EEEE2044 Coursework 2, Digital Modulation

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Task 1: Change the parameter "Stop time" until you see that convergence of the BER value is achieved. Do this for at least 3 digital modulation techniques, namely QPSK, 16PSK and 16QAM. Once you have shown convergence you will need to use the appropriate value for the "stop Time" for the rest of the coursework.

In Fig.1 plot the BER w.r.t. stop time for QPSK, 16PSK and 16PSK and comment on the results.

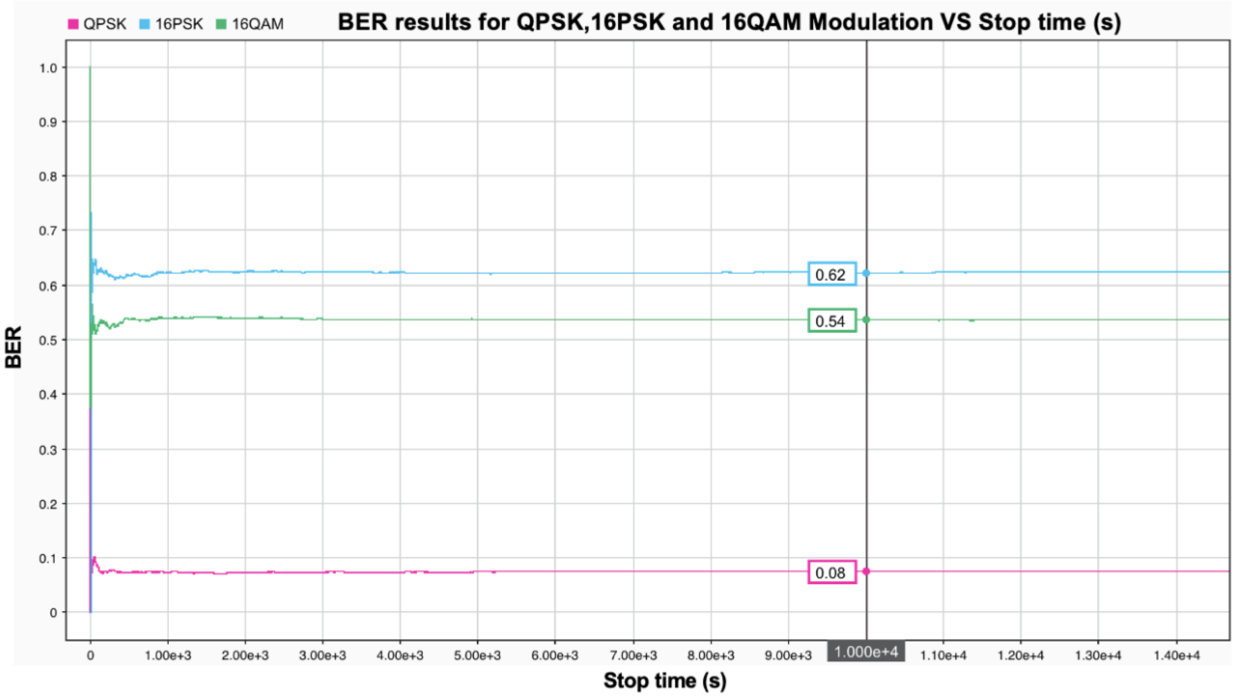

Fig.1. Convergence of BER results for QPSK, 16PSK and 16QAM modulations

Figure 1 shows the BER results for QPSK, 16PSK, and 64PSK at Eb/No = 5 dB and stopping times from 1 s to 15000 s. convergence occurs roughly at a stopping time of around 1000 s, but was chosen to have a stopping time of 10000 s. As Monte Carlo simulations need to be run in the later tasks to estimate the average BER, a longer simulation time to achieve the required level of accuracy. The phenomenon observed in Figure 1 and its interpretation is:

For QPSK, it is a simple modulation technique that encodes two bits per symbol. Convergence occurs when the stopping time is around 1000 s. The BER at a stop time of around 1000 s is stable at around 0.08.

For 16PSK, which is a more complex modulation technique encoding four bits per symbol. it is more susceptible to noise than QPSK as the phase transitions get closer together. Convergence occurs when the stop time is around 1000 s. The BER stabilises at a stop time of around 10000 s at around 0.62.

For 16QAM, which is the most complex of the three modulation techniques, coding 4 bits per symbol, it is also the most susceptible to noise. This is because 16QAM changes both the amplitude and phase of the signal, making it more susceptible to noise-induced amplitude and phase shifts. Convergence occurs when the stop time is around 1000 s. The BER stabilises at a stop time of around 10000 s at around 0.54.

Task 2: In Fig.2 plot the BER for QPSK, 8PSK, 16PSK, 64PSK, 4QAM, 8QAM, 16QAM and 64QAM. The graph for each modulation is obtained by changing Eb/N ratio in AWGN block and reading the value in display block. The BER axis should be on a log scale.

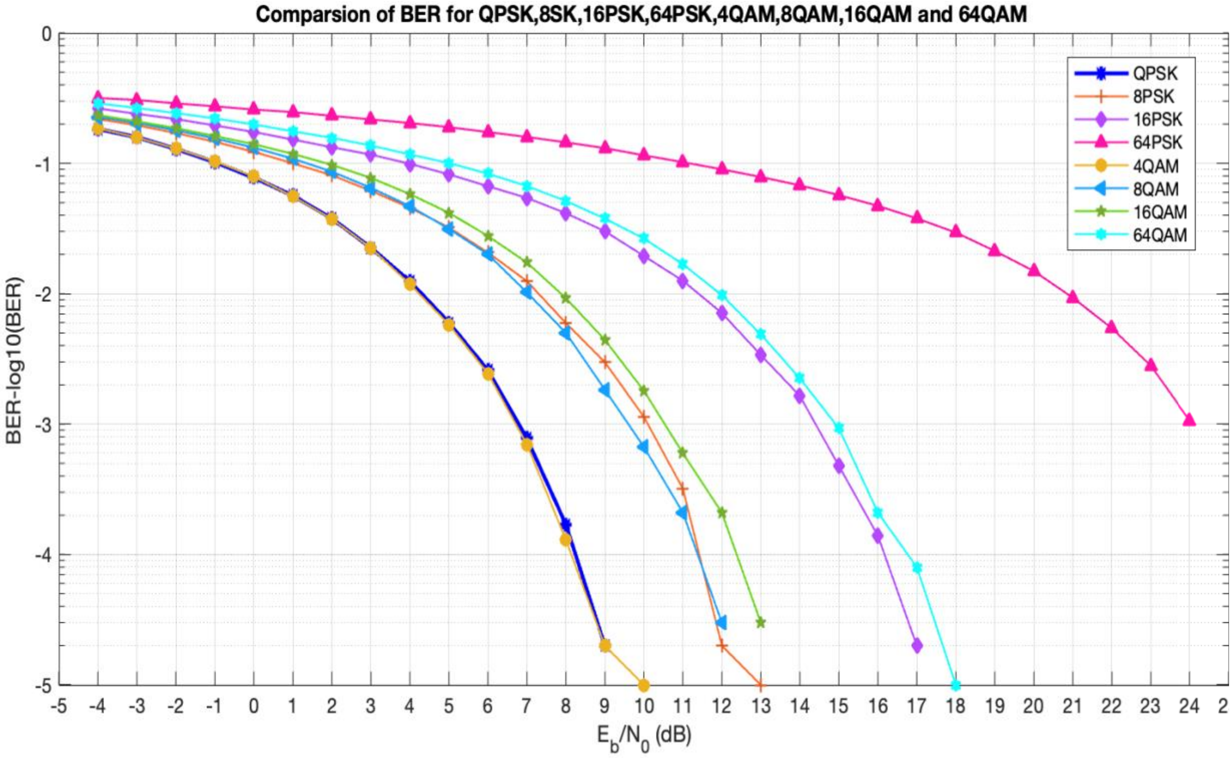

Fig.2. Comparison of BER for QPSK, 8PSK, 16PSK, 64PSK, 4QAM, 8QAM, 16QAM and 64QAM

The results of various modulation schemes in Figure 2 show approximately the same trend and distribution as the BER and Eb/No waterfall diagrams on page 62 of the PowerPoint provided during the lesson. The difference is that the stop time selected here is 10000s, which is not sufficient to detect BER when the Eb/No is too large. In the figure, there is no BER display for QPSK after Eb/No is greater than 9 dB. This phenomenon can be achieved by increasing the stop time to bring the result closer to the the theoretical value, but it can also result in greater execution time. In general, different modulation scheme results follow the following points, which can be verified in Figure 2:

1. When Eb/No is the same, the higher order modulation scheme results in a larger BER. When Eb/No=8dB, the BER of 64PSK > 16PSK > 8PSK > QPSK, and the BER of 64QAM > 16QAM > 8QAM > 4QAM. This is because higher order modulation technology has higher spectral efficiency and data rate, and each symbol has higher bits, which can carry more information. But at the same time, its phase is closer, each symbol is more susceptible to noise and interference, resulting in a greater BER.

2. For the same modulation scheme, BER decreases as Eb/No increases. BER of QPSK is 0.078 when Eb/No = 1 dB, and 0.00078 when Eb/No = 8 dB. This is because a higher Eb/No indicates that the signal is stronger relative to noise, the interference is relatively less significant, resulting in a lower BER.

3. When the Eb/No is the same, the performance of QAM with the same order is better than that of PSK. When Eb/No = 8 dB, the BER of 64QAM is less than 64PSK, 16QAM is less than 16PSK, and 8QAM is less than 8PSK. This is because QAM signals use both amplitude and phase modulation, which enables them to use a larger signal constellation than PSK signals. Larger constellations provide greater distance between symbols, making the signal more robust to noise and interference. The results of QPSK in the figure are approximately the same as those of 4QAM. Although these two modulation schemes use different constellations, because they are essentially the same modulation scheme, using the same energy per bit to transmit symbols, the results are also a78pproximately the same.

Task 3. Compare your results from the Task 2 with theoretical values and discuss. For this task only consider QPSK, 16PSK, 64PSK, 16QAMand 64QAM.

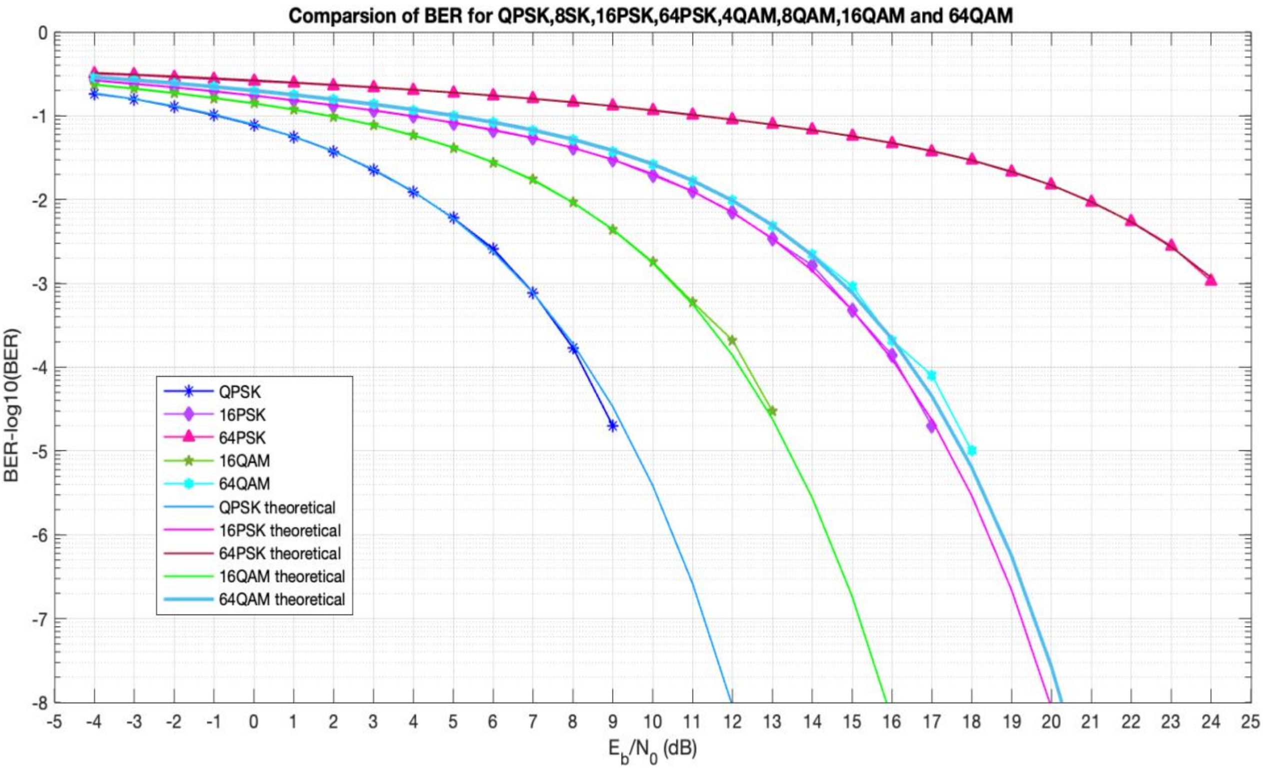

Fig.3. Comparison of BER for QPSK, 16PSK, 64PSK, 16QAMand 64QAM

Figure 3 shows the comparison of simulated and theoretical values for different modulation schemes. It can be found that at low Eb/No, the simulated values highly coincide with the theoretical values, while at high Eb/No, there are some deviations or even no display of the simulated values. This is because the stop time taken in this simulation is 10000 s, which is not sufficient to detect a small error. Theoretically, taking a longer stop time can obtain more data and thus closer to the theoretical value. The following characteristics are met for different modulation schemes:

1. High order modulation scheme results in a larger BER. When Eb/No = 8 dB in the figure, the BER of 16PSK $>$ 64PSK $>$ QPSK, and the BER of 16QAM $>$ 64QAM. This is mainly because higher order modulation schemes provide higher data rates, but are more susceptible to noise and interference, resulting in higher BER.

2. For different modulation methods, the performance of PSK is better than that of QAM. When Eb/No = 8 dB in the figure, the BER of 16QAM $<$ 16PSK, and the BER of 64QAM $<$ 64PSK. This is because QAM is a combination of ASK and PSK, where both amplitude and phase are modulated to transmit digital data. PSK only modulates the phase of the carrier signal. QAM allows for more different constellation points on the signal plane, which allows each symbol to transmit a higher level of information. Therefore, QAM with the same order has a smaller BER than PSK.

3. Equations below are used to calculate the theoretical BER for different modulation schemes, from which it can also be seen that the larger the M (number of decimal places) at the same Eb/No, the larger the BER. For the same Eb/No and M, the BER of PSK is greater than that of QAM.

$$QPSK: 0.5erfc\left(\sqrt{\frac{E_b}{N_o}}\right) \quad M-PSK: \frac{1}{m}erfc\left(\sqrt{\frac{E_b}{N_o}}\sin\left(\frac{\pi}{M}\right)\right) \quad M-QAM: \ \frac{2}{m}(1-\frac{1}{\sqrt{M}})erfc(\sqrt{\frac{3mE_b}{(2M-1)N_o}})$$

Task 4 Tasks 1-2 have explored ideal coms channel with additive white noise. In reality communication channels are more damaging to the signal and can cause frequency shift of the carrier and time delay of received signals. These effects are incorporated in this Simulink example. Please familiarise with the example and then conduct BER analysis for the case of QPSK modulated signal.

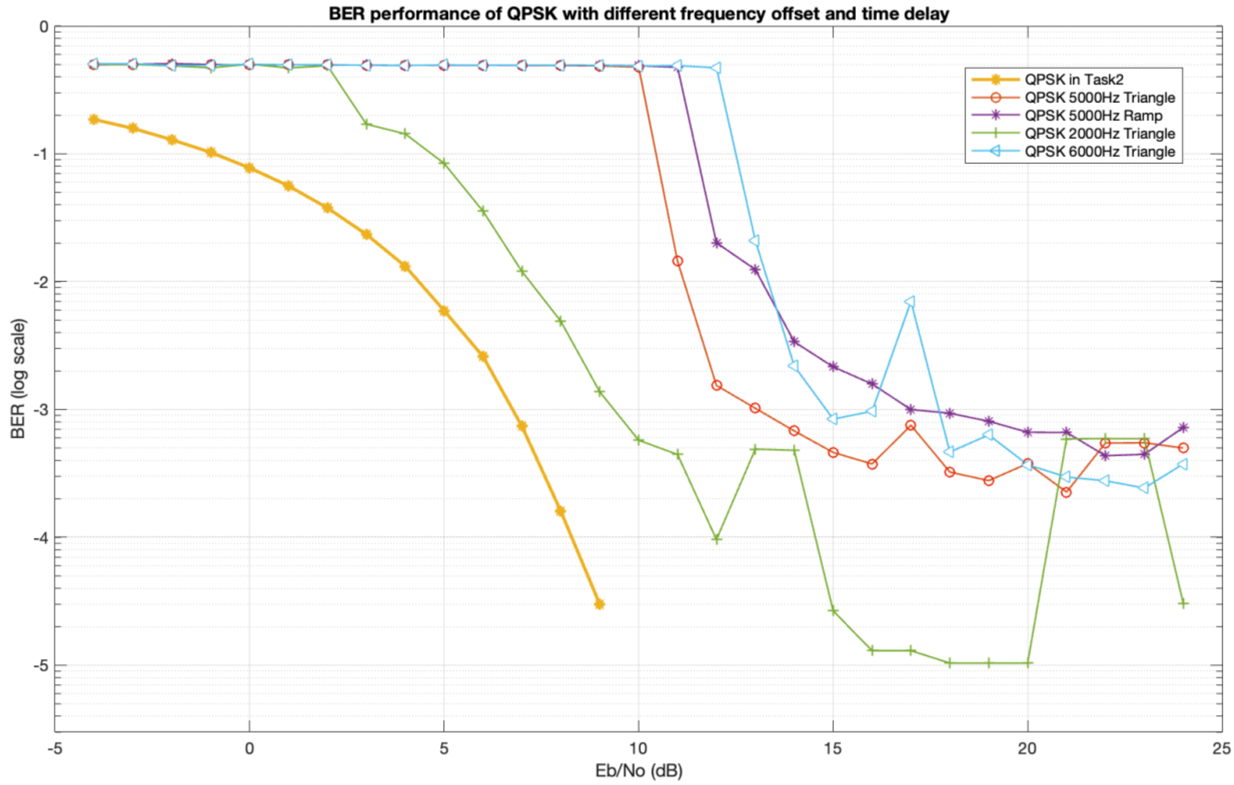

Fig.4. Comparison of BER results

In Figure 4, there are five lines: yellow line for QPSK in Task 2, red line for QPSK with frequency offset of 5000 Hz, delay type of triangle, green line for QPSK with frequency offset of 2000 Hz, delay type of triangle, blue line for QPSK with frequency offset of 6000 Hz, delay type of triangle, purple line for QPSK with frequency offset of 5000 Hz, delay type of ramp. The BER of the above five cases decreases with the increase of Eb/No. The difference is:

1. For the same delay type, the higher the frequency offset, the greater the BER. When Eb/No=8 dB, the BER of the QPSK in task 2 is -3.7, when the frequency offset is 2000 Hz, it is -2.3, when the frequency offset is 5000 Hz, it is -0.3, and when the frequency offset is 6000 Hz, it is -0.3. This is because in QPSK modulation, four different phases of the carrier wave are used to transmit information. The receiver detects these phases and decodes them to restore the original information. When there is a frequency offset between the transmitted signal and the receiver's carrier frequency, the receiver detects incorrect phases more frequently, resulting in errors in the decoded information. As a result, BER increases as the frequency offset increases.

2. When the frequency offsets are the same, those with time delays cause greater BER, and the Ramp type causes greater errors than Triangle. When Eb/No = 15 dB, the BER of the QPSK with the triangle time delay type is -3.4, it is -2.6 with the Ramp time delay type. This is because in QPSK modulation, delays in the received signal cause the phase of the signal to shift in time relative to the expected phase. When the received signal is demodulated, this time shift can lead to errors in the phase and amplitude of the detected symbol, resulting in higher BER. When its frequency offset is the same, the peak to peak variation of the delta delay in the delay function is smaller than the ramp delay, which means that it causes smaller variations in phase rotation, resulting in lower BER.