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Performance analysis of adaptive channel coding with OFDM modulation over Rayleigh fading channels

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ABSTRACT

In the contemporary wireless communication system, the orthogonal frequency division multiplexing (OFDM) in conjunction with the use of the error correction code scheme is important towards ensuring a reliable transmission of data through the fading channel. This work is a complete analysis of performance of OFDM modulation combined with adaptive channel coding schemes are low-density parity check (LDPC), turbo, and convolutional code while using the Rayleigh fading channel. Error correction schemes such as LDPC, turbo, and convolutional code are used with a variety of trade-offs on their error correction performance. The system is coded in MATLAB/Simulink and run with 64 subcarriers, a length of cyclic prefix of 16 and a 16-quadrature amplitude modulation (16-QAM) modulation, channel coding techniques which are preferred upon the levels of signal-to-noise ratio (SNR) between 0 to 20 dB and the level of performance is measured by bit error rate (BER). The simulation findings prove that LDPC code achieves the highest performance at high SNR values, convolutional code has moderate BER at mid-SNR range, and turbo code has superior performance at low-SNR range and outperforming both LDPC and convolutional codes. These findings indicate that adaptive channel coding in the OFDM system is effective over Rayleigh fading.

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1. INTRODUCTION

The wireless communication systems are very weak to impairments like fading, interference, and noise that impair the reliability and the throughput of the systems. The Rayleigh fading channels can be actively employed to simulate the multipath environment that does not include a line-of –sight element, and thus they are among the most difficult cases to achieve the error-free transmission. It is against this background that the channel coding and modulation are critical in the provision of effective and reliable data transmission. Current solutions like the orthogonal frequency division multiplexing (OFDM) have alleviated inter symbol interference, though they are not sufficient in the absence of a powerful channel cipher. Turbo, convolutional, and low-density parity check (LDPC) have been suggested to improve the error correction, but the fact that they work more effectively when compared to other in the same conditions of OFDM-Rayleigh fading is not fully discussed in the previous literature.

Adaptive communication paradigm appears as a viable way to manage the changing needs and problems of modern communication networks as technology progresses and the demand for effective and dependable wireless communication increased. With this technique, the transmitter adjusts the transmission parameters (such as power, modulation symbol, and coding system) intelligently modified based on the varying wireless channel state information (CSI). Thus, a channel code with a lower code rate and a lower modulation symbol might be utilized if the channel conditions are poor. Similarly, instead of using a high modulation symbol, if channel conditions are favorable, a relatively high code rate or even none at all can be employed. The communication bandwidth of transmission medium whether wired or wireless is almost always given a lot of attention by the OFDM [1], [2]. The ratio of data rate of bandwidth is spectral efficiency and supported bit rates are often proportional to the bandwidth. The spectral performance of these media is damaged by interference. Increasing the power sent is not a good answer, as it increases the interference, not to mention the desired signal. In wireless radio, all users' traffic operates on the identical channel. The transmission of one user acts interference to other users. A significant 6G strategies is adaptive OFDM (AOFDM). In a manner that improves performance, adaptive transmission technique with the application of OFDM is employed in AOFDM following the situation of channel fading [3].

Adaptive modulation modifies the modulation scheme, coding rate, and power level with respect to the channel conditions to maximize the performance of data transmission [4]. The modulation technique (binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), 16-quadrature amplitude modulation (16-QAM), and 64-QAM) and coding rate of an AOFDM system are dynamically chosen in response to the estimated signal-to-noise ratio (SNR) or channel circumstances. Although low modulation approaches are more resilient to resulting in the reduction of small data rates, high modulation approaches have high data rates yet are more susceptible to error in noisy channels. OFDM modulation with the support of error correction coding system that include LDPC, turbo, and convolutional code schemes can provide a strong solution to the effective and reliable transmission of data in wireless channels. Convolutional codes provide reliable performance with moderate complexity, turbo codes achieve virtually Shannon limit error rates through iterative decoding, and LDPC codes are use in modern standards because of their high capabilities at high data rates and high-quality iterative decoding algorithms. Combination of these coding schemes with AOFDM enables high error robustness even in extremely challenging Rayleigh fading channels. The primary contribution of the work is that this research evaluates the bit error rate (BER) performance of LDPC, convolutional, and turbo codes when fading occurs in an OFDM system.

Coding techniques: LDPC coding scheme: the LDPC codes are a class of error correcting codes, which is characterized by their superior error correction properties especially at high block-data rates and block–lengths [5]. LDPC codes are a linear block code, defined by sparse parity checks matrices, which also make these codes easy to decode, and with low error floors. LDPC codes are distinguished by sparse parity check matrices, often represented by H or H^T, where H denotes the parity check matrix and H^T represents its transpose. The structure of the parity check matrix determines the code's error correction capabilities and decoding complexity. LDPC codes typically exhibit a low density of 1s in H, hence the name "low-density parity-check" codes.

In LDPC coding, the encoded code word is obtained through matrix operations involving the information bits and the parity-check matrix. The encoding procedure can be expressed mathematically as (1):

$$c = m \times H \tag{1}$$

where, c represents the codeword vector; m denotes the information bit vector, and H is the parity check matrix.

The error correction of above code is excellent and in many cases is near the Shannon limit of reliable communication over noisy channels. The functionality of LDPC codes depends on such variables as the code rate, block length, and LDPC construction of the code. There are many LDPC decoding methods which have different names due to their independent derivation and optimization on several occasions. The most popular algorithms are the bit-flipping algorithms and the sum-product algorithm. Two types of decoding are commonly used. Because the processing of the decoding algorithms can be considered the flow of data on the edges of a Tanner graph, or more precisely, as the flow of data between symbol nodes and a check node, they are all known as message-passing algorithms. When the received code words have been encoded, they are inputted into an algorithm that successfully identifies nodes and sends the encoded code words across variables until an erasure-free result is obtained. Therefore, LDPC can also be known as iterative decoding algorithm.

Turbo codes: one type of error correction code, the turbo codes, is the most famous due to its high performance particularly in bad channel conditions and high data rates. Turbo codes utilize the iterative decoding algorithm along with parallel connection of two or more convolutional codes are formed by concatenating two or more constituent convolutional codes in parallel. In this structure, an interleaver is typically inserted between the component encoders, after which the outputs of the constituent encoders are added by a combiner [6]. The interleaver helps to increase the error correction capabilities in general by decreasing the correlation between errors that are caused by the constituent encoders. Turbo codes use the information bits and send them over all the constituent encoders, whereby the bits are interleaved and then the encodings sequences are combined together during the encoding process. The encoding procedure can be mathematically stated as (2):

$$c = c_1 \oplus c_2 \tag{2}$$

where c represents the encoded codeword; c_1 and c_2 denote the outputs of the constituent encoders; and $\oplus$ represents the bitwise XOR operation.

Iterative decoding techniques are used to decode turbo codes. The most used decoding algorithm is the turbo decoding algorithm, founded on the logarithmic max-logarithmic a posteriori probability (Log-MAP) algorithm. Until a valid code word is obtained or a halting requirement is satisfied, the Log-MAP algorithm iteratively passes extrinsic information between the constituent decoders. Turbo decoding also makes use of additional decoding methods, such as the Max-Log-MAP and soft-output Viterbi algorithm (SOVA). Turbo coding uses a parallel concatenated convolutional structure with an interleaver length of 1024 bits and Log-MAP decoding with eight iterations. When it comes to dependable communication over noisy channels, turbo codes have outstanding error correction performance—they almost reach the Shannon limit. A number of variables, including the code rate, interleaver architecture, and the particular turbo code composition, affect how well they function. Because of their reliability and effectiveness, turbo codes are frequently utilized in a variety of communication systems, such as optical, satellite, and wireless communication.

Convolutional codes: a class of error correction codes called convolutional codes is frequently employed in digital communication systems to ensure dependable data transfer over noisy channels. Convolutional codes use shift registers and modulo-2 adders to continually encode data streams as opposed to block codes, which work with fixed-length data blocks. Convolutional codes are capable of identifying errors and error repair because of this continual encoding process. Convolutional codes are distinguished by the length of their constraints and their generator polynomials. A convolutional encoder's architecture usually includes modulo-2 adders and shift registers. The first shift register receives the input data stream. To produce several delayed versions, the shift registers delay the input data. The encoded output is produced by combining the delayed data streams using modulo-2 adders, often known as XOR gates.

In convolutional codes, the input data stream is shifted through shift registers and the delayed data streams are combined using modulo-2 addition throughout the encoding process. Redundant bits are created by combining delayed data streams, and these bits are then combined with the original data stream to create the encoded output. The encoding procedure can be mathematically stated as (3):

$$c = m \times G \tag{3}$$

where c represents the encoded output; m denotes the input data stream; and G is the generator matrix of the convolutional code. A convolutional code's generator polynomials yield its generator matrix (G). These polynomials determine the convolutional code's error correcting capabilities and encoding rules. Usually, the generator polynomials are expressed in octal form, where each polynomial represents a tap link in the convolutional encoder's shift registers. Convolutional coding is implemented with a constraint length of 7 and generator polynomials (133, 171) in octal notation. At the receiver, soft-decision Viterbi decoding with a trace back depth of 35 is employed.

The motivation behind this research lies in the need to understand the performance of AOFDM modulation combined with different error correction coding schemes over Rayleigh fading channels. By evaluating the performance of LDPC, turbo, and convolutional codes in an AOFDM system, the study attempts to explore the effectiveness of each coding scheme in mitigating errors and maximizing data throughput under varying channel conditions. This research investigation examines the results when error-correcting codes—like convolutional, turbo, and LDPC codes are applied over Rayleigh fading channels. Note that while some works (e.g., the aforementioned works) have assessed the performance of convolutional, LDPC, or turbo codes separately using particular standards, this paper presents a simultaneous performance analysis of all three codes using the Rayleigh channel model.

Related works: Al-Askary [7] proposed a turbo coded adaptive modulation technique in which changes are made based on thresholds for the SNR. Atta-ur-Rahman *et al.* [8] used LDPC codes were employed to address the coded bit allocation and power loading issues in single-antenna OFDM systems. This work was initially prompted by Atta-ur-Rahman *et al.* [9]. Across all adaptive coding and modulation schemes mentioned above, the channel coding was variable while the modulation scheme remained constant

[10]. Alternatively, Adaptive modulation was used alongside a fixed channel coding scheme. Convolutional, turbo, and LDPC codes have all received significant attention in the literature review above because of their robust correcting capabilities and practical decoding methods. Because of their increased decoding complexity, product codes are concatenated serial linear blocks codes are typically ignored. Hall and Wilson [11] presented an adaptive modulation and coding (AMC) strategy in which both the modulation symbol and code rate are dynamically adjusted for each carrier, utilizing product codes for forward error correction and QAM as a modulation technique in this proposal. Product codes are decoded through an adapted form of the iterative decoding algorithm (MIDA) [12], a hard decision decoder.

The authors in [13]-[16] highlighted the important role played by channel conditions, that is the additive white gaussian noise (AWGN) and multipath Rayleigh fading channels, the successfulness of different modulation techniques. Through the comparison of the BER of the various modulation schemes in these various channel conditions, the paper identifies the influence of channel impairments like noise and multipath fading against the data transmission robustness and reliability. In the study [17], design challenges were investigated in turbo codes in correlated fading channels such as fully-interleaved and exponentially correlated Rayleigh channels. It would be useful in situations where the turbo codes cannot be directly simulated, and the overall performance of the turbo code over a huge variety of SNRs can be evaluated. A new method of the adaptive decision feedback equalizer (DFE) implementation has just been advanced. Thus, to perform channel prediction and equalizer vector adaptation concurrently, both the least squares (LS) and recursive least squares (RLS) algorithms were used. The effectiveness of the suggested process was almost the same as maximum likelihood equalization. Adamu *et al.* [13] used BPSK and QPSK modulations whereby the iteration count was varied to test the performance of a turbo minimum mean square error (MMSE) equalizer in uplink narrowband internet of thing systems in terms of the BER versus SNR performance. The simulations in MATLAB were executed. The investigation results proved that the modulation of BPSK and QPSK has a similar performance to give a reliable estimate which was better than linear MMSE equalization. The newly proposed equalizer was expectation propagation (EP), as a turbo equalizer [17]. Unlike the linear MMSE equalization, the authors' proposed EP equalizer using gain boosting in the frequency range between 1.5 and 5 dB.

To enhance the BER performance, a total iterative method that applied feedback between a luby transform (LT) decoder and an LDPC in raptor code was applied in [18]. Fujia *et al.* [19] could use their combined equalization and raptor decoding method to use the efficient data of raptor decoders. It was observed that the performance of polar codes and the LDPC codes with channel equalization could be compared with the aid of free space optical transmission arrangement. Polar codes were realized to perform better in the form of block error rate (BLER). In order to decrease the feedback information, polar codes with adaptive channel equalization were employed in [20]. In order to alleviate the effect of mistakes estimation, a hybrid error control system using automatic repeat reQuest (ARQ) was applied. According to the results, the proposed method was more effective compared to turbo equalization. The main issue is to estimate the coefficients values of the equalizer filter to recover the signal transmitted with a small error rate. To come up with this conclusion, the channel model was initially obtained in [21]. Then, the equalizer filter coefficient adjustments were optimized based on this estimate. It is highly desirable to optimize these coefficients in a way that best reduces the likelihood that errors would occur. This study proposes a number of optimization criteria, including zero forcing (ZF) and MMSE. A study was conducted in [22] to examine the use of decision feedback in conjunction with a turbo equalizer to enhance the limits of linear equalizers. The use of time-varying linear equalizers along with interference cancellers provided performance over the turbo DFE based on soft posterior feedback with symbol wise invariant filters, while the turbo DFE utilizing hard feedback with symbol-wise adaptive filters performed badly at low spectral efficiency. Okubo *et al.* [23] compared turbo and LDPC codes with e-ultra downlink OFDM context and found that turbo codes require SNR values of 0.2-0.3 dB which is lower than that of LDPC. In turbo-coded OFDM systems, Ortín *et al.* [24] demonstrated that the choice of decoding algorithm has a substantial effect on performance-complexity trade-offs. Prior research indicates that 5G NR LDPC codes provide a maximum coding gain of 15 dB at a BER of 10^{-3} in Rayleigh and Nakagami-m fading environments [25].

The current studies of AMC have seen a trend in changing the constant and threshold based design to intelligent and learning-aided techniques in dealing with the dynamic wireless environment. Modulation classification works using data driven algorithms have shown the ability to improve flexibility in changing channel conditions, especially in the case of an OFDM [26], [27]. The scenario aware and vehicular AMC schemes also demonstrate the relevance of contextual intelligence in the rapidly time-varying channels [28] more recently [29] investigated the application of large language models to AMC decision-making, which is a wider trend in the direction of foundation models in cross–layer wireless optimization. Such methods have a better flexibility, but can be computationally complex and are frequently not interpretable, making them harder to apply to real time in real world systems. Similarly, to learning–based AMC, much has been made in regard to the performance of channel coding and iterative receiver algorithms in fading and dispersive channels.

A comparative analysis of convolutional, turbo, LDPC, and polar codes between OFDM and newly developed modulation schemes like OTFS show that advanced iterative codes can be used to achieve a better BER performance, especially in the moderate-to-high SNR regions, but at higher decoding costs [30], [31]. Experiments on turbo equalization and EP-based receivers show a significant improvement in reliability of doubly dispersive and overloaded channels using iterative information exchange [32]-[34] and have been experimentally validated in practice deployments of LTE [35]. Survey studies also highlight that machine-learning-based solutions are attractive, although more basic adaptive schemes based on physical–layer metrics, including SNR are considered appealing due to their robustness and simplicity of implementation [36], [37]. Nonetheless, no rigorous and reproducible analysis of adaptive channel coding schemes based on SNR that gives the assessment of a fair comparison of convolutional, turbo, and LDPC codes under common framework of a single channel in Rayleigh fading effects is available which this research intends to fill.

The AMC scheme involving dynamically changing transmission parameters explored to improve the spectral efficiency and consistency in time-varying wireless systems [38]. The concepts of interference immunity over multipath fading channels, which emphasize the need to use strong signal processing to achieve reliable energy efficient communication examined in [39]. The receiver design advances by introducing a concatenation EP and turbo equalization scheme on overloaded massive MIMO systems, which proved to be better at detection in the high-capacity scenario were analyzed in [40]. Monte Carlo-based simulations have issues with complexity related to performance assessment of complex communication systems, and it is important to have scalable and efficient computation methods explained in this paper [41]. The use of machine learning in chance-constrained optimization, as one of the examples to demonstrate uncertain and complex machine level phenomena effectively addressed in this paper [42].

The rest of this paper is structured as follows. Section 2 provides method, system model and the parameters used in the study, section 3 provides results and discussions with detailed comparisons, interpretations, and implications of the findings. Section 4 concludes the work with key insights, limitations, and directions for future research.

2. METHOD

2.1. Analysis of coding techniques over Rayleigh channel

The choice of OFDM was motivated by its effectiveness in mitigating frequency –selective fading. Rayleigh fading was selected since it accurately represents urban multipath scenarios. LDPC, turbo, and convolutional coding were chosen for their widespread use in wireless standards. The AOFDM system was executed in MATLAB/Simulink with meticulous coding and modulation settings to guarantee consistency. The Rayleigh channel model including PDP (2 taps with relative powers [0 -3] dB, doppler frequency (100 Hz), LDPC codes with a block length of 648 bits and a rate of 1/2 (as specified in IEEE 802.11n/5G NR standards), Turbo codes utilizing constituent encoder polynomials (13, 15) in octal, a constraint length of 4, and Log-MAP decoding with a maximum of 8 iterations, as well as convolutional codes featuring a constraint length of 7, generator polynomials (133, 171) in octal, and Viterbi decoding were utilized.

The simulated communication system in the provided Simulink model in Figure 1 encompasses processes such as data generation, encoding, modulation, transmission over a simulated channel, reception, demodulation, decoding, and performance evaluation. These processes collectively simulate the end-to-end communication process, allowing for analysis and optimization of system performance in various communication scenarios. The description of each block is explained below.

2.2. Data generation and encoding

The communication process starts with the creation of binary data, and this is usually digital information that the transmission process is going to attempt to transmit. It is common to use a source block to generate such binary data, including the Bernoulli binary block, which attempts to generate binary bits according to a given probability distribution. After the binary data has been produced, it is encode so as to add redundancy in the data to provide the benefit of error correction. Simulink model supports various encoding schemes such as LDPC, convolutional, and turbo encoding. All the encoding schemes work in different ways. LDPC encoding uses sparse parity check matrices, convolutional encoding uses shift registers, modulo-2 adders, turbo encoding uses parallel concatenated convolutional codes.

2.3. Modulation

Once the data is coded it is then modulated to fit the data onto carrier signal which can be sent through a communication channel. The OFDM modulation is used in the Simulink model. OFDM splits the data stream into several orthogonal subcarriers, which carry a fraction of the encoded data. The technique has a positive role in overcoming frequency selective fading and effective use of available spectrum. The

Simulink model modulates the digital data sent through the program using the OFDM modulator block which transforms the encoded digital data into the form of OFDM symbols that get sent across the circuit.

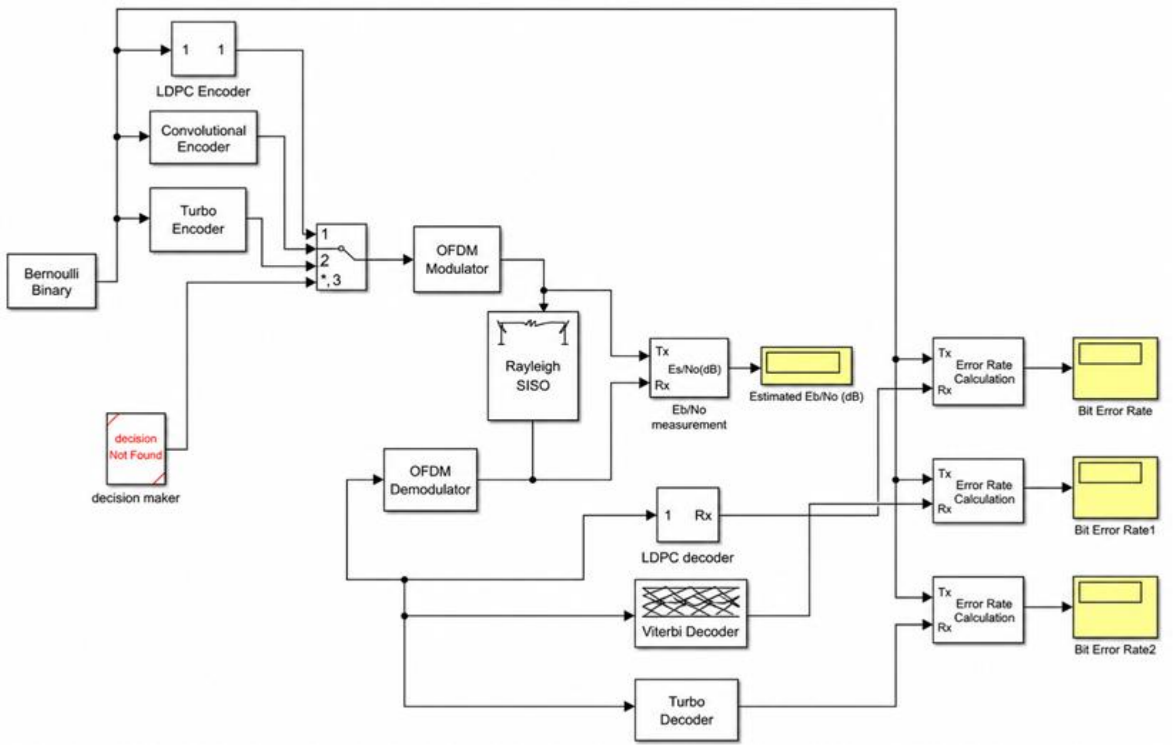

Figure 1. Overall proposed adaptive model with LDPC, convolutional, and turbo codes using Rayleigh channel

2.4. Channel modeling and adaptive mechanism

The modulated signal is sent through a simulated communication channel, which is often modeled to reflect real-world channel characteristics. In the provided Simulink model, the channel is represented as a Rayleigh fading SISO channel. Rayleigh fading captures the stochastic variations in signal strength due to multipath propagation, while SISO exploits spatial diversity to enhance communication reliability and throughput. The channel introduces noise, interference, and fading effects on the transmitted signal. Based on the adaptive rule, adaptation is achieved using predefined SNR thresholds. Turbo coding for low SNR values, Convolutional coding is selected for medium SNR conditions, and LDPC coding for high-SNR scenarios. Perfect CSI is assumed at the receiver, while the transmitter relies on SNR feedback without instantaneous CSI. The adaptive mechanism dynamically modified the coding according to the instantaneous SNR, with thresholds established such that turbo coding was utilized for low SNR <8 dB, convolutional code with medium SNR for 8–13 dB, and LDPC coding for high SNR ≥14 dB. The adaptive mechanism operates as follows:

- Transmit symbols within each OFDM frame.
- Estimated SNR is compared against the predefined threshold values.
- Based on the SNR range, the appropriate coding technique (LDPC, convolutional, and turbo) selected.
- The selected technique applied uniformly across all the OFDM subcarriers for the subsequent frame.

2.5. Signal-to-noise ratio calculation

The signal is then further processed to determine its quality in relation to the SNR. This measure is used to measure the strength of incoming signal as compared to the level of the background noise. The Es/No block of the Simulink model is used to determine the SNR in decibels (dB) using the energy of the received signal and the noise power spectral density.

2.6. Demodulation and decoding

The signal received at the receiver is demodulated in order to obtain the transmitted symbols. OFDM demodulation can be done in the Simulink model to recover the modulated symbols of the received signal. The demodulated symbols are then decoded in accordance to the encoding schemes applied at the transmitter. The received data is decode using LDPC decoding, Viterbi decoding, and turbo decoding blocks in order to reconstruct the original information bits and also reduce the number of errors induced during transmission, which illustrates the robustness of the advanced coding methods in different operating conditions.

3. RESULTS AND DISCUSSION

The simulation results are carried out using MATLAB and adaptive model is created using Simulink. Table 1 shows the parameters considered for AOFDM model using Rayleigh fading channel. The OFDM system consists of 64 subcarriers. OFDM divides the available frequency range segmented into orthogonal subcarriers to improve spectral efficiency and combat frequency-selective fading. The length of the cyclic prefix is set to 16. The cyclic prefix helps in combating inter-symbol interference (ISI) caused by multi-signal arrival by adding timing gap to each OFDM symbol. The number of fast Fourier transform (FFT) points is set to 64. FFT is used to convert the time-domain OFDM signal into the frequency-domain signal for transmission and reception. BER is performance measure used to calculate the impact of error correction coding schemes in mitigating errors during data transmission over communication channels. SNR is a metric that shows the degree to which a signal is contaminated by power in the communication channel, typically expressed in dB. A greater SNR signifies improved signal quality and lower levels of noise.

Table 1. Parameters for adaptive channel coding

Parameters	Values
SNR	0 to 20 dB
Modulation	16-QAM and OFDM
Coding	LDPC, convolutional, and turbo code
Channel model	Rayleigh fading
Number of sub carriers	64
Cyclic prefix length	16
Number of FFT points	64

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Table 2 presents the average BER values for different coding techniques (LDPC, turbo, and convolutional) at various SNR levels (5 dB, 10 dB, 15 dB, and 20 dB). The results demonstrate the performance of LDPC, turbo, and convolutional coding techniques in mitigating errors at different SNR levels. LDPC and Turbo coding schemes generally outperform convolutional coding in terms of achieving lower BER values across all SNR levels as shown in Figure 2 shows that as the SNR increases, the BER decreases for all modulation schemes, indicating improved error correction performance in higher signal quality conditions. This indicates that a higher SNR which means a better-quality communication channel results in fewer errors in the received data. The graph also illustrates that more complex modulation schemes (like 16-QAM) have higher BERs at lower SNRs compared to simpler schemes (like BPSK). This is because complex modulation schemes are more subject to noise and interference, which results in a higher probability of bit errors. Hence, this work utilizes 16-QAM adaptive coding strategy along with OFDM over Rayleigh channel. The use of LDPC coding is intended to improve the BER performance in communication systems, especially in challenging channel conditions like those modeled by Rayleigh fading, which is characteristic of environments with multiple signal paths and no line of sight. Figure 3 shows that as SNR vs BER of turbo code for all different modulation, which is expected as better signal quality (higher SNR) generally results in fewer bit errors. The turbo code appears to perform the best overall, with the lowest BER across the SNR range shown, while the convolutional coding performs the least effectively of the three coding schemes.

Table 2. Comparison of BER of without OFDM for coding techniques

SNR (dB)	Coding techniques	Average BER
at 5	LDPC	1.20E-02
	Turbo	8.50E-02
	Convolutional	9.80E-02
at 10	LDPC	1.10E-03
	Turbo	4.14E-03
	Convolutional	2.36E-02
at 15	LDPC	1.87E-04
	Turbo	6.54E-04
	Convolutional	3.21E-03
at 20	LDPC	2.35E-05
	Turbo	1.00E-04
	Convolutional	5.17E-04

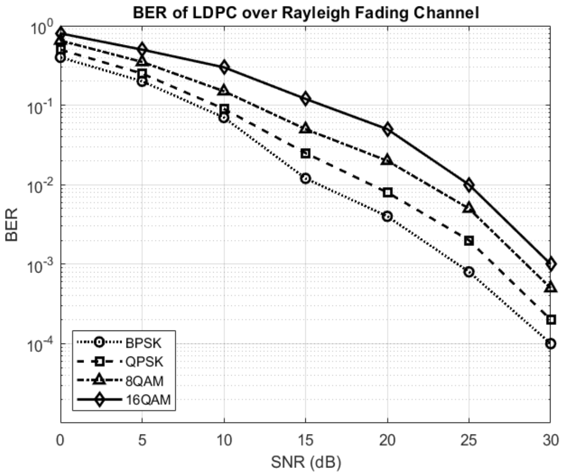

Figure 2. BER vs. SNR of LDPC code

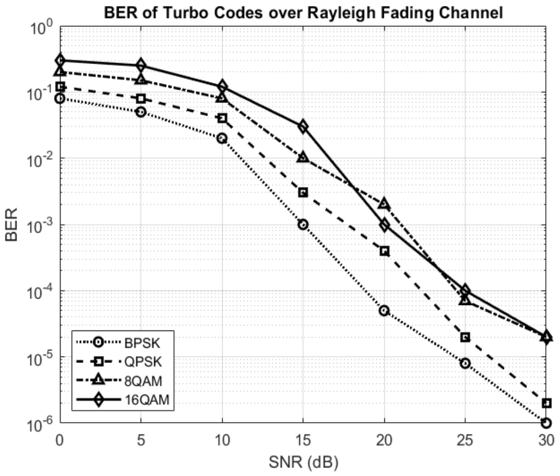

Figure 3. BER vs. SNR of turbo code

Table 3 shows the BER performance of the LDPC, convolutional, turbo, and adaptive channel coding techniques with OFDM over Rayleigh fading channel in the SNR values of 0 dB to 20 dB. Figure 4 indicates that the LDPC code achieves the lowest BER of 10^{-5} at 20 dB, while Turbo code attains a BER of 10^{-4} at 15 dB. The convolutional code exhibits a BER of 10^{-2} at low SNR values. In Figure 5 the findings have clearly shown the high dependence of coding performance on operating SNR and have supported the proposed adaptive coding strategy. At low SNR values (0-7 dB), turbo coding achieves the lowest BER, values of 10^{-5} while convolutional coding shows BER of the order of 10^{-3}. This performance of turbo coding is superior in this region, resulting in improved BER compared to fixed coding schemes. In the moderate SNR region (8-13 dB), convolutional coding demonstrates more stable BER behavior than turbo coding, with BER values decreasing steadily as SNR increases. The adaptive scheme correspondingly switches to convolutional coding and closely follows its performance, maintaining BER values in the range of 10^{-4} to 10^{-3}. At high SNR values (≥14 dB), the adaptive scheme switches to LDPC coding according to the predefined selection rule. However, the LDPC coded system exhibits BER values close to 0.5 in this region, leading to a significant degradation in adaptive BER performance at high SNR.

Table 3. BER of individual and adaptive channel code over Rayleigh fading channel

SNR (dB)	BER of channel coding techniques			BER of adaptive channel code
	LDPC	Convolutional	Turbo	
0	5.1994E-01	2.437E-03	9.844E-04	3.906E-04
2	5.2500E-01	1.859E-03	1.094E-04	4.688E-05
4	5.3043E-01	1.344E-03	1.561E-05	6.250E-05
6	5.3807E-01	1.516E-03	4.688E-05	1.563E-05
8	5.3448E-01	1.203E-03	4.688E-05	1.563E-05
10	5.0097E-01	1.437E-03	1.563E-04	1.406E-03
12	5.0011E-01	1.031E-03	1.094E-04	1.156E-03
14	5.0002E-01	7.813E-04	9.375E-05	1.063E-03
18	5.0010E-01	1.914E-04	0.000E+00	5.0070E-01
20	5.0000E-01	6.430E-04	0.000E+00	4.9991E-01

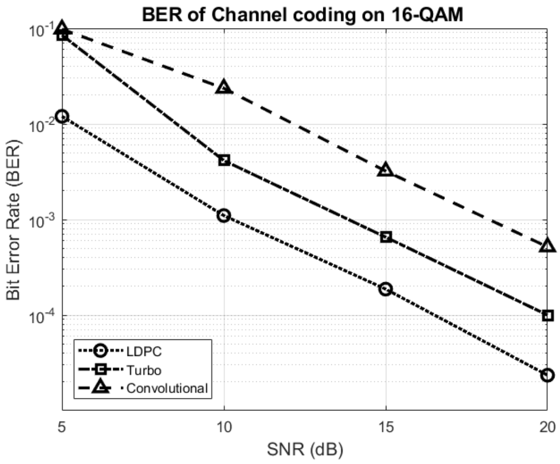

Figure 4. BER vs. SNR of channel coding with 16-QAM

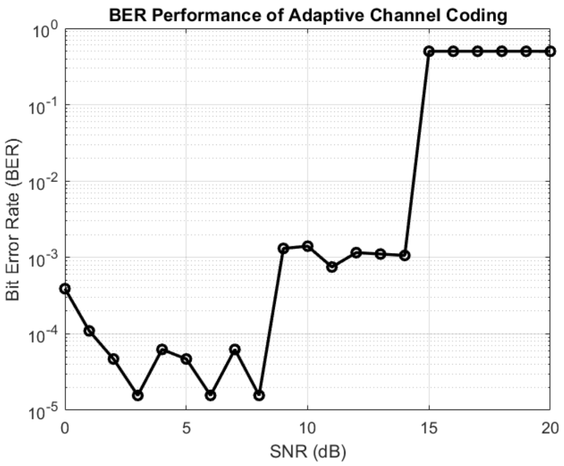

Figure 5. BER performance of adaptive channel coding with OFDM over Rayleigh fading

3.1. Discussion

The implementation of 16-QAM modulation clearly demonstrates the relationship between spectral efficiency and BER performance, particularly in fading settings. The selected SNR range (0–20 dB) encompasses both noise-constrained and almost optimal transmission situations, demonstrating the resilience of sophisticated coding techniques across various operational environments. The Rayleigh fading channel model brings out practical challenges when using multipath wireless propagation. Turbo coding exhibits superior performance due to its iterative decoding process and the use of interleaving. This effectively mitigate burst errors caused by Rayleigh fading. Similar observations have been reported in comparative studies of turbo and LDPC codes in OFDM-based wireless systems, where Turbo coding shows strong robustness in noise-limited conditions [23], [24]. Convolutional coding provides reliable and consistent error correction in the moderate SNR region due to trellis-based Viterbi decoding, which offers a favorable trade–off between performance and decoding complexity. This justifies the adaptive selection of convolutional coding in this SNR range. Although LDPC coding is theoretically capable of achieving near-capacity performance at high SNR, the observed degradation in LDPC performance can be attributed to practical constraints such as finite block length, limited decoding iterations, and suboptimal parameter configuration. Similar limitations of LDPC codes under multipath fading conditions have been reported in recent studies, where careful decoder optimization is required to realize their full performance potential [24], [25].

Overall, in this work 16-QAM adaptive channel coding with OFDM strategy effectively exploits the strengths of different coding techniques across varying SNR based on the Rayleigh fading channel situations. The adaptive scheme chooses Turbo coding in low-SNR regimes dominated by noise, convolutional coding at moderate SNR levels, and LDPC coding at high SNR where the impact of noise is minimal. the proposed adaptive approach aims to minimize the BER while balancing complexity, consistent with adaptive coding principles reported in the literature [22]-[25].

4. CONCLUSION

The given paper introduced an adaptive channel coding algorithm combined with the OFDM in wireless communication in a Rayleigh fading channel. Comparison of the turbo, convolutional, and LDPC code schemes were run under the same simulation conditions and proposed an adaptive channel coding scheme to minimize the BER across changing SNR conditions. The results demonstrated that no single coding scheme provides optimal performance across all SNR regions, thereby motivating the need for adaptive coding. The outcomes show that an adaptive channel coding choice is much better at enhancing BER performance relative to fixed coding schemes. The turbo coding achieved lowest BER in low SNR instance and convolutional coding exhibited stable and reliable performance suitable in moderate SNRs whereas LDPC code performs better at high SNRs. The study framework proposed is realistic, repeatable and in the line with theoretical anticipants, can be applied to design adaptive wireless communication system. The proposed adaptive coding scheme successfully exploited the strengths of different coding techniques by dynamically selecting Turbo coding at low SNR, convolutional coding at moderate SNR and LDPC coding at high SNR. Overall, the adaptive approach demonstrated improved BER performance compared to fixed coding schemes and provided a practical solution for reliable communication over Rayleigh fading channels.

The current research can be expanded in various ways to enhance the performance and applicability of the system. It is important to point out that the study is restricted to software simulations and Rayleigh fading channels. The following research shall focus on extending the research to include these additional channels, comparing the higher-order modulation methods, and strengthening the results by hardware prototyping using field-programmable gate array (FPGA) and software-defined radio (SDR) platforms necessary to establish the feasibility. The future research can consider machine learning based adaptive coding schemes in real-time decision making.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis

I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting

Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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