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Energy Optimized LDPC Codes for Next-Generation MIMO OFDM Systems

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ABSTRACT: With the increasing prevalence of internet services in our daily lives, there is a growing demand for spectrum, resulting in a shortage of available frequencies. This is primarily due to the recent surge in subscribers seeking faster and more dependable data rates. Researchers globally have suggested various solutions to combat the spectrum shortage through technologies, modulation schemes, beamforming, intelligent reflective surfaces, and channel coding schemes. With respect to channel coding, multiple codes have been proposed to overcome challenging and uncertain channel conditions including Turbo, Fountain, and LDPC (Low Density Parity Check) Codes. In addition to this, several transformation techniques such as wavelet transforms have also been evolved to enhance the spectral efficiency. This paper introduces a DWT (Discrete wavelet transform)-incorporated LDPC system to meet the rigorous demands of 5G deployment and use cases. A comparative analysis of the proposed codes is conducted to assess their suitability for next-generation communication networks, considering SNR (Signal-to-Noise Ratio), BER (Bit Error Rate), and spectral efficiency. Simulation results indicate that the proposed code outperforms the existing codes by achieving a BER of 10^{-4} with SNR=7dB for Rayleigh Faded wireless channel Further, the proposed system is employed in STBC (Space Time Block Coded) and SFBC (Space Frequency Block-Coded) systems for high-speed communication. Simulated results reveal that the proposed system works well in SFBC systems and deemed to be the most suitable code for the successful deployment of 5G and beyond systems.

Keywords: Keyword 1, keyword 2, number of keywords is usually 3-7, but more is allowed if deemed necessary

1. INTRODUCTION

Currently, the wireless industry is confronted with the challenge of accommodating a vast number of users in a limited spectrum while maintaining high reliability [1-5]. The surge in wireless traffic has heightened the need for energy-efficient and spectrally optimized channel coding techniques for next generation wireless networks. In 1948, Shannon established an upper limit on the bandwidth efficiency achievable for error-free transmission [6]. Since then, researchers have concentrated on creating channel coding techniques that can meet this Shannon capacity limit. Turbo codes, invented by C. Berrou [7], are among the capacity-approaching codes which are constructed by concatenating two short block codes in a serial/parallel manner, interlinked via interleaving. Following the invention of Turbo codes, LDPC Codes (originally invented by Robert Gallager [8]) were rediscovered by Mackey in 1995 [9]. LDPC codes have supplanted Turbo codes in numerous wireless standards, including IEEE 802.11, IEEE 802.16, and IEEE 802.22 [10, 11]. Other than to be a part of many wireless standards, these codes are used for many communication paradigms such as satellite communications, UWB (ultra-wideband) communications [12], cognitive radio networks [13], and healthcare systems [14]. Several forms of LDPC Codes have been explored till date. They belong to the family of multiple-parity check codes and are among the top contenders for 5G channel coding [10]. LDPC codes are mainly classified as random and structured [15]. Quasi-Cyclic Low-Density Parity Check (QC-LDPC) codes are a type of structured LDPC codes, and have become increasingly popular due to their appealing characteristics, such as decreased encoding and decoding complexity, straightforward hardware implementation, and enhanced iterative decoding performance.

The Orthogonal Frequency Division Multiplexing (OFDM) waveform, in the realm of 5G millimeter-wave communications, is an enabling technology has a potential to combat the ISI (Inter-Symbol Interference) by converting

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frequency-selective channels into flat fading channels [16]. MIMO (Multiple-Input Multiple-Output) technology is another powerful technology that can reduce bit-error rates to make wireless communication systems/networks more reliable. Considering the benefits offered by these technologies, Space-Time Block Coding (STBC) is used with a Multiple-Input Multiple-Output (MIMO) system architecture to mitigate the bit-error rate and enhance the system's diversity gain. The article presents an energy- and spectrally-efficient MIMO OFDM system utilizing QC-LDPC coding.

1.1 RELATED WORK AND RESEARCH GAPS

LDPC (Low-Density Parity-Check) codes are widely used in various communication systems, including next-generation MIMO (Multiple Input Multiple Output) OFDM (Orthogonal Frequency Division Multiplexing) systems. MIMO OFDM is a key technology in modern wireless communication systems, providing higher data rates, improved spectral efficiency, and better reliability in various environments. They are known for their excellent error correction capabilities and low decoding complexity, making them an attractive choice for MIMO OFDM systems. They are part of the coding schemes used for error correction in the physical layer of communication systems.

LDPC codes have gained popularity due to their capacity-approaching performance, which means they can achieve performance close to the Shannon limit. Moreover, advancements in hardware and algorithms have significantly reduced the decoding complexity of LDPC codes, making them feasible for use in real-world next-generation MIMO OFDM systems. Significant literature is available on these codes for the successful implementation of next-generation communication networks. Table 1 shows the overview of some of the significant developments in these codes to date.

Table 1. - Related Work and Research Gap

Ref. No.	Year	Description
[16]	1948	The work published by Shannon revolutionized the channel coding field. Since then the researchers focused on investigating the channel coding techniques that can achieve the Shannon capacity.
[17-19]	1949, 1960	An overview about algebraic codes such as Hamming codes, Golay Codes, Reed-Muller Codes, and Bose Chaudhari codes is presented. These codes helps in reducing the error rate significantly while attaining channel capacity limit.
[15]	1993	Turbo codes invented by C.Berrou are among the capacity-impending codes. These codes are built by the serial or parallel concatenation of two short block codes interlinked via interleaver.
[20-21]	1963, 1997	After the invention of Turbo codes, LDPC Codes (originally invented by Robert Gallager were rediscover ed by Mackey in 1997. These codes are named Gallager-based LDPC Codes. Due to the randomized encoding method, these codes have large complexity.
[22]	2013	This paper presents a new structured way to design the parity check matrix of LDPC Codes and are named as Quasi-cyclic LDPC Codes. QC (Quasi-cyclic codes) are one of these structured codes whose encoding process includes the use of simple shift registers. Their error performance is identical with random codes but because of lesser intricacy these codes are gaining attention as compared with random LDPC codes.
[23]	2015	Paper shows that the fountain codes aid in reducing the PAPR ratio, thus improves the performances of th e wireless systems. These codes are also capacity-approaching codes.
[24]	2019	This paper compared LDPC and Turbo codes on the basis of several parameters including complexity, maximum data rate and error correction ability. It has been observed that It has been observed that LDPC codes have lesser decoding complexity and LDPC incorporated systems provide higher data rates.
[25]	2016	The authors have proposed a new self-cancellation method based upon Discrete Wavelet Transform so as to improve the performance of OFDM systems and to reduce the effect of ICI (Inter Carrier Interference). Thus, DWT based OFDM systems have the advantage of lesser ICI too.
[26]	2017	The researcher showed the impact of using DWT transform as compared with the FFT in WiMAX systems employing convolutional coding as an error correction technique. Also, it has been observed that the DWT-based system has provided better bit-error-rate as compared with the FFT based system.
[27]	2021	The author described the enormous advantages of using wavelets including better spectrum efficiency, lesser inter-symbol interference, and lesser inter-carrier interference. Convolutional coding is used as a channel coding technique. Rayleigh and Rician channels are considered as the channel environments. WHT is used as a precoding technique. It has been observed that the wavelet-based WIMAX system requires SNR of 40dB while the conventional WIMAX system requires an SNR of 48 dB in order to attain a bit-error rate of 10^{-5} over Rayleigh channels. Shankar elaborated on the implication of SFBC OFDM systems over different channels and elaborated on this system as a choice of 5G scenario. Precoding technique used is Fractional Fourier Transform. The conventional system is highly affected by frequency variations which can be conquered by the proposed precoded system.

[28]	2023	The author elaborated on the application of QC-LDPC Codes This paper illustrates an improved QC-LDPC Code using DWT as a precoding scheme thereby enhancing bandwidth efficiency and lowering the bit-error rate of the wireless system. This technique provides SNR improvement thereby enhancing bandwidth efficiency too.

Table 2. - Comparison of previous research and proposed work

Ref. No.	LDPC Code	Parameters	Precoding Technique	STBC/SFBC System	Channel under consideration
[29]	QC- LDPC Codes	Bit-error-Rate	No	MIMO	High-Speed Channels
[30]	QC-LDPC Codes	Bit-error-Rate and Spectral Efficiency	No	No`	Free-Space Optical Channels
[31]	LDPC	Bit-error-Rate	Yes	Yes	Gamma Fading Channel
[27]	Convolutional Codes	Bit-error-Rate	Yes	Yes	Rayleigh Fading Channel
[28]	QC-LDPC Codes	Bit-Error-Rate and Spectral Efficiency	Yes	No	Rayleigh Fading Channel
Proposed	QC-LDPC Codes	Bit-Error-Rate and Spectral Efficiency	Yes (DWT and WHT)	Yes	Rayleigh Fading Channel and High-speed channels

In most of the previous works, researchers have focused on the development of codes with high cardinality. However, to the best knowledge of the authors, no work related to the implementation of various transformation schemes in the MIMO SFBC system employing capacity approaching channel codes (LDPC, Turbo, and Fountain codes) and precoding techniques is available to date. Based on research gaps highlighted in Table 2, novel energy-optimized LDPC codes are proposed in this paper for next-generation MIMO OFDM systems.

1.2 PAPER CONTRIBUTIONS

Drawing from the research gaps identified in the preceding section, this paper's principal contributions are summarized below:

1. A methodical exposition of the encoding and decoding procedures of LDPC codes is presented.
2. The Discrete Wavelet Transform (DWT) is integrated into the system in order to enhance its spectral efficiency.
3. This paper demonstrates the deployment of a DWT-incorporated LDPC system on the STBC architecture and provides an analysis of its BER performance for Rayleigh faded channels.
4. This paper undertakes a comparative evaluation of two parameters, namely spectrum efficiency and bit-error rate, for LDPC, Turbo, and Fountain codes.

1.3 PAPER ORGANIZATION

The subsequent paragraphs of the paper are delineated as follows: The first section, Section I, outlines the essential conditions necessary for encoding 5G LDPC codes. Section 2 gives a comprehensive survey on the decoding methods employed for Repetition codes, Single Parity Check codes, and LDPC codes. Section 3 expounds on the system model and the research methodology adopted for the proposed system. The fourth section, Section 4, highlights the simulated results and discussion on them. Lastly, the paper concludes in Section 5.

2. QUASI CYCLIC LDPC CODES

Among various error correction techniques, LDPC codes have gained attention and have become one of the leading contenders for 5G channel coding [10]. LDPC codes are characterized by a parity check matrix, originally conceived by Robert Gallager in his doctoral dissertation, which possesses a distinctive attribute of having a relatively small number of ones. Consider H as the parity check matrix with dimension$(n-k)\times k$. The count of ones, N_o is less than the total number of elements present in the matrix i.e. $N_o \ll (n-k)k$ [8]. Much like the parity check matrix employed in LDPC codes, the Tanner Graph serves as a graphical representation for LDPC codes. Considering a parity check matrix defined in (1) as:

$$H = \begin{bmatrix} 1 & 0 & 1 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 1 & 1 & 0 & 1 \\ 1 & 0 & 0 & 1 & 1 & 1 \end{bmatrix} \quad (1)$$

Figure 1 illustrates the Tanner Graph corresponding to H. Degree of each bit node and parity node represents the number of edges arising out of that particular bit node, b_i and parity node p_j respectively where $1 \leq i \leq k$ and $1 \leq j \leq (n-k)$. Both the construction of the parity check matrix, as well as the decoding algorithm, significantly impact the efficacy of LDPC codes. Recent research has focused on developing efficient and effective algorithms for encoding and decoding LDPC codes. Protograph-based LDPC codes, which possess advantageous properties, have gained widespread use in practical applications [17-19]. The following outlines the encoding and decoding procedures for Protograph-based LDPC codes, a type of QC-LDPC code.

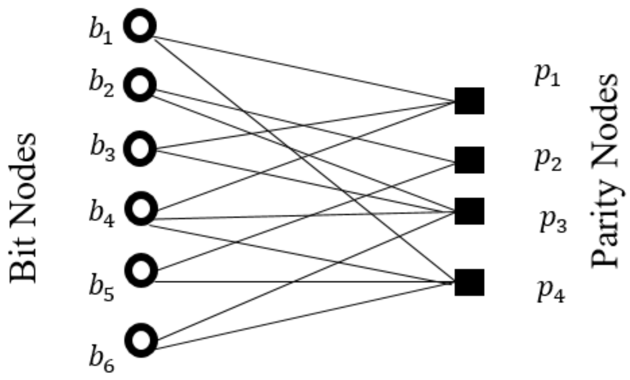


FIGURE 1. - Tanner Graph corresponding to'H

2.1 LDPC Encoding Procedure

The development of parity check matrix for 5G LDPC codes relies on proto-matrices, also known as base graphs, which are repeatedly duplicated through circular permutations. The dimensions of the different proto-matrices are enlisted in Table 3. 5G LDPC Codes use two base graphs named B_a, B_b of dimensions 46×68 and 42×52 respectively as defined by (2).

$$B_a or\ B_b = \begin{bmatrix} A & B & C \\ D & E & F \end{bmatrix} \quad (2)$$

Table 3. - Dimensions for submatrices in Proto-matrix

Sub matrices in Proto-matrix B_a or B_b	Dimensions for B_a	Dimensions for B_b
A	4×22	4×10
B	4×4	4×4
C	4×42	4×38
D	42×22	38×10
E	42×4	38×4
F	42×42	38×38

Rate matching allows the use of a part of the Proto-matrix to send the output code word to construct LDPC Codes of variable rates. Table 4 shows the method for expansion from the proto-matrix (i.e. for constructing a parity check matrix from the proto-matrix),

Table 4. - Expansion from Proto-matrix to Parity Check Matrix

Elements in Base Matrix	Corresponding Expansion in Parity Check Matrix
-1	$E \times E$ all zero matrix
$0 \leq j \leq E-1$	Shifting the identity matrix j times

Considering H as Parity Check Matrix with rate ,$R = 1/2$ in systematic form i.e. $H = [P|I]$ where matrix P contains parity bits and I is an identity matrix as depicted in (3)

$$H = \begin{bmatrix} 1 & 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

where H must satisfy the (4)

$$cH^T = 0 \quad (4)$$

For this parity check matrix, the output code-word

$$c = [x_1\, x_2\, x_3\, p_1\, p_2\, p_3] \quad (5)$$

where p_1, p_2, p_3 are the parity bits [11,19].

2.2 LDPC Decoding Procedure

To have a vivid illustration of the decoding procedure of the LDPC Codes; Repetition codes [20,21] and Single Parity check codes are mathematically investigated first.

2.2.1 Repetition Codes

Figure 2 shows the system model for SISO decoder. To understand the working, consider the example for Repetition codes with repetition of 4, i.e. corresponding to a single message bit x_i, the code word is $c_i = [x_i\, x_i\, x_i\, x_i]$.

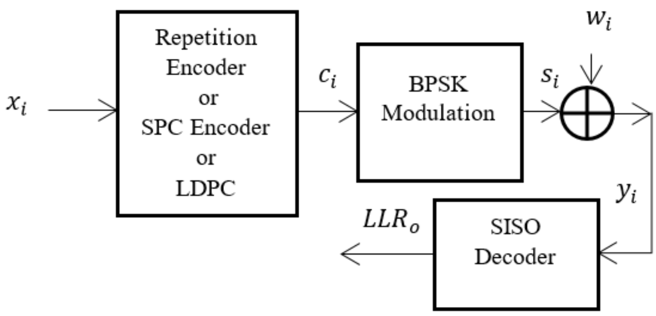


FIGURE 2. - System Model for SISO Decoder

Log-likelihood Ratio can be computed as: Consider posterior probabilities as $P_r(c_1 = 0|y_1)$and $P_r(c_1 = 0|y_1)$ where $P_r(c_1 = 0|y_1)$ represents the probability of decoded bit as 0 if y_1 is the received signal, Using Baye's Theorem:

$$P_r(c_1 = 0|y_1) = \frac{f(y_1|c_1=0)}{f(y_1)} P_r(c_1 = 0) \quad (6)$$

In a similar way,

$$P_r(c_1 = 1|y_1) = \frac{f(y_1|c_1 = 1)}{f(y_1)} P_r(c_1 = 1) \quad (7)$$

Dividing (6) and (7) and considering the prior probabilities as half as there is an equal probability to transmit 1 or 0.

$$\frac{P_r(c_1 = 0|y_1)}{P_r(c_1 = 1|y_1)} = \frac{f(y_1|c_1 = 0)}{f(y_1|c_1 = 1)} \quad (8)$$

Now, if $c_1 = 0$, $y_1 = 1 + N(0, \sigma^2)$, where $N_0(0, \sigma^2)$ represents Gaussian noise distribution with zero means and σ^2 variance. Similarly, if $c_1 = 1$, $y_1 = -1 + N_1(0, \sigma^2)$. Thus, (8) can be written as

$$\frac{e^{-((y_1-1)^2/2\sigma^2)}}{e^{-((y_1+1)^2/2\sigma^2)}} = e^{\frac{2y_1}{\sigma^2}} \quad (9)$$

This defines the intrinsic likelihood ratio for y_1. So, the intrinsic log-likelihood ratio (LLR) for y_1 can be obtained by taking the log of (9)

$$LLR_1 = \frac{2y_1}{\sigma^2} \tag{10}$$

As output LLR. i.e., LLR_o is defined by SISO Decoder as the combination of intrinsic (depends only on y_1) and extrinsic LLRs (which are dependent upon y_2, y_3 and y_4).

$$LLR_o = log\ \frac{P_r(c_1 = 0|y_1, y_2, y_3, y_4)}{P_r(c_1 = 1|y_1, y_2, y_3, y_4)} = log\ \frac{f(y_1, y_2, y_3, y_4|c_1 = 0)}{f(y_1, y_2, y_3, y_4|c_1 = 1)} \tag{11}$$

Proceeding in a similar way as in (8-10), we get:

$$LLR_o = \frac{2y_1}{\sigma^2} + \frac{2y_2}{\sigma^2} + \frac{2y_3}{\sigma^2} + \frac{2y_4}{\sigma^2} = \frac{2(y_1 + y_2 + y_3 + y_4)}{\sigma^2} \tag{12}$$

2.2.2 Single Parity Check Codes

In Single Parity Check Codes, considering input bits as $\{x_1, x_2 \ldots\ldots, x_k\}$ i.e. of length k and output code word with length $n = k + 1$ as $c_i = \{x_1, x_2 \ldots\ldots, x_k, p\}$ where p is the single parity bit and has a value of $p = x_1 \oplus x_2 \oplus x_3 \ldots\ldots \oplus x_k$. Considering a (3,2) Code where code word length is three and two input bits are taken from the input block. In this case, LLR_o (say for y_1) is a function of intrinsic information about c_1(which is obtained from y_1)and extrinsic information about c_1 (that is obtained from y_2, y_3 and y_4). Likelihood Ratios are specified as:

Intrinsic Likelihood Ratio

$$LR_1 = \frac{P_r(c_1 = 0|y_1)}{P_r(c_1 = 1|y_1)} = \frac{2y_1}{\sigma^2} \tag{13}$$

Extrinsic likelihood Ratio

$$L_{ext,1} = \frac{P_r(c_1 = 0|y_2, y_3)}{P_r(c_1 = 1|y_2, y_3)} \tag{14}$$

As c_1 is obtained by XORing of c_2 and c_3 i.e. $c_1 = 0$ if both are the same and $c_1 = 1$ if both are different. Thus if $P_r(c_i = 0|y_2, y_3) = P_i$ for $1 \leq i \leq 3$, then

$$P_r(c_1 = 0|y_2, y_3)\ or\ (P_1) = P_2P_3 + (1 - P_2)(1 - P_3) \tag{15}$$

Similarly

$$P_r(c_1 = 1|y_2, y_3) or (1 - P_1) = P_2(1 - P_3) + P_3(1 - P_2) \tag{16}$$

Subtracting (15) from (16)

$$(P_1) - (1 - P_1) = P_2\big(P_3 - (1 - P_3)\big) + (1 - P_2)\big((1 - P_3) - P_3\big) \tag{17}$$

On expanding (17), we get

$$\frac{(P_1)-(1-P_1)}{(P_1)+(1-P_1)} = \frac{(P_2-(1-P_2))}{(P_2)+(1-P_2)} \frac{(P_3-(1-P_3))}{(P_3)+(1-P_3)} \tag{18}$$

Dividing by P_1, we get

$$\frac{(1)-\frac{(1-P_1)}{P_1}}{(1)+\frac{(1-P_1)}{P_1}} = \frac{(1-\left(\frac{1-P_2}{P_2}\right))}{(1+\left(\frac{1-P_2}{P_2}\right))} \frac{(1-\left(\frac{1-P_3}{P_3}\right))}{(1+\left(\frac{1-P_3}{P_3}\right))} \tag{19}$$

Also, (14) can be written as

$$L_{ext,1} = \frac{P_1}{(1-P_1)} \tag{20}$$

Thus, using eq.(20), (19) can be written as

$$\frac{(1)-\exp(-L_{ext,1})}{(1)+\exp(-L_{ext,1})} = \frac{(1-\exp(-L_{ext,2}))}{(1+\exp(-L_{ext,2})} \tag{21}$$

As $\tanh(x) = \frac{1-\exp(-2x)}{1+\exp(-2x)}$, Using this expression, (21) can be expressed as

$$\tanh\left(\frac{L_{ext,1}}{2}\right) = \tanh\left(\frac{L_{ext,2}}{2}\right)\tanh\left(\frac{L_{ext,3}}{2}\right) \tag{22}$$

Eq.(22) is known as tanh rule[20,21].

2.2.3 Low-Density Parity Check Codes

Assume that c_i where $1 \le i \le n$ be the code-word of length n and the received signal by $y_i = s_i + w$ where y_i be the received signal and s_i be the BPSK-modulated signal. In Single Parity Check, only two random variables are considered as expressed in (22). The same can be expanded to $'v'$ random variables as

$$\tanh\left(\frac{L_{ext,1}}{2}\right) = \tanh\left(\frac{L_{ext,2}}{2}\right)\tanh\left(\frac{L_{ext,3}}{2}\right) \dots \dots \tanh\left(\frac{L_{ext,w}}{2}\right) \tag{23}$$

Taking an example of a part of LDPC matrix

$$H = \begin{bmatrix} 1 & 0 & 1 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 \\ 1 & 1 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 & 1 & 1 \end{bmatrix} \tag{24}$$

Here the information about the first bit is obtained from the intrinsic information obtained using (13) (First estimated value) and extrinsic information is obtained from Rows 1, 3 and.4. Thus, the extrinsic information is:

$$\begin{aligned} &Row\ 1 && L_{11} = c_1 + c_3 + c_4 = 0 \\ &Row\ 3 && L_{13} = c_1 + c_2 + c_6 = 0 \\ &Row\ 4 && L_{14} = c_1 + c_4 + c_5 + c_6 = 0 \end{aligned} \tag{25}$$

Here addition is Modulo 2 addition. Thus, all bit nodes will pass their intrinsic information to all the check nodes and the check nodes will further compute the SISO calculations and forward the extrinsic information to the bit nodes. Thus, the decoding process proceeds in two steps as follows:

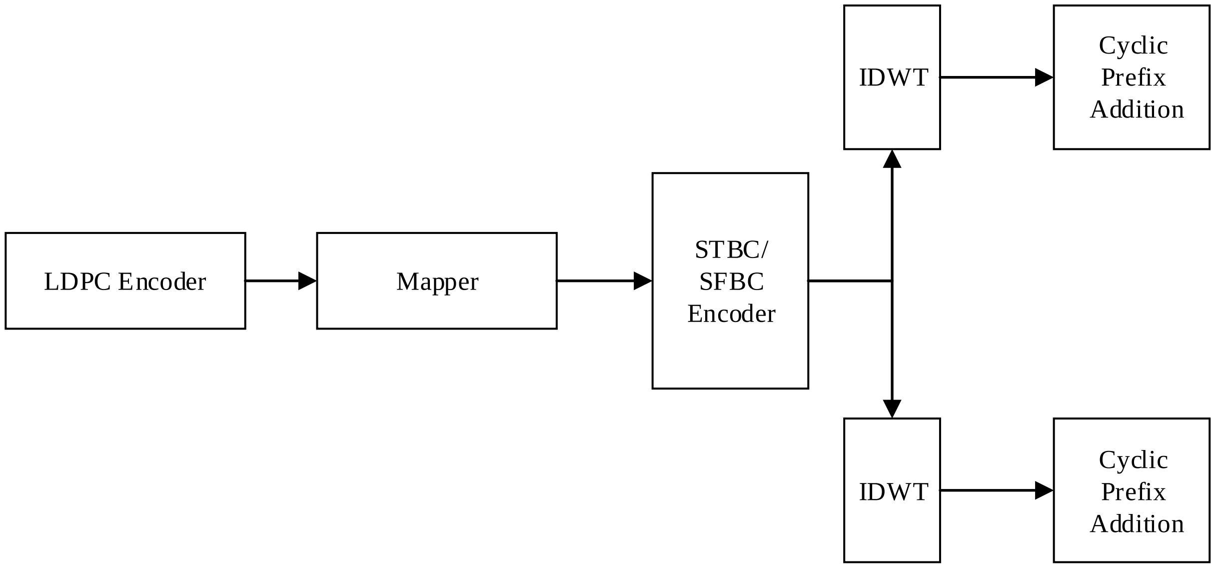
Step 1: Check node update: Row operations are performed and the process is similar to single parity check SISO decoding for each check node.

Step 2: Bit node update: Column operations are performed and the process is just like repetition code SISO decoding for each bit node.

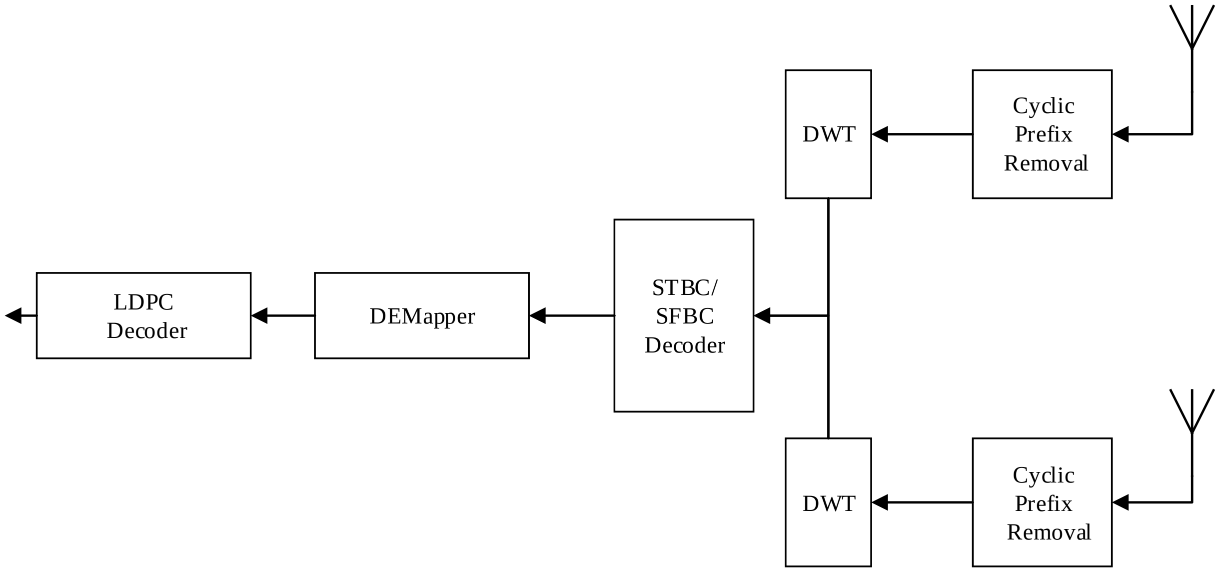
The two steps are repeated iteratively and the final decision is made after several iterations [20].

3. RESEARCH METHODOLOGY

Figure 3 describes the block diagram of LDPC Coded STBC system using DWT methodology. The algorithm I specify is the traditional model of FEC (Forward Error Correction) Coded FFT system. The proposed system model along with its corresponding algorithm is depicted in Fig.3a)-b). Simulation Parameters are chosen as particularized in Table 3. Data bits are sent to the QC-LDPC Encoder of Rate(R=1/2). Transformation techniques such as FrFT (Fractional Fourier Transform), WHT (Walsh Haar Transform), DCT (Discrete Cosine Transform), and DWT (Discrete wavelet) have been applied in various fields including biomedical research [24-25], wireless communications [26], signal processing [27], and power line communications [23-30] [32]. The proposed algorithm incorporates the use of DWT instead of using FFT in a conventional LDPC coded OFDM system. DWT (Discrete wavelet transform) has the benefits of consuming lesser bandwidth thus enhancing the spectral efficiency and also aids in reducing bit-error rate. In addition, Alamouti system model is used which further enhances the diversity gain there by decreasing the bit-error-rate. Simulations are performed on MATLAB environment.



(a)



(b)

FIGURE 3. - Block Diagram of LDPC encoded STBC System Model (a) Encoder (b) Decoder

ALGORITHM I : CONVENTIONAL ALGORITHM

Step 1: Initialize he system parameters as in Table 3.
Step 2: Implement QC- LDPC Encoding and choose BPSK as signal constellation.
Step 3: Execute IFFT as a transformation technique
Step 4: Data transmission over AWGN channel.
Step 5: Apply FFT transformation technique.
Step 6: Perform Channel Decoding and Demodulation technique.
Step 7: Compute BER for various SNR values

ALGORITHM II : PROPOSED ALGORITHM

Step 1: Initialize he system parameters as in Table 3.
Step 2: Execute QC-LDPC Encoding and chose B-PSK as signal constellation.
Step 3: Execute Alamouti STBC Encoding.
Step 4: Apply IDWT transformation technique.
Step 5: Transit the data via AWGN and Rayleigh channel.
Step 6: Apply DWT transformation technique and perform STBC Decoding.

Step 7: Accomplish Channel Decoding and Demodulation techniques
Step 8: Calculate BER for various SNR values.

4. RESULTS AND DISCUSSIONS

This paragraph showcases the outcomes of simulations conducted in MATLAB to verify the suggested system model. The simulations were performed on the AWGN channel, utilizing three distinct channel coding techniques, namely Fountain Codes, Turbo Codes, and LDPC Codes. The simulation process utilized the DWT as the transformation technique and BPSK as the signal constellation. Alamouti STBC was incorporated to reduce the effects of fading. Two performance metrics, bit-error-rate and spectral efficiency, were considered, and graphs were studied for different channel coding techniques.

Table 5. – Simulation Parameters

Parameter	Value
FFT size	128
Transformation Technique	Discrete-Wavelet-Transform (DWT)
Channel Encoding	QC-LDPC(R=1/2), LTE-Turbo, LTE-Fountain
Signal Constellation	B-PSK
Precoding Scheme	Walsh Hadamard Transform
Decoding Algorithm	LLR Iterative Decoder (For LDPC Codes) Trellis-Based Decoder (For Turbo Codes) Iterative Decoder (For Fountain Codes)
Diversity Technique	Alamouti STBC
Simulated environment	AWGN (Additive White Gaussian Noise) Channel, Rayleigh Channel

Figure 4 illustrates a comparison between the BER and SNR for both FFT-based STBC and DWT-based STBC systems, utilizing LDPC, Turbo, and Fountain coding methods. The findings indicate that the DWT-based LDPC coded STBC system outperforms other coding techniques, achieving a BER of 10^{-4} at a lower SNR of 7dB. In contrast, the traditional LDPC coded OFDM system requires an SNR of 8.3dB, resulting in a 1.3 dB improvement in SNR as depicted in Table 5. Additionally, Figure 5 demonstrates that the proposed system model exhibits better spectral efficiency.

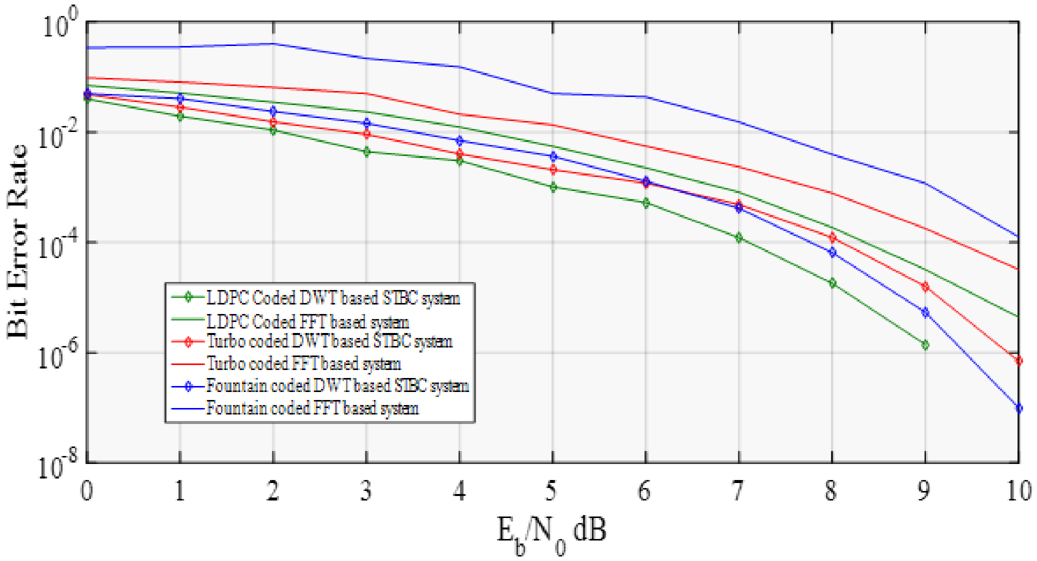


FIGURE 4. - BER comparison of the FEC-Coded DWT based STBC systems with the conventional systems

Figure 5 presents the spectral efficiency versus SNR graphs for two systems: the DWT-based STBC system and the conventional FFT-based STBC system. The graph shows that the DWT-based STBC system has better spectral efficiency, which improves with increasing SNR. The graph is also analyzed for three different channel coding schemes: LDPC, Turbo, and Fountain codes. It is observed that LDPC-coded DWT-based STBC systems have better spectral efficiency than Turbo and Fountain coded DWT-based STBC systems.

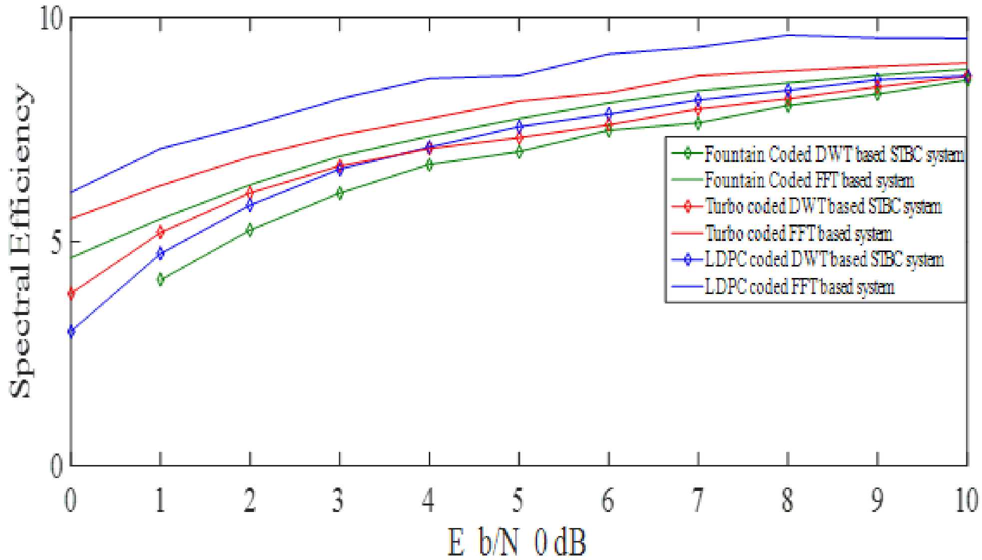


FIGURE 5. - **Spectral Efficiency comparison of the FEC-Coded DWT based STBC systems with the conventional systems**

Table 6. – BER Comparison of DWT based STBC systems

BER values of DWT based STBC systems using Algorithm II	SNR (in dB) required to attain the bit-error-rate of 10^{-4}
LDPC coded .DWT based STBC system	7dB
Turbo coded .DWT based STBC system	7.8dB
Fountain-coded DWT based STBC system	8.1dB

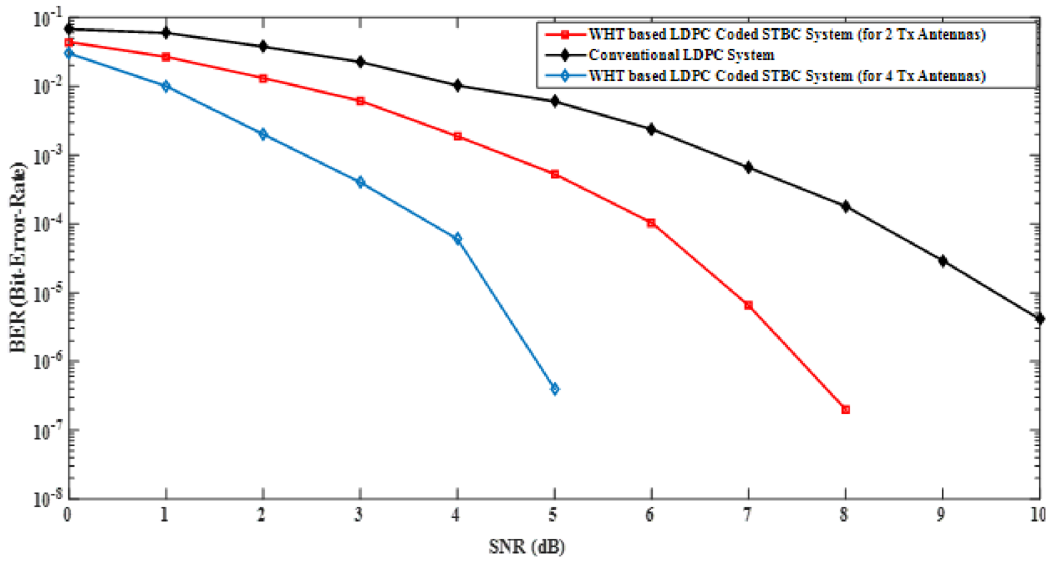


FIGURE 6. - **Diversity gain obtained using two and four transmit antennas**

Figure 6 compares three systems including WHT based LDPC Coded STBC system incorporating two transmitting antennas, WHT based LDPC Coded STBC system incorporating four transmitting antennas and conventional LDPC systems. The graph illustrates that the system incorporating four transmitting antennas provides lesser bit-error-rate and the diversity gain of the system is quantified in Table 7.

Table 7. – **Diversity gain using 4 antennas at transmitter**

BER	SNR (dB) 2 Transmitting Antennas	SNR (dB) 2 Transmitting Antennas	Diversity Gain
10^{-2}	2.3	1	1.3

10^{-3}	4.1	2.4	1.7
10^{-4}	6	3.35	2.65

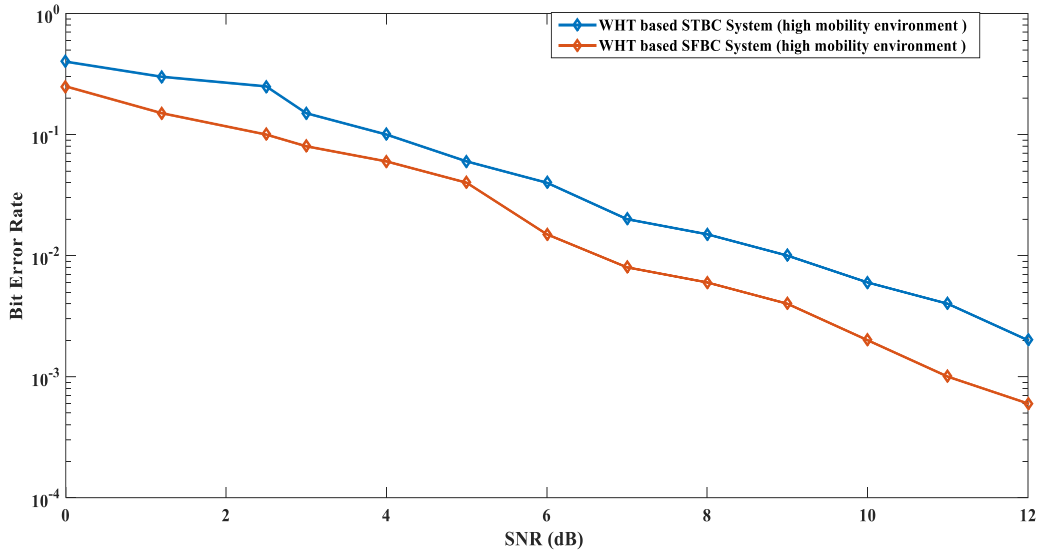


FIGURE 7. - Comparison of STBC and SFBC systems under high mobility environment

Figure 7 compares two systems STBC and SFBC systems. It has been observed that WHT based SFBC system performs well under high mobility conditions as compared with WHT based STBC system.

5. CONCLUSION

A novel approach is introduced to fulfill the stringent requirements of 5G communication systems, specifically in terms of achieving higher spectral efficiency and minimizing bit error rates. The proposed method employs a Discrete Wavelet Transform (DWT) based LDPC-OFDM system. By leveraging the DWT technique, the proposed model significantly reduces bandwidth usage, leading to enhanced spectrum efficiency. Extensive MATLAB simulations have been conducted to validate the efficacy of the proposed model. The results demonstrate a remarkable improvement in SNR of 1.3dB as compared to conventional LDPC Coded systems. The proposed system has been incorporated in STBC and SFBC systems. Although, STBC incorporated in the proposed model improves diversity gain and consequently reduces bit error rates; the comparison of STBC and SFBC incorporated proposed systems reveal that the proposed model works better in SFBC system under high –speed channel conditions.

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CONFLICTS OF INTEREST

The author declares no conflict of interest.

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