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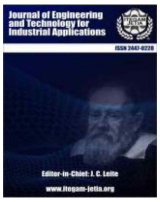

RESEARCH ARTICLE OPEN ACCESS

IMPROVEMENT IN BER PERFORMANCE OF GFDM BASED 5G COMMUNICATION SYSTEM USING NEW HYBRID ERROR-CORRECTING CODE

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ABSTRACT

In 5G wireless communication system, Generalized frequency division multiplexing (GFDM) is a promising substitute to OFDM that offers improved spectral efficiency and lower PAPR. However, performance of GFDM based wireless communication system can still be degraded by channel impairments such as noise and fading. The error correction codes are one of the techniques used for improving the performance. Different error correction codes are used for error correction in 4G and 5G communication system. This paper proposes a hybrid error-correcting code (ECC) scheme that combines polar code and convolution code to improve the bit error rate (BER) performance of GFDM compare to conventional ECCs. Simulation results illustrate that the proposed hybrid ECC scheme outperforms traditional error correcting code, in terms of BER performance. The proposed scheme also achieves near-optimal BER performance under various channel conditions.

I. INTRODUCTION

In 5G wireless system, non-orthogonal multiple access with different modulation techniques like GFDM, FBMC, UFMC etc are used in place of OFDM i.e. promising technique for 4G, to achieve better performance to meet the required specification. GFDM is a promising modulation scheme that offers several advantages over OFDM, including lower PAPR, better spectral efficiency, and improved robustness against channel impairments [1-2]. Error-correcting codes are used in GFDM to lessen the effects of channel impairments such as fading and channel noise. Error correcting code (ECC) schemes can be broadly classified into convolutional codes and block codes as shown in the figure 1 [3]. Block codes, such as Reed-Solomon code, encode a fixed-length block of data into a longer codeword. Convolutional codes, on the other hand, encode a continuous stream of data bits into a longer stream of code bits.

Recently, polar codes have emerged as a powerful class of block codes with near-optimal error correction capability. Polar codes are constructed from a simple channel transformation that polarizes the channel into a set of high-capacity and low-capacity channels. By carefully selecting the encoding and decoding indices, polar codes can achieve near-capacity performance over a wide range of channel conditions [3]. This paper, proposes a hybrid ECC scheme that combines polar code and convolution code to improve the BER performance of GFDM. The proposed scheme first encodes the GFDM data using polar code. The polar code encoded data is then interleaved to spread the errors and improve the performance of the subsequent convolutional code. Finally, the interleaved data is encoded using a convolutional code. The resulting coded data is then transmitted over the Raleigh channel.

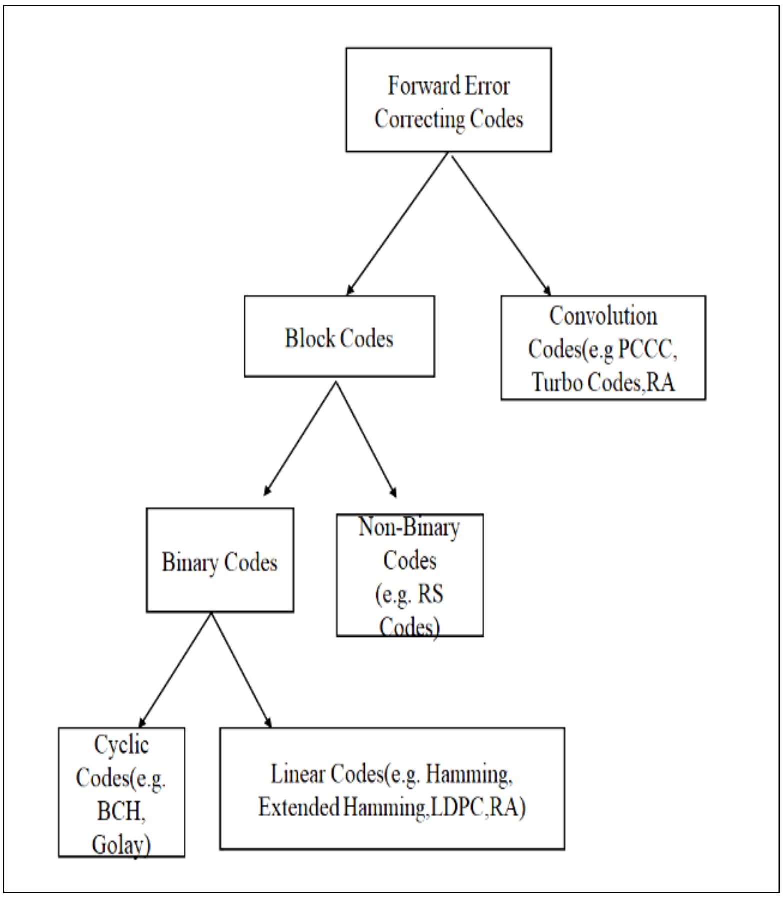

Figure 1: Classification of error correcting codes.
Source: [3].

II. GENERALIZED FREQUENCY DIVISION MULTIPLEXING (GFDM)

[4-10] reviews and analyzes 5G technologies such as Universal Filtered Multicarrier (UFMC), Filter Bank Multicarrier (FBMC), Filtered-Orthogonal Frequency Division Multiplexing (F-OFDM), and Generalized Frequency Division Multiplexing (GFDM). Generalized Frequency Division Multiplexing (GFDM) is a promising non-orthogonal waveform for next-generation wireless communication systems. It offers flexible subcarrier and time-slot configurations while reducing out-of-band emissions. However, GFDM exhibits higher interference levels compared to Orthogonal Frequency Division Multiplexing (OFDM), necessitating robust error correction techniques. Generalized Frequency Division Multiplexing (GFDM) is a modulation scheme where each subcarrier is individually and independently modulated with multiple symbols. In this process, each subcarrier is passed through a circularly shifted prototype filter applied in both the time and frequency domains. This filtering approach is designed to reduce out-of-band emissions (OOBE), thereby enabling flexible spectrum allocation, such as split-spectrum and dynamic spectrum distribution, without causing significant interference to the GFDM system itself or to neighbouring users. [11] To enhance the reliability of GFDM transmission, this study integrates Convolutional Coding and Polar Coding. Convolutional codes provide strong error correction with low decoding complexity, while Polar codes, known for achieving Shannon capacity, further improve robustness. The combined GFDM system is evaluated over a Raleigh fading channel in terms of Bit Error Rate (BER) performance [12].

III. CHANNEL CODING

In order to provide dependable data transmission, channel coding is utilized to mitigate the effects of a channel. In order for the recipient to identify and perhaps fix transmission faults, this technique adds redundant bits to the message being sent. Linear error-correction codes, such as Turbo and Convolutional codes, are employed in 4G networks. Polar codes and Low-Density Parity Check (LDPC) codes were suggested by the Third Generation Partnership Project (3GPP) for 5G networks. [13]

III.1 CONVOLUTION CODES

Convolutional codes are a class of error-correcting codes that operate by transforming the input bitstream into coded output symbols using convolution operations. Unlike block codes, which encode data in discrete blocks, convolutional codes process data in a continuous stream, making them particularly suitable for real-time communication systems. The encoding is performed using shift registers and modulo-2 adders, and the output depends not only on the current input but also on a number of previous input bits, known as the constraint length. In this paper the most common decoding techniques for convolutional codes is used which is Viterbi algorithm [14-16].

III.2 POLAR CODES

First introduced by Erdal Arıkan in 2009, represent a groundbreaking class of capacity-achieving error-correcting codes for binary-input symmetric memoryless channels. The concept of channel polarization forms the basis of polar codes, wherein certain synthesized channels become extremely reliable while others become highly unreliable as the code length increases. Data is transmitted only over the reliable channels, with the remaining channels assigned fixed, known values (frozen bits). Information bits are transmitted over the reliable subchannels, while fixed (frozen) bits are sent over the unreliable ones. Polar codes are known for their low encoding and decoding complexity of O (N log N), where N is the code length. Due to their capacity-achieving properties and structured construction, polar codes have been adopted as part of the control channel coding scheme in the 5G New Radio (NR) standard, particularly for eMBB (enhanced Mobile Broadband) scenarios. [17-23]

IV. SYSTEM MODEL

The data for simulating the GFDM system is x which is the sequence of bits. These bits sequence is coded by convolution and polar code. The output sequence y_i [n] of convolution coding for the i-th output at time n can be expressed as:

$$Y_i[n] = \sum_{j=0}^{k-1} \sum_{l=0}^{m} g_{i,j}[l] x_j[n-l] \tag{1}$$

where,

$x_j[n-l]$: Input sequence for the j-th input at time n-l
$g_{i,j}$ [l]: Coefficient of the generator polynomial connecting the j-th input to the i-th output with l representing the delay.[24]
Further polar code is applied on y[n] as follows,

$$w= y * G_N \tag{2}$$

Where y is the input vector consisting of information and frozen bits and w is the encoded output vector. [25] Given $N=2^n$ independent copies of a binary-input discrete memoryless channel (B-DMC) W, combine them to form a vector channel W_N. This combination is achieved using a transformation matrix

$$G_N = B_N F^{\otimes N}$$

where,

$F=\begin{bmatrix}1 & 0\\1 & 1\end{bmatrix}$ is the basic polarization matrix.
$F^{\otimes N}$ denotes the n-th Kronecker power of F and B_N is a bit-reversal permutation matrix.
The transformation G_N polarizes the channels, resulting in the sets of synthesize channels $W_N^{(i)}$ for i=0,1,…,N-1.

IV.1. MODULATION QAM

Let GFDM block consists of K number of subcarriers allotted in total M number of time slots, then the modulated GFDM symbol (S(n)) can be expressed as,

$$S(n)= \sum_{k=0}^{K-1} \sum_{m=0}^{M-1} d_{k,m}\, g_{k,m}\, (n) \tag{3}$$

where:

K = Number of subcarriers
M = Number of time slots
$d_{k,m}$ = QAM-modulated data symbol at subcarrier k and time slot m
$g_{k,m\,(n)}$ is the filter response corresponding to $d_{k,m}$.
The $g_{k,m\,(n)}$ can be expressed as **:**

$$g_{k,m}(n) = g(n-mM)e^{j2\pi kn/K} \tag{4}$$

Where: g(n) is the pulse-shaping function (typically a raised cosine filter) and mM is Time shift applied to the pulse for time slot mm $e^{j2\pi kn/K}$ = Frequency shift applied to map the pulse to subcarrier k. This formulation allows GFDM to provide flexibility in spectrum shaping while maintaining good spectral efficiency. Unlike OFDM, which uses orthogonal subcarriers without time-domain overlapping, GFDM introduces time-domain flexibility, making it suitable for applications like 5G and IoT [26].

V. SIMULATION FRAMEWORK AND RESULTS

The proposed communication system architecture shown in figure 2 integrates hybrid channel coding with Generalized Frequency Division Multiplexing (GFDM) to enhance data reliability and spectral efficiency in wireless environments. Initially, a random binary data stream is encoded using a hybrid coding scheme that combines convolutional and polar codes, leveraging the error-correction strengths of both. The encoded bits are interleaved and mapped onto QAM symbols, followed by sub-band allocation. These symbols are converted from serial to parallel and processed through an N-point IFFT and Root Raised Cosine (RRC) filtering to shape the spectrum. A cyclic prefix (CP) is inserted to mitigate inter-symbol interference before RF conversion and transmission through a Rayleigh fading channel. At the receiver, the signal undergoes RF-to-baseband conversion, CP removal, and matched filtering.

The received symbols are then demapped, converted back to a serial stream, de-interleaved, and decoded using the hybrid decoder to retrieve the original data. This framework effectively combines robust error correction with the flexibility of GFDM, making it suitable for 5G and beyond communication systems operating in multipath fading environments. Simulation results were conducted to evaluate the performance of the proposed hybrid ECC scheme. The simulations were performed over a Rayleigh fading channel with additive white Gaussian noise (AWGN). The BER performance of the proposed scheme was compared with other ECC schemes, such as convolution code polar code, no code. The simulation also identified the optimum roll off factor of root raised cosine filter of GFDM system by parametric analysis. In second phase, the optimum roll off factor with hybrid ECC is used for improved performance of GFDM based wireless communication system. The parameters of simulation are shown in table 1. To identify the roll off factor (alpha), a parametric analysis has been performed with the different values of alpha as shown in table1 for no coding convolution coding and polar coding.

Table 1: Parameters of simulation

S. No.	Parameter	Value
1	ECC	Convolution, Polar, Hybrid
2	Mapping Method	QAM (32,64,256.512)
3	Up sampling factor	8
4	GFDM filter	Root Raised Cosine
5	Roll off Factor	0.01 to 0.35
6	Channel	Rayleigh flat fading
7	SNR	0 to 30 dB
8	Decoder	Viterbi Decoder

Source: Authors, (2026).

V.1.BER WITHOUT CHANNEL CODING

Simulation for QAM modulated GFDM signal, which was transmitted over Rayleigh fading channel, was performed with the parameters shown in table 1. Different values of alpha (roll off factor of Root Raised Cosine filter used for GFDM signal generation) in simulation were taken for parametric analyses. The result with no error correcting coding is shown in figure 3.

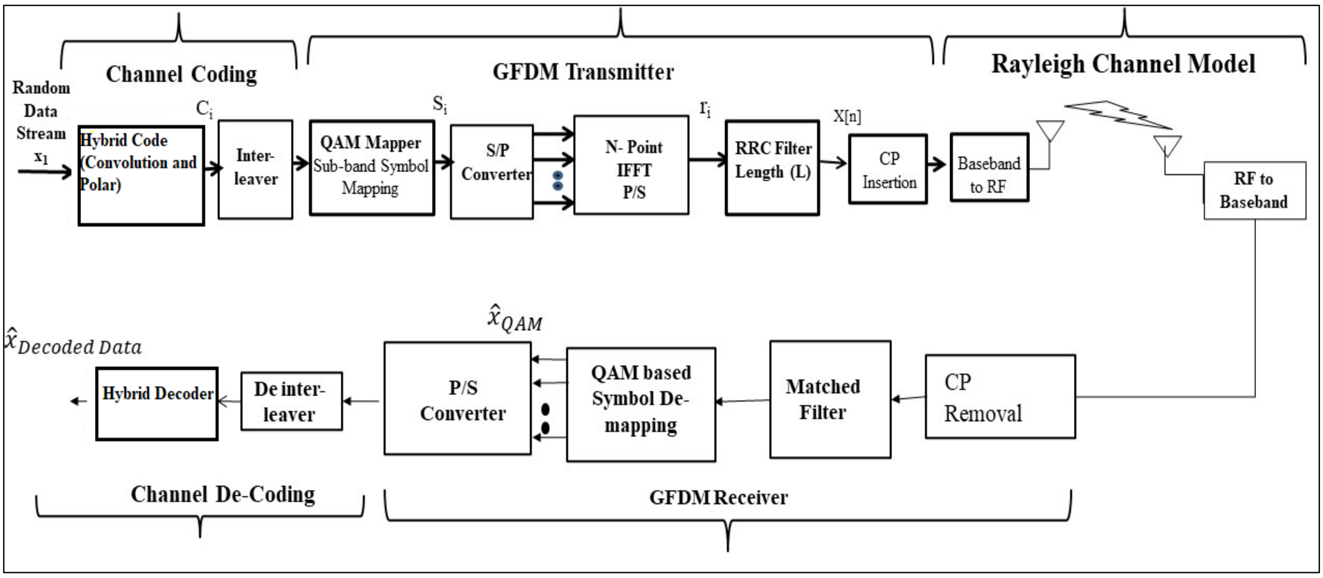

Figure 2: Scheme of the GFDM based wireless communication system.

Source: Authors, (2026).

The simulation results illustrate the impact of the roll-off factor alpha on the Symbol Error Rate (SER) vs. Signal-to-Noise Ratio (SNR) performance in the GFDM system. Increasing α improves SER performance up to an optimal range (α=0.2 to α=0.3), after which the gains become negligible. At high SNR (≥15 dB), α=0.2 to α=0.3 provides the better error performance, reducing SER to nearly 10^{-5}. A very low α=0.1, leads to significant degradation in performance, making it less suitable for GFDM applications requiring low SER. Hence, A moderate roll-off factor (α=0.2 to α=0.3) provides an optimal trade-off between spectral efficiency and error performance in GFDM systems.

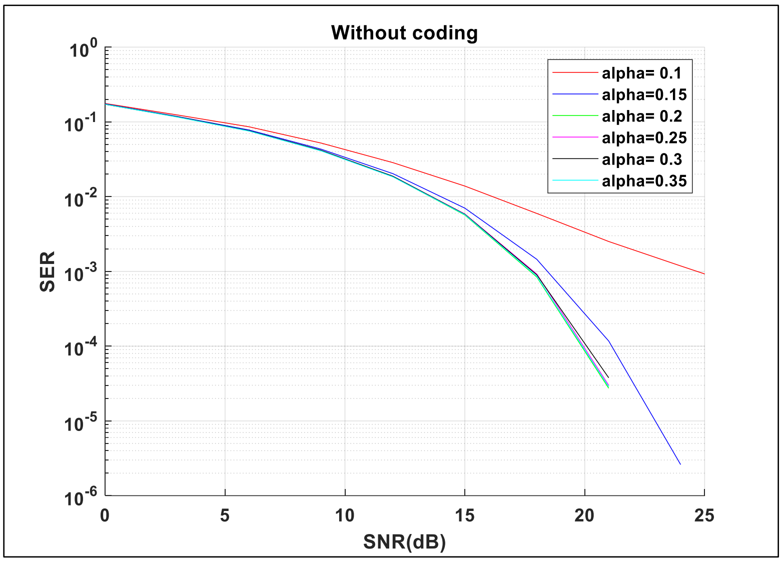

Figure 3: BER performance of GFDM system with different value of alpha (roll- off factor).
Source: Authors, (2026).

V.2.BER WITH CONVOLUTION CODING

Further, error-correcting codes i.e. convolution code is used for simulation for QAM modulated GFDM system. BER performance with convolution code was recorded for different values of alpha. The result with convolution code based GFDM system is shown in figure 4.

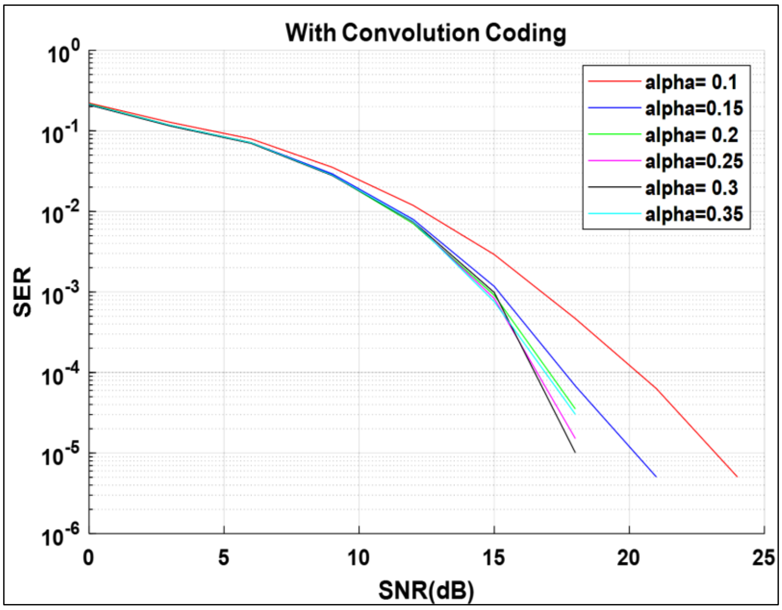

Figure 4: BER performance of GFDM system with convolution code for different value of alpha.
Source: Authors, (2026).

It is apparent from the figure 4 that the value of alpha of 0.25 is providing the optimum performance of the GFDM system. However, there is no significant changes in performance of BER for different value of alpha like the case of no coding. It is also observed, there is significant improvement in the BER performance with convolution coding compare to no coding. The SNR requirement has reduced to ~ 4 dB for BER value of <0.001.

V.3.BER WITH POLAR CODING

Further, another error correcting codes i.e. Polar code was used for simulation for QAM modulated GFDM system. BER performance with this code is shown in figure 5. It is observed from the figure 5 that significant improvement in the BER performance with compare to convolution coding. The SNR requirement has further reduced to ~ 2 dB for BER value of <0.001. It is apparent from the figure 5 that the value of alpha of 0.25-0.35 is providing the optimum performance of the GFDM system. The typical errors with alpha are shown in figure 6.

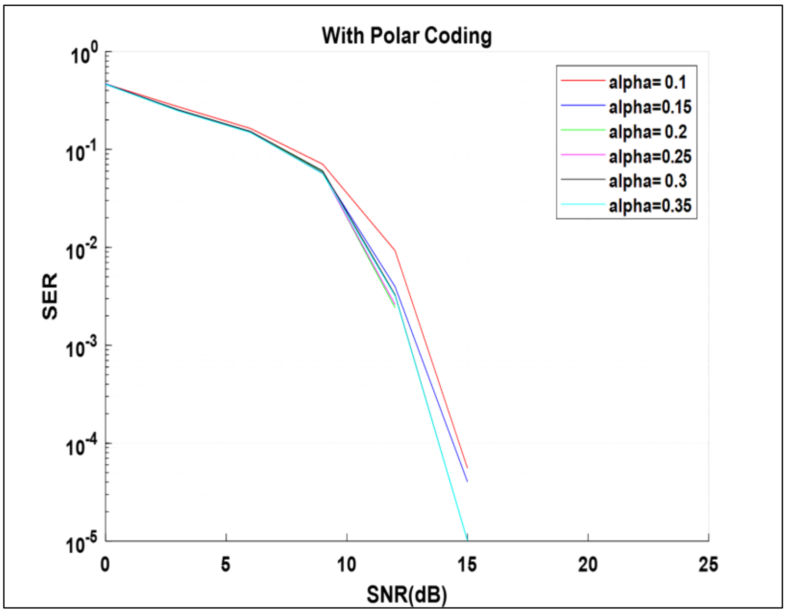

Figure 5: BER performance of GFDM system with Polar code for different value of alpha.
Source: Authors, (2026).

V.4.BER WITH PROPOSED ECC

Further, the hybrid scheme of ECC was used for simulation for QAM modulated GFDM system. BER performance with this code is shown in figure 7. It is observed that above > ~12 dB SNR, the hybrid Coding scheme achieves the lowest Symbol Error Rate (SER) among others. The simulation results demonstrate that the proposed hybrid ECC scheme outperforms traditional ECC schemes in terms of BER performance. The proposed scheme also achieves near-optimal BER performance under various channel conditions. This demonstrates that Hybrid Coding provides nearly a 100x improvement over the uncoded system and about a 10x improvement over Polar Coding, making it the most efficient error correction technique for GFDM at high SNR values.

VI.CONCLUSIONS AND FUTURE WORK

This paper proposed a hybrid ECC scheme that combines polar code and convolution code to improve the BER performance of GFDM. The proposed scheme offers significant BER improvement compared to traditional ECC schemes. The simulation results shows that the Hybrid Coding scheme significantly enhances the error performance of the GFDM system, for mid to high SNR level (>12 dB). BER at SNR of 15 dB show ~ 100 times lower than individual coding scheme. These findings highlight that Hybrid Coding is the most efficient error correction technique particularly mid to high SNR level. Future work, the further optimization of this hybrid ECC may explore by optimization its parameters. The use of this code for adaptive modulation and coding (AMC) system for 5G wireless communication system for lower bit error rate may be explored.

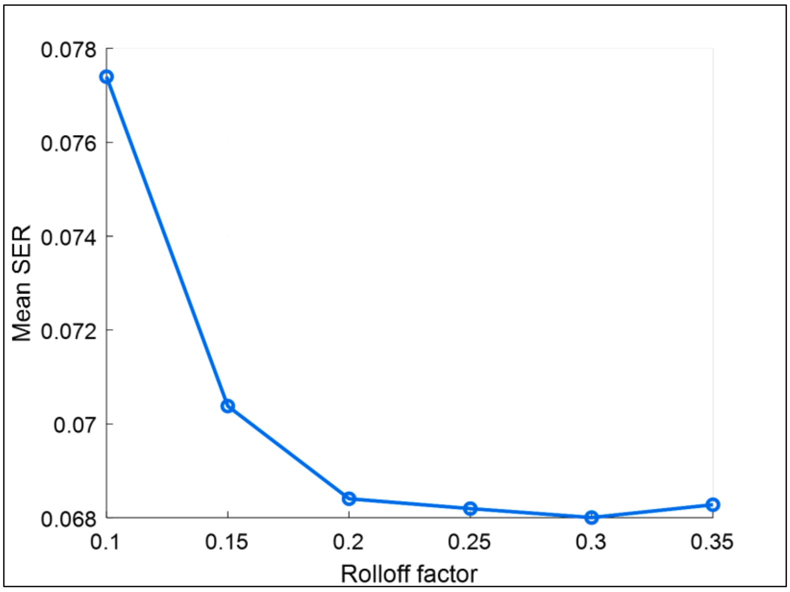

Figure 6: Typical graph of mean SER with different alpha.
Source: Authors, (2026).

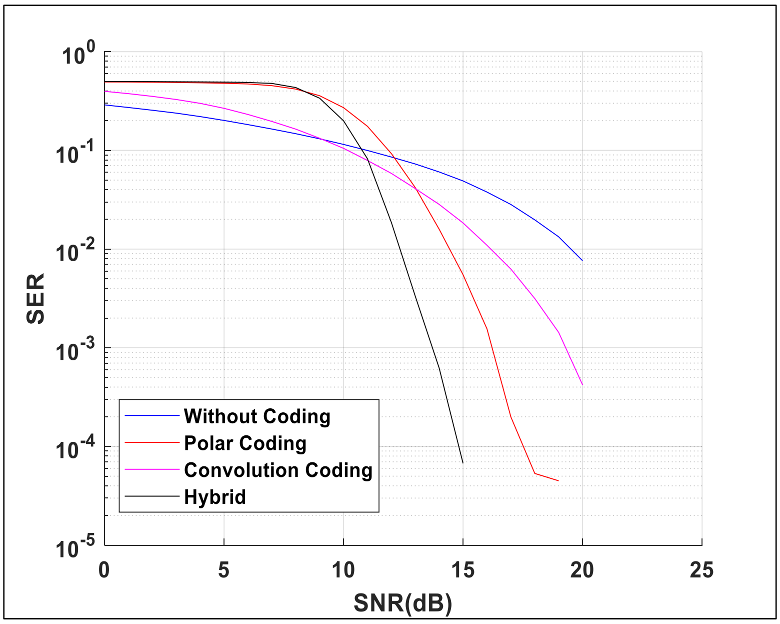

Figure 7: BER performance of GFDM system with Proposed code for different value of alpha.
Source: Authors, (2026).

VII. AUTHOR'S CONTRIBUTION

Conceptualization: Divya Jain, Debendra Kumar Panda and Smita Prajapati.
Methodology: Divya Jain and Debendra Kumar Panda.
Investigation: Divya Jain
Discussion of results: Divya Jain and Smita Prajapati.
Writing – Original Draft: Divya Jain
Writing – Review and Editing: Divya Jain and Smita Prajapati
Resources: Debendra Kumar Panda.
Supervision: Divya Jain and Debendra Kumar Panda.
Approval of the final text: Divya Jain, Debendra Kumar Panda and Smita Prajapati.

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