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BER Analysis of Coherent and Non-Coherent GMSK over Coding Techniques for Cellular systems in Next Generation Communications

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Abstract

The Gaussian Minimum Shift Keying (GMSK) is the most prominent effective modulation used in current wireless communications has seen tremendous growth from the recent years. Due to these advancements, the communicating speeds also reached gigabit rate per second. Despite of the technological development it also brings some major challenges due to the random behavior of the wireless environment. In particular, the error rate performance severely decays with the fading characteristics of the wireless channel. Forward error correction plays a key role to detect and correct the transmission errors. Hence, there is a need to study the performance of these systems under various network conditions. In this article, the Bit Error Rate (BER) analysis of the wireless scheme has been carried out using RS and BCH codes. Adaptive modulation techniques like MSK and GMSK have been used for simulation analysis. It is revealed that RS coded GMSK modulation performs well under burst error channels and BCH codes are able to provide better error correction capability under shift keying modulations. The comparison has been done to highlight the importance of these codes under erroneous wireless channel conditions.

Keywords:

Minimum Shift Keying (MSK), Gaussian Minimum Shift Keying (GMSK), Binary BCH code, Non-Binary RS code, Bit Error Rate (BER), Signal to Noise Ratio (SNR).

1. Introduction

The GMSK is most wide spectrum and power efficient used in mobile communications. The cellular standard most preferably uses GMSK at now current systems. Two major types of detectors that are coherent and non-coherent modems widely used. The non-coherent systems are most preferable than the coherent systems and generally reduce the complexity. The GMSK technique is studied to estimate the error rate of coherent and non-coherent modulations. The MSK and GMSK

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are considerably to estimate system performance and limit the trade-off [1-2].

The Figure. 1 representing baseband modulation is line coding namely non-return -to –zero (NRZ) level, namely unipolar return -to –zero (RZ) level, and biphase –(Manchester) level. The NRZ level says (symbol '1' ----> +ve pulse with 'T' and symbol '0' ---> -ve pulse with 'T'), unipolar RZ level (symbol '1' ----> +ve pulse with 'T/2' and nothing for symbol '0'), Manchester level (symbol '1' ----> +ve half with 'T pulse' and -ve half with 'T pulse' and reverse for symbol '0'). The other technique is differential coding which works with both baseband and bandpass modulations based on modulo-2 addition. The binary carrier modulations are ASK, FSK, PSK based on characteristic parameters: amplitude, frequency and phase. The modulator burst of carrier for every '1' and no signal for every '0' is on-off keying (OOK).

The variety of other modulations is derived from basic shift keying principle. The Phase Shift Keying (PSK); Quadrature Amplitude Modulation (QAM); Minimum Shift Keying (MSK, GMSK); Space Shift Keying (SSK, GSSK). Some other modulations are also considered into account that is Constant Envelope Modulation, Bandwidth Efficient Modulation, Continuous Phase Modulation, Trellis Code Modulation etc.[3-5].

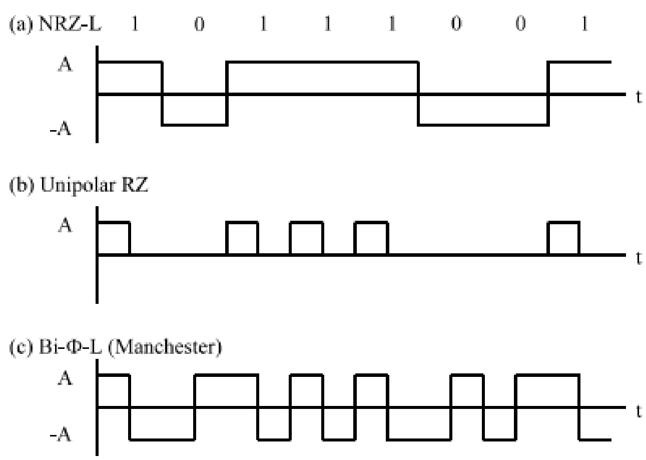

Fig. 1 Baseband digital modulation examples (a–c).

The error rate or error probability (BER) is inversely proportional to Eb/No (SNR is usually in dB). The general formula for BER is given by coherent case

$$P_b = Q\left(\sqrt{\frac{Eb}{No}}\right) \qquad (1)$$

For non-coherent case, it was

$$P_b = e^{-Eb/2No} \qquad (2)$$

Q –function is defined as

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$$Q(x) = \int_{x}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-u^2/2} du \qquad (3)$$

As, E_b is average bit energy

N_o is noise PSD

P_b is error rate

Q(x) is monotonic decreasing function

$$P_b = Q\left(\sqrt{\frac{2Eb}{No}}\right) \qquad (4)$$

Here, the system complexity decided according to circuits' usage and also proper preferable modulations considering in account. Basically demodulators are more complex than the modulators so choosing is major concern. The coherent detectors are much more complex than non-coherent detectors meanwhile its carrier recovery. The proper chosen modulation mainly on system complexity and bandwidth efficiency [4-5]. The most FEC code is extensively used in cellular networks to style at ease to code signal. The coding tolerates to diminish the data error rate meanwhile preserving a steady broadcast rate.

1. Linear Block codes
2. Hamming code, Cyclic codes
3. BCH codes, RS codes
4. Golay code, Polar codes
5. LPDC codes, Reed-Muller codes

The RS/BCH code are the fundamental codes to correct the error services in communication systems. The (n,k) bits designed at 't' symbol and both codes are effectively identify them. The symbols in the codeword are arranged in the form of n=2m -1. An error in t symbols are corrected by using RS code[6-7]. This paper organized as section II discusses about binary and non-binary codes. The section III proposed the GMSK transceiver structure with suitable codes. The BER simulations are achieved for BCH and RS codes in Section IV. Finally, it concluded and given future scope in section V and VI.

2. Related work

Among the coding techniques, binary and non-binary code (BCH/RS) is the most vital role of LBC codes. The RS codes were invented and autonomous work by BCH codes. Even though RS codes form a subfamily of BCH codes, they were constructed independently. The decoding of a BCH/RS code needed to require the resolve both the locations and the symbol errors. The BCH/RS codes can also be decoded and all these algorithms can be reformed to correct symbol errors and erasures. The RS codes proved to be decent error-detecting codes, and their weight distribution has been completely determined [6-7, 13-15].

The (n,k) of degree n-k over GF(q) is generated as

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$$g(X) = g_0 + g_1 X + ... + g_{n-k-1} X^{n-k-1} + X^{n-k} \quad (5)$$

Here, $g(X) \neq 0$ and $g_i \in GF(q)$

The $g(X)$ is a factor of $X^n - 1$. A polynomial $v(X)$ is degree of n-1 over GF(q) and declared as code polynomial $\Leftrightarrow v(X)/g(X)$. The Galois filed $GF(q^m)$ is constructed same as $GF(2^m)$. Let α be the roots of polynomial p(X) with $0, 1, \alpha, \alpha^2, ..., \alpha^{q^m-2}$ for all $GF(q^m)$ and $\alpha^{q^m-1} = 1$.

The every component β in $GF(q^m)$ can be expressed as Polynomial in α,

$$\beta = a_0 + a_1\alpha + a_2\alpha^2 + ... + a_{m-1}\alpha^{m-1} \quad (6)$$

Here, $a_i \in GF(q)$ for $0 \le i < m$, vector $a_0, a_1, ..., a_{m-1}$ of β. The $GF(q^m)$ is derived from $X^{q^m} - X$ and $\phi(\beta) = 0$.

e be the non-negative integer, $\beta^{q^e} = \beta$.
e be the exponent of β and $e \le m$.
The components $\beta, \beta^q, \beta^{q^2}, ..., \beta^{q^{e-1}}$

$$\phi(X) = \prod_{i=0}^{e-1}\left(X - \beta^{q^i}\right) \quad (7)$$

$\phi(X)$ divided by $X^{q^m} - X$.

2.1 Binary Primitive BCH Codes

For non-negative integers m (acceptable $m \ge 3$) and t (acceptable $t < 2^m - 1$), heresubsists a binary BCH code:

1. Block length is $n = 2^m - 1$,
2. Parity-Check digitsare $n - k = mt$,
3. Minimum distance is $d_{\min} \ge 2t + 1$.

The t-error-correcting (t-ec) BCH code are can be described as capable of correcting t errors in code length n=2^m-1. The g(x) be the generator polynomial having roots from the Galois field GF(2^m). Assume that α is primitive component in GF(2^m).

$$g(\mathrm{X}) = \alpha, \alpha^2, ..., \alpha^{2t} \quad (8)$$

The roots are $g(\alpha^i) = 0, \quad 1 \le i \le 2t$

$$g(\mathrm{X}) = LCM[\phi_1(X), \phi_2(X), ..., \phi_{2t}(X)] \quad (9)$$

Let, $\phi_i(X)$ be min polynomial of α^i

The above equation can be altered as binary as t-ec BCH code in block length n=2^m-1

$$g(\mathrm{X}) = LCM[\phi_1(X), \phi_2(X), ..., \phi_{2t-1}(X)] \quad (10)$$

The each degree $\phi_i(X)$ is $\le$ m, the degree g(X) is max mt and namely n-k =mt.

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2.2 Binary Non-Primitive BCH Codes

Here, designed distance with t- ec BCH code is 2t+1 and the dmin is designed distance in many case and may not equal for all cases. However, for some cases dmin ≥ designed distance. Let the binary BCH codes with length $n \neq 2^m - 1$ is same as the case $n = 2^m - 1$. Let β be non-primitive component n-order in GF(2^m) and n be the factor of $2^m - 1$.

$$g(\mathrm{X}) = \beta, \beta^2, \ldots.., \beta^{2t} \tag{11}$$

As it roots $g(\beta^i) = 0, \quad 1 \leq i \leq 2t$

$$g(\mathrm{X}) = LCM[\psi_1(X), \psi_2(X), \ldots.., \psi_{2t}(X)] \tag{12}$$

Let, $\psi_i(X)$ be min polynomial of β^i

The above equation can be altered as binary as t-ec BCH code in block length n=2^m-1

$$g(\mathrm{X}) = LCM[\phi_1(X), \phi_2(X), \ldots.., \phi_{2t-1}(X)] \tag{13}$$

Because $\beta^n = 1, \beta, \beta^2, \ldots.., \beta^{2t}$ are the roots of $2^n + 1$.

In this the factor of $2^n + 1$.

The $g(X)$ as t-ec BCH code w.r. to length n similar to n= $2^m - 1$, the parity check bits at most mt, min distance at least 2t+1 [6-7].

2.3 Decoding of BCH Codes

Suppose codeword is transmitted

$$v(X) = v_0 + v_1 X + v_2 X^2 + \ldots\ldots.. + v_{n-1} X^{n-1} \tag{14}$$

The received vector:

$$\mathrm{r}(X) = r_0 + r_1 X + r_2 X^2 + \ldots\ldots.. + r_{n-1} X^{n-1} \tag{15}$$

Let e(X) be the transmission error . Then,

$$\mathrm{r(X)=v(X)+e(X)} \tag{16}$$

commonly, For decoding a t-ec primitive BCH code and the syndrome be 2t-tuple:

$$S = \left(s_1, s_2, \ldots, s_{2t}\right) = rH^T \tag{17}$$

Here, H is product of $v_0, v_1, \ldots, v_{n-1}$ and $1, \alpha^i, \ldots, \alpha^{(n-1)i}$ to form matrix is zero. Find that ith component of the syndrome is

$$\begin{aligned} S_i &= r\left(\alpha^i\right) \\ &= r_0 + r_1\alpha^i + r_2\alpha^{2i} + \ldots. + r_{n-1}\alpha^{(n-1)i} \end{aligned} \tag{18}$$

For $1 \leq i \leq 2t$.

Outline the error correcting way has three major steps:

1. Compute the syndrome $S = \left(s_1, s_2, \ldots, s_{2t}\right)$ from the polynomial r(X).
2. Compute the err-location polynomial $\sigma(X)$ from the components $S_1, S_2, \ldots., S_{2t}$.
3. Conclude the err-location number $\beta_1, \beta_2, \ldots., \beta_v$

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by $\sigma(X)$ roots and check the errors
in r(X).

The decoding algorithm has Steps 1 and 3 are quite simple; step 2 is complicated portion of decoding a BCH Code [6-7, 9-10].

2.4 Non-Binary RS codes

The RS codes are exceptional case of q-ary BCH codes for which m=1 is the utmost weighty subfamily of q-ary BCH code digital communications. Assume that α be primitive component in GF(2^m). The g(x) be stated that

$$g(\mathrm{X}) = \alpha, \alpha^2, ..., \alpha^{2t} \qquad (19)$$

as all its roots.

Because α^i is component of GF(q), its min polynomial $\phi_i(X)$ is simply $X - \alpha^i$.Then,

$$g(X) = (X-\alpha)(\mathrm{X}-\alpha^2)...(X-\alpha^{2t})$$
$$= g_0 + g_1 X + g_2 \mathrm{X}^2 + ... + g_{2t-1} X^{2t-1} + X^{2t} \qquad (20)$$

with $g_i \in GF(q)$ for $0 \le i \le 2t$.

Since $\alpha, \alpha^2, ..., \alpha^{2t}$ are roots of $X^{q-1} - 1$, g(X) divides $X^{q-1} - 1$.

Therefore, g(X) corresponds to a code word of weight exactly 2t+1. The dmin of the RS code caused by the g(X) is exactly 2t+1, and the code is capable of correcting t symbol errors. In summary the t-ec RS code has:

1. Block length is n=q-1,
2. Parity-check symbols are n-k=2t,
3. Dimension is k=q-1-2t,
4. Minimum distance is dmin= 2t+1.

Thus, the RS codes have the features: 1) the code length is < the code size, and 2) the dmin is > the parity-check symbols. Code with dmin > the parity-check is maximum distance separable (MDS) codes [6-7].

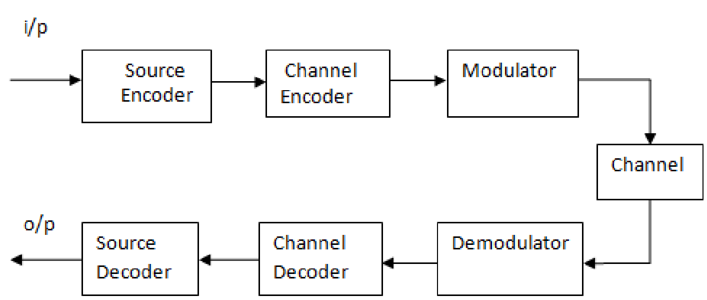

Fig. 2. Typical error control coding block

The figure 2 representing here to control the error coding in conventional systems.

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2.5 RS code decoding Algorithm

The error/erasure decodingalgorithms for both binary and non-binary codes having same steps except step 3 and 4 is to evaluate the error value.

1. Compute the syndrome $S = \left(s_1, s_2, ..., s_{2t}\right)$.
2. Compute the err-location polynomial $\sigma(X)$.
3. Conclude the err-value evaluator.
4. Evaluate the error location numbers, error values andcheck the error correction.

There are two algorithms are for error/erasure decoding i) Berlekamp iterative algorithm ii) Euclidean algorithm [6-7, 8-11].

3. Proposed Methodology

The MSK is special class of continuous phase FSK which is popularly used in next generation communications.The shift keying is digital modulation is most attractive technique in next generation mobile systems. Basically the shift keying are ASK, FSK, PSK, QAM, MSK, SSK, GMSK etc. There are no discrete components in MSK unlike FSK/PSK and it offers better handling properties due to its constant envelope features. The M-signalling is implemented for its higher orders based on situations and applications. The BER of BFSK is as

$$P_e = \frac{1}{2}\left[1 - erf\ \frac{1}{\sqrt{2}}\left(Eb/No\right)^2\right] \qquad (21)$$

However, it's cross correlation is not zero

$$\rho = \int_0^{T_0} \cos\left(2\pi f_1 t\right)\cos\left(2\pi f_2 t\right)dt \neq 0 \qquad (22)$$

In the M –signalling, i.e. M indicating the M –carriers and they can be orthogonal or not but the orthogonal carriers have superiorerror rate. The M-FSK requires considerably greater BW compared to M-PSK nevertheless BER degraded as M increases and it is most demerit. The typical behaviour frequency deviation is 0.25 and modulation is 0.5 in MSK.

The MSK signal is

$$S(t) = \sqrt{\frac{2Eb}{Tb}}\cos\left(2\pi f_c t + \theta(t)\right) \qquad (23)$$

The GMSK is constructed with Gaussian filter and MSK modulator i.e. Signal is passed through the Gaussian filter and then fed to MSK modulator which was having in phase and quadrature phase components. The MSK's spectrum density was fall down, but not falls fast, so that inference between adjacent signals in their frequency band can be avoided by GMSK. Here,

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the GMSK demodulator constructed by low pass filter of in phase and quadrature phase components after that fed through the arc tan and differentiator [4-5].

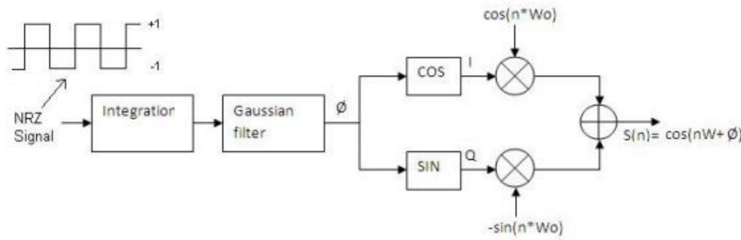

Fig. 3: GMSK Modulator

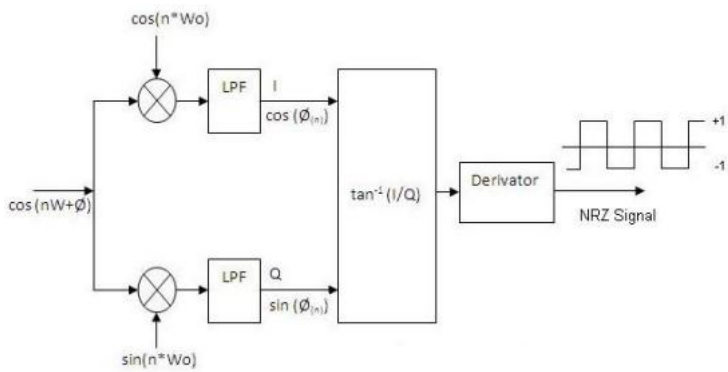

Fig. 4: GMSK Demodulator

The Figure 3 and 4 representing the GMSK modulator and demodulator process here in the transceiver diagram which is in Figure. 5. Here the GMSK signal is very helpful to modulate and demodulate the coding signals in BCH and RS process.

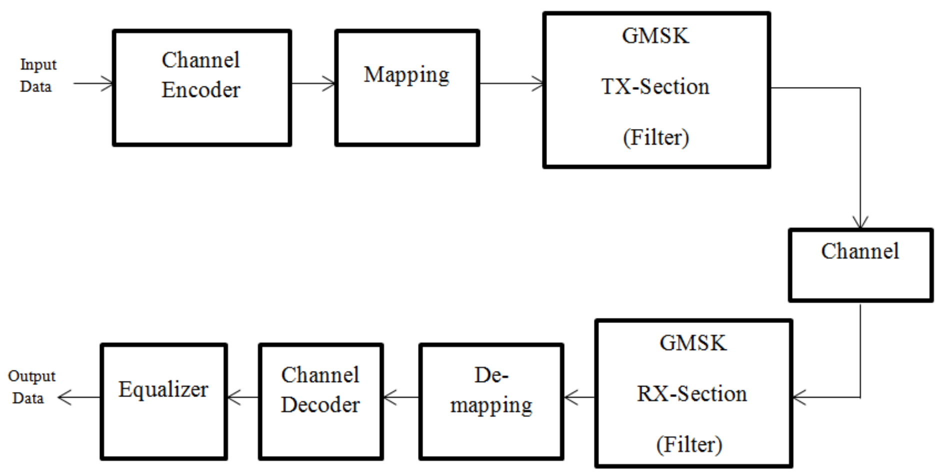

Fig. 5: GMSK transceiver.

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The MSK signal provides constant envelope carrier signal with no amplitude variations. Therefore most efficient power amplifiers with constant envelope can be reduces the power consumption [4-5]. The MSK spectrum width influenced by the frequency deviation of FSK. The spectrum width is broad when transitions and its slew rate are higher by phase deviation (width is more proportional to transitions and slew rate). The MSK has time-bandwidth product is infinity meanwhile Gaussian filter has WTb. The GMSK spectrum drops quickly than MSK based the product decreased and it is roll-off [12-13].

$$P_b \approx Q\left(\sqrt{\frac{2\alpha Eb}{No}}\right) \qquad (24)$$

$$P_e \approx \frac{1}{2} erfc\left(\sqrt{\frac{\alpha Eb}{2No}}\right) \qquad (25)$$

$$\alpha = \begin{cases} 0.68, & for\ GMSK\ with\ BT = 0.25 \\ 0.85 & for\ simple\ MSK\ (with\ BT \to \infty) \end{cases}$$

3.1 The correction of errors and erasures:

Case i) BCH Code with dmin is capable of correcting t -errors all recipes of v (unknown) random errors and e (known) erasures provided that

$$2v + e + 1 \leq d_{\min} \qquad (26)$$

Case ii) a q-ary t-error-corresponding binary BCH/non-binary RS code can be used to correct all recipes of v symbol errors and e symbol erasures provided that the inequality holds.

$$v + e/2 \leq t \qquad (27)$$

The decoding is find the locations, error symbols and erasure symbols. The erasure locations corresponding to erasure positions [6-7].

4. Simulation Results

The BER Performance of BCH and RS Codes over AWGN channel: here, the binary modulations are first implemented next to that higher orders and trade off the BER thru higher orders. The suitable MSK and GMSK modulations are adopted here. In the Figure. 6-7 illustrates the SNR between the curves with (n, k) where n=127, k=106 at t. The curves are resulting in low SNR means high BER performance as usual for any of the modulations. For MSK, RS code (10^{-4} at 3dB) it is having low SNR which results in high BER performance, BCH code (10^{-4} at 6dB) it almost doubles the system performance. For GMSK, RS code (10^{-4} at 7.8 dB) it is having low SNR which results in high BER performance, BCH code (10^{-4} at 10.7dB) it almost 28% improve the system performance.

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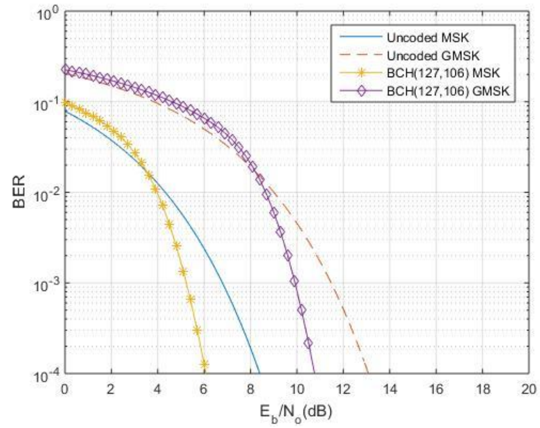

Fig. 6. Uncoded vs BCH(127,106) code, MSK, GMSK modulation.

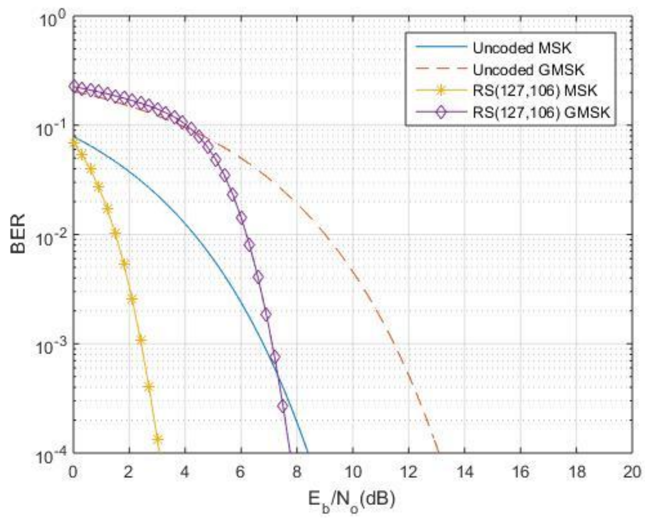

Fig. 7 Uncoded vs RS(127,106) code, MSK, GMSK modulation.

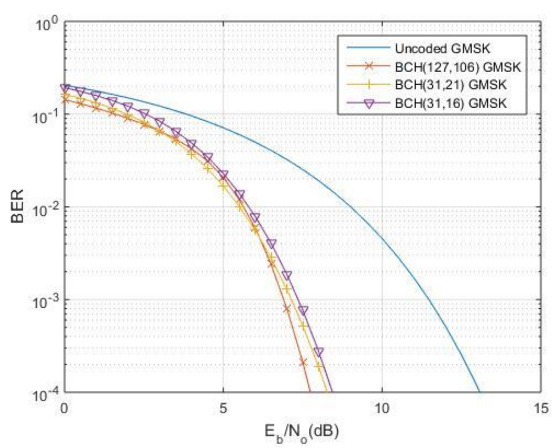

Fig. 8 BER for BCH(n,k) code, coherent GMSK modulation.

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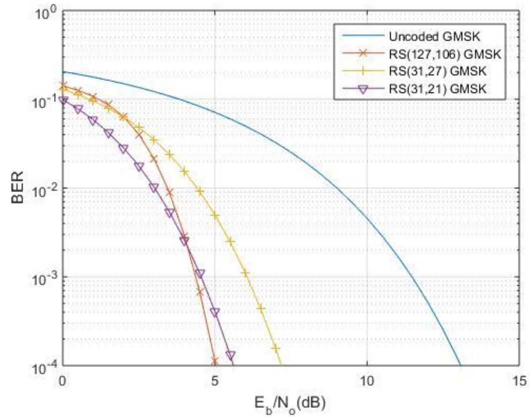

Fig. 9 BER for RS(n,k) code, coherent GMSK modulation.

In the above Figure. 8-9 illustrates the SNR between the curves with (n, k) where n=127,31, at suitable k, t. For coherent GMSK, BCH code it is having high SNR (7-8 dB) which results in low BER performance. But the RS code having SNR (near 5dB) with greater improvement 29% -- 38% in BER performance. The error probability or error rate for GMSK modulation is

Case i) coherent modulation

$$P_e \approx \frac{1}{2} erfc\left(\sqrt{\frac{\alpha Eb}{No}}\right) \qquad (28)$$

Case ii)) non -coherent modulation

$$P_e \approx \frac{1}{2} \exp\left(-\frac{\alpha Eb}{No}\right) \qquad (29)$$

The error rate analysis was carried out and RS code-GMSK outperforms the BCH code-GMSK which was described in the Table 1.

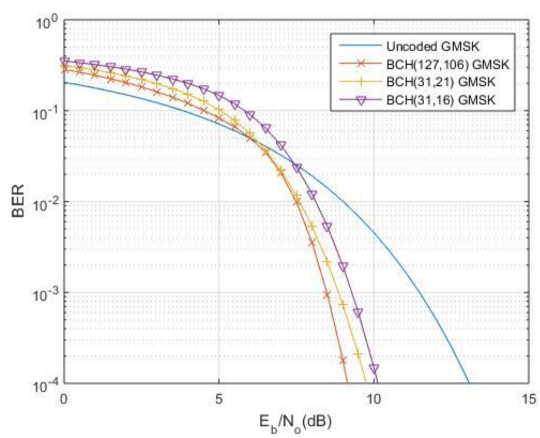

Fig. 10 BER for BCH(n,k) code, non-coherent GMSK modulation.

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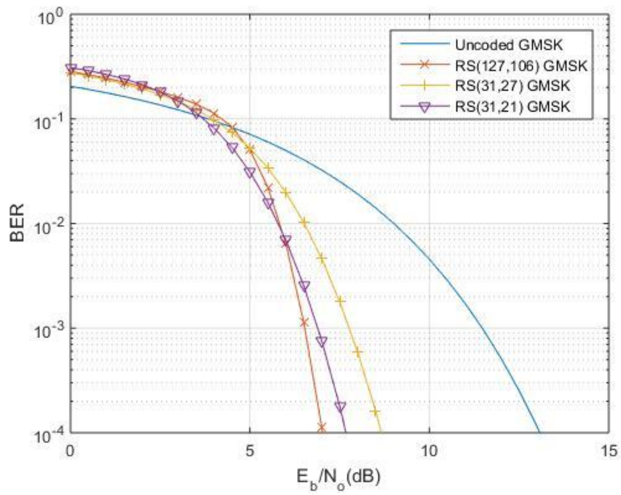

Fig. 11 BER for RS(n,k) code, non-coherent GMSK modulation.

TableI. The BER vs SNR for BCH/RS codes based on coherent/non-coherent GMSK modulations

Type	Bit Error Rate									
	SNR in	GMSK vs BCH code				SN R	GMSK vs RS code			
		GMSK	(127,	(31,	(31,		GMSK	(127,	(31,	(31,
cohere nt	4	0.0956	0.0428	0.0372	0.0488	3	0.1220	0.0213	0.0350	0.0102
	5	0.0712	0.0193	0.0167	0.0228	4	0.0956	0.0025	0.0153	0.0025
	6	0.0499	0.0056	0.0056	0.0079	5	0.0712	0.0001	0.0049	0.0004
Non-cohere nt	6	0.0499	0.0502	0.0562	0.0908	5	0.0712	0.0524	0.0524	0.0311
	7	0.0324	0.0220	0.0220	0.0416	6	0.0499	0.0069	0.0197	0.0069
	8	0.0191	0.0035	0.0053	0.0122	7	0.0324	0.0001	0.0046	0.0007

In the above Figure. 10-11 illustrates the SNR between the curves with (n, k) where n=127,31, at suitable k, t. For non-coherent GMSK, BCH code it is having high SNR (9-10 dB) which results in low BER performance. But the RS code having SNR (near 7-8dB) with less improvement 20% in BER performance.

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5. Conclusions

In this paper the BER analysis of linear block code is studied using BCH/RS coding techniques with MSK/coherent and non-coherent GMSK modulations. The simulation results indicating that the RS coded have efficient than BCH coding for cellular systems. It achieves better performance even at low Eb/No. The comparison among coherent and non-coherent GMSK is represented using the obtained standard. Though RS coded systems performs well, the complexity is traded off compared to BCH coded system. Hence, in the most of wireless communicating equipment RS codes are employed. Here, the coherent modulation vs non-coherent modulation is performed at 6dB for BCH code and 5 dB for RS code. Finally, RS code with coherent GMSK gave better features than BCH , non-coherent cases. The four case: 1) BCH, coherent GMSK 2) RS, coherent GMSK 3) BCH, non-coherent GMSK 4) RS, non-coherent GMSK. The 2nd case performs better among the other cases whose the BER =0.0001 at 5dB and also easier than other. The error rate is also considerable in broadband communications.The comparison among coherent and non-coherent GMSK is represented for BCH/RS coding systems towards the cellular communications. This work can be further extended using error correcting codes like Golay sequence, Reed Muller, LDPC and Polar codes. These codes have approached Shannon theoretical bounds for the communication link.

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