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Performance Evaluation of Coded OFDM Using 4QPSK and 16QAM

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***Abstract*—The goal of modern communication systems is to transmit information from one point to another through a communication channel quickly and effectively. Mobile wireless users will move around while always being connected to the network. This necessitates the transmission of digital material through wireless networks and satellites, which has grown to be a significant problem over time. The main goal of this study is to compare the performance and efficiency of OFDM to that of other coding schemes, such as LDPC, Turbo, and Convolution. In this simulation, multiple forms of modulation, such as 4 QPSK with a coding rate of 0.663 and a BER of 0.001 at 0.59 dB Eb/No and an efficiency of 1.326, were compared with LDPC, Turbo, and Convolution codes. The performance is improved in the following simulated comparison of 16 QAM with a coding rate of 0.479, which has a BER of 0.001, an Eb/No of 3.26 dB, and an efficiency of 1.914. Using unique, not tried before LDPC code rate of 0.313, with efficiency of 1.25, 0.001 BER, and Eb/No, of 0.65 dB, the simulation proved that the performance of BER and Eb/No, using LDPC and 16 QAM results in a more efficient coding compared with Convolution code and Turbo code. This work has the unique contribution of using untried rates from the 3GPP sheet under three different coding techniques (LDPC, Turbo, and Convolution), which resulted in a lower BER per AWGN channel under OFDM, QPSK, and 16 QAM. The simulation implemented a regular OFDM system over AWGN channel noise, which was done in MATLAB.**

***Keywords*—OFDM, 5G NR, channel coding, Signal to noise ratio (SNR), BER, LDPC, Turbo, convolution, simulation, additive white gaussian noise**

NOMENCLATURE

Symbols/acronyms	Meaning
3GPP	Third Generation Partnership Project
AWGN	Additive White Gaussian noise
B	Transmission bandwidth (hertz)
BF	Bit Flipping
BP	Belief Propagation
CN’s	Check Nodes
Eb	Energy per bit
eMBB	The enhanced mobile broadband
Es	Energy per symbol
FEC	Forward error correction
FFT	Fourier Transformation
IFFT	Inverse Fourie transformation
ISI	Inter symbol interference
LDPC	Low Density Parity Check
LLR	Log Likelihood Ratios
LTE	Long-Term Evolution
MCM	multicarrier modulation
MCW	Multicarrier waveform
mMTC	The massive machine type communication
NGCN	Next generation communication network
OCT	Orthogonal cyclic transpose
OFDM	Orthogonal frequency division multiplexing
OOB	Out of band
PAR	Peak to average power ratio
PCCC	Parallel connected convolutional code
PD	Power density
PSK	Phase Shift key
PUSCH	Physical uplink shared channel
QAM	Quadrature Amplitude modulation
QC-LDPC	Quasi – cyclic low density parity check
QPSK	Quadrature phase shift keying
SPA	The Sum Product algorithm
URLLC	The ultra-reliable low latency communication
UWBoF	Ultra-wide band-Over-Fiber Communications
ZP	Zero pad

I. INTRODUCTION

Shannon made it clear in 1948 that information can be sent without errors over a channel with noise if the rate of transmission is equal to or less than a certain limit, called the channel capacity bound. Since then, a great deal of

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work has been done to develop new transmission methods in an effort to approach the limit of the available bandwidth. One of the main methods that enables such near-capacity functioning is channel coding. By establishing organized redundancy (analyzing) at the transmitter and using it (synthesizing) at the receiver, the possibility of large errors is reduced. It is possible to perform detection and correction [1].

There are a lot of new studies that suggest that the traditional OFDM waveform could be replaced with a different MCW waveform. The NGCN would provide increased spectrum efficiency, low latency, and high throughput. In this sense, the NGCN is facing a significant scientific challenge with the creation of the MCW. The idea of supporting a large number of 5G users [2].

To improve the BER performance of the M-QAM system by optimizing the probability distribution of constellation points. They use the XOR technique to achieve good performance with OFDM over an AWGN channel. The BER performance of the proposed OFDM transmission system can be improved by comparing the probability distribution of the 16-QAM system to that of the system without bit XOR [3].

While proposing a streamlined method for calculating the LLRs in two ways using the conventional equation. The signal is anticipated to be encoded by a convolutional encoder, travel through the OFDM system, pass through an AWGN channel, and then be decoded by a Viterbi decoder utilizing the calculated soft information. The system's foundation is 4-QAM soft information computation, and M-QAM soft information computation may be simply added [4] to maximize the use of the available spectrum. The OFDM communication system is an effective technique for that. The utilization rate of spectrum may be significantly increased when M-QAM is used in this system. FEC is often used to lower the error rate of a system [5].

The transmitter and receiver implement an end-to-end PUSCH channel structure in accordance with the improvements made to forward error correction and are based on the 3GPP 5G NR physical layer standard FEC. As a result of these improvements, the turbo codes used in 4G LTE have been replaced with QC-LDPC codes, which have been shown to allow for faster transmission rates and better hardware implementations [6]. However, in order to achieve memory module sharing, a hardware module is used to accomplish the sub-block interleaving in the Turbo Code rate matching in the 4G LTE downlink and the LDPC code bit interleaving in the 5G NR downstream [7].

The system's flexibility is increased, the storage size is decreased, and this approach varies between the two interleaving coding schemes, the NR physical layer standard and the FEC. As a result of these improvements, the turbo codes used in 4G LTE have been replaced with QC-LDPC codes, which have been shown to allow for faster transmission rates and better hardware implementations [6].

Thus, in order to achieve memory module sharing, a hardware module is used to accomplish the sub-block interleaving in the Turbo Code rate matching in the 4G LTE downlink and the LDPC code bit interleaving in the 5G NR downstream. According to experimental findings, the system's flexibility is increased, the storage size is decreased, and this approach varies between the two interleaving coding schemes. Interleaving in code and interleaving in the channel have been accomplished with existing interleaving algorithms using various standards [7].

The next generation of standards for wireless communication, such as 5G, is currently being developed. The technology of the fifth generation has developed into the fundamentals of wireless communications for the next-generation platform, with high data rates (hundreds of “gigabytes” in a short time) and more channel capacity.

OFDM is now a good method of multicarrier access that can be used on the 5G standard platform to handle difficult channel conditions. Performance degrades when OFDM transmission is used as an unbeatable access method (BER and ISI, even with 5G), because multipath channels lose strength over time. Also, investigate Turbo and LDPC coding for 5G and determine the effectiveness of LDPC with regard to 5G requirements. They find LDPC with 5G specifications has better performance and a lower bit error rate [8].

Better performance with OFDM is found, and the code rates over the regions are different, which is why the unused code rate was introduced to reduce the effect of BER.

The main study of this paper is to have a good performance of OFDM modulation by using three types of coding to establish a system with a lower bit error rate. The required basic knowledge of OFDM and modulation is presented in the literature review. In terms of identifying errors and handling them, the LDPC encoding and decoding algorithms follow a technique similar to that of conventional and turbo encoders, as discussed in Materials and Methods. Results and Discussion contain the findings of LDPC, turbo, and convolution methods. Last, the conclusion and future efforts are presented.

II. LITERATURE REVIEW

Many studies have been done to see how different coding methods and modulated signals can be used to improve OFDM channels. The goal was to make FEC for OFDM and test how well it worked over an AWGN channel with LDPC codes and two different decoding methods [9] by comparing the BF and the SPA for how effectively they decode.

The parameters utilized for BF and SPA are BER and Eb/No. According to the findings, LDPC codes on OFDM may, on average, decrease errors by 1.5% when compared to those without LDPC. Additionally, SPA decoding is best for BF. However, they emphasized how LTE needs a robust approach to avoid errors occurring in the transmission channel [10].

Errors are handled by adding parity bits to the signal data stream. These parity bits are used to identify problematic bits and correct them. Another effective technique for fixing faults is forward error correction and detection using convolutional encoding and Viterbi decoding. To accurately decode the original message, they use this encoder.

The URLLC and mMTC channel codes have not yet been determined; however, the LDPC code has already been selected as the eMBB channel code [11]. Turbo codes, LDPC codes, Polar codes, and Rate Less codes are the main channel codes that could be used for 5G URLLC. The most important things for 5G channel codes are throughput, latency, the ability to fix errors, flexibility, and how hard they are to set up. By discussing LDPC codes, a type of FEC code, they have a parity-check matrix with a few non-zero values. It's fine to choose it because it can reach capacity and is a strong contender in the race to standardize 5G channel codes [12].

In another study, they did a thorough analysis of a turbo-coded OFDM scheme under several realistic noise scenarios, such as AWGN, phase noise, Rayleigh fading, Rician fading, and Doppler shift, using a PCCC technique in the presence of a channel [13, 14]. To achieve high performance, low BER, and large capacity, new modern technologies are used. The channel frequencies used by the network significantly influence OFDM communication.

In a noisy channel with AWGN distribution and OFDM, in order to increase the distance of FD communication, they proposed a PD to extend the transmission range. One sort of distortion that occurs across the channel is inter-carrier interference. Data can be distributed across multiple carriers separated by different exact frequencies when using OFDM spectrum. Researchers in [15] investigated how well LDPC, Turbo, and Polar codes worked for wireless PD. They fixed situations when the system confronted high and low SNRs on the bits and, consequently, on the symbols originating from the same code word.

The SNR dispersion at the transmitter is known as a priori. This is a drawback of a system where FD interference has damaged some of the symbols. By using coding methods to improve the 128 QAM MB-OFDM UWBoF system's transmission performance by utilizing OFDM over fiber, In their model, they employed LDPC code with OCT precoding. In practical applications, the model was able to lower the dispersion between sub-channels and average the SNR of sub-carriers [16], with the intention of calculating the OFDM signals' channel variance.

Their strategy proposed using the ZP as the OFDM symbol's first step in the time domain. The channel is then estimated at the pilot signal in the OFDM symbol in the middle of the ZP interval using a pilot sample impulse signal. The last phase of the method uses the linear model to estimate the channel variance across an OFDM signal [17].

OFDM remains an important component in the design of waveforms for various multicarrier wireless communication techniques. It is used according to the various generations, is well-known in the wireless community, and is an established technology. OOB is one of the issues addressed in the recommended waveforms in their research. Raji *et al.* [18] showed that the number of iterations has no impact on the performance of the OFDM-LDPC system when the SNR is low. Increasing the number of iterations will enhance the system's performance when the SNR is high. When the SNR is high, the number of iterations has a significant impact on the bit error rate [19].

OFDM, a well-known modulation technology that can handle impulse noise and channel interruptions, is also called multicarrier modulation (MCM) or discrete multitone (DMT). In the 1950s, two modems, the Collins Kineplex system and the Bell System, were used to set up multi-carrier modulation. For a multicarrier system to work better, the transmit spectra of the subcarriers must overlap. But they must also be different from each other so that sorting and processing at the other end is not too hard [20].

The main idea behind OFDM is to divide the frequency band into several sub-channels and sub-carriers. By making all of the sub-channels narrowband, which makes it easy to make adjustments to get high spectral efficiency, the frequency band can be split into several sub-channels and sub-carriers [21].

The multi-carrier transmitter typically includes several modulators, each with a unique carrier frequency. The transmitter generates the transmitted signal by combining the modulator's outputs. Assume the N data to be transmitted are Si(t), I = 0, 1, and N-1, and Si(t) is a number in a particular constellation, such as QPSK or QAM. Assuming that the carrier frequency for Si(t) is Ai or Bi, Eqs. (1–2) yield the complex-valued multi-carrier transmitter, for instance, (n) subcarrier QPSK.

$$S_i(t) = \sqrt{\frac{2Es}{Ts}}\, cos(2\pi f_c t + \emptyset_i) \ ,0 \le t \ \le T \quad (1)$$

where I = 0,1, 2…, n

$$S_i(t) = A_i\sqrt{\frac{2Es}{Ts}}\, cos(2\,\pi f_c\, t\,) + B_i\sqrt{\frac{2Es}{Ts}}\ \ sin(2\pi f_c t) \quad (2)$$

where:

$$A_i = \pm 1, \pm 3, \pm 5 \ldots$$

$$B_i = \pm 1, \pm 3, \pm 5 \ldots$$

Number of A_i, B_i *bases is* $\sqrt{m}$

OFDM is described in [22] as a multicarrier multiplexing technique that transmits data over a range of small frequency channels with equal bandwidth. To provide the orthogonality of all subcarrier signals during the symbol period Ts. The symbol rate 1/Ts was adjusted to be equal to the separation factor of the nearby subcarriers. Orthogonal subcarriers may be able to avoid unnecessary guard bands and increase spectral efficiency by allowing sub-channel bands to overlap.

Fig. 1 depicts an OFDM modulation and demodulation block diagram. In reality, a modulation set is mapped onto the number of encoded bits, which results in a complex matrix that matches the parallel modulated subcarriers.

With the use of an inverse fast Fourier transform (IFFT), the modulation and multiplexing can then be done digitally.

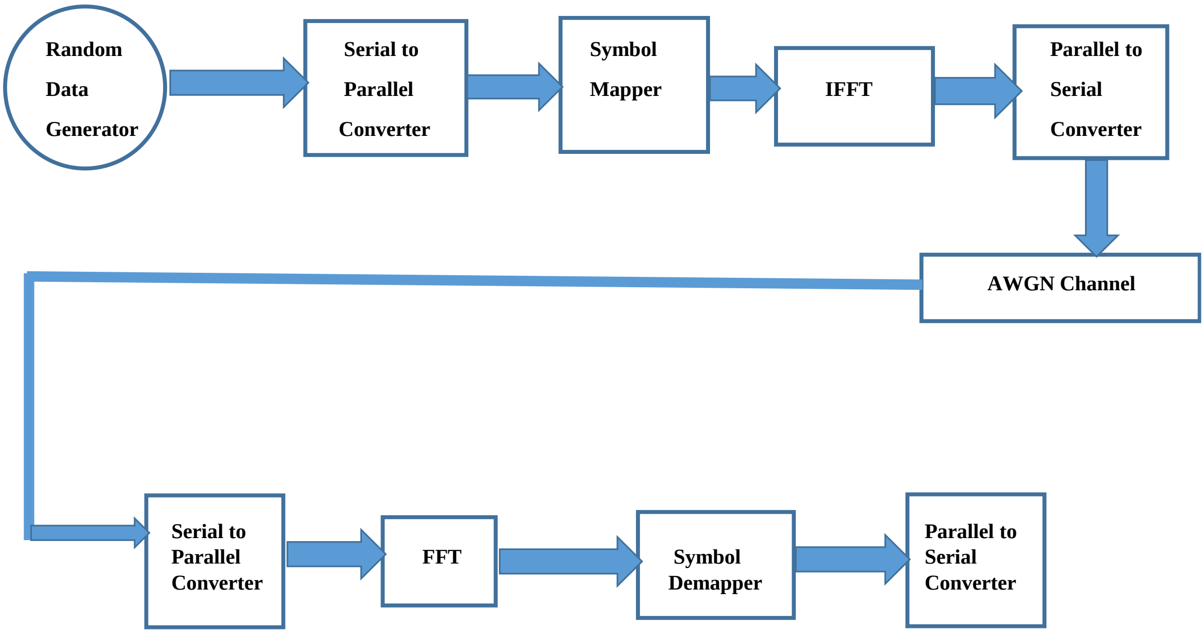

Figure 1. Block diagram of OFDM modulation and demodulation.

The fast Fourier transform (FFT) processing block changes the OFDM signals (demodulation) from the time domain to the frequency domain. This is done before they are de-mapped to the right constellation patterns. OFDM is very sensitive to noise in both frequency and phase, so it needs pilot symbols in the data packet. They are used to estimate the channel transfer function, and the channel is taken into account by applying the inverse Fourier transform to each subcarrier OFDM signal in order for OFDM to speed up the equalization process by converting a frequency-selective channel into a flat channel. During demodulation, the phase and amplitude of the OFDM signals that were received are set by using the pilot subcarriers that the receiver already knows.

III. Materials and Methods

In non-linear code, for example, it is hard to cut down on bit error rates to improve efficiency. The goal of this project is to reduce noise and improve productivity. It is necessary to have prior knowledge of the encoder and decoder parameters as well as precise information on the CSI of the OFDM in order to recover transmitted data at the receiver. However, the primary goal is to use an LDPC code to investigate how well OFDM modulation performs in terms of BER in the AWGN channel. On the other hand, to determine how low BER was observed, a comparison between the LDPC code, the convolutional code, and the turbo code was done. By employing MATLAB simulation with little cost, it will be feasible to identify better code rates like LDPC, Turbo, and Convolutional to achieve improved efficiency and a lower bit error rate. Table I shows the unused 3GPP code rates.

TABLE I. Used and Unused 3GPP code Rates

Code	**BER**	**Efficiency**	**Eb/ No**	**Code rates**	**Modulatio n**
Used Code (3GPP) sheet	0.001	1.91	3.26	490/1024	QAM
	0.001	1.74	1.57	378/1024	QAM
	0.001	1.32	0.90	340/1024	QAM
	0.001	1.35	0.62	690/1024	QPSK
Unused Code	0.001	1.25	0.65	320/1024	QAM
	0.001	1.29	0.38	660/1024	QPSK

The reason for using these unused codes is because different regions of the world use different code rates, which is why they were introduced. The approach of this work is to look at the following issues:

- Performance of OFDM modulation and its effect on bit error rate (BER) in AWGN channel by employing a low-density parity-check (LDPC) code.
- To establish coding effect on BER level by comparing LDPC code with the Convolutional

code and Turbo code, with focus on obtaining lowest BER.

- Establish a resilient, and reliable coding system, which has lowest BER compared to existing OFDM systems. Such system should enable more efficient communication with higher channel capacity.

The overall process using MATLAB to resolve this problem is illustrated in Fig. 2.

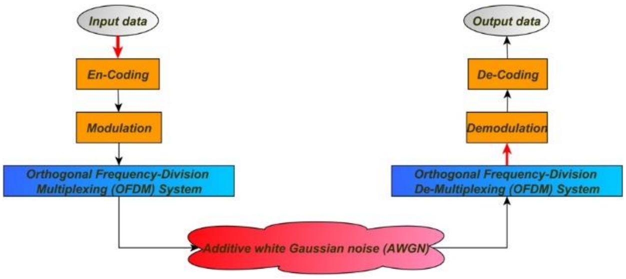

Figure 2. Proposed system flow chart.

As shown in Fig. 2, the process of handling a signal over a noisy channel and how the signal travels over blocks to achieve a low bit error rate (BER) is explained.

The presented work considers existing OFDM used with 5G networks and employs 3GPP TS 38.214. As for the fundamental channel codes, LDPC, Turbo, and Convolution were in use with OFDM in the system that was already in use. If 5G wireless communication could support Turbo and Convolution codes, those codes would have backwards compatibility with 3G and 4G, which would save money for the cellular communications sector. Rather than replacing parts, they can update them to accommodate new generations.

The main contribution of this paper is to study three types of coding (LDPC, Turbo, and Convolution) used with OFDM and analyze the channel performance in terms of BER. There is a need to establish a robust channel that suffers minimum AWGN effects. The anticipated channel will be established based on the coding technique that results in the lowest BER.

A. Possible Modulation of OFDM in 5G and Beyond

Applications for 5G and beyond wireless networks cover a wide range of new and unusual needs. Due to the huge variety of future devices, applications, and services like enhanced mobile broadband (eMBB), massive machine-type communications (mMTC), and ultra-reliable low-latency communications (URLLC), it is hard for a single radio technology to meet the needs of multiple services at the same time. The concept of a flexible, multi-numerology, OFDM-based frame structure It proposes parameterization as a possible solution to this problem. The type of modulation is one of the many things that is expected to have a big effect on how well the OFDM waveform can meet the different needs of 5G services [23].

B. AWGN Channel

The addition of wideband or white noise with a constant spectral density and a Gaussian distribution amplitude may be thought of as an additive white Gaussian noise (AWGN) channel model. Y = x + n, where x and y are the input and output signals, respectively, and n is the additive white Gaussian noise, may be used to represent any wireless system operating in an AWGN channel. The AWGN channel model has a fault in that it ignores fading, frequency selectivity, and dispersion. Additive noise, black body radiation from hot objects, thermal vibrations of atoms in antennas, and other natural phenomena are only a few examples of the sources of Gaussian noise.

However, by employing this channel as a paradigm, numerous satellites and deep-space communication lines may considerably benefit. Examples of channel factors that influence channel capacity include received signal intensity and noise power. The channel capacity for a channel that adds noise and uses Gaussian noise may be calculated using Eq. (3).

$$C = B\, log_2\left(1 + \frac{p}{N0B}\right) \tag{3}$$

C. AWGN Effect on the OFDM Channel

The OFDM symbol is changed by noise when there is noise present in the actual modulation, as shown in Eq. (4).

$$x = Q^{-1}X + n = \ Q^{H}X + n \tag{4}$$

The presence of AWGN noise (n) affects the modulated OFDM signal's phase and amplitude. The equation is mathematically implemented as in Eq. (5) below, which accounts for the distorted signal [24].

$$x[n] = \sum_{i=0}^{N-1} (W_N^{ni})^H X[i] + n[i] \tag{5}$$

where:

$$W_N = e^{j2\pi/N}$$

$$0 \leq n \leq N-1$$

D. Channel Coding in OFDM

1) Convolutional coding

To explain how the encoder turns a small amount of information (k bits) into an n-bit codeword by modulating the information bits with a convolution code and sending them through a linear finite-state shift register [24]. For its codeword, the encoder produces an n-bit output from a k-bit input. The encoder construction consists of n binary addition operations and K-stage shift registers with k bits per stage. Each bit produces an output codeword by adding specific bits from each step in binary order. The encoder has 2(K-1) k total potential states, a coding rate of k/n, and a constraint length of KK [25]. The convolution process is shown in Fig. 3.

The trellis diagram depicts the convolutional encoder. Either hard-decision decoding or soft-decision decoding may be used to use the Viterbi algorithm to decode convolutional codes based on the trellis diagram. The Viterbi method determines the route across the trellis diagram that has the smallest Hamming distance from the received sequence during hard-decision decoding.

While in soft-decision decoding, the algorithm chooses the route from the incoming sequence that yields the smallest Euclidean. In hard-decision decoding, one figures out the Hamming distance for a certain path in a trellis diagram, where c is the actual codeword, y is the quantized received sequence, and m is the total number of branches in the trellis diagram. The decoder chooses the data sequence from the route with the shortest hammering distance [26].

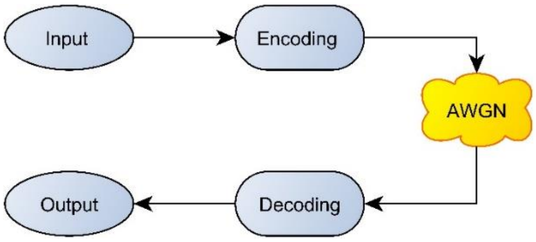

Figure 3. Convolution encoding

2) *Turbo coding*

Interleaving can be done in parallel, as in turbo coding, recursive coding, and systematic convolutional coding. They have found a way to get closer to the Shannon limit in terms of performance by using an iterative decoder with two soft input and soft output component decoders connected in series and sharing reliability information between them.

It is possible for the two recursive, systematic, convolutional encoders to be equivalent. R1 and R2 are the relative coding rates for the two encoders. It makes use of an interleaving permutation function. It is often a pseudo-random interleaving that rearranges bits in line with a defined but randomly created rule.

There are two interleaved parallel convolutional encoders in it. In response to the input m, each encoder emits the data bits m as well as the parity bits X_1 and X_2. The input and output of the channel are, respectively, the data bits m and the parity bits X1 and X2. The turbo encoding process is shown in Fig. 4.

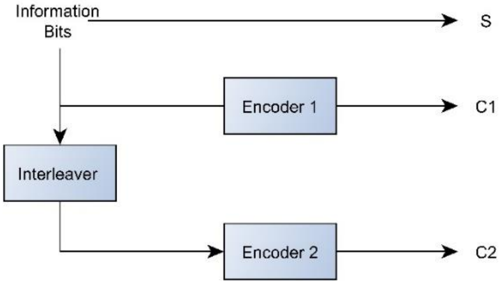

Figure 4. Turbo encoding.

3) *LDPC coding*

LDPC code is a class of linear block LDPC code in [27]. As part of the codeword design, Dv and Dc are defined. Because they are small relative to the codeword length, they produce parity. N 1s in each column and M 1s in each row are used to check matrix H. Because there aren't many non-zero elements in H, the parity-check matrix has a low density, hence the term “low-density parity-check codes.”

When S is the output codeword, R is the input block, and H is the generating matrix, the encoding may be present. The generator matrix G is not the design parameter for LDPC codes. Instead, it is the parity check matrix H. The generating matrix may still be determined using the parity check matrix, however. This is often done by systematizing H through proper elimination before finding the generating matrix directly [28]. The LDPC encoding is shown in Fig. 5.

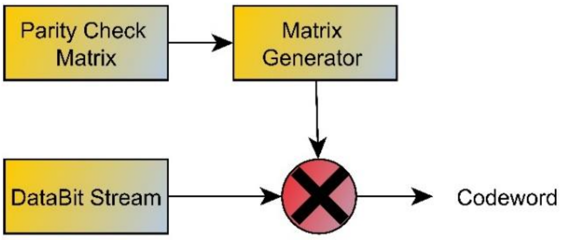

Figure 5. LDPC encoding.

The Sum Product Algorithm (SPA) is used to break LDPC codes [29]. It is based on the Tanner graph’s (CNs and VNs) communication with each other. The connected CNs receive channels LLR and LJ from the VNs at the start. Following their computation, the CNs transmit signals to their associated VNs.

Performance may vary depending on the order in which the nodes are scheduled. The schedule mentioned above, where all CNs and, subsequently, all VNs update their messages concurrently, is known as the “Flood schedule.” If serial scheduling is carried out, performance can be enhanced. Layered Belief Propagation (LBP) is a method for doing this that yields nearly twice as fast convergence as the flood schedule (in terms of iterations).

The communication system models in this paper are built using MATLAB functions for signal modulation and demodulation, employing AWGN channels, and coding techniques (LDPC, convolutional, and turbo codes), as shown in Table II.

TABLE II. MATLAB FUNCTIONS OF MODULATION AND DEMODULATION TECHNIQUES.

MATLAB QAM Mod	
nrSymbolModulate	Modulated Symbols
To map the bits in codeword to complex modulation symbols	codedBits
QAM, QPSK	Modulation
MATLAB QAM De-mod	
nrSymbolDemodulate	demodulatedSymbols
To demodulates the complex symbols using soft decision.	decodedBits
QAM, QPSK	demodulation
Compute the root mean square power divide by 10^(SNR/10)	noise_power
OFDM Modulation Functions	

To Generate transmit data	numSymbols = ceil
To Generating the resource grid (RG)	reshape
To Generating the time domain data	IFFT
To convert serial to parallel	RXtimeDataSymbol
Length of cyclic prefix adding to OFDM symbol	Add Cyclic Prefix (CP)
MATLAB OFDM De-mod Functions	
To Obtain the transmitted bits	reshape
To Generating the time domain data	FFT
To convert from Parallel to serial	TXtimeDataSymbol
Length of cyclic prefix subtracting form OFDM symbol	Remove Cyclic Prefix (CP)
AWGN Channel Functions	
To Select from noise variance (or signal to noise ratio Eb/No, Es/No, and SNR)	NoiseMethod
To use a variance property or manually applying variance through an input port	VarianceSource
LDPC Encoding Functions	
Used to Generate coded bits	nrDLSCHInfo
Used to Transport block CRC attachment	nrCRCEncode
Used for Code block segmentation and CRC attachment	nrCodeBlockSegmentLDPC
Used for LDPC encoding	nrLDPCEncode
Used for Rate matching	nrRateMatchLDPC
LDPC Decoding Functions	
LDPC decoding	nrLDPCDecode
Code block DE segmentation and CRC decoding	nrCodeBlockDesegmentLDPC
To Transport block CRC decoding	nrCRCDecode
Convolutional Encoding Functions	
To encode the binary vector MSG using the convolutional encoder defined by the MATLAB structure TRELLIS	convenc
To encode the input punctured CODE (Trellis structure of convolutional code)	Trellis structure
Convolutional Decoding Functions	
To decode the vector CODE using the Viterbi algorithm	Vitdec
Turbo Encoding Functions	
Trellis structure of turbo code	TrellisStructure
To interleave indices sources is selected from either an input port or a specific property	InterleaverIndicesSource
Turbo Decoding Functions	
Trellis structure of turbo code	TrellisStructure
To interleave indices sources is selected from either an input port or a specific property	InterleaverIndicesSource
Maximum positive number of iterations for Turbo decoding algorithm	MaximumIterationCount

IV. RESULT AND DISCUSSION

A. LDPC-OFDM

The procedure of generating bits randomly and passing them to the LDPC encoder, which then passes them through the OFDM modulation, will then pass through the AWGN channel. The LDPC decoder will be used to consider how the system will operate over different sizes of QAM modulation. The execution steps of the LDPC code with OFDM over AWGN to calculate the bit error rates are shown in Fig. 6.

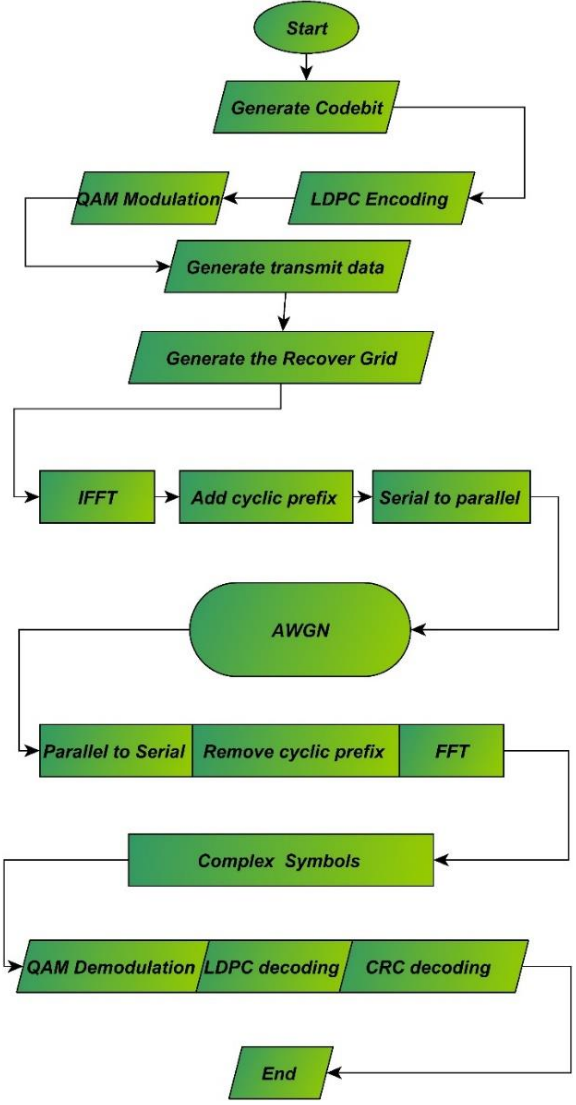

Figure 6. The process of low-density parity check code flow chart.

B. Turbo-OFDM

Fig. 7 describes the flow diagram for the turbo coding process and shows the input bit process moving from the input to the output through the turbo coding system over an OFDM system via the AWGN noise channel. From the input, the process then goes backwards to the output to see how the system is operating and how many mistakes are being made.

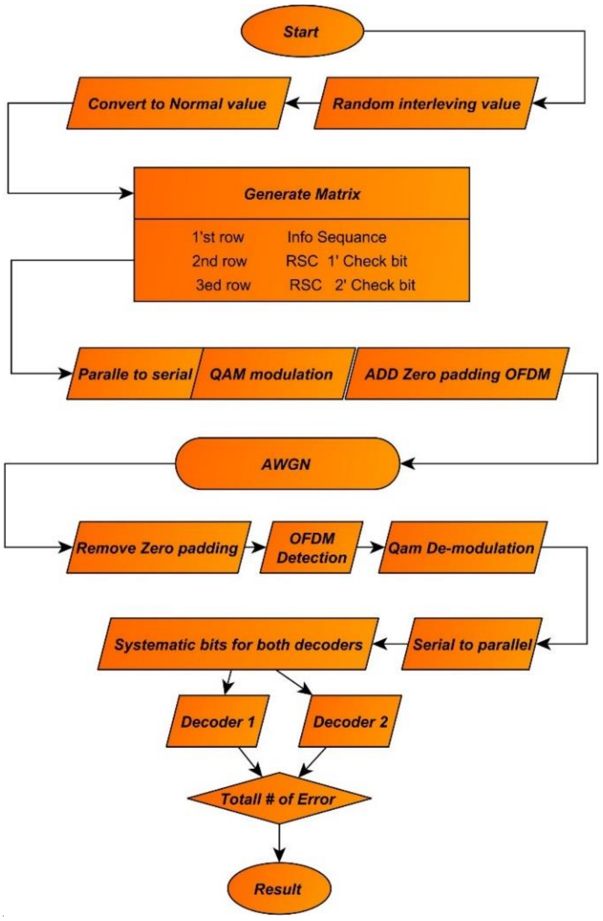

Figure 7. The process of Turbo code flow chart.

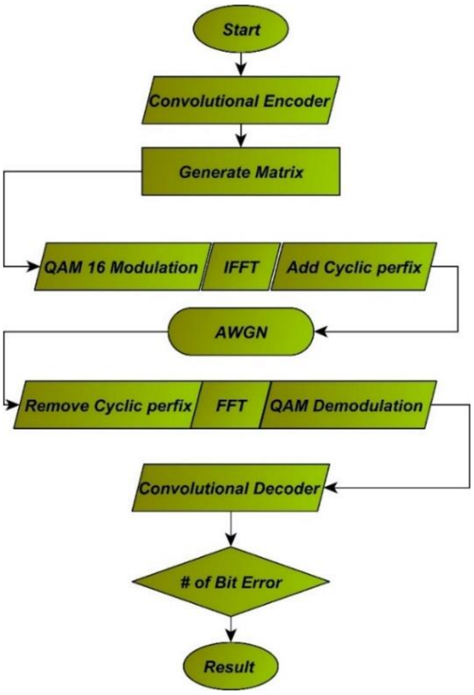

Figure 8. The process of Convolution code flow chart.

A. Convolution Code

The convolutional code is the simpler version of the turbo code that doesn't use interleaving. As illustrated in Fig. 8, a QAM modulator and a soft-decision decoder will be used to carry out encoding.

C. OFDM Comparison for (4 QPSK) Encoder and (4 QPSK) Decoder Using LDPC, Turbo, and, Convolutional codes

The three types of coding with the OFDM system are compared, and they show that the 0.645 LDPC code rate has the lowest BER of 0.001 to 0.38 Eb/No, turbo code has a 0.001 BER at 6.53 Eb/No, and convolutional has a BER of 0.001 to 4.75 Eb/No. The OFDM system model is shown in the waterfall figure by using the three types of coding and showing the BER using 4QPSK modulation (see Table III).

TABLE III. QPSK COMPARISON

	Eb/No	**BER**	**Eb/No**	**BER**	**Eb/No**	**BER**	**Modulation**
	LDPC		**TURBO**		**Convolution**		
Code Rate	660/1024		2/3		2/3		
1	**0.18**	0.034	1.59	0.046	2.24	0.093	**4 QPSK**
2	**0.283**	0.012	2.72	0.020	3.31	0.018	
3	**0.342**	0.004	4.23	0.006	4.18	0.003	
4	**0.37**	0.001	6.46	0.001	4.74	0.001	

As shown in Table IV, the best encoding and decoding method to use is LDPC-QPSK. This is an original and new contribution to coding using simulation, as, after thorough research, no research article has presented such results using such rates with detailed results and comparisons between three coding techniques. The simulation used is described in detail in the proposed system flow chart, which covers LDPC (Fig. 6), Turbo (Fig. 7), and Convolution (Fig. 8), as shown in Fig. 9.

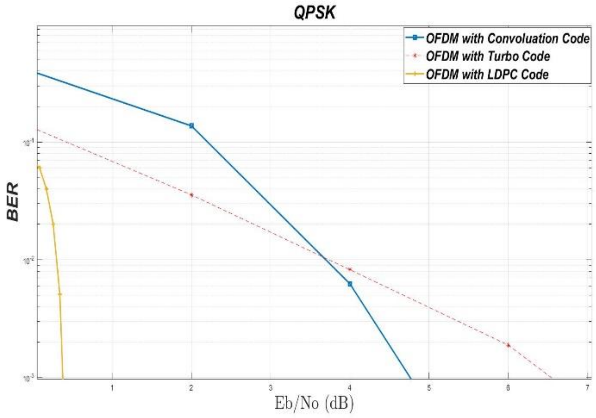

Figure 9. Comparison of three types of coding with unique 0.645 QPSK modulation over the AWGN channel.

Furthermore, comparing the three types of coding with the OFDM system shows that the 0.663 LDPC code rate has the lowest BER of 0.001 to 0.62 Eb/No, Turbo Code has a 0.001 BER of 6.40 Eb/No, and Convolutional has a BER of 0.001 to 4.75 Eb/No.

The OFDM system simulation is shown in Fig. 10. The three codes are used, and both the Figure and Table IV show the BER using 4QPSK modulation. So, the LDPC-QPSK is the best code to choose from the 3GPP sheet.

TABLE IV. THREE TYPES OF CODING RESULTS WITH A QPSK MODULATION

	Eb/No	**BER**	**Eb/ No**	**BER**	**Eb/No**	**BER**	**Modulation**
	LDPC		**TURBO**		**Convolution**		
Cod Rate	**679/1024**		**2/3**		**2/3**		
1	0.35	0.047	1.59	0.046	2.24	0.093	**4 QPSK**
2	0.51	0.017	2.72	0.020	3.31	0.018	
3	0.59	0.004	4.23	0.006	4.18	0.003	
4	0.62	0.001	6.46	0.001	4.74	0.001	

The simulation used to get these results is described in detail in the proposed system flow chart, which shows LDPC (Fig. 6), Turbo (Fig. 7), and Convolution (Fig. 8).

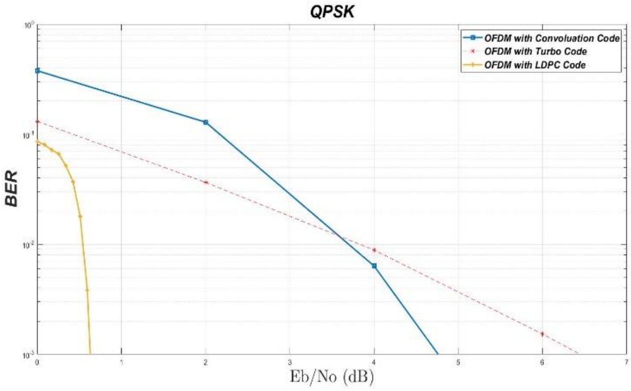

Figure 10. Comparison of three types of coding with 0.663 QPSK modulation over the AWGN channel.

D. OFDM Code Comparison for (16 QAM) Encoder and (16 QAM) Decoder Using LDPC, Turbo, and, Convolutional Codes

OFDM over an AWGN channel is used to compare convolutional, turbo, and LDPC codes. The simulations used are described in detail in the proposed system flow chart, which covers LDPC (Fig. 6), Turbo (Fig. 7), and Convolution (Fig. 8). The result of that simulation shows that the convolution comes with a BER of 0.001 at 7.95 Eb/No. Also, Turbo Code has a 0.023-bit error rate with a 7.98 Eb/No, so there is no big difference between them. LDPC with two rates was used and found to have a lower bit error rate of 0.001 at 0.65 and 3.26 Eb/No.

With an OFDM system over an AWGN channel with 16QAM modulation, this simulation compares the BER vs. Eb/No performance of the LDPC code, the Convolutional code, and the Turbo code, as shown in Fig. 11. The LDPC with a code rate of 0.313 has a low error rate of 0.001, a 0.65 Eb/No, an efficiency of 1.25, is better than Turbo and Convolutional, and has a minimum Eb/No.

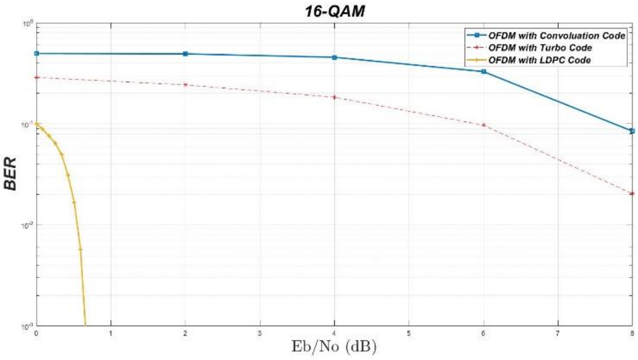

Figure 11. Comparison of three types of coding with 16 QAM modulation over an AWGN channel with LDPC rate of 0.313.

Table V shows that the LDPC code performs better than turbo and convolution. Because of this unique (un-used) ability to produce fewer errors, LDPC with the 5G specification is superior to other types of coding in terms of error correction.

TABLE V. COMPARISON OF THREE TYPES OF CODING

	Eb/No	**BER**	**Eb/No**	**BER**	**Eb/No**	**BER**	**Modulation**
	LDPC		**TURBO**		**Convolution**		
Code Rate	320/1024		1/3		1/3		
1	0.35	0.044	1.96	0.243	2.07	0.490	**16 QAM**
2	0.552	0.009	4.01	0.182	3.89	0.455	
3	0.619	0.002	6.01	0.095	6.01	0.325	
4	0.65	0.001	7.99	0.020	7.96	0.086	

The BER performance comparison between the LDPC code, Convolutional code, and Turbo code with an OFDM system over an AWGN channel, as shown in Fig. 12. The LDPC has code rate of 0.479 a low error rate of 0.001 with a 3.30 Eb/No, an efficiency of 1.91, is higher than Turbo and Convolutional. And detailed in Table VI.

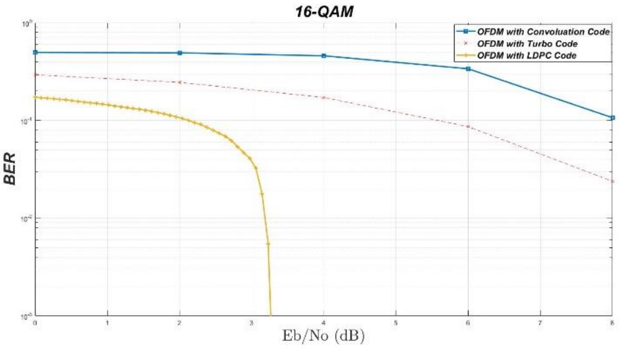

Figure 12. Comparison of three types of coding with 16 QAM modulation over an AWGN channel with LDPC rate of 0.479.

Fig. 13 shows the comparison between the three types of coding (LDPC, Turbo, and Convolution). LDPC is better than the two other codes, as seen in the figure and more fully detailed in Table VII, with a minimum BER of 0.90 Eb/No.

TABLE VI. THREE TYPES OF CODING RESULTS WITH A QAM MODULATION

	Eb/No	BER	Eb/No	BER	Eb/No	BER	Modulation
	LDPC		TURBO		Convolution		
Code Rate	490/1024		2/3		2/3		
1	1.01	0.053	2.15	0.237	2.60	0.482	16 QAM
2	2.00	0.019	4.19	0.173	5.00	0.391	
3	3.00	0.005	5.84	0.101	6.35	0.267	
4	3.30	0.001	7.97	0.023	7.97	0.099	

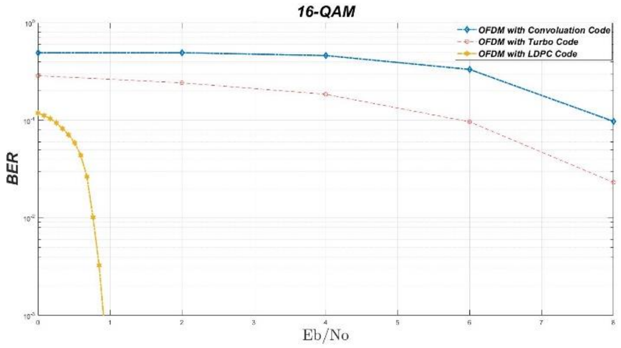

Figure 13. Comparison of three types of coding with 16 QAM modulation over an AWGN channel with LDPC rate of 0.332.

TABLE VII. THREE TYPES OF CODING RESULTS WITH A QPSK MODULATION

	Eb/No	BER	Eb/No	BER	Eb/No	BER	Modulation
	LDPC		TURBO		Convolution		
Code Rate	340/1024		1/3		1/3		
1	0.53	0.053	2.15	0.237	2.60	0.482	
2	0.70	0.019	4.19	0.173	5.00	0.391	
3	0.80	0.005	5.84	0.101	6.35	0.267	
4	0.90	0.001	7.97	0.023	7.97	0.099	16 QAM

Also, the used code in the 3GPP sheet shows LDPC has better performance than turbo and convolution code, as detailed in Table VIII and Fig. 14.

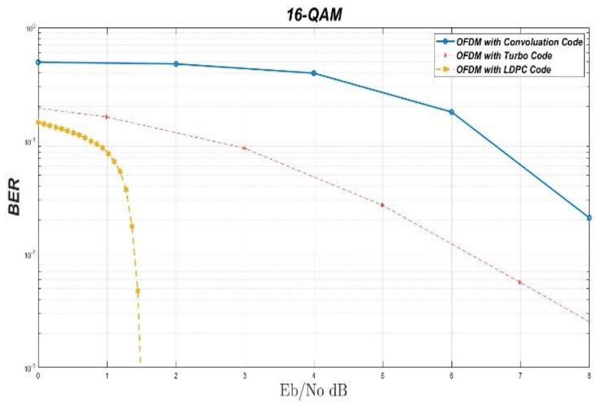

Figure 14. Comparison of three types of coding with 16 QAM modulation over an AWGN channel with LDPC rate.

TABLE VIII. COMPARISON OF THREE TYPES OF CODING.

	Eb/No	BER	Eb/No	BER	Eb/No	BER	Modulation
	LDPC		TURBO		Convolution		
Code Rate	378/1024		1/3		1/3		
1	0.237	0.131	1.96	0.243	2.07	0.490	16 QAM
2	0.99	0.071	4.01	0.182	3.89	0.455	
3	1.43	0.016	6.01	0.095	6.01	0.325	
4	1.75	0.001	7.99	0.020	7.96	0.086	

Using signal-to-noise ratio analysis, revealed that LDPC outperformed turbo and convolution codes. The BER performance comparison between the LDPC code, the convolutional code, and the turbo code with an OFDM system over an AWGN channel, as shown in Fig. (15), The LDPC has a code rate of 0.424, a low error rate of 0.001, a 2.55 SNR (dB), an efficiency of 1.69, is better than turbo and convolutional, and has a minimum BER of 0.111 and 0.452, respectively.

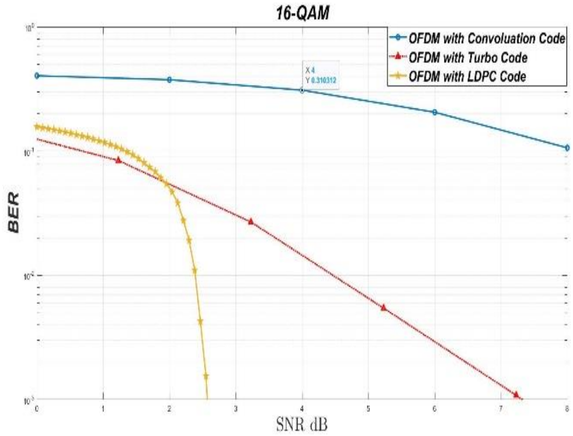

Figure 15. Comparison of three types of coding with 16 QAM modulation over an AWGN channel with LDPC rate of 0.424.

E. Statistical Comparison between LDPC, Turbo, and Convolution

In this section, Average BER is used to compare the three simulated coding techniques. This is shown in Figs. 16–17.

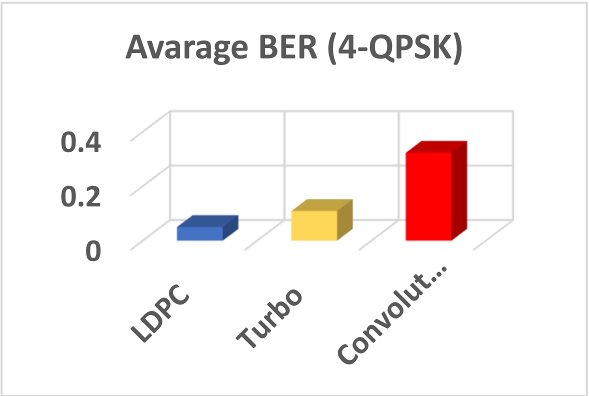

Figure 16. Comparison of three types of coding with 4 QPSK modulation.

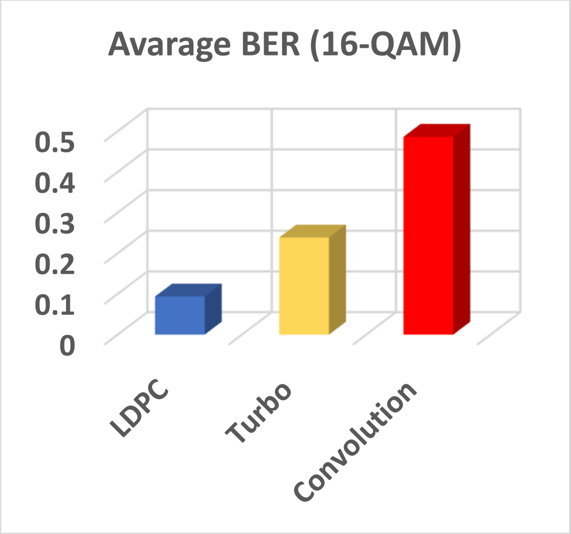

Figure 17 Comparison of three types of coding with 16 QAM modulation.

When all three ways of coding were compared, the average LDPC BER was the lowest. As shown in the figures, this indicates that LDPC is the most efficient technique for encoding and decoding compared to Turbo and Convolution codes. This is reflected in Eqs. (6–7).

Eqs. (7–8) can be extended to model average values and relate BER to R within a dynamic range covered by correlation parameters, α and β.

$$\boldsymbol{B}ER(LDPC) = \alpha BER(Turbo) \qquad (6)$$

where:

$$\boldsymbol{0.39 \leq \propto \leq 0.71}$$

$$BER(LDPC) = \beta BER(Convolution) \qquad (7)$$

where:

$$0.15 \leq \beta \leq 0.26$$

Eq. (9) shows how the rate and BER of very high-order modulation formats relate to each other and how it is computed [30].

$$R = 1 - BER_{in} \log_2 BER_{in} + (1 - BER_{in}) \log_2 (1 - BER_{in}) \qquad (8)$$

where:

$$BER_{in} = \frac{1}{2} erfc \frac{Q_{in}}{\sqrt{2}}$$

This specifies the absolute minimum Q value required to get the lowest BER.

F. Statistical Comparison between LDPC, Turbo, and Convolution

Table IX shows the simulation results of three investigated coding schemes.

TABLE IX. SIMULATION RESULT OF THE COMPARING CODES

Code type	Eb/No	BER	Eb/No	BER	Eb/No	BER	Number Of Bits
	LDPC		Turbo		Convolution		
Code Rate	779/1024		2/3		2/3		
1	0.3	0.058	0.3	0.108	0.3	0.321	**4**
2	0.4	0.041	0.4	0.101	0.4	0.304	
3	0.5	0.019	0.5	0.095	0.5	0.288	
4	0.6	0.001	0.6	0.089	0.6	0.273	
Code Rate	320/1024		1/3		1/3		
1	0.3	0.056	0.3	0.280	0.3	0.492	**16 unique**
2	0.4	0.035	0.4	0.278	0.4	0.492	
3	0.5	0.017	0.5	0.275	0.5	0.492	
4	0.65	0.001	0.65	0.272	0.65	0.492	
Code Rate	490/1024		1/3		1/3		
1	0.5	0.16	05.	0.28	0.5	0.495	**16**
2	1.5	0.128	1.5	0.25	1.5	0.492	
3	2.5	0.077	2.5	0.225	2.5	0.484	
4	3.5	0.001	3.5	0.191	3.5	0.468	

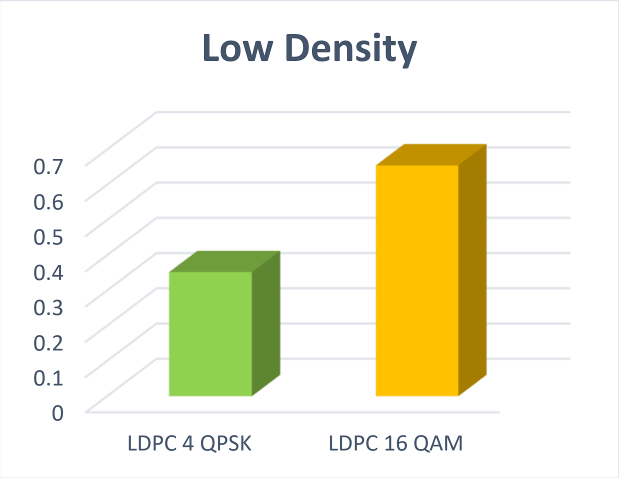

Figure 18. Comparison of low density LDPC values QPSK and QAM modulation.

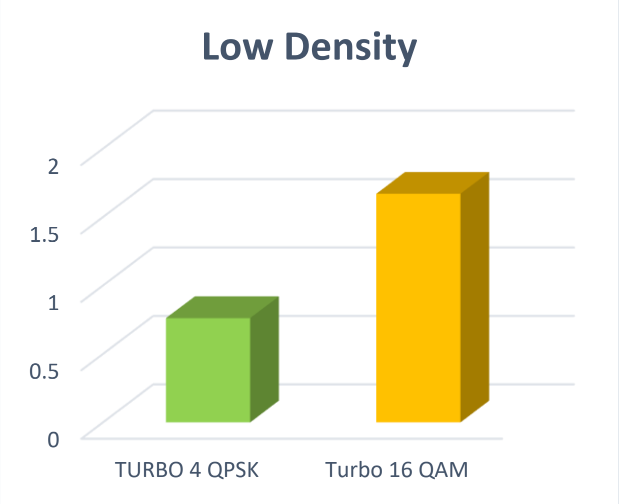

Figure 19. Comparison of low-density Turbo values QPSK and QAM modulation.

Figure 20. Comparison of low-density Convolution values QPSK and QAM modulation.

Assuming that the channel behavior is affected by the number of bits, Figs. 18–20 compare the three coding types (LDPC, Turbo, and Convolution) at low density rates for each type in two pairings, QPSK and QAM Modulation. It is observed that, depending on the number of coded bits, the channel encoding and decoding processes for identical channel circumstances would provide various outcomes. This suggests that BER levels are influenced by channel characteristics.

To apply the simulated system in real life, it requires high-performance wireless communication system design, installation, and on-board testing using distributed wireless and mobile nodes. Thus, to enable and optimize implementation, which results in a well-organized design, implementation, and validation process, the method used provides a reliable and general technique that shows the value of MATLAB throughout the FPGA prototype phases by using a unique HDL design entry. To figure out how well the suggested method works, a prototype of a real-time MIMO mobile WiMAX system is used in a case study. Tools:

1) Basic transmitter modeling
2) Hardware validation of the baseband transmitter model
3) Basic receiver modeling
4) Signal impairment modeling
5) System model refinement:

- RTL-implementation awareness
- Translation to fixed-point arithmetic
- Hardware constraints and specification awareness
- Satisfy a trade-off between numerical complexity and system performance.

1) MATLAB/HDL co-simulation
2) Data post-processing

Using a real-time direct link between the transmitter and receiver on the intended hardware platform the conversion phases may then be added to the scenario to make it more complete (i.e., ADC and DAC). This means that the MATLAB and HDL code must be re-simulated before the FPGA implementation can be checked in real time. This is done by connecting the output of the DAC device to the input of the ADC device with a cable. The final testing cycle can be broken up into two sub-stages: the first is connecting the RF front ends directly with cables, and the second is adding channels with antennas or a real-time channel emulator. Both sub-stages can be simulated in MATLAB and HDL before they are done. This progressive testing strategy enables the system's gradual characterization.

V. CONCLUSION

The simulation and modeling results show that the OFDM system using LDPC encoding and decoding over the AWGN channel has a better BER. The rates of 3GPP TS 32.214 that were used for LDPC least-significant codes across different region types by measuring BER performance over 5G specifications in the simulation for this work are used at different rates than over an AWGN channel and compared to other encoding techniques (Turbo, Convolution) in a limited, constrained environment (MATLAB).

Simulations at different rates produced new results using LDPC coding, which may become an official reading in the future. The simulated results proved to be more efficient with a low BER. Thus, it gives better performance compared to Turbo and Convolution codes. Due to the results of the simulation, LDPC showed to possess the best performance over all types of modulation levels and rates. This is obtained using code compilation and modifications for LDPC, Turbo, and Convolution. Two correlative equations with a distribution range are presented for the relationships between LDPC and Turbo and LDPC and Convolution for the conditions described in the analysis.

The main contribution of this work is that it simulates different types of coding using MATLAB code. The goal is to get a full picture of how well each encoding method works and how well it can be used in 5G networks.

This study's results show that OFDM with LDPC has better performance to reduce BER with an Eb/No of 0.65, while other studies produced a 1.7 Eb/No. Given that the findings are different from the rates listed in the 3GPP tables, they may be utilized as references for reliable coding and adaptive categorization. LDPC is now good enough to be in the fifth generation.

The same methods may be used in the future to study the error distributions of coded OFDM in 5G networks, utilizing different forms of noise distribution and comparison with polar code instead, but with LDPC QAM modulation of 512, 1024, and 2048 bits instead. Additionally, an adaptive communication channel must be constructed to allow for optimization in relation to the density of coded bits in order to support and take into consideration different coding rates.

CONFLICT OF INTEREST

The author declares no conflict of interest.

AUTHOR CONTRIBUTIONS

Mohammed A. Aljubouri carried out design, initial mathematics, simulation, and writing the draft copy. Mahmoud Z. Iskandarani carried out analysis of results, mathematical modeling; all authors had approved the final version.

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