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BIT ERROR RATE ANALYSIS OF GFDM BASED WIRELESS COMMUNICATION SYSTEM AND SPECTRAL EFFICIENCY IMPROVEMENT USING AMC TECHNIQUE

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Abstract

The ever-increasing demand for wireless communication, high data rate is driving researchers to explore advance fields that can maintain high data rates under variable channel conditions, ultimately enhancing the performance of communication systems. The integration of 5G techniques like GFDM, FBMC, UFMC etc. with adaptive modulation and coding (AMC) is a promising technique for maximizing data rates under diverse channel conditions in wireless communication systems. In previous research, AMC have reported for OFDM with Convolutional code, Polar Code etc. This paper analyses the performance of generalized frequency division multiplexing (GFDM) in combination with AMC technique for fluctuating channel conditions. In this paper, the system employs a dynamic channel coding strategy, which intelligently switches between turbo codes, convolutional codes or without coding. This adaptation enables robust performance and high spectral efficiency across a broad range of channel conditions. Through simulations, we derive a mapping between different modulations, channel coding scheme and SNR conditions. The results demonstrate a substantial improvement in BER performance and spectral efficiency across a wide range of SNR values.

Keywords: AMC, GFDM, Turbo code, Convolutional code, OFDM, BER etc.

I Introduction:

The rapid proliferation of smartphones, tablets and diverse mobile services have spurred the development of innovative applications like augmented reality (AR), internet of things (IoT) and virtual reality (VR), which significantly transforming everyday life. These diverse services introduce diverse communication requirements concerning data rates, latency, reliability, energy efficiency and the sheer volume of connections [1]. Fifth generation (5G) wireless communications employ the orthogonal frequency division multiplexing (OFDM) scheme [2] due to its robustness in fading channels [3] and efficient implementation using fast Fourier

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transform (FFT) algorithms. Despite its advantages, OFDM is not well suited for future requirements due to reduced spectral efficiency from cyclic prefix (CP) overhead [4] and significant out of band (OOB) radiation, making it less attractive for cognitive radio applications [5] and it requires synchronisation [6] to preserve orthogonality.

To mitigate these limitations multiple carrier schemes like UFMC [7], FBMC [8] and GFDM [9] are explored by researchers. This paper focuses on a new multicarrier transmission scheme, i.e. generalized frequency division multiplexing (GFDM) [9]. The flexibility of the GFDM system definitely arises from its ability to utilize both non-orthogonal and orthogonal filters in its design. This is a key discriminator from traditional orthogonal frequency division multiplexing (OFDM), which firmly relies on orthogonal subcarriers accomplished through rectangular pulse shaping in the time domain (which corresponds to a Sinc function in the frequency domain) [10]. By employing alternative cyclic pulse shaping filters, GFDM reduces CP length, The insertion of CP in each block instead of each symbol increases the spectral efficiency of GFDM compared to OFDM [10]. Additionally, pulse shaping controls out of band (OOB) leakage and self-interference [11]. Lower OOB radiation means that GFDM signals cause a lesser amount of interference to adjacent frequency bands and other wireless systems operating adjacent. This is particularly significant in progressively crowded spectrum circumstances and for applications like cognitive radio [12] where dynamic spectrum access is critical. In the research paper [13], it is shown that GFDM accomplish significantly lower out-of-band (OOB) radiation compared to OFDM (around 15 dB).

An adaptive modulation and coding (AMC) method is invariably used in 4G and 5G. AMC technique dynamically alters modulation and coding schemes based on channel conditions [14]. In this technique, spectral efficiency and bit error are optimized according to the estimated SNR through channel state information (CSI). Lower order modulation and lower channel coding rate are suitable for channels with higher interference, while higher-order modulation and higher channel coding rate are advantageous in better channel conditions [15].

In this paper AMC technique with GFDM is simulated. To enhance error detection and correction capabilities, convolutional code [16] and turbo code [17] are employed. These powerful codes are particularly beneficial for high data rate applications where additional coding gain is crucial to maintain link performance with limited power. This objective is achieved when the channel state information of wireless communication system is available with feedback from a receiver to the transmitter. The channel state information allows us to send symbols based on the Channel condition. This paper is organized as follows: Section II presents the literature review; Section III presents the proposed AMC system model with GFDM. Simulation results and plots of BER performance for uncoded, convolutional coded, turbo coded and AMC with GFDM systems are illustrated in section IV and Section V concludes the paper.

II Literature review:

Following are the research contributions of some of the researchers in the field of wireless communication.

To enhance network performance, many works have proposed the joint implementation of MAC layer QoS reservation and scheduling strategies with physical layer AMC. For instance, Liu et al. [18] proposed a hybrid framework that combines MAC layer QoS reservation and scheduling with physical layer AMC. Works [19] have proposed a model for continuous-rate adaptive modulation and coding. Work [20] studies the performance of AMC technology in Rayleigh channels. Furthermore, work [21] introduces an adaptive modulation and coding model tailored for free-space optical links.

Manolakis et al. [22] introduced a frequency-selective link adaptation approach tailored for OFDM-based 3GPP LTE systems. In this scheme, the modulation order is dynamically adjusted for each resource block, while a single, consistent coding rate is applied across the entire transmission. The encoding process involves a fixed-rate turbo encoder generating variable-length codewords, followed by a rate matcher and a channel interleaver.

In [23], authors proposed adaptive data transmission using polar codes and hybrid automatic request to achieve the channel capacity. However, it requires switching among various constellation sizes and the receiver must be notified about the selected modulation which increases the system complexity.

Multicarrier techniques inherently possess the capability for frequency-selective link adaptation, meaning their modulation and coding schemes can be dynamically adjusted based on the channel quality across different frequency subcarriers. The subsequent multicarrier scheme is being considered as a future alternative to the widely used OFDM in wireless communication.

Filter band multi carrier (FBMC)

FBMC is a multicarrier modulation technique that builds upon OFDM by incorporating a filter bank, thereby obviating the need for the conventional Cyclic Prefix (CP) in the transceiver. By removing the CP, FBMC achieves superior performance compared to traditional OFDM. Specifically, it demonstrates reduced side lobe levels and lower Inter-Carrier Interference (ICI), which makes the CP unnecessary and results in improved bandwidth efficiency [7]. While FBMC offers some advantages, its broad filter duration can indeed lead to a longer decoding period in MIMO systems. Additionally, the complexity of the receiver design can be a significant drawback. Consequently, FBMC might not be the most effective choice for systems demanding rapid communication or those sensitive to delay [24].

Universal filter multi carrier (UFMC)

UFMC is a strong contender for 5G technology, skilfully blending aspects of both Filter Bank Multi-Carrier (FBMC) and Orthogonal Frequency Division Multiplexing (OFDM). A key distinction from FBMC lies in UFMC's application of filtering to groups (or clusters) of subcarriers,

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rather than individual ones. This strategic approach effectively minimizes unwanted side lobes and boosts the overall efficiency of the system [8]. In UFMC, the available bandwidth is intelligently divided into several sub-bands, which are then distributed across the various subcarriers. However, designing optimal filters for each sub-band in UFMC to achieve the desired spectral containment and minimize interference can be a complex task. The choice of filter length and characteristics impacts both performance and computational complexity.

Generalized Frequency Division Multiplexing (GFDM)

GFDM [9] is a block based multicarrier scheme that decomposes transmitted data into frequency and time domains, with each subcarrier pulse shaped using a pulse shaping filter. A key feature of GFDM is that each subcarrier's signal is shaped by its own pulse shaping filter. This design grants GFDM a significant advantage in its ability to adapt to a wide array of application scenarios and varying channel conditions. Indeed, by fine-tuning the pulse shaping filters and the dimensions of the time-frequency block (i.e., the number of subcarriers and sub-symbols), GFDM can be specifically configured to meet demanding requirements like low latency, high data rates, and efficient transmission of short data packets [25].

Existing research in OFDM has considered AMC integrated with coding techniques such as convolutional code, polar code, LDPC code etc. In contrast, this paper introduces a flexible multi carrier GFDM technique with AMC, where the choice of channel coding (Turbo, convolutional, or uncoded transmission) is dynamically tailored to the current SNR.

III. AMC system model with GFDM

Block diagram for proposed AMC GFDM system model is displayed in Fig. 1.

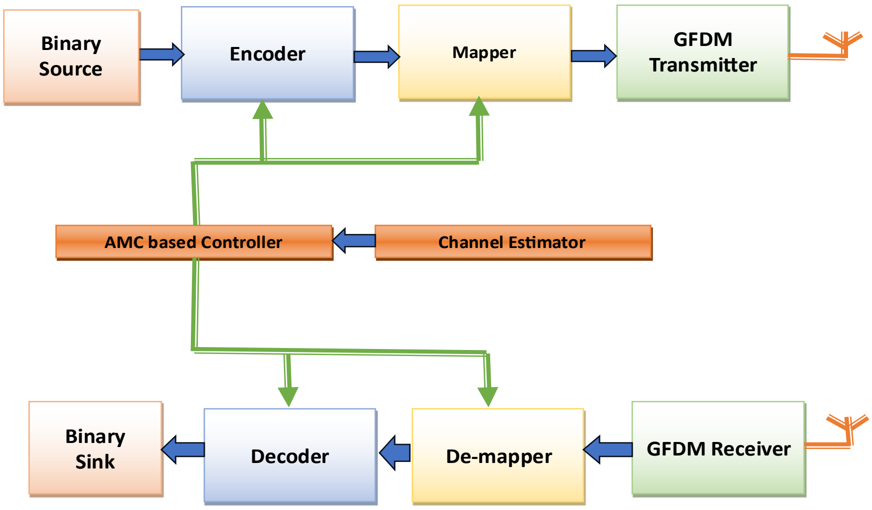

Figure -1: Block diagram of AMC -GFDM system model

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A binary data source provides data (b), which is encoded to obtain data b_E and then mapped to symbols. This mapping, often done using QAM, selects symbols from a 2^M-valued constellation, where M is the modulation order. At the transmitter, the AMC block comprises of different modulator orders and coding methods. The best modulation mode and coding method is chosen for the next transmission GFDM symbol by the channel quality estimate. The mapper's output is a vector d representing a data block containing N elements. Each of these N elements can be viewed as being distributed across K subcarriers and S sub symbols, with the total number of these individual data points satisfying the relationship N=K×S. Specifically, each element dk,s within this data block represents the data that is transmitted on the kth subcarrier and during the sth sub symbol of the entire block.

Each dk,s, is transmitted by a corresponding pulse shape filter. Pulse filter response is given as [25]

$$g_{K,S}[n] = g\,[(n-sK) \bmod N] \cdot \exp\,[-j2\pi\, k/K.n] \qquad [1]$$

With n representing the sampling index, each gk,s[n] is prototype filter g[n] through shifts in both time and frequency. Specifically, the modulo operation on the time index in gk,s[n] results in a circular time shift, while the multiplication by a complex exponential achieves the frequency shift.

The superposition of all transmit symbols leads to the GFDM [25] signals x[n]

$$x[n] = \sum_{k=0}^{K-1}\sum_{s=0}^{S-1} g_{k,s}[n]d_{k,s} \quad n = 0,1\ldots\ldots\ldots\ldots\ldots N-1 \qquad [2]$$

The instantaneous channel state information of each GFDM block is known at the transmitter with a feedback path from the receiver to the transmitter. The transition rate and power can be adapted at the receiver. Channel quality estimation of the each GFDM symbols is measured at the receiver.

At the receiver, the signal after GFDM demodulation is DE mapped to produce a sequence of bits and then passed to a decoder to obtain binary data [25].

From the preceding description, it can be inferred that GFDM provides a more degrees of freedom, compared to both Orthogonal Frequency Division Multiplexing (OFDM) and Single Carrier Frequency Domain Equalization (SC-FDE). GFDM becomes OFDM when S = 1 and becomes SC FDE when K = 1 [26]. However, the key distinction that sets GFDM apart from OFDM and SC-FDE lies in its inherent ability to divide a given time-frequency resource grid into K independent subcarriers and S sub symbols. This fundamental characteristic enables the design of the signal spectrum to precisely match specific requirements and allows pulse shaping to be applied to each subcarrier. As a result, GFDM offers the flexibility to be designed, without altering the sampling rate, using either a large number of narrow band subcarriers, much like OFDM, or a small number of wide band subcarriers, similar to SC FDM [27].

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IV Simulation and Results

A simulation environment for the data flow shown in figure 1 has been generated with the random data source. The parameter of simulation for the performance evolution and enhancement of GFDM based wireless communication system using AMC.

S. No.	Parameter	Specification
1	GFDM filter	Root Raised Cosine Filter
2	Roll over factor of filter	0.25
3	Wireless Channel	Rayleigh flat fading channel
4	BER level for AMC	0.001
5	Mapping Technique	QAM
6	Modulation Order	16 to512
7	Channel Coding	Convolutional and Turbo code
8	Bandwidth	2 MHz

The simulation was conducted for several cases, taking into account the parameters mentioned above.

BER Performance for different modulation order without coding

The Fig.2 shows, the BER performance with no coding in GFDM modulation [28].

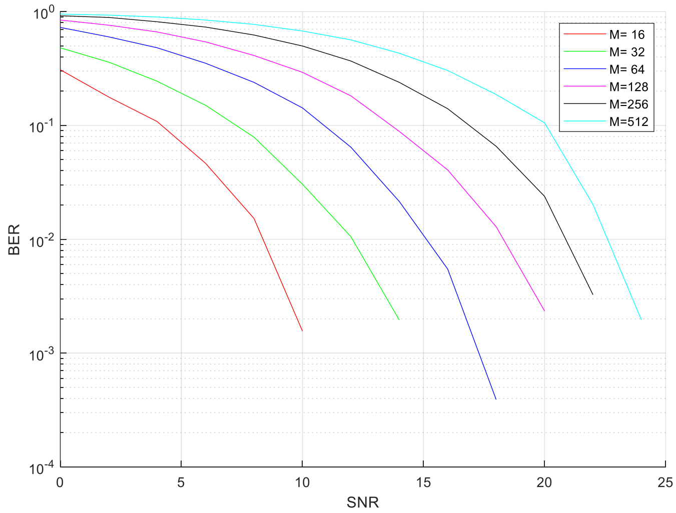

Figure. 2: BER performance with no coding in GFDM modulation

This figure gives BER performance which is as expected, as higher SNR means less noise, leading to fewer errors. Different curves represent different modulation orders (M=32, 64, 128, 256, 512). Higher modulation orders offer higher spectral efficiency but are more susceptible to noise. This is reflected in the graph: higher-order modulations (e.g., M=512) require higher SNR to achieve a specific BER compared to lower-order modulations (e.g., M=32).

BER Performance for different modulation order with Convolutional Coding

The Fig.3 shows, the BER performance by employing convolutional coding in GFDM [28].

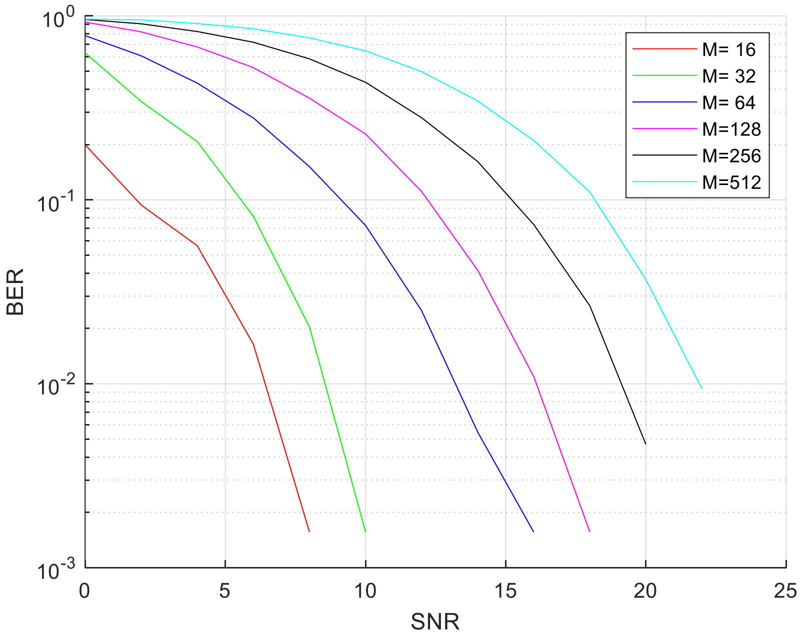

Fig.3: BER performance by employing convolutional coding in GFDM modulation

Different curves represent different modulation orders (M=32, 64, 128, 256, 512). Higher modulation orders offer higher spectral efficiency but are more susceptible to noise. This is reflected in the graph: higher-order modulations (e.g., M=512) require higher SNR to achieve a specific BER compared to lower-order modulations (e.g., M=32).

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BER Performance for different modulation order with Turbo Coding

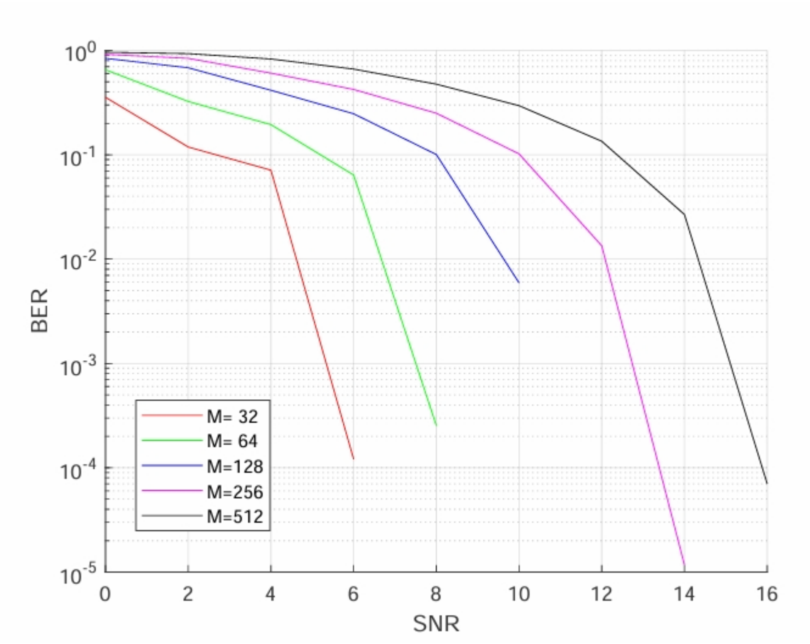

Fig.4 BER performance by employing Turbo coding in GFDM modulation

Fig.4 shows, the BER performance by employing Turbo coding with three number of iterations in GFDM modulation. The use of Turbo Coding significantly improves the BER performance compared to a system without coding and convolutional coding. It allows for lower BER at lower SNR values. Overall, the graph demonstrates the effectiveness of Turbo Coding in improving the BER performance of GFDM systems. By combining higher modulation orders with turbo coding, it's possible to achieve higher data rates while maintaining acceptable error rates.

BER and Spectral efficiency for AMC-GFDM

Based on the channel conditions, the system selects modulation and coding method to meet the need for data transmission with a BER less than the threshold value i.e. 0.001. According the channel conditions, the system adopts adaptive modulation and coding technology as shown in figure 5 and figure 6.

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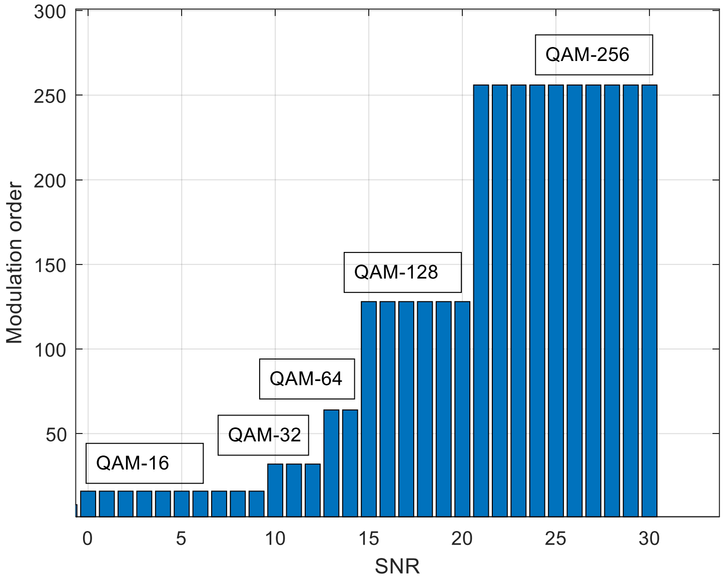

Fig. 5 Typical graph for selection of modulation order with SNR

Figure 5 shows the transition of the modulation order, which is not so frequent that means less number of switching is required in this praposed scheme even though the targeted BER is higher i.e. 0.01.

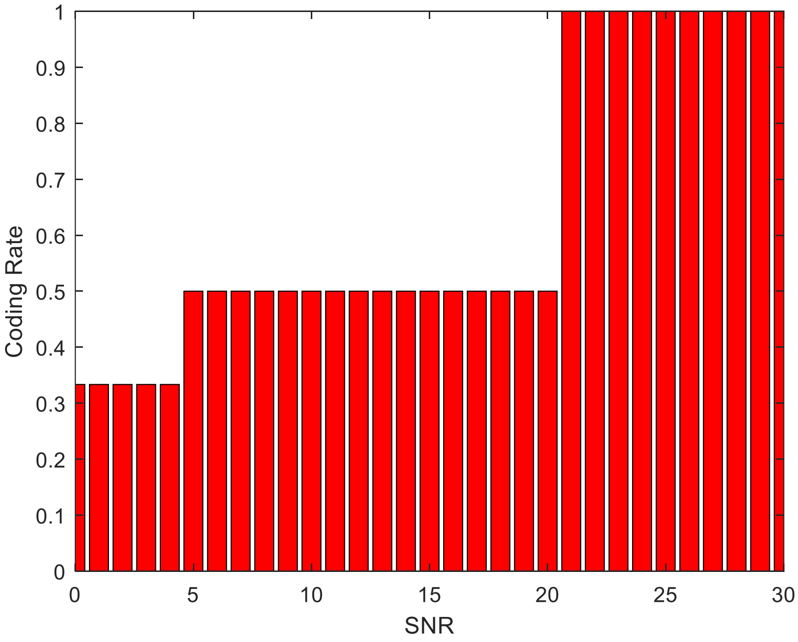

Fig. 6 Typical graph for selection of coding Scheme with SNR

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Figure 6 shows the typical graph for selection of coding Scheme with SNR for BER ≤ 0.001 respectively, i.e. For poor channel condition (low SNR), lower coding rate of 1/3 (Turbo code) is employed, as the channel conditions become better (SNR increases) higher coding rate of 1/2 (convolutional code) is employed and so on.

Table 1: AMC table

BER=0.001			
SNR range (In dB)	Modulation order	Code rate	Remark
≤ 4	16	1/3	Turbo code
>4 & ≤9	16	1/2	CC
>9 & ≤12	32	1/2	CC
>12 ≤15	64	1/2	CC
>15 & ≤20	128	1	CC
>20	256	1	NC

As shown in table 1 When SNR is low i.e. less than 4, then system selects lower order modulation QAM 16 and turbo code. When SNR lies between 4 to 9, then system selects convolutional code. When SNR lies between 9 to 12, then system selects more higher order modulation QAM 32. When SNR lies between 12 to 15, then system selects more higher order modulation QAM 64 and convolutional coding. When SNR lies between 15 to 20, then system selects more higher order modulation QAM 128 and convolutional coding. When SNR becomes greater than 20, then system selects more higher order modulation QAM 256 and no coding. To accommodate diverse channel conditions, the system selects from a range of modulation and coding methods to optimize data transmission.

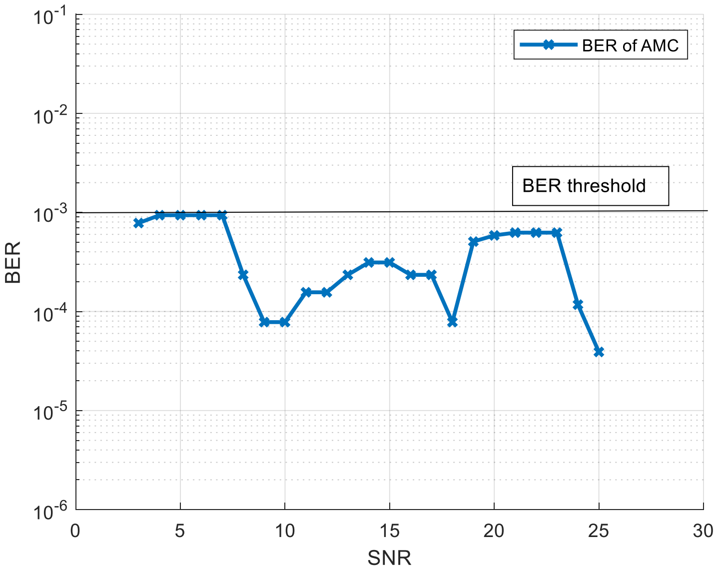

Fig.7 BER performance of GFDM AMC for BER ≤ 0.001

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From figure 7, it is clear that the for all SNR range BER is below the specified threshold of 0.001. Bit Error Rate (BER) of 0.001 (one error in every 1000 bits) strikes a balance between acceptable data integrity and system performance. It is considered suitable for a range of applications. A BER of 10−3 is often considered a threshold for acceptable voice quality in digital communication systems.

Figure 8 shows the spectral efficiency for AMC with GFDM by employing convolutional coding [28].

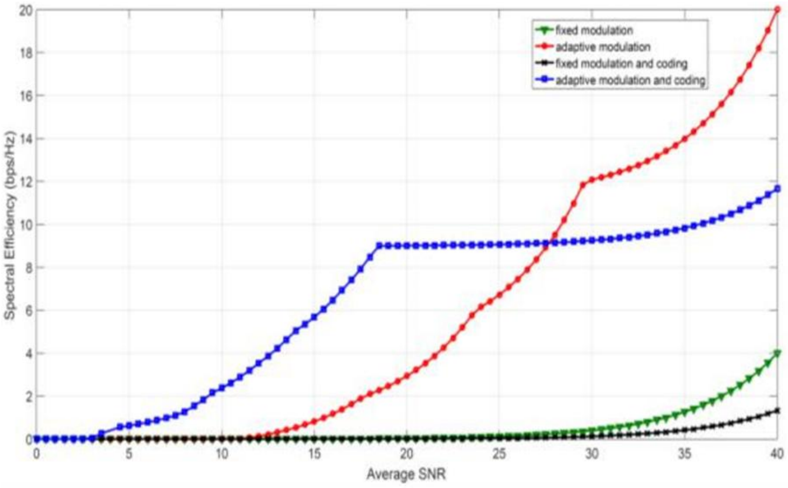

Figure 8: Spectral efficiency for GFDM AMC by employing convolutional coding [28]

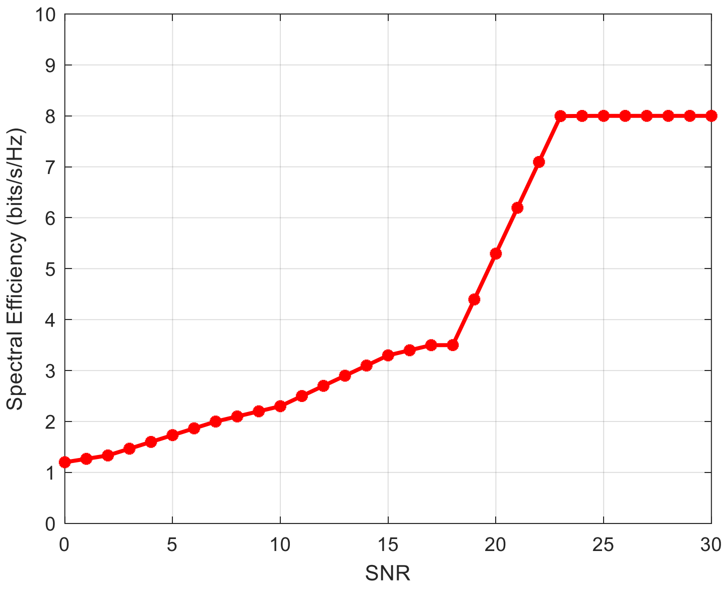

Figure 9: Spectral efficiency for GFDM AMC by employing combination of turbo and convolutional coding

As shown in Figure 9, GFDM AMC with combined Turbo and convolutional coding exhibits superior spectral efficiency at low SNR compared to the convolutional coding in Figure 8. Figure 9 illustrates that spectral efficiency remains achievable even at low Signal-to-Noise Ratios (SNRs), whereas Figure 8 indicates a negligible spectral efficiency under similar low SNR conditions. This system leads to improved spectral efficiency performance.

V. Conclusion

This paper delved into the GFDM with AMC to optimize resource allocation and enhance data rates in wireless communication systems. By employing GFDM and dynamically adjusting modulation order and channel coding schemes based on SNR levels, we achieved significant improvements in BER performance and spectral efficiency. The proposed AMC scheme effectively maps modulation orders and channel coding schemes i.e. Turbo code, Convolutional code or No code to specific SNR ranges. This combination is unique framework for AMC. It can be easily implementable due to similarity in turbo and convolutional code. Future research directions include exploring advanced interference mitigation techniques, joint optimization of power allocation and user scheduling and the application of deep learning for intelligent resource allocation. By addressing these areas, we can further unlock the potential of GFDM and AMC in future wireless communication systems.

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