Channel Coding

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✿ Linear Block Coding

Linear block codes are one of the most widely used and implemented channel coding techniques. They introduce controlled amount of redundancy in the transmitted data, giving the receiver the capability to detect and correct errors caused by a noisy communication channel. The communication system is become with the aid of coding techniques is shown in the figure-1 below.

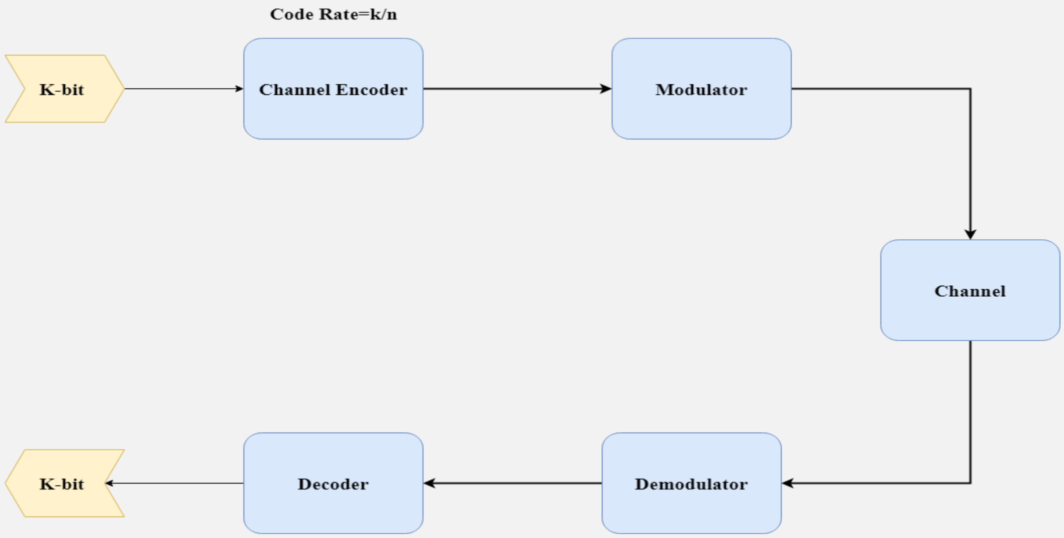

Figure 1 Block diagram of communication system

There exists several types of channel coding techniques and the task of choosing a specific code is made easier by some metrics. Some of the metrics on which the channel codes are compared against each other are:

Coding efficiency

An efficient code has a relatively small number of encoded bits per data symbol. It is defined in terms of code rate. Assume that each input symbol to the encoder is made up of k bits and each output symbol from the encoder is of n bits (n = k+ p), where p is the number of redundant bits added by the encoder. Then, the code rate is given by:

$$R = \frac{k}{n}$$

More the code rate, more is the efficiency. A decrease in the number of redundant bits reduces the error correction capability of channel codes. Therefore, there should be a trade-off between code efficiency and error correction capability.

Coding gain

The coding gain of a coding scheme is defined as the reduction in signal-to-noise ratio (SNR) in the coded system compared to the uncoded system, for the same BER and at the same data rate.

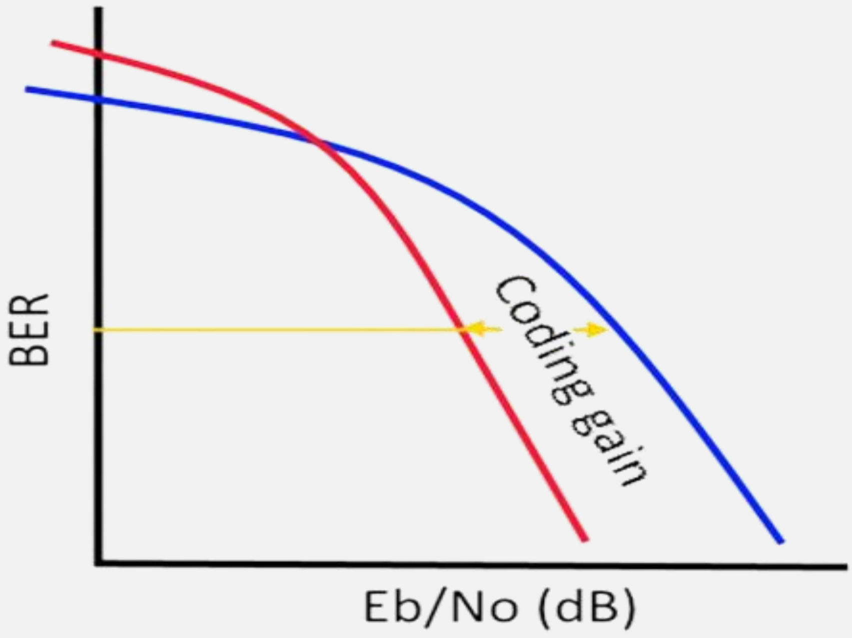

Figure 2 Measuring coding gain

Hamming codes

Linear binary Hamming codes fall under the category of linear block codes that can correct single bit errors. All such Hamming codes have a minimum Hamming distance $d_{min} = 3$ and thus they can correct any single bit error and detect any two bit errors in the received vector. The characteristics of a generic $(n; k)$ Hamming code is given below.

$$Codeword\ length: n = 2^p - 1$$

$$Number\ of\ information\ symbols: k = 2^p - p - 1$$

$$Number\ of\ parity\ symbols: n - k = p$$

$$Minimum\ distance: d_{min} = 3$$

$$Error\ correcting\ capability: t = 1$$

In this article the Hamming code technique using hard-decisions, and their performance simulations in AWGN, Rayleigh fading channel are discussed.

❁ Simulation

For the simulation, BPSK modulation is used, and two values are chosen for the number of parity bits. The simulation is first conducted for the AWGN channel, followed by the Rayleigh fading channel.

AWGN channel

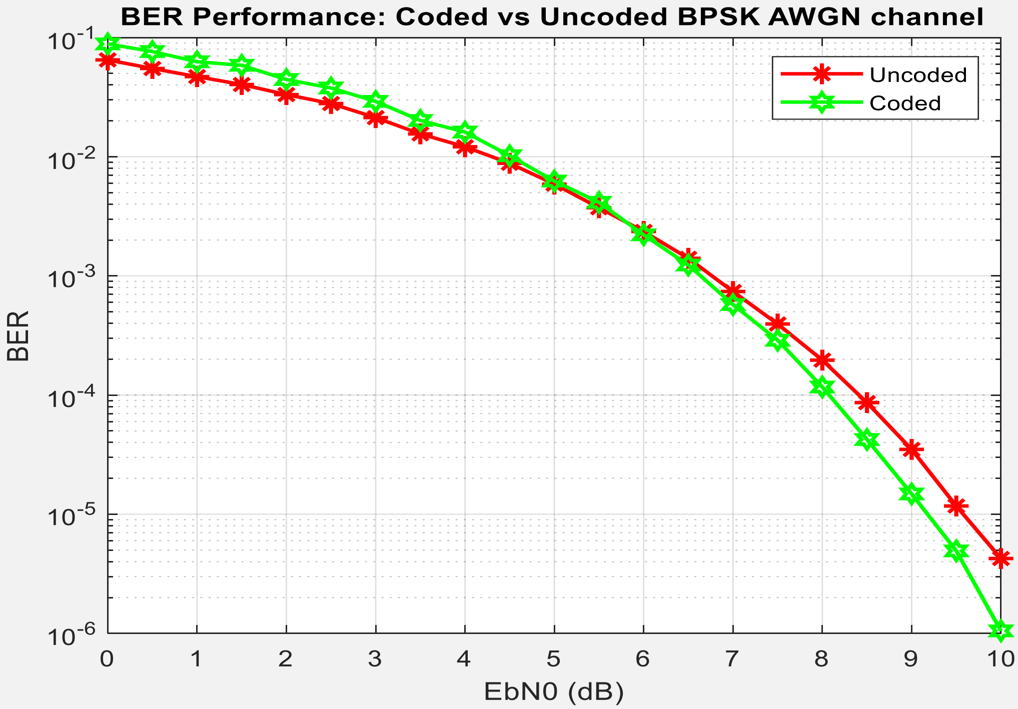

Figure 3 BER curve for AWGN channel, P=3

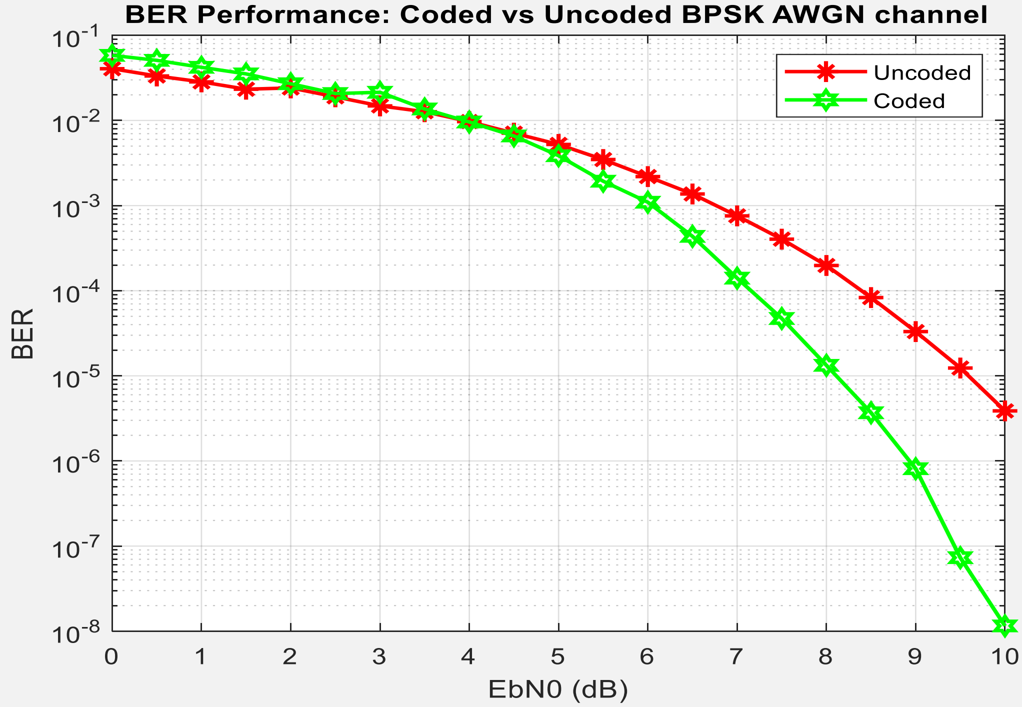

Figure 4 BER curve for AWGN channel, P=5

Rayleigh Fading Channel

The channel parameters are defined as follows:

1. Number of paths: 6
2. Path delay: $[0, 200, 800, 1200, 2300, 3700] * 10^{-9}$second.
3. Path gain: $[0, -3, -4.9, -8, -7.8, -23.9]$ dB
4. Doppler shift: $50Hz$

These parameters are used to simulate a multipath fading environment, which is typical in wireless communication systems. The Rayleigh fading channel introduces random variations in the signal amplitude and phase due to multipath propagation and Doppler effects. The magnitude of impulse response or Fading coefficients for the channel in different time is shown in figure-5.

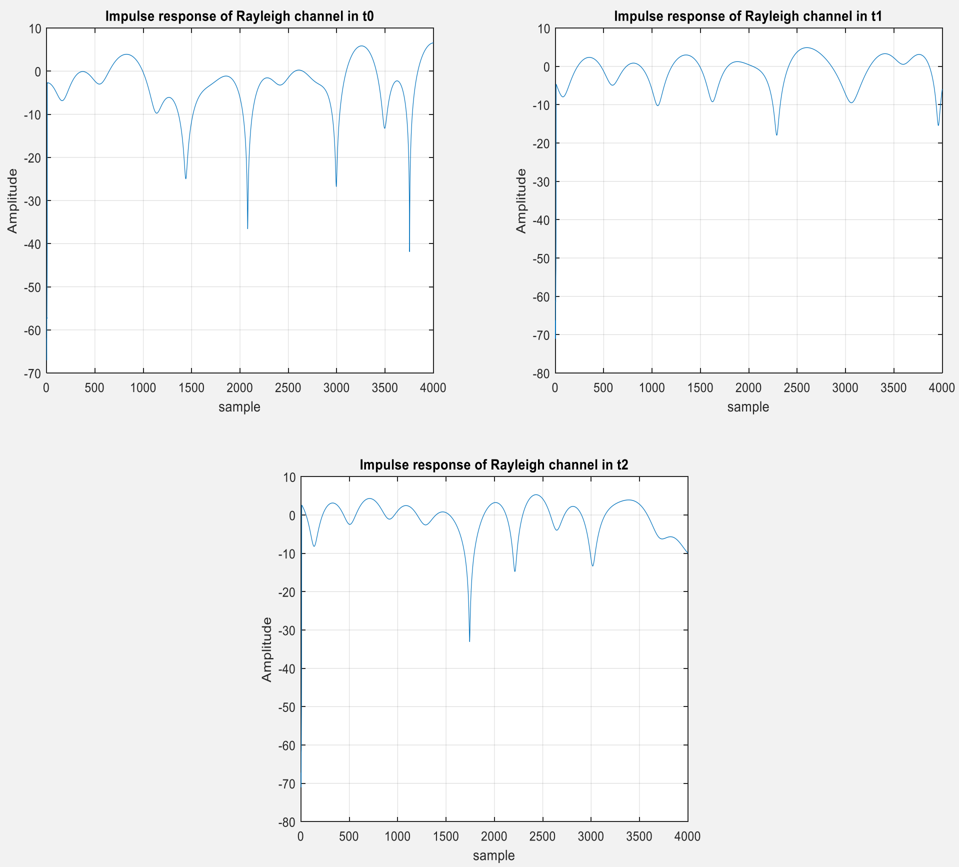

Figure 5 Magnitude of Impulse response for Rayleigh channel in different time

To study the performance, we pass the sequence of symbols through the channel by taking the dot product of the transmitted data and the fading coefficients. On the receiving side, we intentionally avoid performing equalization. This is done to observe and analyze the effect of fading on each symbol without any compensation.

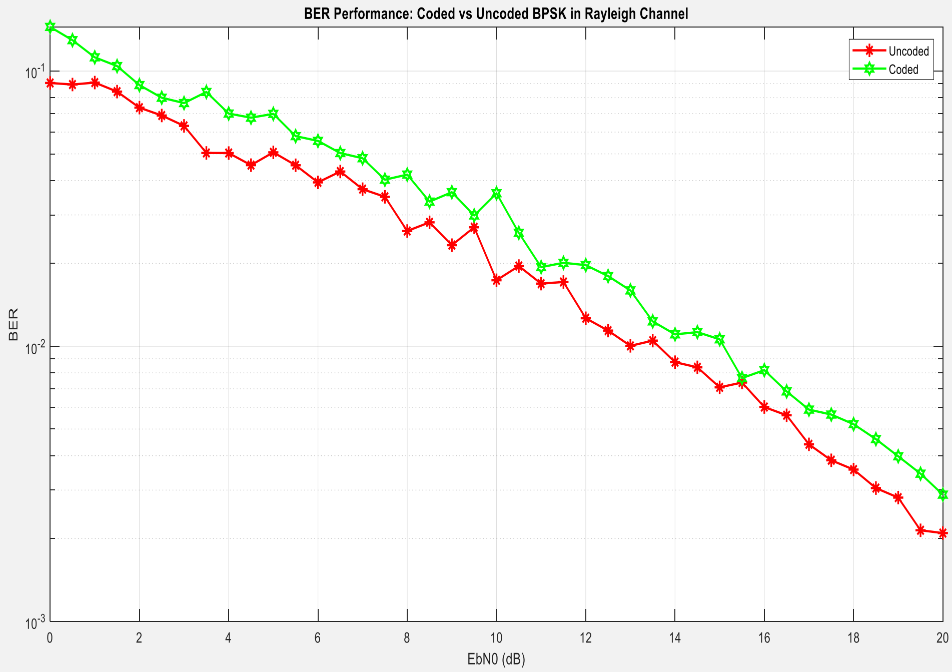

Figure 6 BER curve for Rayleigh channel, P=3

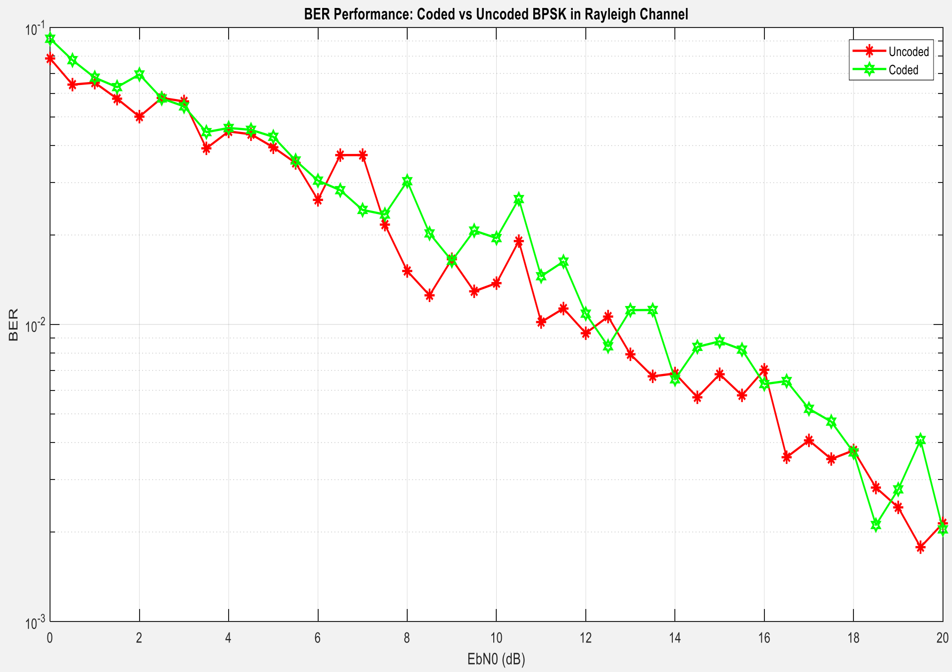

Figure 7 BER curve for Rayleigh channel, P=5

One of the most popular ways to correct burst errors is to take a code that works well on random errors and interleave the bursts to “spread out” the errors so that they appear random to the decoder. To enhance the performance of the system, we will use interleaving, which spreads the symbols of each message across multiple data blocks. This helps mitigate the impact of burst errors caused by fading or noise in the channel. We use a random interleaver, which rearranges the elements of its input vector using a random permutation. The incoming data is rearranged using a series of generated permuter indices. A permuter is essentially a device that generates a pseudo-random permutation of given memory addresses. The data is arranged according to the pseudo-random order of memory addresses. Below we redraw BER curve for three cases.

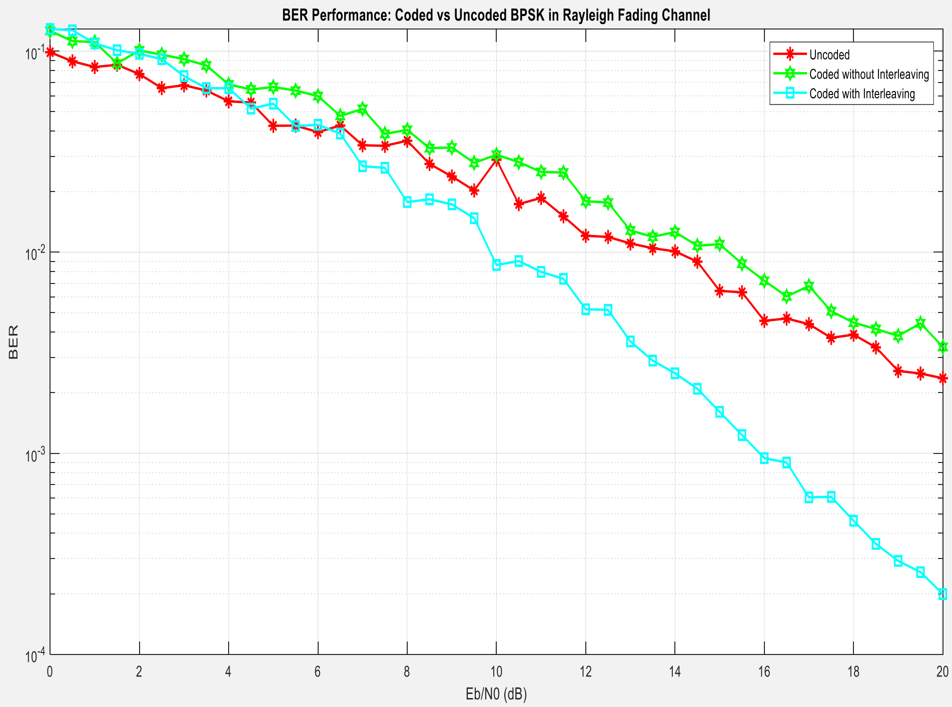

Figure 8 BER curve for Rayleigh channel, P=3

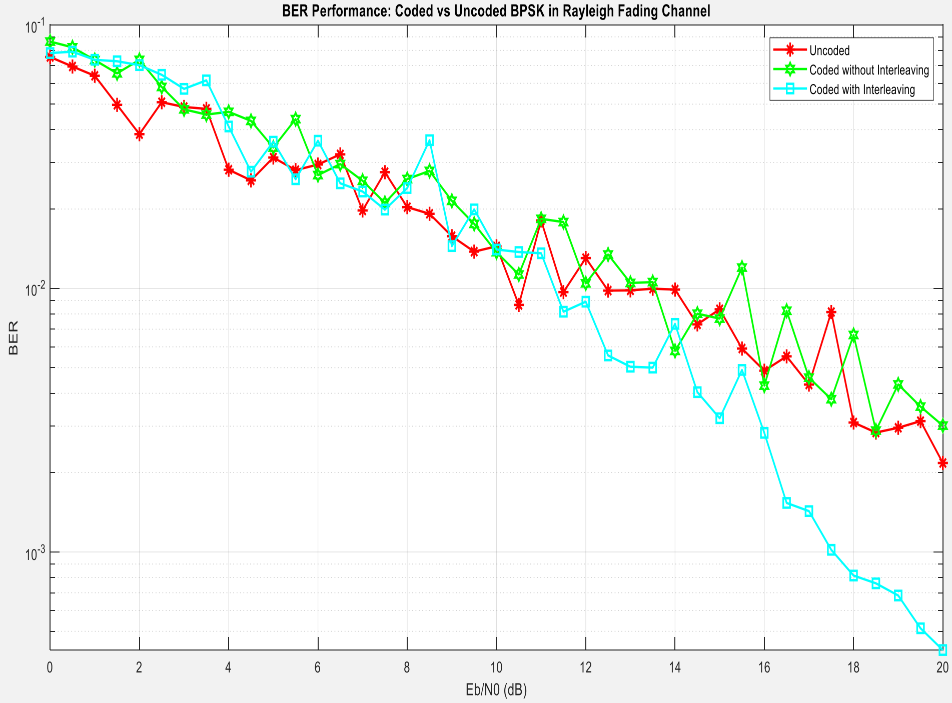

Figure 9 BER curve for Rayleigh channel, P=5

Results:

- AWGN Channel:
  The Hamming code provides significant coding gain, especially at higher SNR values .The BER decreases as the number of parity bits increases.

- Rayleigh Fading Channel:
  The BER performance degrades due to the random variations introduced by fading. Interleaving significantly improves the BER performance by mitigating the effect of burst errors. Decrease the code rate which put more redundant symbols make the performance worse and that due the capability of correct one error in Hamming code.

✿ Conclusion

These results highlight the importance of channel coding and interleaving in designing robust communication systems for wireless environments. The Hamming code, combined with interleaving, significantly improves BER performance in fading channels, demonstrating the effectiveness of these techniques in mitigating the effects of noise and multipath fading.

References:

[1] B. Sklar, Digital Communications Fundamentals and Applications, Englewood Cliffs, New Jersey: Prentice Hall, 1988.

[2] Concatenation and Advanced Codes – Applications of interleavers- Stanford University.

[3] Proakis J.G, Digital Communications, fifth edition, New York, McGraw–Hill, 2008.

The source code: https://github.com/hassansaker/Channel-coding.git