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CHANNEL CODING SCHEMES IN 5G NEW RADIO

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ABSTRACT

The objective of this project is to implement the Channel Coding Schemes in 5th Generation (5G) New Radio (NR) to meet high data rates with low complexity requirements for future mobile communication systems. The two channel coding schemes of 5G technology are - low-density parity-check (LDPC) codes and Polar codes.

Channel coding is the most basic component in any communications system. The 5G LDPC codes are forward error correcting codes that allow transmission errors under noisy channels to be corrected efficiently. The 5G wireless systems standardization has adopted Polar codes to control information regarding the uplink and downlink for the enhanced mobile broadband (eMBB).

Algorithms, architectures, and implementations for channel coding are being presented. Implementation of the original Low-Density-Parity-Check (LDPC) decoder algorithm by Robert G. Gallager is considered first. One decoder algorithm from each LDPC and Polar codes are selected for implementation in the industry by considering the requirements in the conformance test as specified by the 5G standards.

Keywords: 5th Generation (5G), Enhanced Mobile Broad-Band (Embb), LDPC (Low-Density Parity-Check) Codes, Polar Codes.

I. INTRODUCTION

Channel coding is considered as the most fundamental part in any correspondences framework. 5G is the remote broadband innovation dependent on the IEEE 802.11ac norm. 5G will give preferable paces and inclusion over the current 4G. It works with a 5 GHz signal and is set to offer rates of up to 1 Gb/s for many associations. Generally acknowledged use cases for 5G organizations are eMBB (Enhanced Mobile Broadband), Massive IoT (Internet of Things), and URLLC (Ultra-Reliable and Low Latency Communications)[1].

Channel coding is a vital part of the physical layer, as it affects latency and reliability. In general, channel encoders and decoders work block-wise, which means that the entire sequence must be accessible at the input for the encoder or decoder to work, which automatically causes a delay. One option to cut down on the delay is to divide the information into smaller parts and encode them separately.

The choice of channel coding, on the other hand, becomes critical as the error correction performance falls as message lengths drop. Furthermore, many existing design and analysis tools (such as EXIT and Density Evolution analysis) become less reliable for short message length channel coding since they rely on asymptotic results. It is frequently used to protect digital data from noise and reduce the bit errors in digital communication systems. The redundant bits are introduced into the transmitted data to achieve channel coding. These redundant bits are utilized to detect and rectify bit errors in incoming data, resulting in more reliable data.

The Error correcting codes add redundancy to the transmitted information signal and by applying soft-input soft-output decoders like, low-density parity-check (LDPC) codes, turbo codes and polar codes we can further enhance the system performance. In NR, we use LDPC codes to process the data and Polar codes for control information.

The two-channel coding schemes that we are going to study in 5G New Radio are LDPC code and Polar code using MATLAB.

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II. METHODOLOGY

a) LDPC Codes

Low density parity check codes are very tough competitors to turbo codes in terms of complexity, performance and they are both based on a similar philosophy. Low Density Parity Check (LDPC) codes are one of the best error correction codes at present that allow transmission errors under noise channels to be corrected efficiently. We define this using a parity check approach that is the low density which means it has few ones and many zeroes. These codes were introduced by Robert. G. Gallager in 1963. With present day technology, they are very practical and have implementation advantages as well[2]. LDPC codes are types of error correction codes that are known for better throughput and good decoding performance.

The main advantage of LDPC codes when compared to turbo codes are as follows:

- Better throughput efficiency and considerably higher available peak throughput.
- Reduced decoding latency and complexity.
- Improved performance.

So, these features make LDPC more suitable for ultra-reliable low-latency communication and very high throughputs in 5G standard.

b) LDPC Encoding:

In the encoding method, data is transformed from one form to another. The main goal of encoding is to convert data into a form that it is can be used by an external process and is readable by most of the systems. New Radio supports two LDPC base graphs, one for small transport block and & another for large transport block. Base graphs are matrices where each entry can be expanded further based on expansion factor Zc.

The size of Base matrix 1 is 46×68 for large transport block, size of Base matrix 2 is 42×52 for the smaller transport block

Block structure of base matrices is given as follows;

$$\begin{bmatrix} A & E & O \\ B & C & I \end{bmatrix} \quad \begin{bmatrix} q \\ p1 \\ p2 \end{bmatrix}$$

For base matrix 1: Size of A is 4×22 it contains information bits, size of E is 4×4 and it consists of double diagonal structure, size of O is 4×42 filled by zeros. The size of B is 42×22 is an extension part of the information block and C has size of 42×4 and the C block is the identity matrix with size of 42×42.

For base matrix 2:

A: 4×20, E:4×4, O:4×38(all zeros)

B:38×10, C:38×4, I:38×38(identity matrix)

The parity check matrix H can be represented by using Tanner graph, for example:

Let parity check matrix H,

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

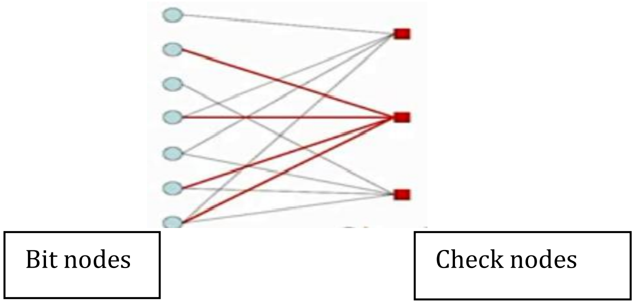

Figure 1: Tanner Graph representation.

Where Bit nodes represent the columns and check nodes represent the rows. Wherever one's are there in matrix H, those columns are connected to each other using lines [3].

c) Fast Encoding Approach:

The name fast encoding is because it obtains the encoded codeword directly by using the properties of base the graph matrix. In this method, the structure and properties of the base matrix is taken into account. Let q be the information bits to be encoded, p1 is the first part of the parity bit and p2 is the second part of the parity bit. The value of k, x and y depend on the base graph type where k is the size of information bits, x is the number of columns and y is the number of rows.

For base graph 1, $k=(22\times Zc)$, $x=(68\times Zc)$, $y=(46\times Zc)$

For base graph 2, $k=(10\times Zc)$, $x=(52\times Zc)$, $y=(42\times Zc)$

The block structure of parity matrix can be written as;

$$\begin{bmatrix} A & E & O \\ B & C & I \end{bmatrix} \begin{bmatrix} q \\ p1 \\ p2 \end{bmatrix} = \mathbf{0} \qquad \text{-----------(1)}$$

The above matrices can be transformed as:

$A.q+B.p1+C.p2=0$ -----------(2)

$D.q+E.p1+F.p2=0$ -----------(3)

Since C is a zero matrix and F is an identity matrix, this can be simplified as:

$A.q+B.p1=0$ -----------(4)

$D.q+E.p1+p2=0$ ----------(5)

The fast encoding can be done using equations 4 and 5.

The first step is to determine the first parity that is p1,

$p1 = B^{-1}+A.q$ ---------(6)

The second step is to determine the second parity that is p2.

$p2 = D.q+E.p1$ ---------(7)

Third step is to puncture the initial $(2\times Zc)$ elements from the information bits q and concatenate the remaining elements of q with the parity bits p1 and p2 to obtain the encoded codeword. This completes the LDPC encoding process.

d) LDPC Decoding:

Layered Sum Product algorithm for Min-Sum Approach: This algorithm is called message passing algorithm, and is an iterative algorithm. The reason for this is that at each round of algorithm messages are being passed from message nodes to check nodes and from check nodes to message nodes and there are many numbers of iterations present in this approach. One of the important classes of message passing is the belief propagation algorithm. The messages passed in this algorithm are beliefs or probabilities.

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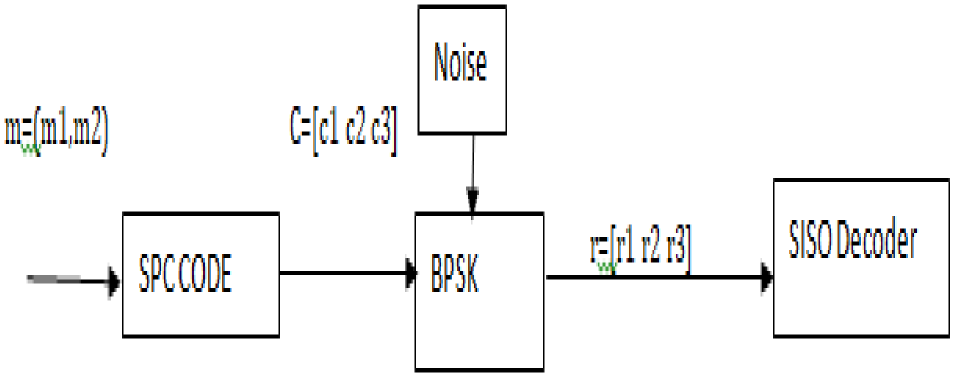

Figure 2: Min-Sum Approach

The above block diagram shows general SPC decoder for m=2 and c=3. Where, c3= c1 xor c2.

The BPSK is used over Additive white Gaussian noise (AWGN) channel, which uniformly distributes the noise over the channel.

For general (n, n-1) SPC decoder,

C= [c1 c2……cn]; r= [r1 r2…. r_n]

Where $r_i=s_i$ +noise

c_i is and codeword bit which can be either 0 or 1

Likelihood ratio for given received bit r_i is given by,

l_i= [Prob{c_i=0|r_i}/Prob{c_i=1|r_i}] ---------------(8)

Log likelihood ratio can be obtained by putting log for above equation,

LLR= log([Prob{c_i=0|r_i}/Prob{c_i=1|r_i}]) ----------------(9)

For the BPSK over AWGN channel $l_i=2r_i/\sigma^2$, usually $2/\sigma^2$ is ignored because its value is almost equal to 1. So l_i is directly proportional to r_i.

Output of LLR is given by considering all the received bit r. which is given as follows,

L_i= log([Prob{c_i=0|r}/Prob{c_i=1|r}]) -----------------(10)

We will approximately and iteratively compute this.

To understand the concept, we will look into the steps involved in decoding that is given below.

Here we will consider the layered decoding. Where it supports the layering and it will result in fewer iteration and faster convergence.

In this algorithm parity check matrix is divided into 2 layers where, C1 is code with H1 as parity check matrix and C2 is code with H2 as parity check matrix.

STEP1: Initialization:

Let us initialize r with some value and another storage matrix L which has same dimension as of H and we have to store the value of r1 in the first column and r2 in the second column of L and so on.

Let us first consider for Layer 1, and in the above matrix put the value of r in the respective columns.

In each row,

Min1=minimum absolute value of all non-zero entries in a row

Min2= Next higher value

Set magnitude of all values (except minimum) = Min1

Set magnitude minimum value= min2

For Sign,

Parity=product of signs of entries in a row

New sign of an entry= (old sign) (parity)

STEP2: Iteration1, Layer1:

Minsum is performed on the first 2 layers and the sum matrix is being obtained.

STEP3: Iteration1, Layer2:

The value of sum is placed in r in the corresponding column of the L matrix. Later the Minsum of 2nd layer is calculated.

STEP4: Iteration 2, Layer 1:

The incoming belief (Sum) by Layer1 is subtracted and the Sum and Layer1 is being updated.

STEP5: Iteration 2, Layer 1:

The Minsum operation is performed for L which is obtained from Step4 and is updated. Later update the Sum by adding the Sum and values in layer1.

STEP7: Iteration2, Layer2:

Repeat the same procedure from step 4 to step 6 for layer2 using Sum obtained from step6 and update the Sum values. Now we obtain the L and Sum matrices after the values are updated.

STEP8: Decision:

Consider the sum obtained from step7 and if,

Sumj>0, Then the decision on Bit j=0

Sum_j<0, Then the decision on Bit j=1

e) Polar Code:

Erdal Arikan came up with the concept of polar coding in 2008. Polar codes are the first and only coding scheme that accomplishes the symmetric capacity of a binary memory-less channel with an explicit construction. Polar codes have been adopted as channel coding for uplink and downlink control information for the enhanced mobile broadband (eMBB) communication service. Polar codes give a low-complexity strategy for constructing polarised channels, with the fraction of noiseless channels approaching the capacity of the original B-DMC. Polar codes are created by concatenating many fundamental polarisation kernels, which results in a cascade reaction that speeds up the polarisation of synthetic channels while keeping decoding and encoding simple. [4].

e) Polar Transform G_2:

Polar transform, also known as Arikan transform, is the most basic construct in Polar code. In the Polar encoding, the generating matrix is used. The standard generator matrix is a two-dimensional square matrix of order two. When the amount of data bits increases, a higher-order generator matrix is used, which is created by taking the Kronecker product from the ordinary generator matrix. This transform converts 2 bits to 2 bits (2×2 matrix), which is the basic beginning matrices or kernel and is the longer version G4, G8.....for any power of 2.

$$G_2=\begin{bmatrix}1 & 0\\ 1 & 1\end{bmatrix}$$

$$[u_1\ u_2]G_2 = [u_1+u_2\ u_2]$$

Where, $[u_1,u_2]$ are input bits.

'+' represents the module 2 addition or X-or operation.

$[u_1+u_2\ u_2]$ are the output bits.

$$u^{(2)}= [u_1+u_2u_3]$$

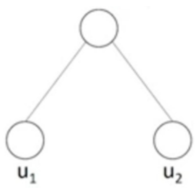

Figure 3: Binary tree representation of G_2

$u^{(2)}$=length-2 vector.

Here u_1 and u_2 are represents the leaf node [5].

Polar Transform G4:

G_4, 4 by 4 polar encoder (4×4 matrix) is obtained by using kronecker product of standard matrix G_2.

Here we will give 4 bits data to encoder, and $G_4 = G_2 \otimes G_2$ by using the Kronecker product each entries of first matrix get replaced by the time of second matrix and 0 get replaced 0 time of second matrix like that each entries get replaced by the second matrix.

$$G_4=\begin{bmatrix}1 & 0\\1 & 1\end{bmatrix} \otimes \begin{bmatrix}1 & 0\\1 & 1\end{bmatrix}$$

$$= \begin{bmatrix}1 & 0 & 0 & 0\\1 & 1 & 0 & 0\\1 & 0 & 1 & 0\\1 & 1 & 1 & 1\end{bmatrix}$$

Hence, $[u_1\ u_2\ u_3\ u_4]G_4 = [u_1+u_2+u_3+u_4\ \ u_2+u_4\ \ u_3+u_4\ \ u_4]$

The general transform is given by,

$G_2{}^n=\begin{bmatrix}1 & 0\\1 & 1\end{bmatrix} \otimes n$, Where n=2,3,4……

G_N: $N \times N$ matrix, Kronecker product of 2×2 kernel

Binary tree representation includes,

Depth n

$U^{[N]}=uG_N$ evaluated on tree with u at bottom and $u^{[N]}$ at top

5G uses up to n=10.

f) Polar Code Decoding:

The principle of decoding is the decision-making of bits at the output of the decoder from the LLR values of the message bits that are sent. Successive cancellation decoder is widely used as it has less complexity.

SC decoding makes its decisions on bits one by one. So only one decision can be made at a time.

The rules used for decoding are as follows:

1) If the i^{th} bit is a frozen bit, then the estimated u_i will be estimated as zero.

2) If the i^{th} bit is not a frozen bit, then u_i is found using SISO Decoder.

The u_i obtained is not the original bit but it can be estimated to a certain value using the SISO Decoder.

$r^{(N)}$ is decoded to u_1 and in turn u_1 along with $r^{(N)}$ is decoded to u_2 and this continues further.

Once in a while we encounter frozen bits during the decoding process, this helps in reducing the error propagation. There are certain operations that will be performed in the interior node. It shall be discussed in the upcoming topics.

Operations performed in the interior node,

Step 1: As shown in the below figure here the beliefs or message bits are sent to the left child. While sending the bits the Min Sum which is represented by f is being performed where L is being divided into two halves being $L_{1:M/2}$ and $L_{1+M/2:M}$. The Min Sum equation is given by,

$$\boxed{f(a_{1:P},b_{1:P})=[f(a_1,b_1)\ f(a_2,b_2)\ ....\ f(a_p,b_p)]}$$

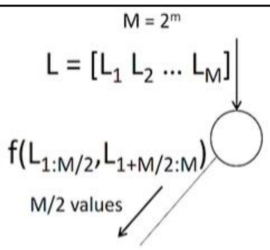

Figure 4: Left child operations

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Step 2: As shown in the figure the parent receives the message from the left child. Here in the right child the 'g' operation is being performed coordinate wise and is given by,

$$\boxed{g(a_{1:P},b_{1:P},c)=[\ g(a_1,b_1,c_1)\ g(a_2,b_2,c_2)\ldots\ldots\ g(a_P,b_{:P},c_p)]}$$

Where c is a binary vector.

The repetition code for the above is given by,

$$\boxed{g(a_1,b_2,b)= r_2+(1-2b)r_1}$$

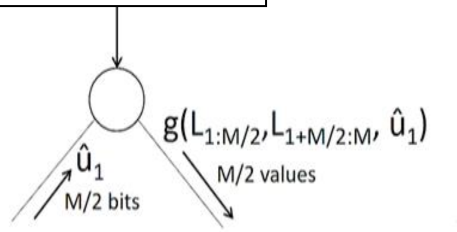


Figure 5: Right child operations

Step 3: As shown in the figure, after receiving the decisions from both right and left child it is sent to the parent node i.e., the u_1 and u_2 which are the M/2 bits each. Hence there are M bits that are received by the parent node.

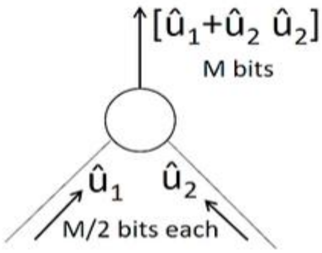


Figure 6: Parent node

When a leaf node is considered, the decision taken doesn't depend on child as there is no child in the leaf. Hence it receives only one belief that it receives for itself.

The leaf node can be in two situations namelv.

If 'I' is a frozen position: $\hat{u}_i=0$

If 'I' is a frozen position: $\hat{u}_i=0$, if $L(u_i)\geq 0$; $\hat{u}_i=1$, if $L(u_i)<0$

Now upon considering the interior node and leaf node, we shall combine all together and perform the sequence of operation.

The sequence of operations involved in the decoder:

Operation starts at the root.

Whenever the node is activated,

If not, a leaf node does step L and goes to the left child.

When the decision is received from the left child, does step R and goes to the right child.

When the decision is received from the right child does step U and goes to the parent.

If it is a leaf node then makes a decision and goes to parent.

III. MODELING AND ANALYSIS

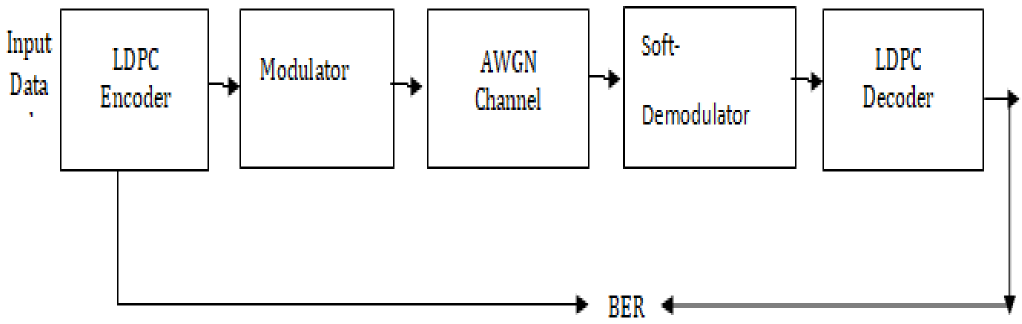


Figure 7: LDPC Code Simulation Setup

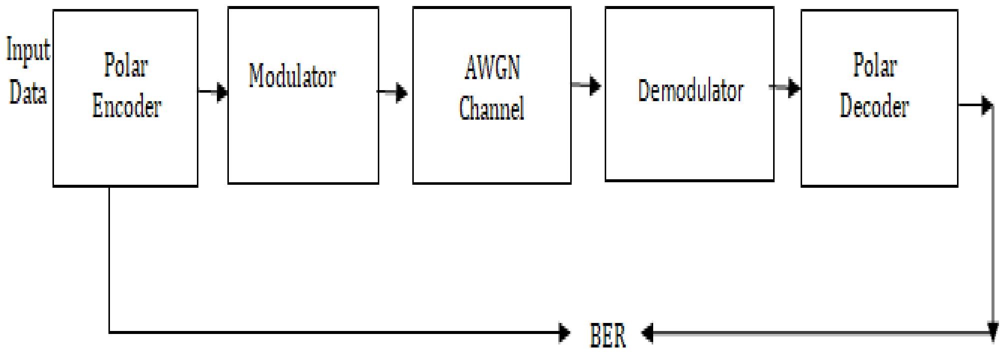
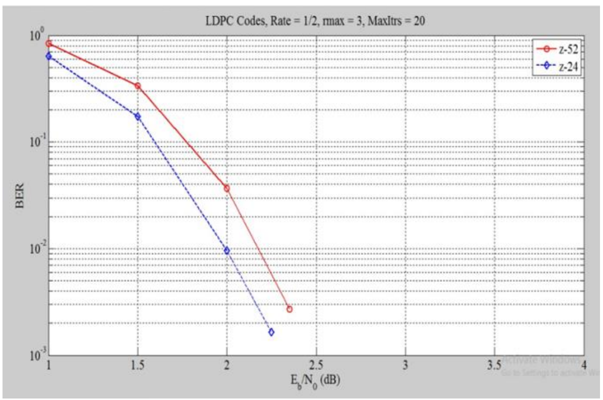


Figure 8: Polar Code Simulation Setup

IV. RESULTS AND DISCUSSION

a) Results of LDPC simulation



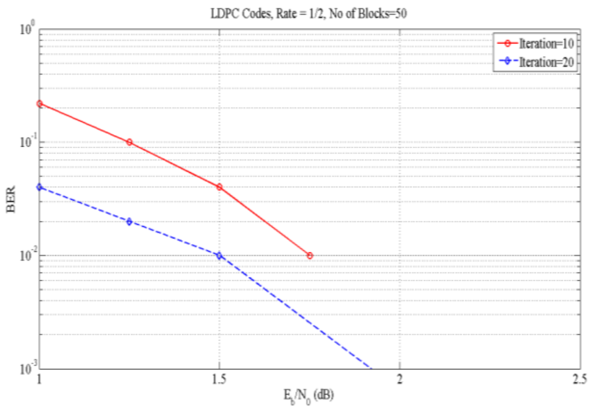


Figure 9: LDPC Codes BER vs EbNo(dB) Performance

Figure 10: LDPC Codes BER Performance Graph for various Iterations

The output is analyzed and also, it is shown that LSPA has a better BER performance with a BER of 0.025 for an SNR value of 1dB taking the number of blocks as 50. It is also found that the decoded message is matching with the input message. The output is analyzed for different values of the number of iteration and the graph is shown in figure 10.

Figure 10 indicates that BER at 20 iterations is high when compared to 10 iterations. So it can be understood that LSPA gives better performance as the number of iterations increases as Bit Error Rate decreases and gain increases. Figure 10 indicates the graph for different values of expansion factor (z) that it takes as input for base graph 2. Figure 9 shows a graph which has been drawn at 20 numbers Iterations. Both the values show the good performance but it can be understood from the graph that BER at z equal to 24 is less than z at 52. So LDPC can be more suited for the transmission of message bits of smaller length.

b) Results of Polar code simulation

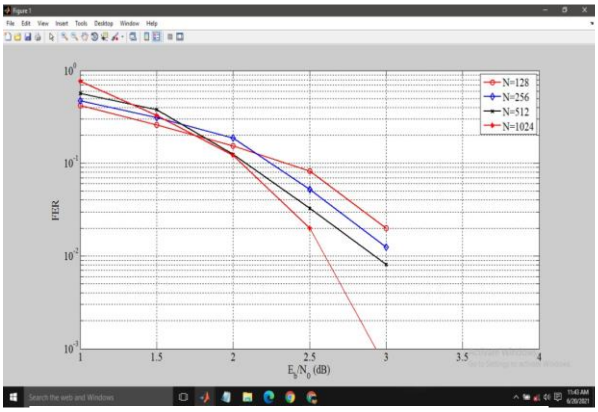


Figure 11: Polar Code BER Performance for various values of N using SC algorithm

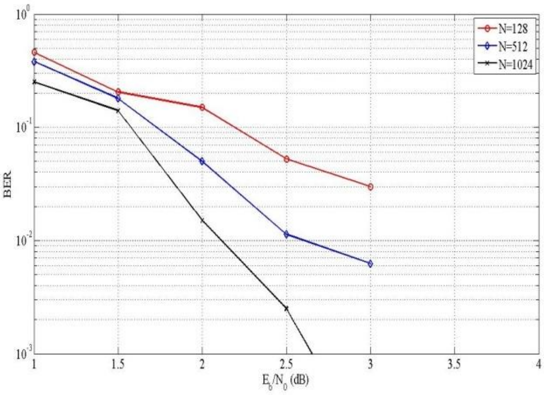


Figure 12: Polar Code BER Performance for various values of N using SCL algorithm

The output is analyzed for different values of Message Length N using successive cancellation (SC) and the graph is shown in the above figure11. It can be observed that the value of BER and SNR increases when the Message Length N increases. Hence, we can say that Polar Codes are suitable for longer Message blocks.

The output is analyzed for different values of Message Length N using successive cancellation list (SCL) algorithms and the graph is shown in the figure12. It is important to observe that the BER performance increases as the list size L is increased from 2 to 8, which proves that the higher the list size, the lower the decoding loss. From above Figure 12, it can be clearly seen that there is a gain of 2dB from SC (converging at −2.5dB). It can be noticed that the SCL decoder has a better performance than SC.

c) Results of comparison between LDPC and Polar codes

The figure 13 shows the graph of comparison between LDPC codes of base graph 1&2 and different algorithms of Polar codes.

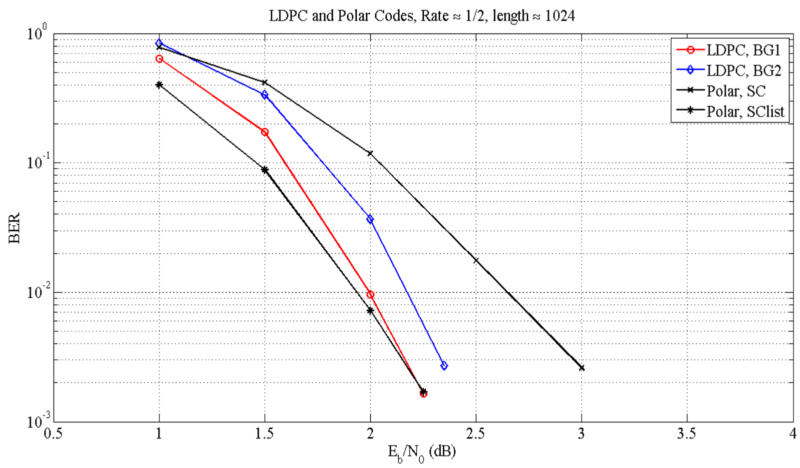


Figure 13: Comparison of BER Performance between LDPC and Polar Codes

The graph has a length of 1024 bits and is drawn at a rate of ½. According to the graph, both codes perform well. When compared to base graph 2, the LDPC code using base graph 1 performs better.

When compared to all other algorithms, successive cancellation list algorithms produce favorable performance since the BER is lower. In addition, when using consecutive cancellation list techniques, the Bit Error Rate drops significantly. This implies that the polar code is more suitable when compared to LDPC codes [6].

The results of this study show that polar code with Successive Cancelation List (SCL) decoding with a short list length (L=8) is the best choice for short lengths (≤128) with low complexity. Using larger list lengths (L≥1024) in SCL decoding for polar code or using non-binary LDPC can provide good performance at the cost of additional complexity with the advantage of better spectral efficiency [7].

V. CONCLUSION

We have looked into the steps involved in the encoding and decoding process for both codes. The decoding algorithm for the respective codes was also studied. The required software was installed.

The execution of the codes using the MATLAB software for the encoder and decoder program for LDPC and Polar code and comparison of the obtained results were carried out. The Layered Sum-Product Algorithm for the LDPC Decoding process was simulated using MATLAB and the output was observed. The Successive Cancellation Decoding and Successive Cancellation List Decoding Algorithms were simulated and the outputs for the same were observed and compared.

The LDPC and Polar Codes were compared using MATLAB and the output was observed. The simulation parameters for both the codes are code rates, expansion factor, number of iterations, message length.

In the performance graph (Figure 13) of LDPC codes against Polar codes, we can notice that Polar codes have a better performance at low code rates and LDPC codes perform better at higher code rates. With this, we can prove that this is one of the reasons for choosing Polar codes for encoding-decoding of control information at low code rates and LDPC codes to encode-decode large data processing blocks with higher code rates.

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