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Comparison Between Reed–Solomon and BCH Code with Various Modulation Schemes Over Coding Gain and Coding Rate

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Abstract

The main objective of this research paper is to make a comparison between the performance of Reed-Solomon (RS) and Bose–Chaudhuri–Hocquenghem (BCH) codes across different modulation schemes concerning coding gain and coding rate within an additive white Gaussian noise (AWGN) channel system, while maintaining a constant transmission bandwidth. In this paper bit error rate (BER) versus signal/noise (S/N) performance of a Simulink model is validated with MATLAB results for a RS GMSK-based system for various (n, k) combinations. In RS GMSK (63, K) system coding gain is although not achieved up to 5 dB but after this it is significantly high which shows the utility if a coded system over uncoded one. For various other RS GMSK (n, k) combinations like (31, k), (127, k) coding gain is achieved right from 0 dB although not as high as compared to RS GMSK (63, k) system. A notable decrease in BER is noticed in RS GMSK-based systems as the number of parity symbols increases or the coding rate decreases. The same effect over coding gain and coding rate is achieved in a RS-based system with other modulation schemes like BPSK, DPSK, QPSK, and FSK but not as comparable to GMSK modulation scheme. The findings indicate that, within a specific bandwidth, opting for RS GMSK instead of BCH GMSK with (63, k) combinations across various modulation schemes yields the lowest BER across different S/N ratios. At the same time, it has been observed that for BCH encoding, the effect of increase in parity symbols over reduction in BER is not observed with any of the modulation schemes although obtained BER values are lesser than that of RS encoding.

Keywords: AWGN, BCH code, bit error rate (BER), DPSK, FSK, Galois field, GMSK, PSK, Reed-Solomon (RS) code, QPSK

INTRODUCTION

The primary goal of every communication system, whether it is a satellite communication system, optical fiber communication system, or any other wireless system, is to transmit data with minimal error rates [1]. Received data becomes wrong when amount of added noise exceeds threshold voltage. That means noise voltage if exceeds a particular amount the reception goes wrong. Likewise, jamming is the second reason which disrupts communication. Jamming is an active attack with the purpose to prevent devices from exchanging information by interfering with their communication [2]. Errors produced by noise can be random or they can be found in nature. Most of the practical communication channels such as magnetic storage systems, telephone lines, optical disks used to store digital data such as CD, DVD etc. are impacted by errors that are clustered within a specific area rather than being random in nature. These errors could result from physical impairments

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like scratches on a disc or lightning strikes in wireless channels. Termed as burst errors, they manifest in numerous consecutive bits. Similarly, two types of jamming is encountered in any communication system under additive white Gaussian noise (AWGN) and both types of jamming are responsible for producing burst error, namely, partial band noise jamming (PBNJ) and band multi tone jamming (BMTJ). In PBNJ, noise power is evenly distributed over some frequency bandwidth which is a subset of total bandwidth. A BMTJ is a jamming strategy which divides its total jamming power into distinct equal powered tones and these n tones are distributed over entire signal bandwidth. The most common measure against jamming is to mitigate its effect by using anti-jamming communication techniques that can resist the attack [3–8].

The methods for combating noise interference and reducing jamming effects are essentially identical, including the utilization of highly directional antennas, implementation of forward error correcting codes, and adoption of spread spectrum communication. As satellite communication is one of an example of wireless communication where effect of burst error which is due to physical damage such as scratch on a disc or a stroke of lightning is more prominent over random error that’s why burst error correcting codes are required whose best examples are Reed-Solomon (RS) code and Bose-Chaudhuri-Hocquenghem (BCH) code. As bit error rate (BER) performance of RS code is much better as compared to BCH code, it is widely applicable in satellite communication. As spread spectrum is one other way to mitigate jamming effect or to provide interference rejection, it is also applied in satellites. Spreading can be done so many ways, for example

a. Direct sequence spreading
b. Frequency hopping
c. Time hopping

In direct sequence spreading a pseudorandom or pseudo noise binary valued sequence is generated so as to spread original binary sequence. The size of spread sequence is much larger as compared to size of original data. In frequency hopped spread spectrum, m bits of a pseudo noise sequence are combined and applied to a frequency synthesizer so as to get generate 2^m frequencies, this frequency is then mixed with the output of modulator and frequency translated signal is transmitted over channel [9, 10].

In satellite communication as many earth stations communicate through a single satellite, it is essential that signals from various earth stations do not get mixed up hence multiplexing or multiple access techniques are required. Frequency division multiple access (FDMA) is a prevalent multiple access technique employed in satellite communication alongside various others. In FDMA, the earth stations can access the satellite on different frequencies by providing a different carrier frequency to each earth station. As all the earth stations use satellite simultaneously so the biggest drawback associated with FDMA is inter carrier or inter channel interference. In inter channel interference, minor lobes of first earth station get interfered with the major lobes of nearby stations, so as to avoid this problem of inter channel interference a suitable modulation scheme is required where there are present no minor lobes and it is possible only in Gaussian minimum-shift keying (GMSK). In GMSK, only major lobe is present while all minor lobes are missing because it has continuities in its transmission, or it has no fast or abrupt change in amplitude at the end of each bit change. The analysis of performance of RS code for GMSK modem about BER is one and the same no matter what the system type is. This paper is organized as follows. The next section gives the block diagram of GMSK modulator and demodulator. Simulink model of the system including GMSK modulation and RS/BCH codes is given in the subsequent section.

The third section presents simulation outcomes utilizing MATLAB tool and Simulink model for GMSK modulation with varying RS coding rates while retaining consistent bandwidth. Additionally, this section evaluates the performance of RS code and BCH code-based Simulink systems with GMSK and alternative modulation schemes. The final section provides conclusions based on these analyses.

SECTION 1

As the paper is prepared over comparison analysis of various systems based on their coding gain and coding rate so better it is to first know what coding gain and coding rate are. Coding gain is the difference between BER of a coded system with that of an uncoded system for a particular amount of signal-to-noise (S/N) ratio. Similarly, coding rate means the ratio of message symbols to code symbols (message symbols + parity symbols).

The code word U(X) for RS code is obtained by the multiplication of generator polynomial and message polynomial, that is,

$$U(X) = g(X)\, m(X) \tag{1.1}$$

here, g(X) is the generator polynomial of degree 2t and given by,

$$g(X)=(X-\alpha)(X-\alpha^2)(X-\alpha^3)\ldots..(X-\alpha^{(n-k)}) \tag{1.2}$$

where m(X) represents message symbols in polynomial form.

In RS code n symbol code word is always appended with n-k parity symbols and rightmost k stages is of message symbols hence code word polynomial U(X) can also be represented as

$$U(X) = p(X) + X^{n-k}\, m(X) = q(X)\, g(X) \tag{1.3}$$

Message m(X) is intentionally multiplied with X^{n-k} to locate it at rightmost k stages of code word.

Here q(X) indicates quotient polynomial & $p(X) = X^{n-k}\, m(X)$ modulo g(X)

The idea about RS code is that by concatenating these parity symbols to the end of message symbols, a code word is created which is exactly divisible by g(x). So when the decoder receives the block, it divides it with the RS generator polynomial. If the remainder is zero, then no errors are detected, otherwise it indicates the presence of errors.

In digital communication, the message type is binary so the common drawback of all rest modulation schemes is discontinuous transmission or there are abrupt amplitude & phase variations. Abrupt change in amplitude gives rise to formation of minor lobes along with major lobe. These minor lobes produce inter channel interference (ICI) or interference of message with other messages which can be removed with the help of band pass filter (BPF).

To enhance transmission continuity, the minimum shift keying (MSK) modulation technique is employed. Although discontinuities in transmission is reduced but they are not totally removed hence, few minor lobes of very small strength are formed along with major lobe which makes its required bandwidth 1.5 f_b. With a purpose to further reduce the modulated signal bandwidth a low pass filter with Gaussian impulse response is used for pre-filtering of the symbols prior to MSK modulator. This modulation scheme is called GMSK.

The Gaussian filter's bandwidth-time (BT) product defines the width of the filter, where B represents the -3dB bandwidth and T represents the symbol period, equivalent to 1 divided by the symbol rate (f symbol rate). The lower the BT product, the narrower is the modulated bandwidth and the higher is the inter symbol interference (ISI). The block diagrams of MSK modulator and MSK demodulator are shown in Figures 1 and 2, respectively.

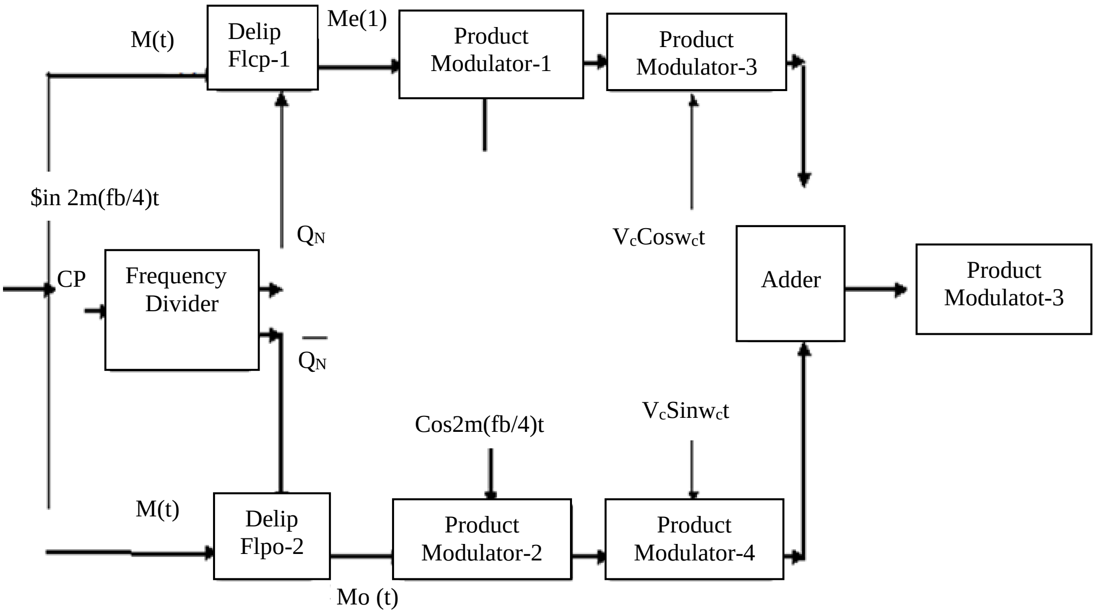

Figure 1. Block diagram of minimum shift keying (MSK) modulator.

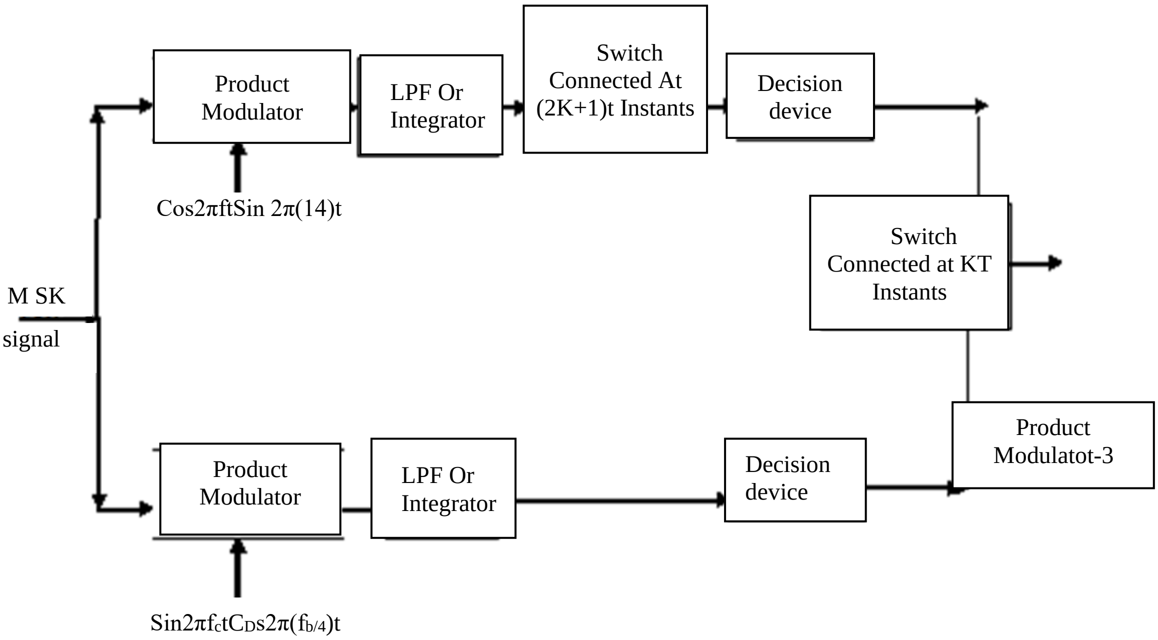

Figure 2. Block diagram of minimum shift keying (MSK) demodulator.

SECTION 2

Description of various blocks of Simulink model is as given in the following text (Figure 3).

Random Integer Generator

The random integer generator block produces uniformly distributed random integers within the interval [0, M-1], where M represents the M-ary number. This M-ary number can be a scalar or a vector equal to the value of k. Here k shows message symbols. The output signal here is a frame-based matrix. As number of samples per frame for the system is taken some integer multiple of M-ary number value, random integer generator is with a purpose to spread the input signal. For frame-based output which contains rows and columns, output data type is double [11–15].

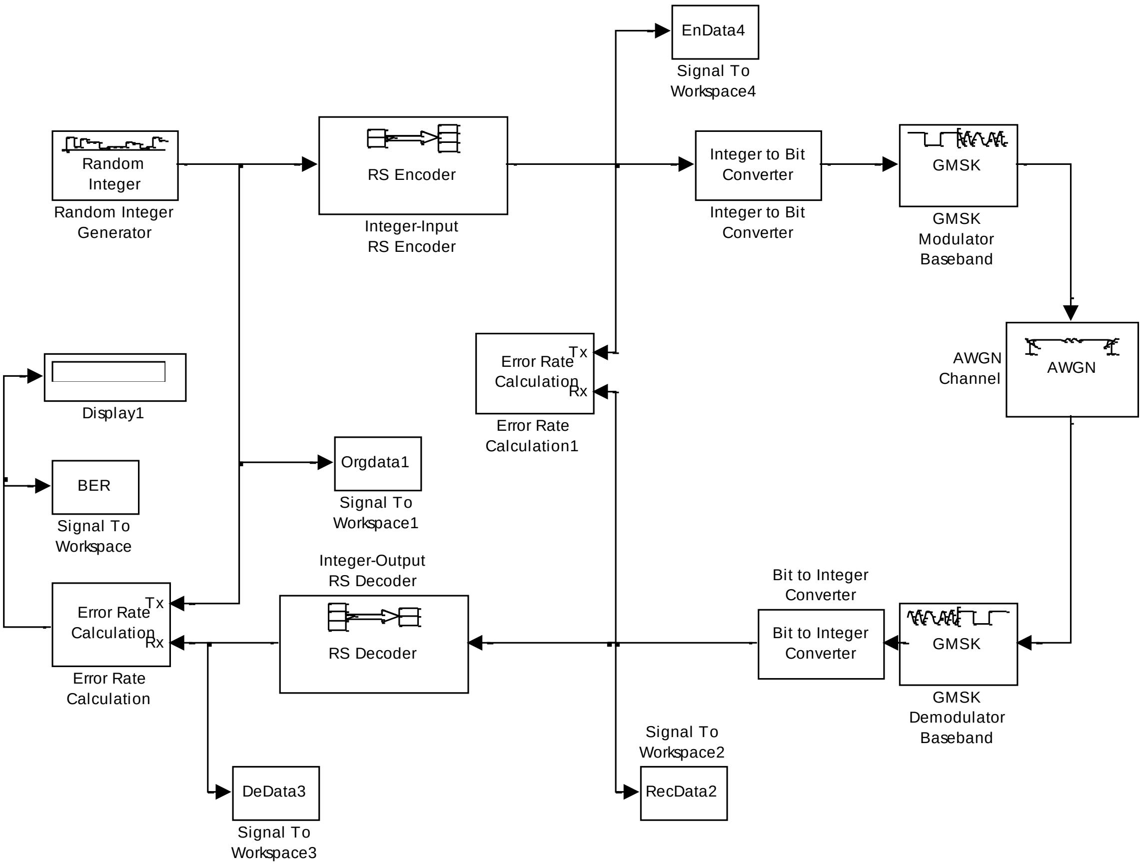

Figure 3. Simulink model of Reed-Solomon (RS) Gaussian minimum key shifting (GMSK)-based system.

RS Encoder

The integer-input RS encoder block generates a RS code with a message length of K and a codeword length of N (where N represents the number of punctures), both of which are directly specified in the block dialog. The code symbols are integers ranging from 0 to 2M-1, which denote elements of the finite field GF(2M). The input should be a frame-based column vector whose length is a multiple of K. An (N, K) RS code has the capability to correct up to (N-K)/2 symbol errors (or baud errors) within each codeword.

Integer to Bit Converter

The block assigns each integer value to a set of M bits, with the selection for the output bit order determining the placement of the most significant bit. This process results in an output vector length that is M times the length of the input vector.

GMSK Modulator

The GMSK modulator block utilizes the Gaussian minimum shift keying technique to modulate the incoming bits, resulting in a modulated signal. Prior to modulation, the digital data stream undergoes shaping with a Gaussian filter. This process enhances spectral efficiency and reduces side lobes and power consumption compared to MSK. The Gaussian filter's width is determined by its bandwidth-time (BT) product, where B represents the -3dB bandwidth and T represents the symbol period, equivalent to 1 divided by the symbol rate (f symbol rate). The lower the BT product, the narrower is the modulated bandwidth and the higher is the inter symbol interference. The BT product parameter, which is a nonnegative scalar, is employed to decrease the bandwidth while simultaneously increasing inter symbol interference. The block specifies the output type as double and determines the number of output samples. As the frequency of output modulated signal in GMSK is different from original carrier frequency that’s it is responsible for frequency hopping of signal.

Additive White Gaussian Noise

The AWGN Channel block introduces white Gaussian noise to a given input signal, whether it is real or complex. In the case of a real input signal, the block adds real Gaussian noise and generates a real output signal. Conversely, for a complex input signal, the block adds complex Gaussian noise and produces a complex output signal as shown in Figure 4. Simulink model of BCH GMSK-based system is shown later.

Description of various blocks of Simulink model for a BCH GMSK based system is given in the following text.

Bernoulli Binary Generator

The Bernoulli binary generator block creates random binary numbers utilizing a Bernoulli distribution. In this distribution, a parameter p determines the probability of generating zero, while the probability of generating one is 1-p. The output signal used is a frame-based matrix. For frame-based output which contains rows and columns, output data type is double.

Buffer

Buffer block converts input sequence to smaller or larger frame size.

BCH Encoder

The BCH Encoder block generates a BCH code with a message length of K and a codeword length of N. Both N and K values are directly specified in the dialog box. The input should be a frame-based column vector containing an integer multiple of K elements.

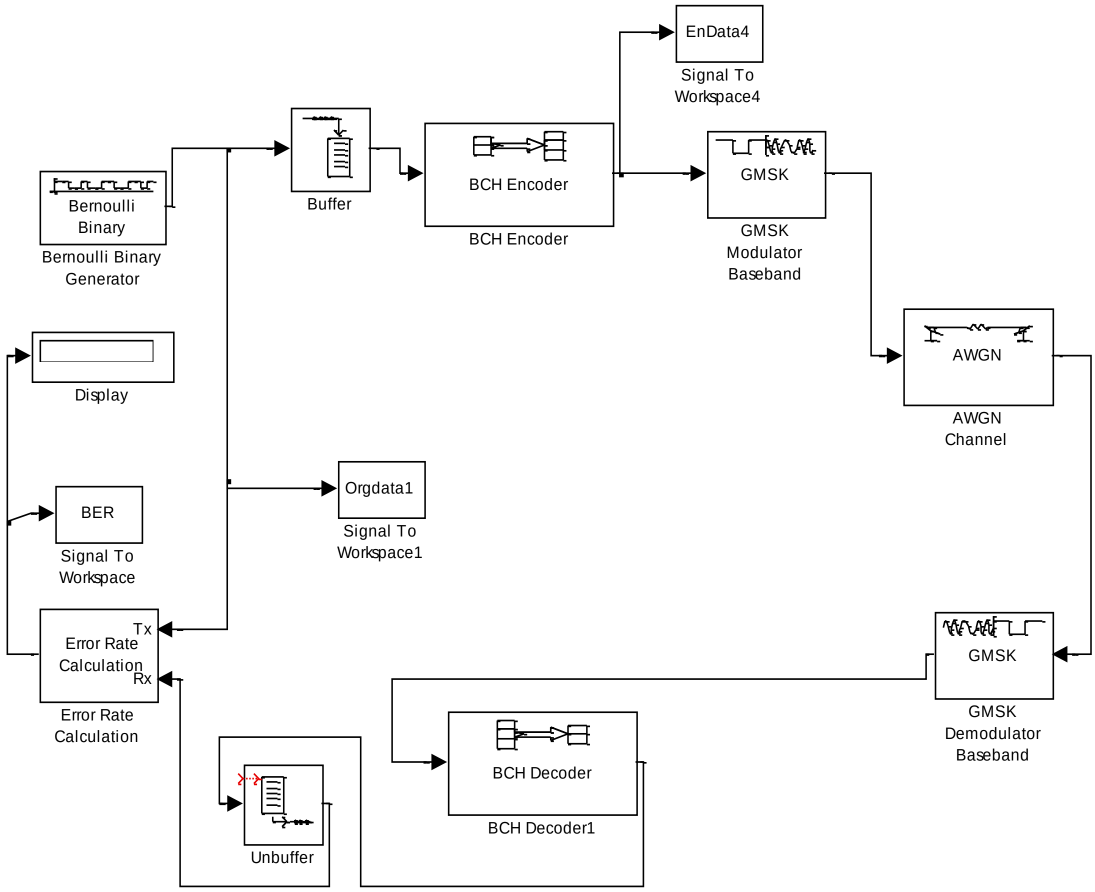

Figure 4. Simulink model of Bose-Chaudhuri-Hocquenghem (BCH) Gaussian minimum key shifting (GMSK)-based system.

Each set of K input elements corresponds to one message word to be encoded. Notably, only certain message lengths K are compatible with a code word of length N in a BCH code. For a complete-length BCH code, N must conform to the form 2M-1. In every (n,k) system n indicates total number of code symbols and k indicates message symbols.(n-k) indicates number of parity or check symbols.

Upon comparing RS GMSK and BCH GMSK for various (63, k) combinations, Tables 1 and 2 indicate that there is no notable reduction in BER, or it remains nearly constant with increasing S/N ratios in the case of BCH GMSK. In contrast, the RS GMSK system demonstrates a significant decrease in BER values with higher S/N ratios, suggesting its superiority as a coding scheme for burst errors.

Table 1. Bit error rate (BER) values for a RS GMSK (63,K) system through Simulink model**.**

S.N.	**BER**				
Eb/No (dB)	***Uncoded GMSK***	***RS GMSK***	***RS GMSK***	***RS GMSK***	***RS GMSK***
		(63,57)	(63,53)	(63,49)	(63,41)
0	0.4378	0.4828	0.5104	0.544	0.6128
1	0.3341	0.3835	0.4119	0.4462	0.5207
2	0.2363	0.2827	0.3077	0.342	0.4199
3	0.1513	0.1911	0.2121	0.2408	0.3152
4	0.0863	0.1122	0.1212	0.1338	0.1823
5	0.0422	0.0456	0.0358	0.0334	0.0378
6	0.0172	0.0091	0.0035	0.0028	0.0019
7	0.0055	0.00074	0.00016	0.00013	0.000101
8	0.0006	0.0000400	0	0	0
9	0.0002	0	0	0	0
10	0.0003	0	0	0	0

Table 2. Bit error rate (BER) values of BCH GMSK (63, K) system through Simulink model.

S.N.	**BER**			
Eb/No (dB)	***BCH GMSK***	***BCH GMSK***	***BCH GMSK***	***BCH GMSK***
	(63,57)	(63,53)	(63,49)	(63,41)
0	0.4988	0.4988	0.4995	0.4993
1	0.4991	0.4987	0.4996	0.4993
2	0.4994	0.4986	0.4995	0.4994
3	0.4998	0.4986	0.4993	0.4992
4	0.4995	0.4988	0.4993	0.4991
5	0.4996	0.4986	0.4992	0.4992
6	0.4995	0.4987	0.499	0.4991
7	0.4996	0.4984	0.4987	0.4992
8	0.4998	0.4984	0.4986	0.4991
9	0.4997	0.4982	0.499	0.4992
10	0.4999	0.4986	0.4994	0.499

From Tables 1 to 5, it is observed that the values of BER reduces with reduce in coding rate (k/n) or with increase in parity symbols for all (n, k) values. This reduction in BER is more clearly visible for S/N amount greater than 5 dB. Also, coding gain is achieved for all (n, k) combinations of RS GMSK based system like (31,k), (63,k), (127,k) , (255,k). It is very clear from Tables 1 to 5 that as compared to BER amounts for uncoded GMSK system, the value of BER is lesser for a system utilizing RS coding that means coding gain is achieved which is the difference between BER of uncoded system and coded system.

Upon comparing RS GMSK and BCH GMSK for various (63, k) combinations, it has been observed through Figures 5 and 6 that there is no notable reduction in BER, or it remains relatively constant with increasing S/N ratios in the case of BCH GMSK. Conversely, in the RS GMSK-based system, BER values show a significant decrease with higher S/N ratios, indicating its effectiveness as a coding scheme for burst errors. Figures 6 to 9 clearly demonstrate that the (63, k) combination outperforms other combinations of RS GMSK, such as (31, k), (127, k), and (255, k), in terms of BER, as it exhibits the lowest BER.

Table 3. Bit error rate (BER) values for a RS GMSK (127,K) system through Simulink model.

S.N.	**BER**					
Eb/No (dB)	***Uncoded GMSK***	***RS GMSK***	***RS GMSK***	***RS GMSK***	***RS GMSK***	***RS GMSK***
		(127,107)	(127,103)	(127,99)	(127,87)	(127,79)
0	0.9923	0.992	0.9915	0.9913	0.9909	0.9911
1	0.9922	0.9919	0.9912	0.9911	0.9907	0.9911
2	0.9923	0.9917	0.9911	0.9911	0.9909	0.991
3	0.9924	0.9916	0.9909	0.9909	0.9907	0.9908
4	0.9924	0.9915	0.9907	0.9909	0.9907	0.9908
5	0.9924	0.9915	0.9908	0.9909	0.9904	0.9908
6	0.9924	0.9915	0.9907	0.9909	0.9904	0.9908
7	0.9923	0.9914	0.9906	0.9908	0.9904	0.9908
8	0.9923	0.9911	0.9904	0.9908	0.9905	0.9909
9	0.9922	0.9911	0.9904	0.9908	0.9905	0.9909
10	0.9922	0.9911	0.9904	0.9908	0.9905	0.9909

Table 4. Bit error rate (BER) values for a RS GMSK (31,K) system through Simulink model.

S.N.	**BER**				
Eb/No (dB)	***Uncoded GMSK***	***RS GMSK***	***RS GMSK***	***RS GMSK***	***RS GMSK***
		(31,25)	(31,23)	(31,21)	(31,19)
0	0.9682	0.968	0.9677	0.9666	0.9673
1	0.9681	0.9684	0.9673	0.9666	0.967
2	0.9685	0.9678	0.9668	0.9673	0.967
3	0.9688	0.9682	0.9667	0.9672	0.9669
4	0.9686	0.9682	0.9667	0.9668	0.9666
5	0.9685	0.9679	0.9663	0.9667	0.9662
6	0.9685	0.9679	0.9662	0.9665	0.9664
7	0.9685	0.9679	0.9662	0.9664	0.9664
8	0.9685	0.9679	0.9662	0.966	0.9664
9	0.9685	0.9679	0.9662	0.9661	0.9664
10	0.9685	0.9679	0.9662	0.9661	0.9664

Table 5. Bit error rate (BER) values for a RS GMSK (255, K) system through simulink model.

S.N.	**BER**				
Eb/No (dB)	***UNCODED GMSK***	***RS GMSK***	***RS GMSK***	***RS GMSK***	***RS GMSK***
		(255,239)	(255,215)	(255,203)	(255,179)
	0.996	0.9961	0.9961	0.9961	0.996
1	0.9961	0.9962	0.9961	0.9963	0.9959
2	0.9959	0.9961	0.9961	0.9961	0.9961
3	0.9959	0.9959	0.9963	0.9964	0.996
4	0.9959	0.9959	0.9963	0.9964	0.996
5	0.9959	0.996	0.9963	0.9963	0.9959
6	0.996	0.996	0.9964	0.9963	0.9958
7	0.9961	0.9959	0.9964	0.9963	0.9958
8	0.996	0.9958	0.9959	0.9961	0.9959
9	0.996	0.9958	0.9959	0.9961	0.9957
10	0.996	0.9958	0.9959	0.9961	0.9957

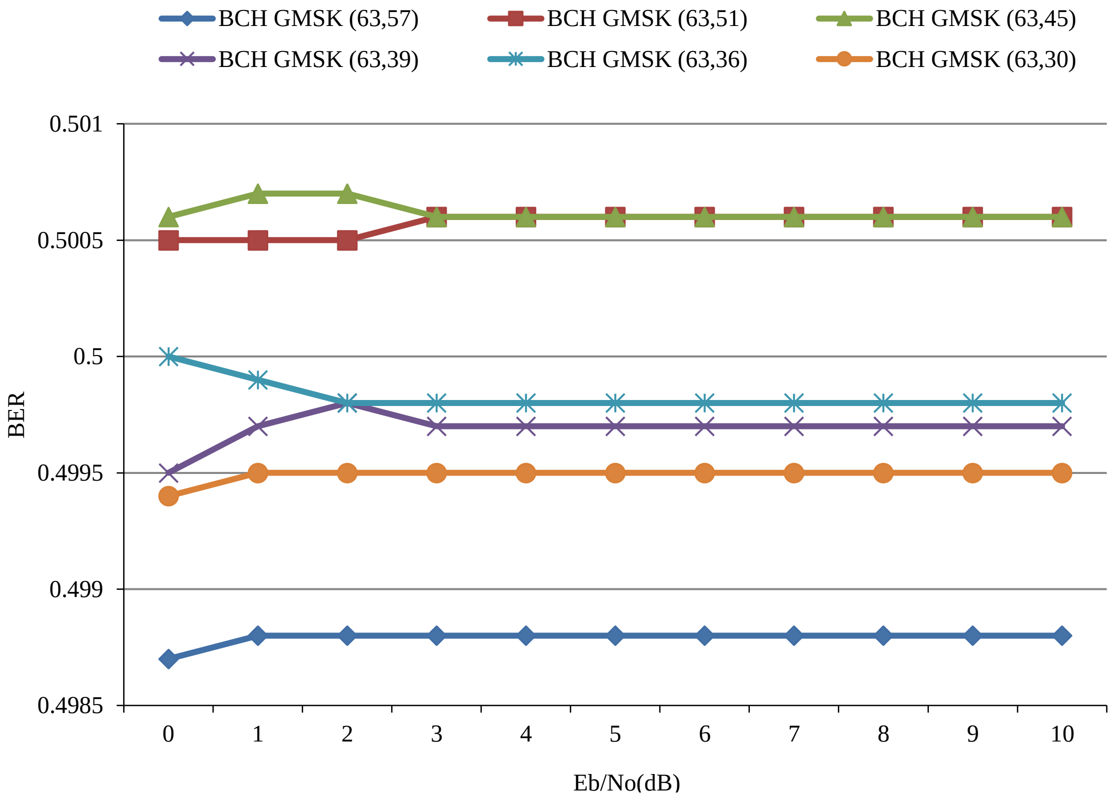

Figure 5. Performance for Bose- Chaudhuri- Hocquenghem (BCH) Gaussian minimum shift keying (GMSK) (63:k) code combinations with the same bandwidth as an uncoded system.

Upon comparing RS GMSK with BCH GMSK for (31, k), (127, k), and (255, k) combinations, as illustrated in Figures 10 to 13, it has been noted that the output BER remains relatively unaffected by variations in input S/N for BCH GMSK, which represents a significant limitation. However, although the BER values obtained for BCH GMSK are considerably lower than those for RS GMSK, increasing the number of parity symbols leads to a notable reduction in BER for RS GMSK, a phenomenon not observed in BCH GMSK, thus representing a major drawback of the latter.

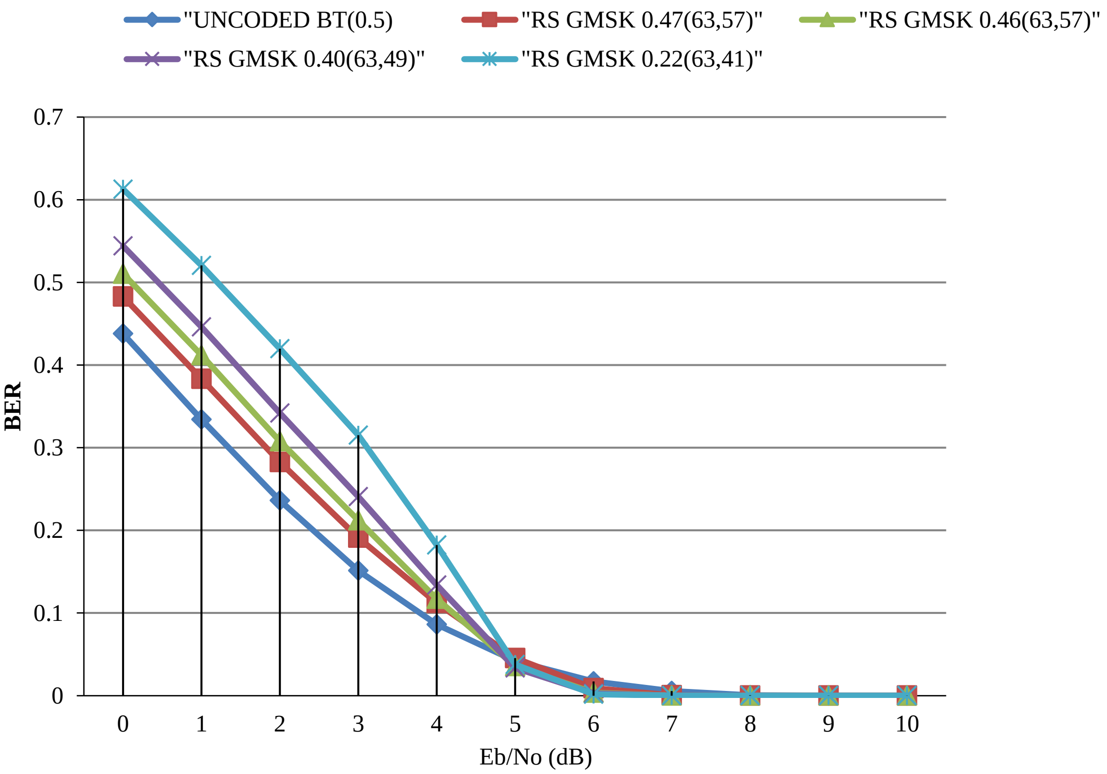

Figure 6. Performance for Reed-Solomon (RS) Gaussian minimum shift keying GMSK(63:k) code combinations with the same bandwidth as an uncoded system.

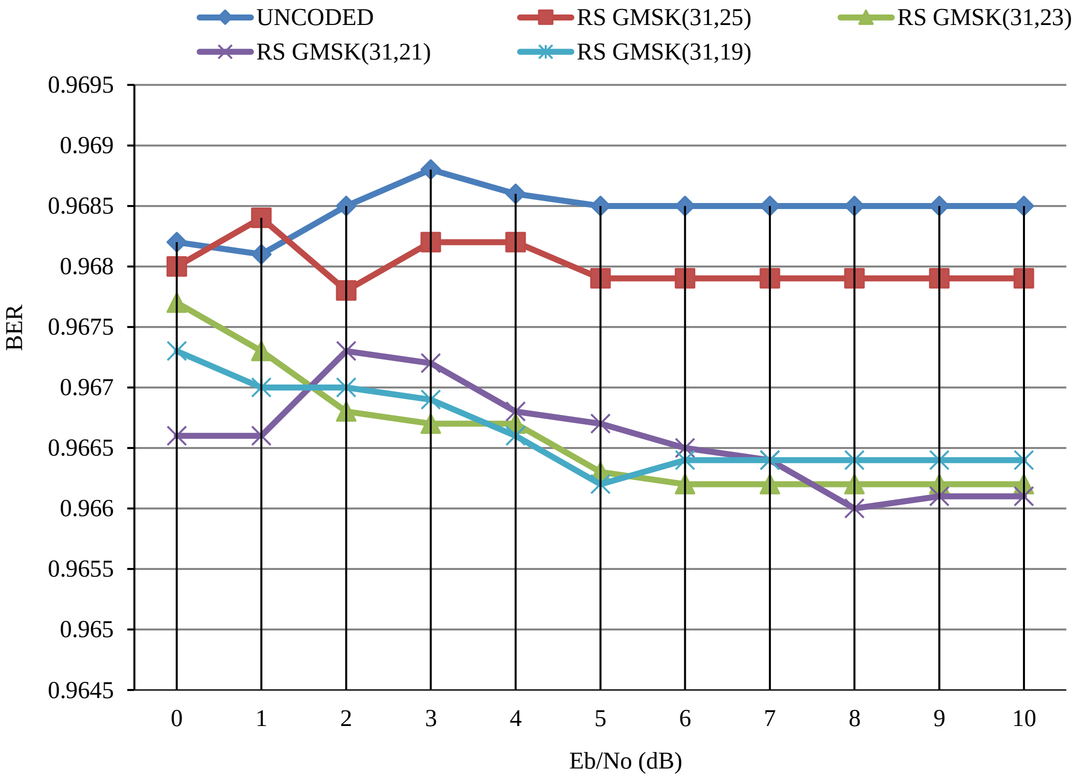

Figure 7. Performance for Reed-Solomon (RS) Gaussian minimum shift keying (GMSK) (31;k) code combinations with the same bandwidth as an uncoded system.

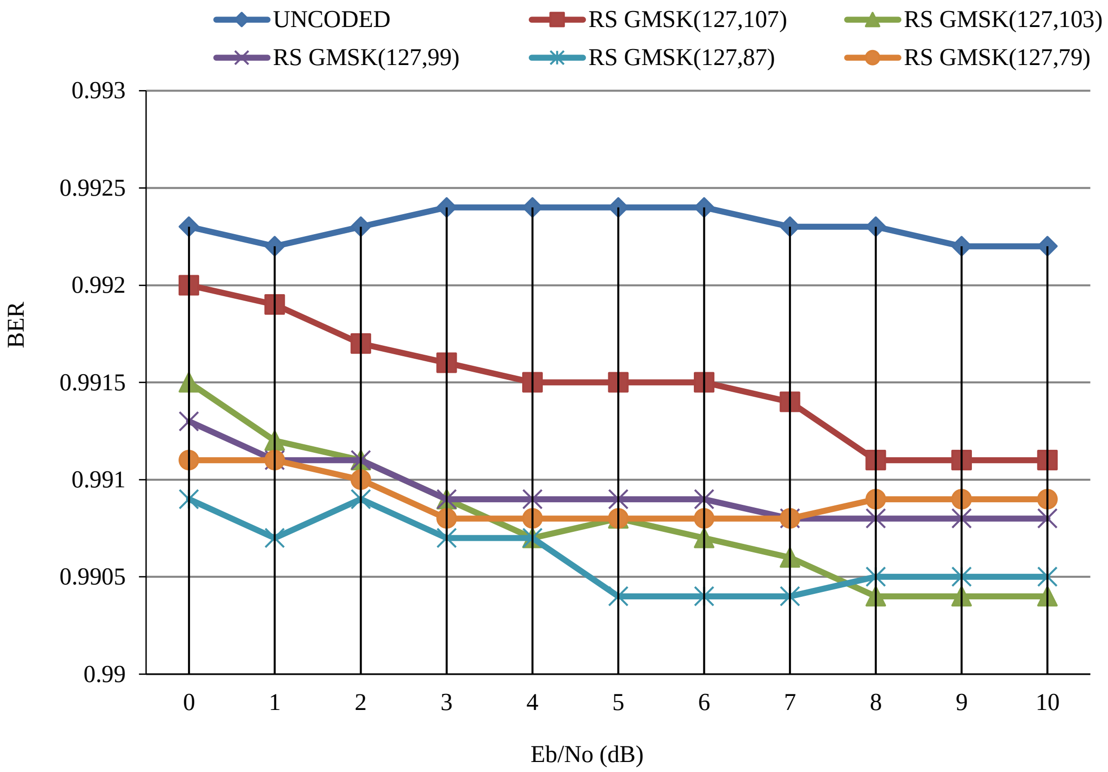

Figure 8. Performance for Reed-Solomon (RS) Gaussian minimum shift keying (GMSK) (127:k) code combinations with the same bandwidth as an uncoded system.

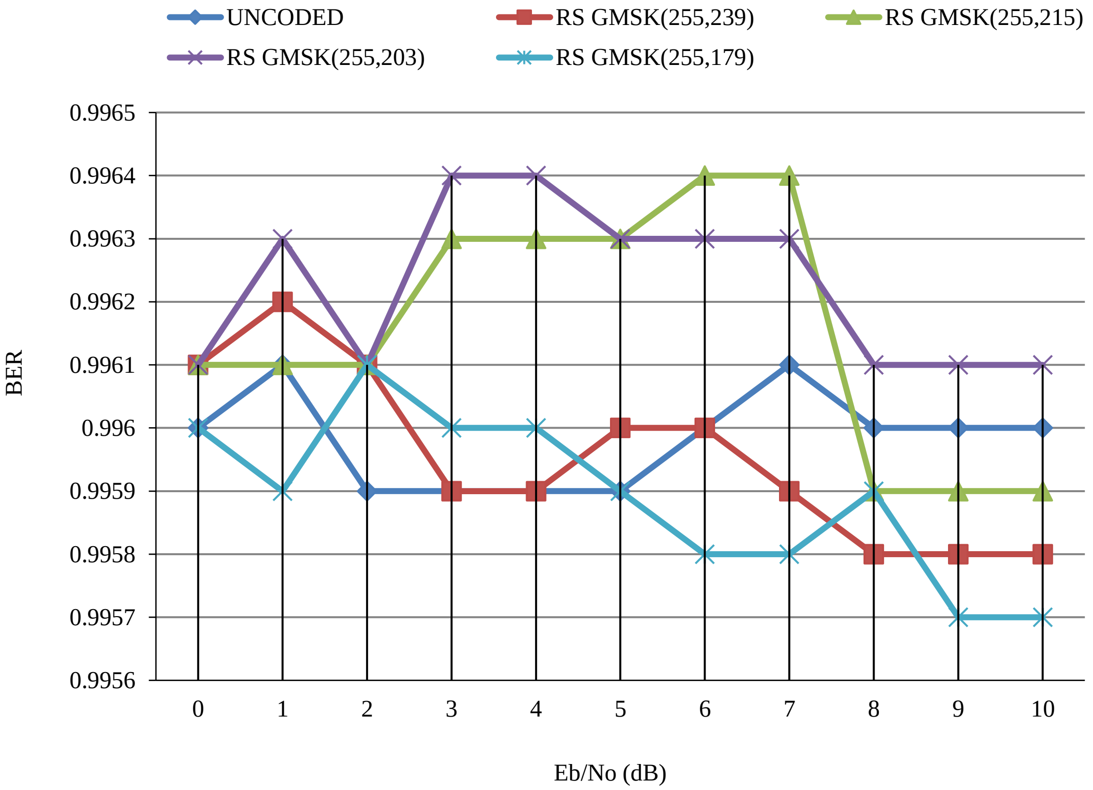

Figure 9. Performance for Reed-Solomon (RS) Gaussian minimum shift keying (GMSK) (255:k) code combinations with the same bandwidth as an uncoded system.

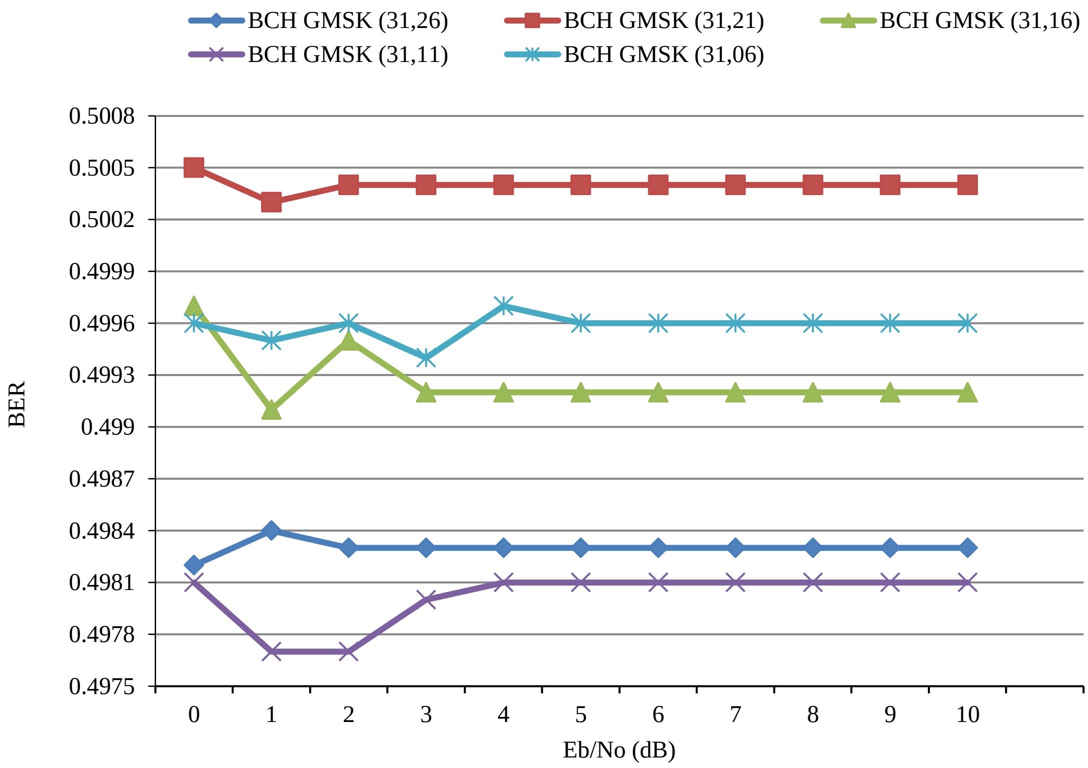

Figure 10. Performance for Bose-Chaudhuri-Hocquenghem (BCH) Gaussian minimum shift keying (GMSK) (31:k) code combinations with the same bandwidth as an uncoded system.

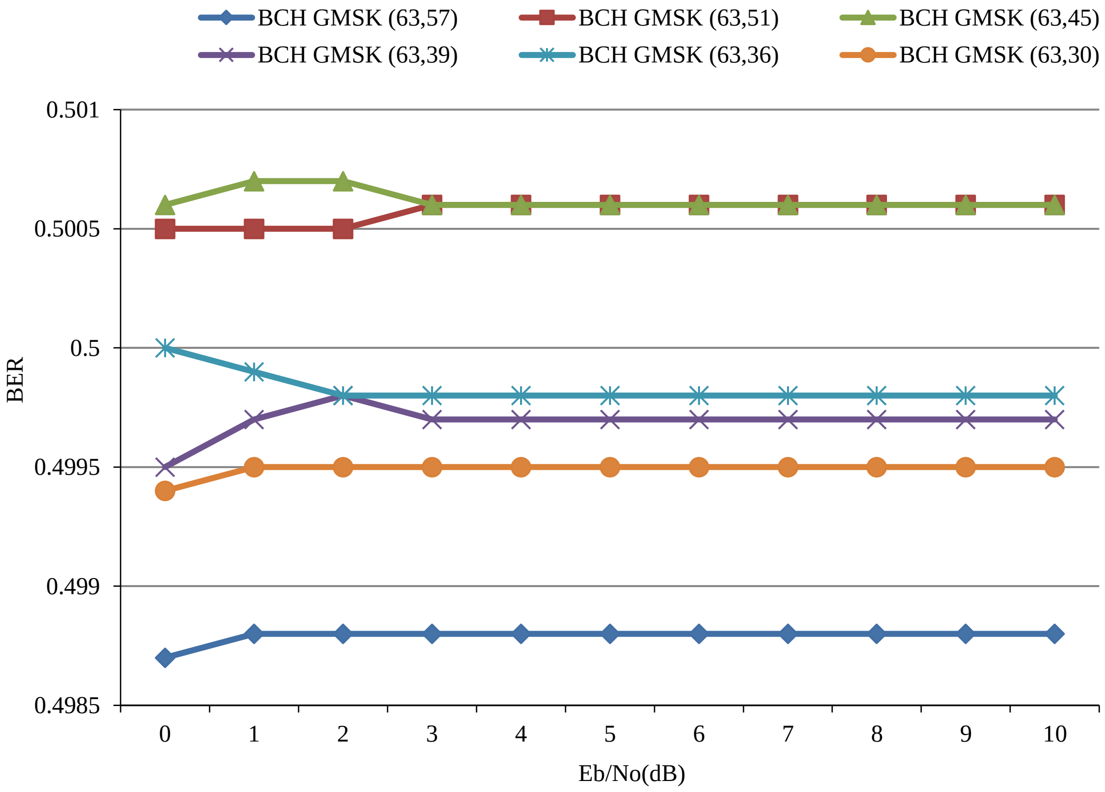

Figure 11. Performance for Bose-Chaudhuri-Hocquenghem (BCH) Gaussian minimum shift keying (GMSK) (63:k) code combinations with the same bandwidth as an uncoded system.

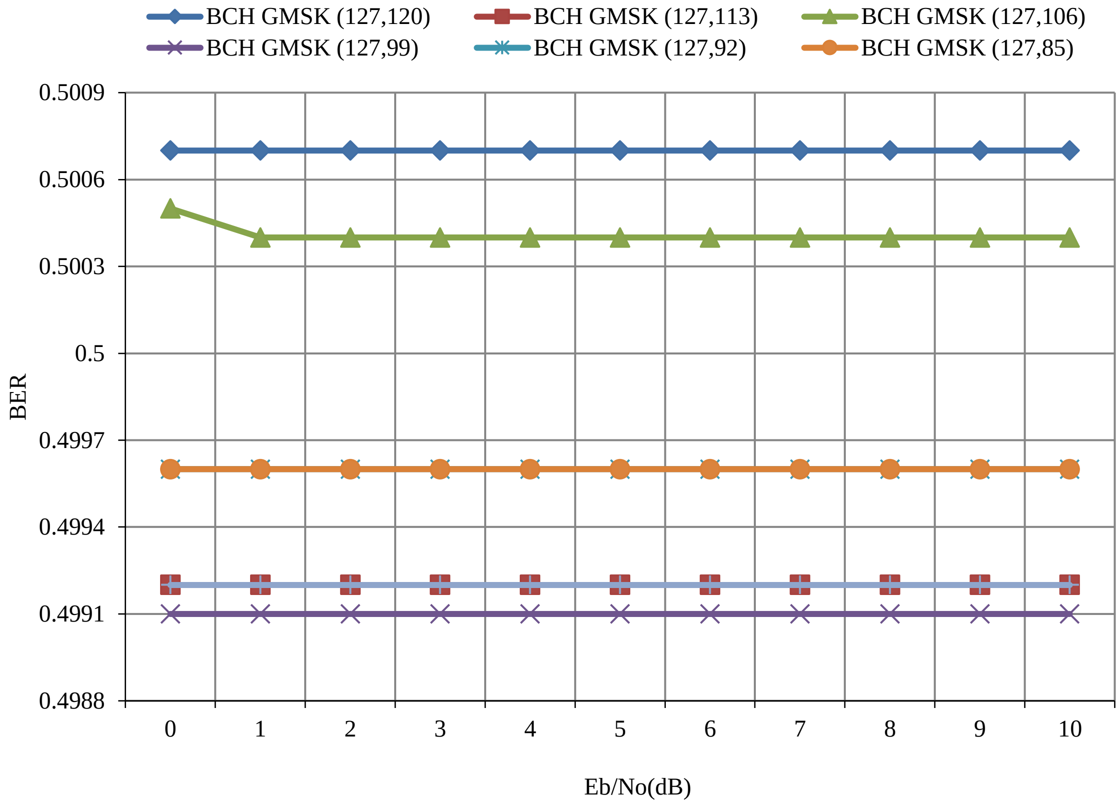

Figure 12. Performance for Bose-Chaudhuri-Hocquenghem (BCH) Gaussian minimum shift keying (GMSK) (127:k) code combinations with the same bandwidth as an uncoded system.

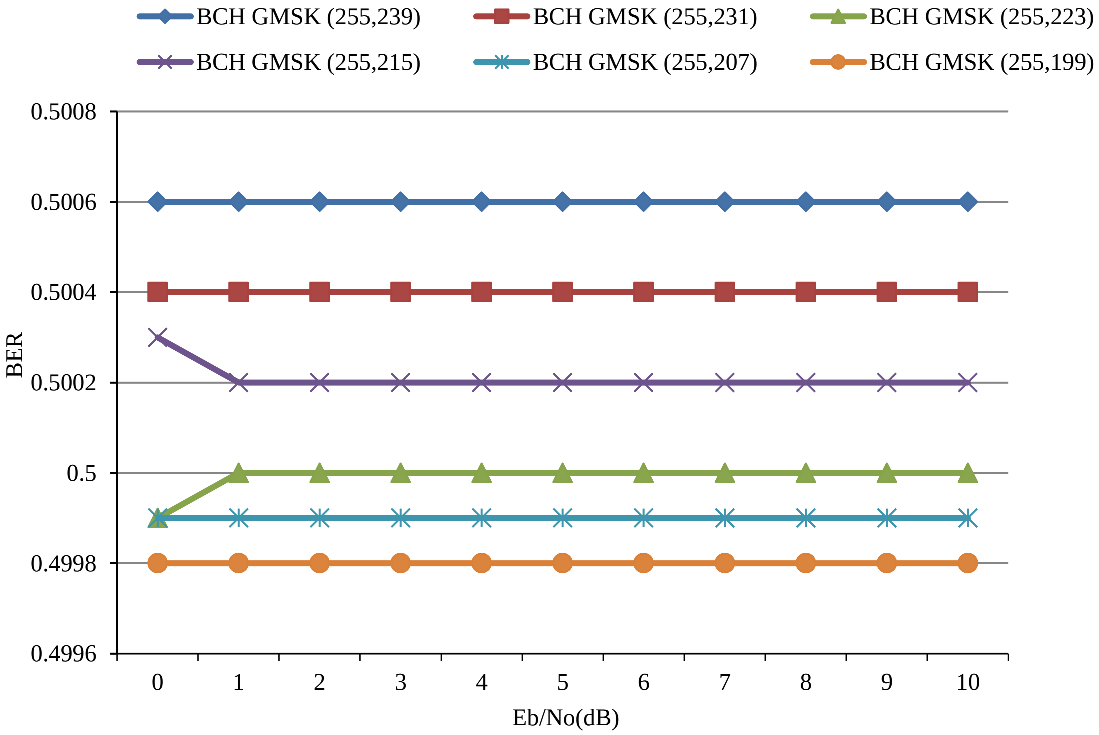

Figure 13. Performance for Bose-Chaudhuri-Hocquenghem (BCH) Gaussian minimum shift keying (GMSK) (255:k) code combinations with the same bandwidth as an uncoded system.

The BER values observed in RS GMSK are initially higher compared to those in BCH GMSK. However, with an increase in parity symbols, there is a noticeable improvement (reduction) in BER for RS GMSK, a characteristic that is not present in BCH GMSK, representing one of its primary limitations.

The impact of increasing parity symbols on reducing BER is evident in RS-based systems across various modulation schemes such as PSK (Phase Shift Keying), DPSK (Differential Phase Shift Keying), QPSK (Quadrature Phase Shift Keying), and FSK (Frequency Shift Keying). However, this effect is not observed in BCH-based systems for the same modulation schemes, highlighting a significant drawback of BCH modulation schemes, as demonstrated in Figures 14 to 23.

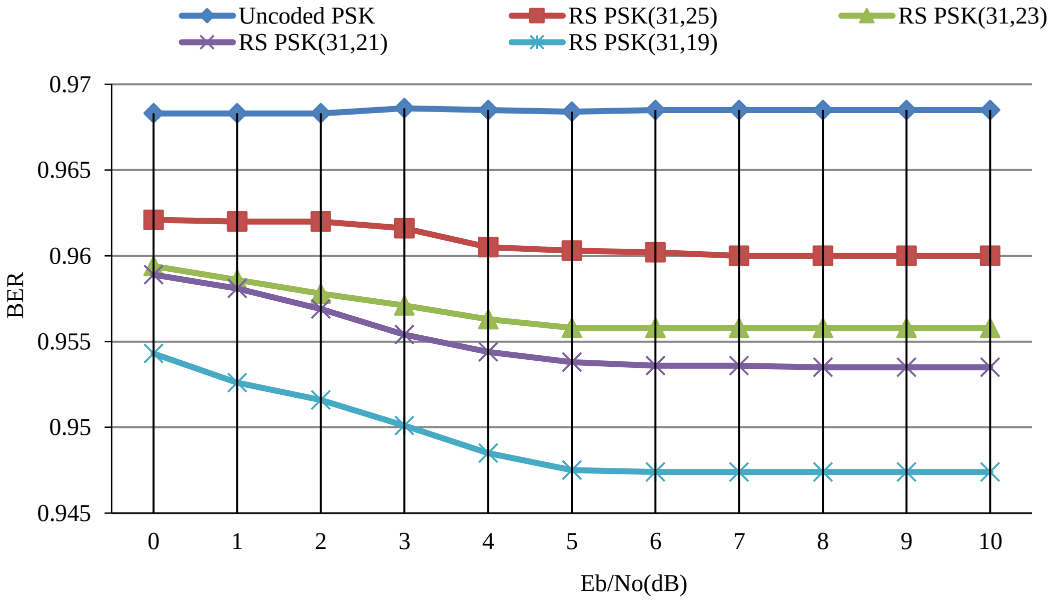

Figure 14. Performance for Reed-Solomon (RS) PSK (31;k) code combinations with the same bandwidth as an uncoded system.

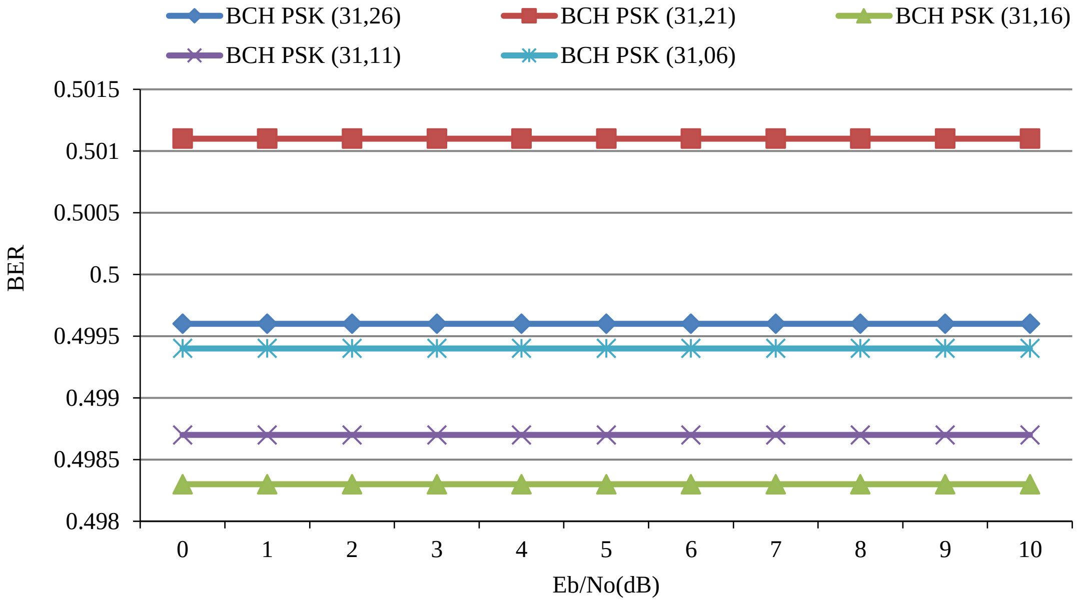

Figure 15. Performance for Bose-Chaudhuri-Hocquenghem (BCH) PSK (31;k) code combinations with the same bandwidth as an uncoded system.

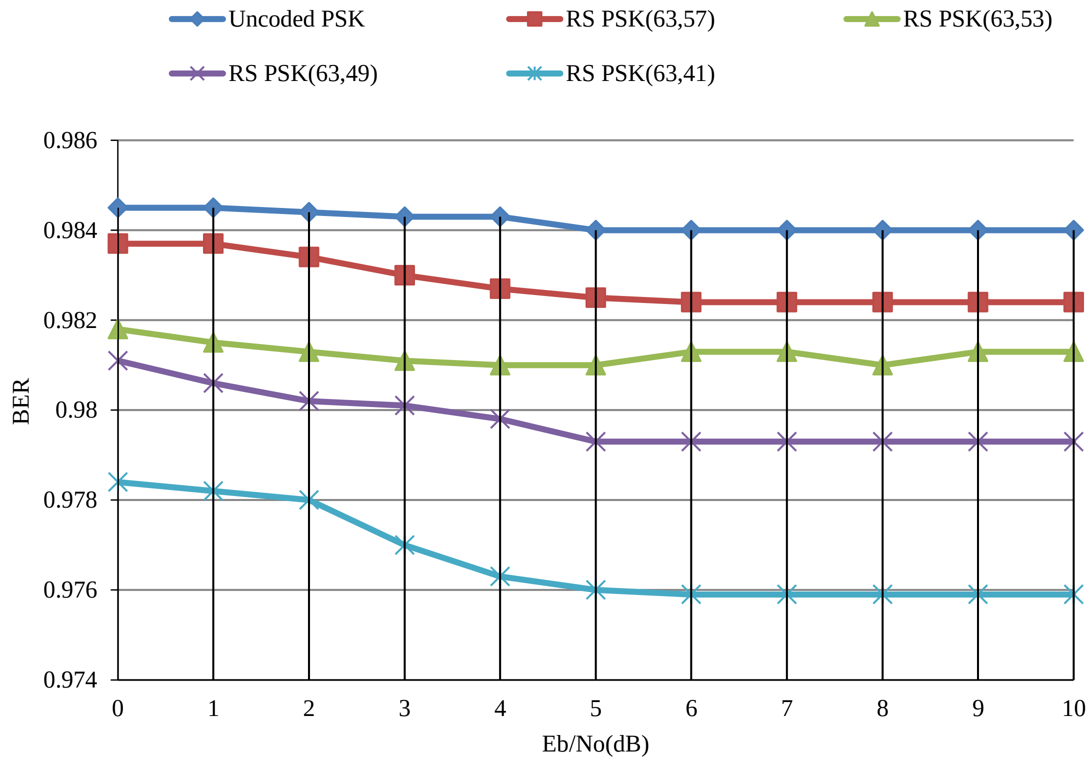

Figure 16. Performance for Reed-Solomon (RS) PSK(63;k) code combinations with the same bandwidth as an uncoded system.

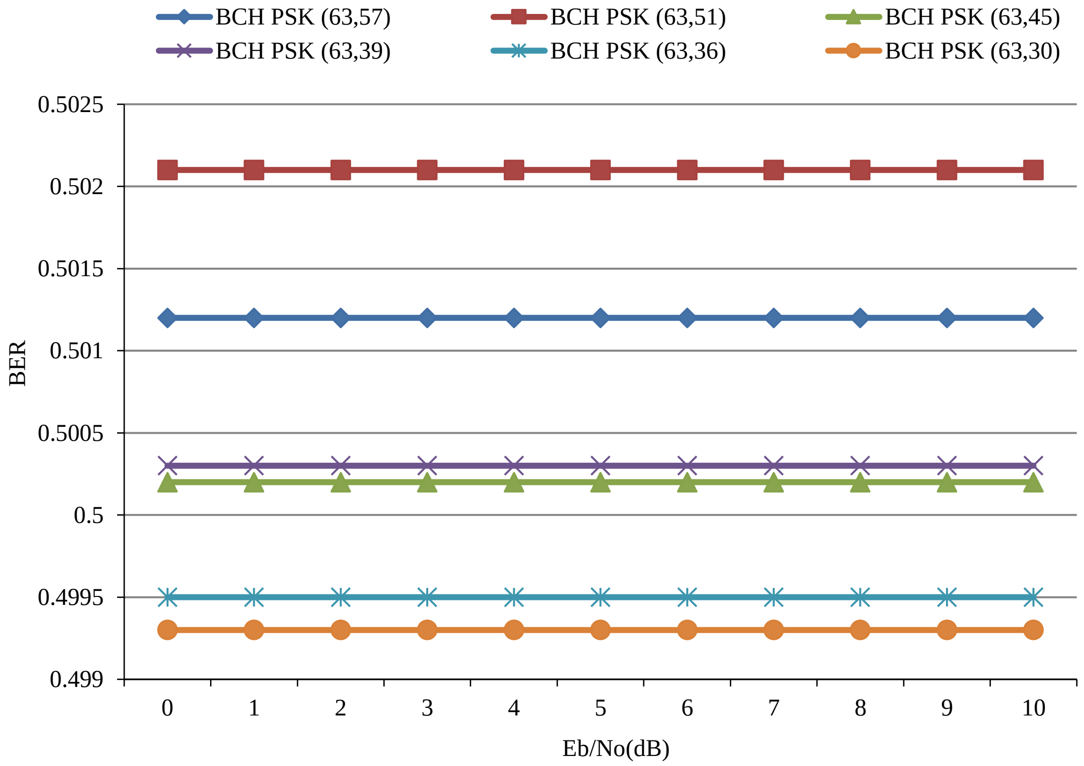

Figure 17. Performance for Bose-Chaudhuri-Hocquenghem (BCH) PSK (63;k) code combinations with the same bandwidth as an uncoded system.

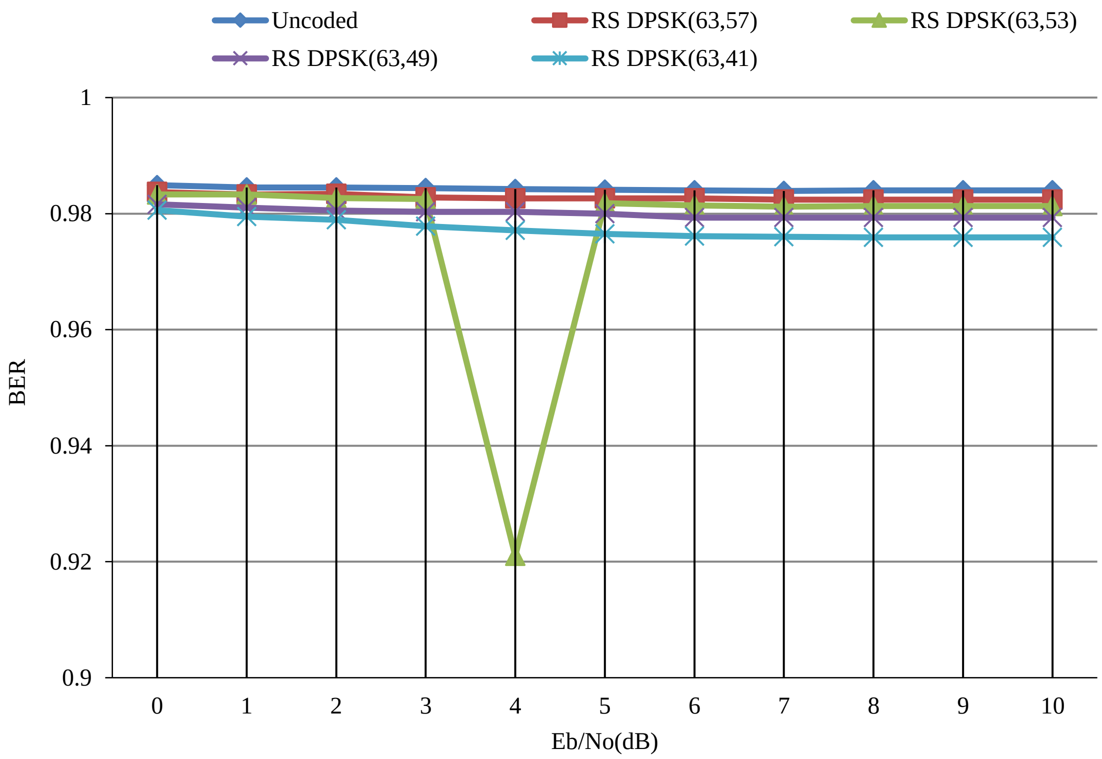

Figure 18. Performance for Reed-Solomon (RS) DPSK (63;k) code combinations with the same bandwidth as an uncoded system.

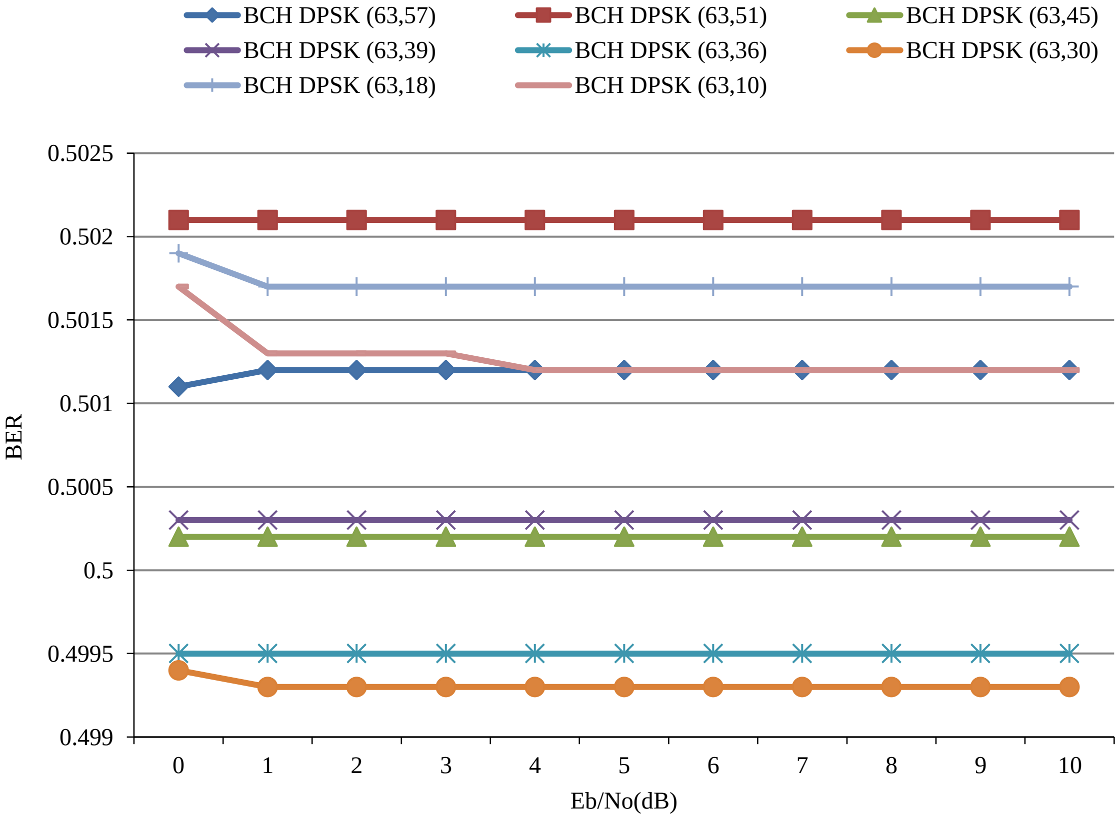

Figure 19. Performance for Bose-Chaudhuri-Hocquenghem (BCH) DPSK (63;k) code combinations with the same bandwidth as an uncoded system.

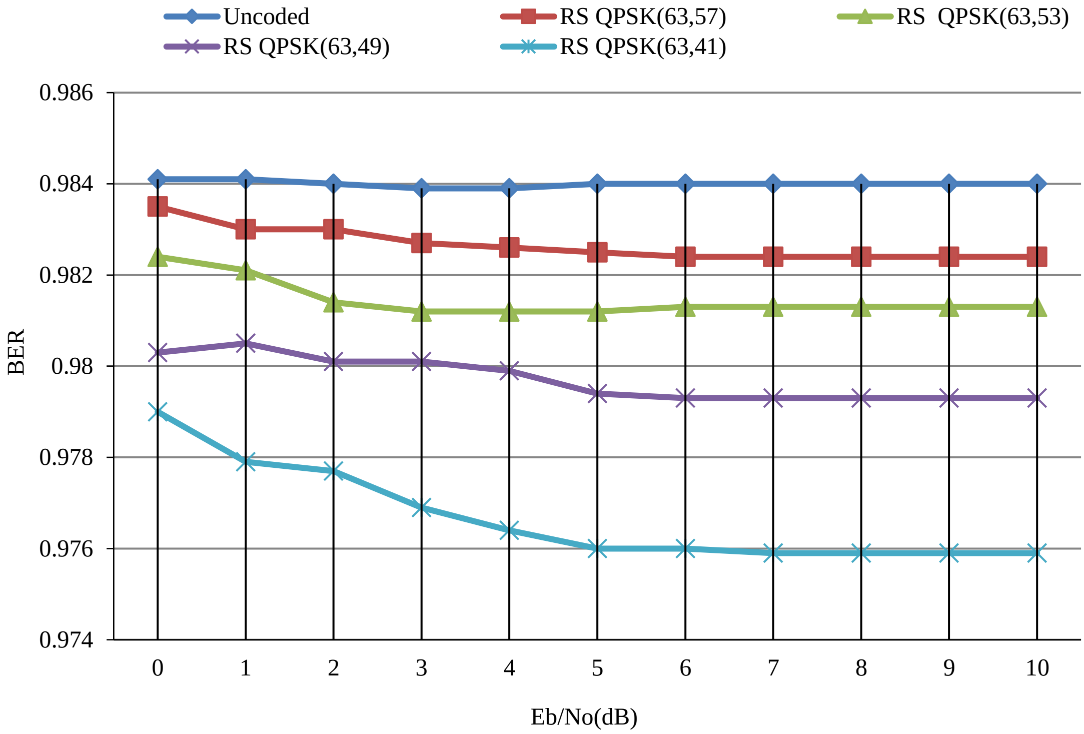

Figure 20. Performance for Reed-Solomon (RS) QPSK (63;k) code combinations with the same bandwidth as an uncoded system.

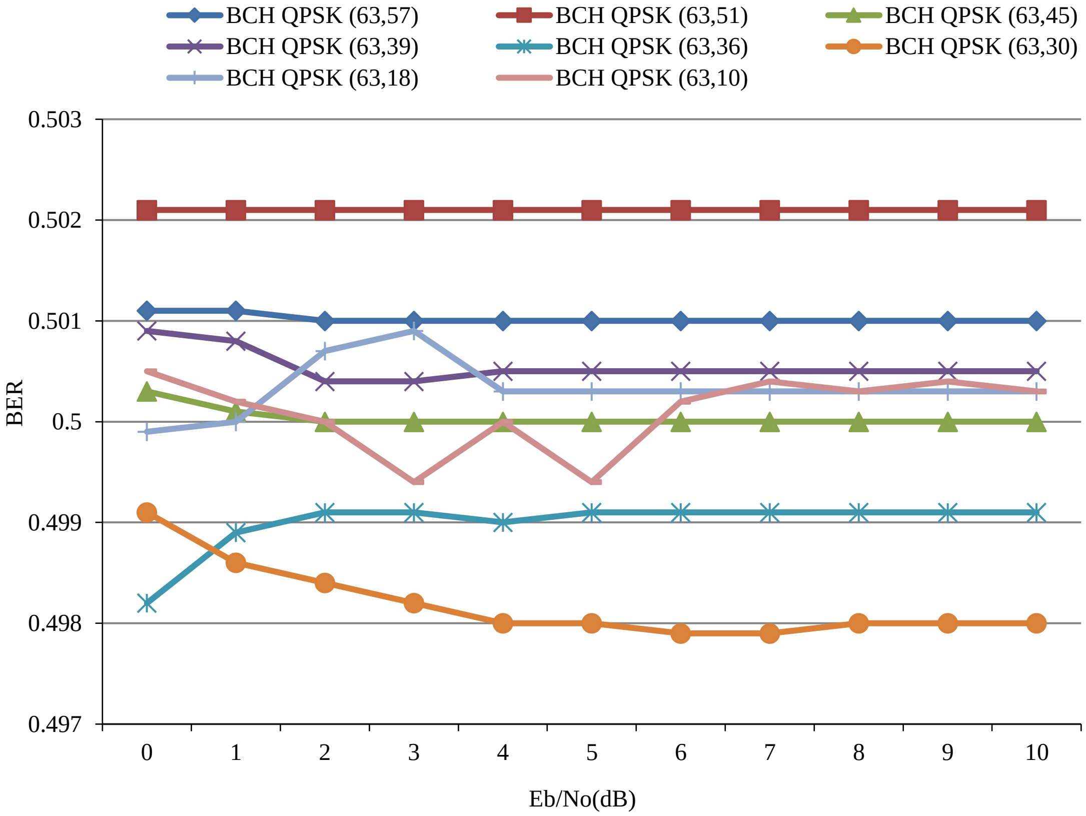

Figure 21. Performance for Bose-Chaudhuri-Hocquenghem (BCH) QPSK (63;k) code combinations with the same bandwidth as an uncoded system.

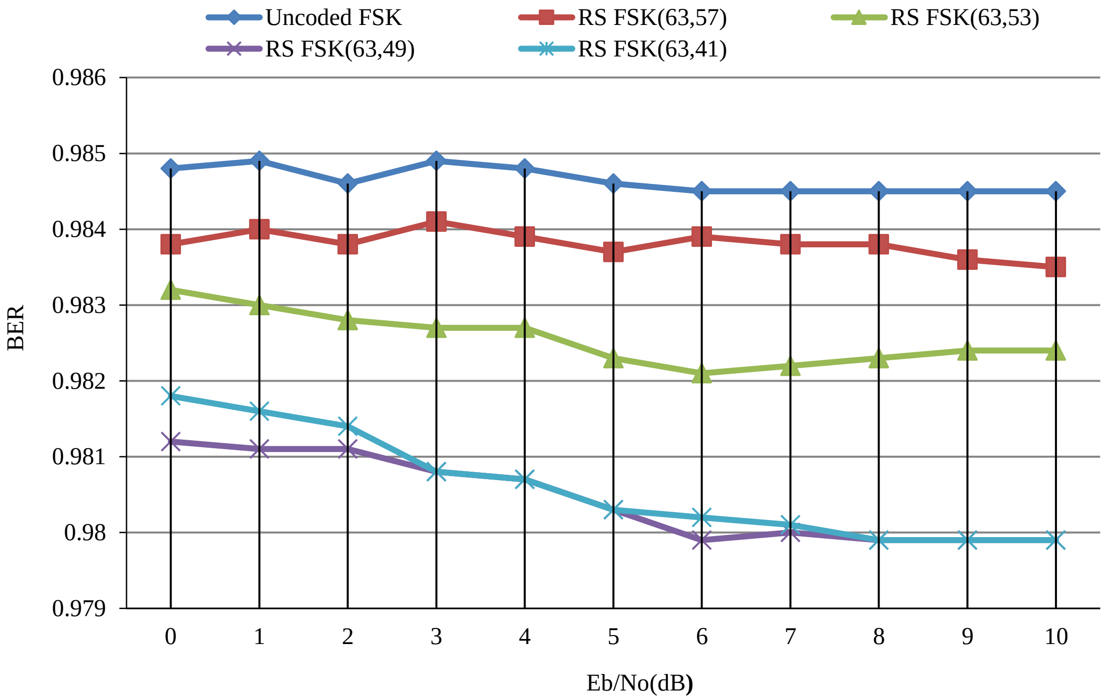

Figure 22. Performance for Reed-Solomon (RS) FSK (63;k) code combinations with the same bandwidth as an uncoded system.

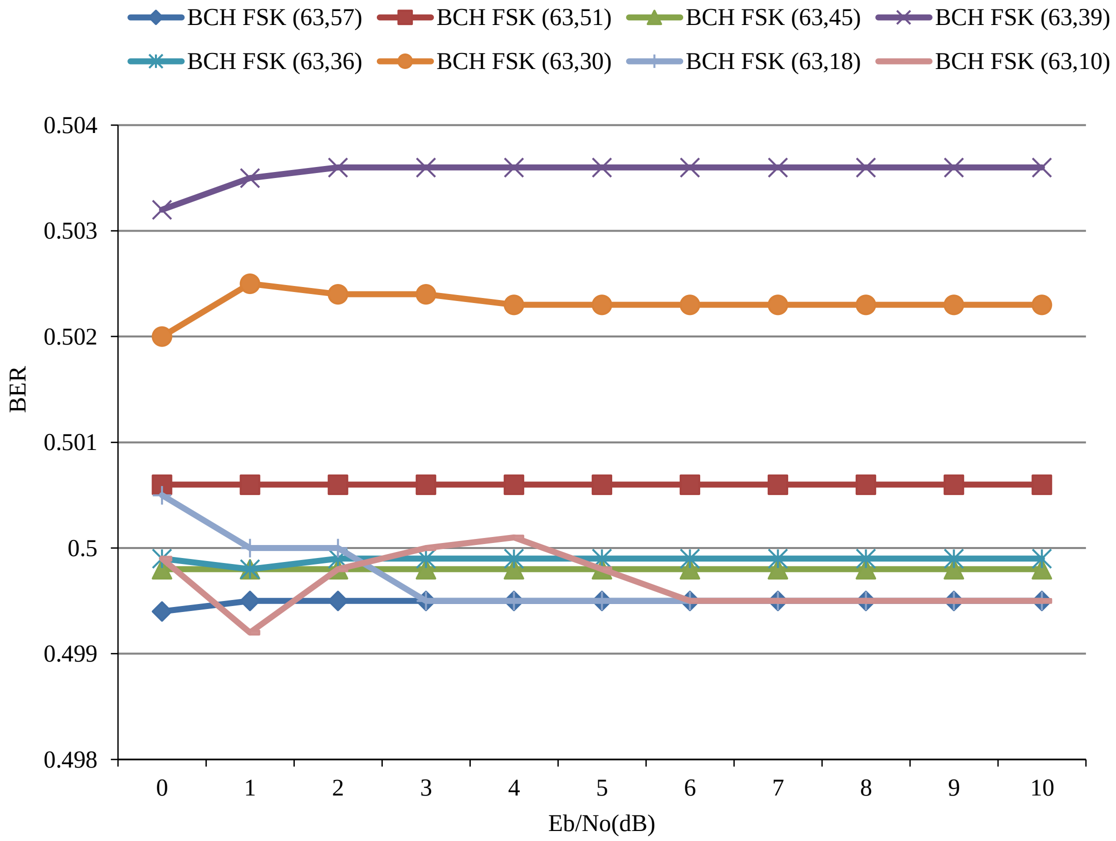

Figure 23. Performance for Bose-Chaudhuri-Hocquenghem (BCH) FSK (63;k) code combinations with the same bandwidth as an uncoded system.

CONCLUSION

This paper investigates the performance of a communication system employing GMSK modulation and utilizing RS and BCH channel coding under a constant bandwidth constraint. Various combinations of RS (n, k) and BCH (n, k) coding schemes are analyzed alongside different modulation methods. The findings suggest that employing a smaller code rate in a coded system can reduce the bit error rate compared to an uncoded system while maintaining the same bandwidth. Among RS GMSK (n, k) combinations, (63, k) demonstrates the best performance in terms of BER. Additionally, coding gain is observed across all (n, k) combinations of RS GMSK systems, including (31, k), (63, k), (127, k), and (255, k). GMSK modulation is found to be preferable over PSK, DPSK, QPSK, and FSK modulation methods for moderate values of "n." The impact of increasing parity symbols on BER reduction is noticeable in RS-based systems across various modulation schemes, whereas this effect is not observed in BCH-based systems, representing a significant drawback of BCH modulation. In scenarios requiring burst error correction, RS coding schemes outperform BCH coding schemes.

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