical system, and show the systems robustness to Gaussian noise. This paper provides a system description of a mapper and slicer, followed by an analysis of the performance of QPSK in AWGN channels through a discussion of some simulation results on randomly generated data. This paper also includes a brief discussion of simulation results from a real-world signal; this signal is in the form of contemporary music that can be heard on the radio.**

I. System Description

A. QPSK Mapper

To understand a QPSK Mapper we must first must understand the role of a Mapper. Here, a Mapper is a system that takes bits of information and converts them into real-valued symbols. The QPSK Mapper takes every two bits of information and stores them in a phase-shift [1]. This phase shift is often corresponding with 90° intervals, starting with 45°, with bits 00, 01, 10, and 11, being paired with their respective phase in order that they appear here. For our model, we match each pair of bits with numeric symbols, 0, 1, 2, and 3, in that order. We then pass the numeric symbols through our channel, where additive white Gaussian noise is added. For this project, we assume that there is no distortion, loss, etc.

An advantage of QPSK over a simple Binary Phase Shift Keying (BPSK) is that QPSK has the ability to send twice as much data as BPSK over the same time internal with the same sampling rate [2]. This is why QPSK is studied here. It is a very simple modulation that is more efficiently than transmitting individual bits alone. Other modulation schemes are even more efficient, but QPSK is a good starting point to understand Mapping and its utility in communication systems.

B. Minimum distance QPSK Slicer

A Minimum distance QPSK Slicer takes the converted symbols from the Mapper and converts them back to their original binary information. Due to the noise added to the system by the channel, this model follows a maximum likelihood determination of the original bits, determined by minimum distance. For a phase-shift slicer, as presented here, it means that the phase of the signal that is most close to its symbol, or defined phase, will determine what bit is output from the Slicer.

The effectivity of a minimum distance QPSK Slicer is largely dependent on the amount of noise in the channel. If the noise is large, and the signal to noise ratio (SNR) is small, then it is unlikely that the minimum distance QPSK Slicer will be able to accurately regenerate the original binary signal. When the SNR is very high, however, indicating low-noise to signal power, the minimum distance QPSK Slicer performs quite well, which we will see in our simulations that follow. An important thing to note is that if the SNR is too low and the signal Slicer is not performing up to the desired standard, it is often a good practice to increase the signal power, but that this has limitations. Increasing the signal power has a logarithmic relationship with SNR, so as the SNR increases linearly, an exponential increase in power is required. This is why it is often a good practice to incorporate duplicators or other forms of redundancy into digital signal transmission systems so that there is an increased likelihood that the original signal is obtained at the receiver.

II. Performance of QPSK in AWGN channels

A. Simulation Results

For our simulations, we generate a random binary sequence of length N. The random sequence is modulated and demodulated in the presence of AWGN at various noise powers. Next, we compare our demodulated signal with our original signal and compute a bit-error rate (BER) at each AWGN noise level.

The BER computed for various SNRs of AWGN in our modulation and demodulation scheme with different binary

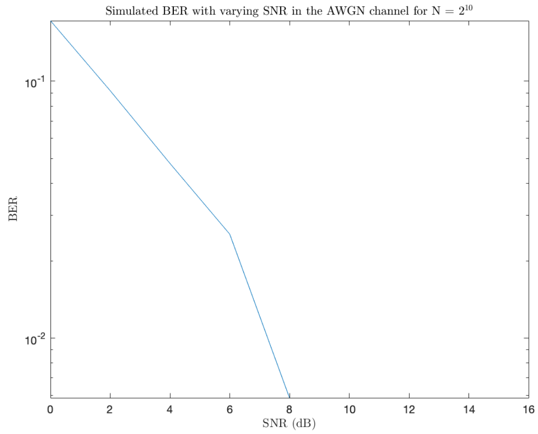

Fig. 1. BER computed for various SNRs of AWGN with signal size N^{10}

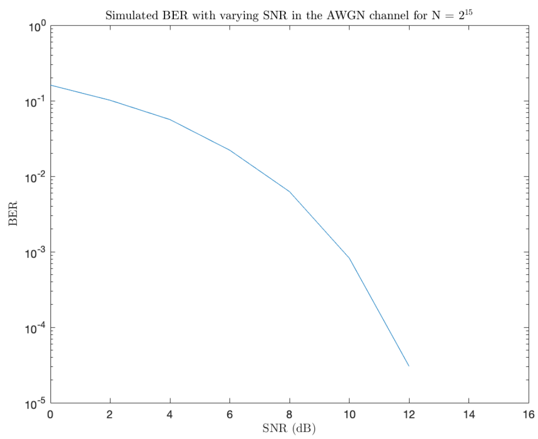

Fig. 2. BER computed for various SNRs of AWGN with signal size N^{15}

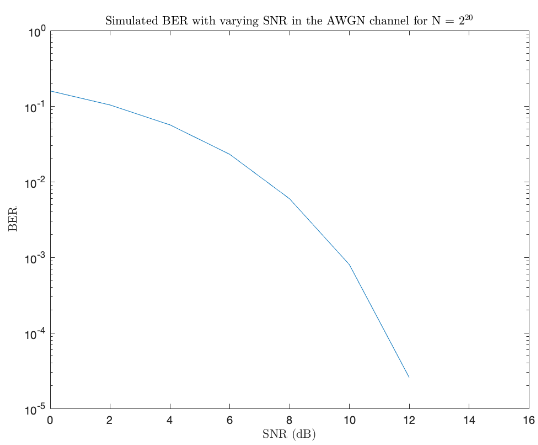

Fig. 3. BER computed for various SNRs of AWGN with signal size N^{20}

sequence lengths can be seen in Fig. 1, Fig. 2, Fig. 3, and Fig. 4, for sequence lengths of 2^{10}, 2^{15}, 2^{20}, and 2^{24}, respectively.

It should be noted in the figures that the smoothness and

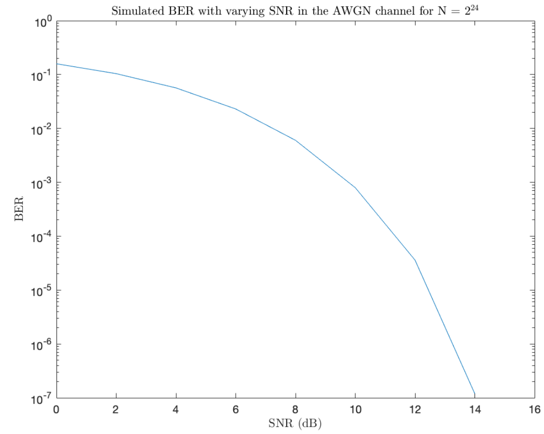

Fig. 4. BER computed for various SNRs of AWGN with signal size N^{24}

accuracy of the BER to SNR curve improves as the sequence length increases. This is because the longer the sequence is, the more chances there are for the system to make and error. In accordance with the law of large numbers, our averages over longer sequences converge closer to the true probabilities than averages over smaller sequences; this is clearly evident in our simulations.

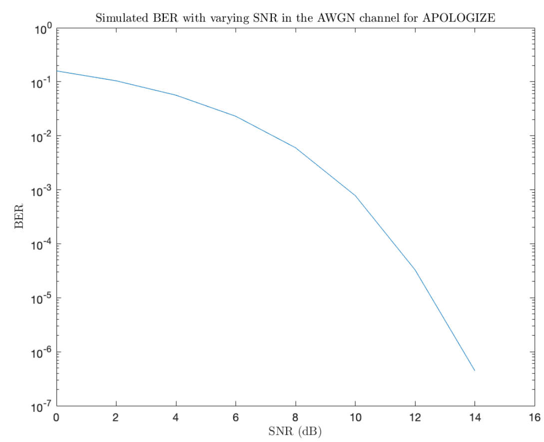

Fig. 5. BER computed for various SNRs of AWGN with signal size $N = 6.72 \cdot 10^6$ for 9 second sample of song APOLOGIZE.

For an additional exercise, this same QPSK Mapper and Slicer process was used for simulating the transmission of a real-world signal. Here, the real-world signal was the song APOLOGIZE by Hykeem Jamaal Carter, also known as Baby Keem [3].

The plot of BER computed for various SNRs of AWGN in our modulation and demodulation scheme for this song can be seen in Fig. 5. A quick visual comparison of Fig. 4 and Fig. 5 will reveal that they are almost identical graphs; this is because the binary sequence size for each were extremely similar. This reinforces the idea that regardless of what signal is passed, when formatted as a binary sequence, we can expect consistent performance of our Mapper and Slicer.

One of the benefits of performing these operations on a real signal is that it was possible to hear how the song sounded after demodulation. As it is impossible to attach the files here, a short explanation of the song after demodulation as the SNR increases will be explained. For a low SNR of the AWGN, the demodulated signal sounded like white noise, entirely static. As the SNR increased, the level of static in the simple decreased until an SNR of around 12 dB, where the song has some popping sounds, but was primarily the original song. This was basically the threshold where the song became tolerable to listen to; the quality seemed like that of an old radio. With a SNR of 14 dB and 16 dB, any errors were indistinguishable to the human error, and the modulated signal sounded exactly like its original.

III. Conclusion

This project has successfully explored the utility and effectiveness of a QPSK Mapper and Slicer in digital communication systems. It was shown that the BER of a simulated QPSK Mapper and Slicer in Matlab decreases as the SNR increases through an AWGN channel. Additionally, the modulation and demodulation accuracy of the simulated system was observed at varying SNRs with a real-world signal, in the form of a contemporary song. This project introduced only a small portion of what is required to have a functional digital communication system, but Key Mapping and Slicing is a key part of many accurate and efficient digital systems, hence, the independent study of them is important. The tangible works of such a study and has been documented through the works presented here.

References

[1] R. Keim, "Understanding quadrature phase shift keying (qpsk) modulation," August 2016.

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[3] H. J. Carter, *APOLOGIZE*. New York City: The Orchard., 2019.