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Channel Encoding Techniques In 5G Cellular Netoworks-LDPC And Polar Code

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Abstract
The term Channel encoding refers to securing the data from noise and other disturbance to the data in other words error free transmission. There are several methods to encode the channel, there is linear block code, cyclic block code, convolutional coding, trellis coding, LDPC (low density parity matrix code), polar coding. In the current 5G and NextGen 6G, where high data rate is a major factor, and there is a high probability of data being prone to noise effects and we shall keep in mind the constraints of the bandwidth used to secure the data.As 5G is concerned, we are focusing on LDPC and polar coding and for 6G integrating it with machine learning for faster computation This paper we will focus on understanding LDPC and polar coding and also exploring the various ways integrating ML to LDPC and polar coding. We will also look into the performance analysis of LDPC along with polar coding for various BER and SNR scenarios.
Keywords: *Channel encoding, 5G, NextGen, LDPC, Polar Coding*

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I. Introduction

The transmitter sends data through the channel, the channel here is wireless and due to interference, attenuation and distortion the data sent is modified and data with error is received at the receiver. Effects of these errors are single bit error, burst error and erasure. In order to avoid such errors during the transmission of data, channel encoding techniques were introduced[1]. There are various channel coding issues with 5G, 6G, next generation of mobile communication networks. 5G networks will have to offer URLLC (ultra-reliable and low latency communication). Ultra-low latency along with ultra-high reliability are two requirements that make the physical layer design of URLLC extremely difficult. LDPC and polar coding and future works which could integrate ML in channel encoding techniques will be the main topics of this paper.

II. Channel Encoding

Overview of channel Encoding

Channel encoding not only ensures that data transmitted is error free, it also ensures that error may be detected as well as corrected. If receiver end knows the pattern or the parity matrix, we can detect which bit has an error. Channel encoding technique plays an important role in communication systems, it ensures signal reliability, data accuracy, transmission efficiency, noise resilience and quality improvement. The importance of forward error correction (FEC) in 5G systems is because of the high reliability, low latency, network robustness.

Functions of LDPC and Polar coding

LDPC codes: LDPC codes have been utilized in control channels because they are more robust to errors than polar codes. Control channels are responsible for communicating critical information such as transmission time and transmitter power levels.[4]. It is important that this information is transmitted without errors, so LDPC codes are a good choice. Polar codes: Polar codes are utilized in data channels because they are more efficient than LDPC codes. Data channels make up the majority of the data volume of the 5G mobile network. With a smaller codeword size, polar codes can accomplish the same error correction as the LDPC codes. This means that polar codes can transmit more data in a given time, which is important for 5G networks that must support high data rates.

III. LDPC – Low Density Parity Check Code

Motivation behind LDPC codes is to design codes that have good error correction capability and are also relatively easy to decipher[3]. LDPC codes are constructed from a bipartite graph, whereby check nodes denote parity bits, as well as variable nodes, signify information bits. The edges of the diagram represent dependencies between bits. Decoding algorithm for LDPC codes is as per belief propagation algorithm, that is a relatively simple algorithm that can be implemented efficiently [5]. Behind polar codes is the design of codes with good error correction capability for multiple channels. The polarization codes are formed by a recursive process that exploits the polarization property of the channel. The channel polarization property states that, for a given channel class, noise can be polarized such that some bits are very easy to decode and others are very difficult to decode. Polar codes are designed to take advantage of this property by encoding easy-to-decode bits first and hard-to-decode bits last.

IV. Understanding LDPC Code

LDPC codes as well as Polar codes are two robust error correction codes widely utilized in 5G communication systems. [6] LDPC codes are renowned for their good error correction performance and low SNR (signal-to-noise ratio). Therefore, they are suitable for use in 5G, a high-speed and noise-sensitive communication system. LDPC codes are also relatively easy to implement, which is important for 5G, a complex system with strict power and latency requirements. Sparse parity check matrices are a distinctive feature of LDPC codes, which makes them suitable for efficient encoding as well as decoding. Tanner graphs are employed in the construction of LDPC codes. It has two different kinds of nodes: control nodes and variable nodes. The encoded information bits are represented by the variable nodes, along with the parity checks applied to the information bits are represented by the check nodes [8]. It has been demonstrated that LDPC codes are highly successful at repairing errors in noisy channels. They are ideal for usage in high-speed communication systems because they can produce very good error correction performance at low SNRs.

Encoding process of LDPC CODE

Data bits are randomly assigned to variable nodes in Tanner graph. Usually, there are significantly less information bits than variable nodes, so there are many more variable nodes than information bits. This gives the decoder more freedom to correct errors. Parity checks are then placed on the information bits by connecting variable nodes to control nodes such that each control node is connected to an odd number of variable nodes[9]. This ensures that the parity of the information bits is always consistent. Figure 2.2 shows that the coded bits are then obtained by computing the parity of the variable nodes connected to each control node. This can be done by adding the bits together and taking the modulo-2 sum. Encoding process of the LDPC code is relatively simple and can be implemented efficiently. Designing the parity check matrix so that code has adequate error correction capability is the primary problem.

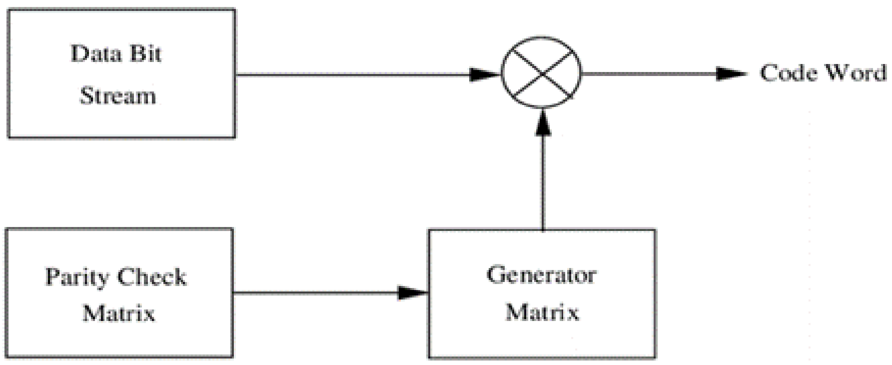

Figure 1: Encoding process of LDPC code

V. Matrix Representation

A decoding complexity that rises only linearly with code length is provided by the sparsity of H (Parity matrix). Apart from requirement that H be sparse, the LDPC code is identical to any other block code. If a sparse parity check matrix may be utilized to represent current block codes, then repeated LDPC decoding algorithms can successfully employ them. LDPC codes may be denoted in essentially 2 ways. They are described as employing matrices, just like all linear block codes. A graphical display is an additional choice. Figure 3.1 provides an illustration of a low-density parity-check matrix. It is a parity check matrix of dimension k ×n for a (6, 3) code, in which n=6 and k=3. These matrices can now be described by two numbers. Wr stands for each row's number of 1s, and wc for each column. A matrix must meet both wc<< k as well as wr<< n to be considered as low density. Typically, a very large parity check matrix is required to do this. If wc=wr · (n/k) is constant for each row and wc is constant for each column regular, then the LDPC code is considered regular.

$$\underbrace{\begin{bmatrix}1 & 1 & 0 & 1 & 0 & 0\\ 0 & 1 & 1 & 0 & 1 & 0\\ 1 & 1 & 1 & 0 & 0 & 1\end{bmatrix}}_{\text{H matrix}}\begin{bmatrix}c1\\ c2\\ c3\\ c4\\ c5\\ c6\end{bmatrix}=\begin{bmatrix}0\\ 0\\ 0\end{bmatrix}$$

We utilize matrix H as "a parity-check matrix. Every column of H denotes a bit in codeword, and every row of H denotes a parity-check equation. Parity-check matrix is therefore a k×n binary matrix for a binary code with k parity-check restrictions as well as length n codewords. A string C=[c1 c2 c3 c4 c5 c6] in matrix form is a valid codeword for the code with parity-check matrix H if and only if it obeys matrix equation" H. Transpose matrix of matrix C is represented as CT=0.

VI. Graphical Represenation

Tanner presented a useful LDPC coding graphical representation. This graph aids in describing the decoding method in addition to offering a graph's comprehensive illustration. Bipartite graphs are Tanner graphs. This indicates that graph's nodes have been separated into 2 discrete "sets, and the edges only join nodes of 2 types. In Tanner graph, there are 2 different kinds of nodes: check nodes (c-nodes) along with variable nodes (v-nodes). A Tanner graph of this type is depicted in Figure 2, which additionally illustrates the code in the matrix above. Making such a graph is a rather easy task. It consists of k check nodes (amount of parity bits) along with n variable nodes (amount of bits in a codeword). The check node ci has been linked to variable node vj if element hij of H is" a 1.

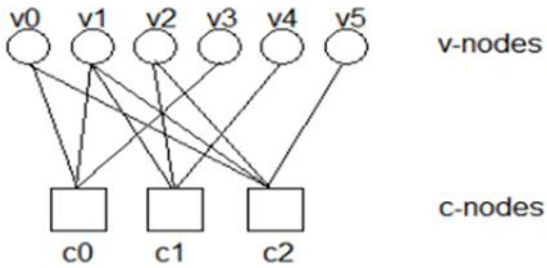

Figure 2: Tanner Graph

VII. 5G Standards For LDPC

LDPC codes are utilized in 5G standard for both control and user data channels. For control channels, Low latency as well as a high data rate are attained by utilizing LDPC codes. For user data channels, to get a high data rate as well as good error-correction performance, LDPC codes are utilized. The 5G standard specifies 2 kinds of LDPC codes:

- Protograph-based LDPC codes: These codes are constructed from protographs, which are small graphs that are used to generate larger graphs. Protograph-based LDPC codes are typically used for control channels because they are relatively simple to implement and decode.
- Quasi-cyclic LDPC codes: These codes are constructed from quasi-cyclic graphs, which are graphs that have a regular structure. Quasi-cyclic LDPC codes are typically used for user data channels because they are more efficient to implement and decode than protograph - based LDPC codes.

The 5G standard specifies a number of different parameters for LDPC codes, for example, code rate, the block length, along with parity bits number. The particular application determines the parameters to be utilized. That includes, for control channels, a high code rate as well as a short block length have been typically utilized to attain a high data rate, low latency. For user data channels, a lower code rate and a longer block length have been typically used to achieve a good error-correction performance.

5G NR BASE MATRIX
Two Base matrices that are usually taken "are:
BG1: 46 X 68 and BG2: 42 X 52
Block structure of the Base matrix is divided as :

A E O
B C I

BG1:
A: 4 X 22 - All zeros
B: 42 X 22 -Identity matrix
C: 42 X 4 - Identity matrix
E: 4 X 4-All zeroes
I: 42 X 42- Identity matrix
O: 4 X 42 – All" zeros

BG2:
A: 4X10 -All zeros
B: 38X10-Identity matrix
C: 38X4- Identity matrix
E: 4X4 – All zeros
I: 38X38 -Identity matrix
O- 4X38-All zeros

Polar code

The polar codes foundation is channel polarization phenomenon, which describes how noise in a memoryless, binary-input channel can become polarized, making some output bits extremely dependable and others extremely unreliable. The virtual channels are then divided into two sets: reliable channels and unreliable channels. Parity bits are then computed from unreliable channels after the information bits have been given to reliable channels.

VIII. Encoding Process Of Polar Code

Bits of data are randomly assigned to the most reliable virtual channels. Parity bits are then calculated based on the unreliable virtual channels. The coded bits are then obtained by concatenating information bits along with parity bits.

Figure 2.4 illustrates encoding process of polar coding in which data bits are first randomly assigned to most reliable virtual channels. This uses a technique called channel polarization, which divides virtual channels into two groups: trusted channels and untrusted channels. Data bits are then assigned to reliable channels, while parity bits are calculated from untrusted channels.

The parity bits are calculated using a recursive process called sequential cancellation coding. Sequential reverse coding is a relatively simple algorithm that can be implemented efficiently. The coded bits are then obtained by concatenating information bits along with parity bits.

Typically, there are twice the number of encoded bits as there are information bits. Encoded bits are then sent over channel. Receiver then decrypts encrypted bits using a technique called sequential cancellation decoding. Sequential cancellation decoding is a relatively simple algorithm that can be implemented efficiently. Because polar codes can accomplish good error correction with low SNR and are simple to encode and decode, they are a good choice for 5G. A recursive procedure known as channel polarization serves as the foundation for the encoding of polar codes. A memoryless, binary-input channel has been transformed by this procedure into a collection of virtual channels, few are highly dependable and some of which are highly unreliable. After that, parity bits are computed from unreliable virtual channels as well as information bits are allocated to most reliable virtual channels.

IX. Channel Polarization

Process that creates N synthetic bit channels from the N independent copies of a B-DMC (binary input discrete memoryless channel) has been termed channel polarization. Then, novel synthetic channels have been polarized, meaning that each one has a variable probability of accurately decoding a single piece and can transmit it with varying degrees of dependability. A low-complexity technique for creating polarized channels is offered by polarization codes, in which the noiseless channels tend' percentage to power of the original B-DMC.

Figure 4 shows bit channel polarization. The discovery of the phenomena of matrix polarization G2=[1 0 1 1], frequently called as fundamental polarization kernel, provides mathematical basis for polar code. This matrix allows encoding a doubtful input vector u=[u0, u1] into a code word d=[d0, d1] of the form d=u · G2, namely d0=u0 ⊕ u1 and d1=u1. Polarization impact caused by G2 is particularly significant in BECs (binary elimination channels), in which a transmitted bit has been either accurately received or else lost with the probability δ.

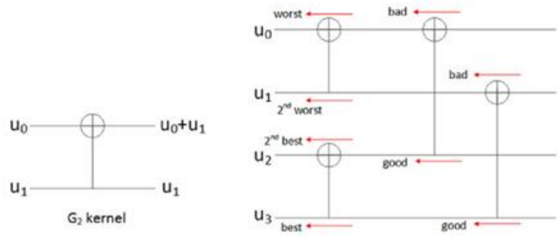

Figure 4: Bit Channel Polarization of Length-4 Polar Codes

X. Polar Code Design

Polar codes utilize concatenation of multiple fundamental polarization kernels, causing a cascade effect which accelerates polarization of the synthetic channels whereas minimizing decoding along with encoding difficulty. This concatenation produces a channel transformation matrix with structure GN=G2 ⊗ n, characterized by n-fold Kronecker product of G2, which may be computed recursively as

$$GN = \begin{matrix} GN/2 & 0 \\ GN/2 & GN/2 \end{matrix}$$

For “smaller values of the n, polarization of the synthetic channels might be incomplete, resulting in intermediary channels which are only partially noisy, whereas for n → ∞ this approach produces channels that are either fully noiseless or else entirely noisy. Bit-channel polarization made possible by concatenation n=10 basic polarization kernels for a BEC with the erasure probability δ=1/2 is displayed in Figure 4.2. While code dimension K, or else amount of information bits conveyed, may have any arbitrary value”, polar codes are designed to only support code lengths which are powers of 2, of form N=2n. “An (N, K) polar code is designed to convey the information bits by determining K best synthetic channels, or else channels with greatest reliability. By estimating each synthetic channel's reliability, it is possible to arrange them in reliability order along with allocating K information bits to most dependable channels, whose indices make up code's information set I. Frozen set F=I C of the code has been constituted by remaining N−K indices”, with no information being carried by the corresponding channels, that are blocked. Figure 5 shows how the information is being carried by different channels.

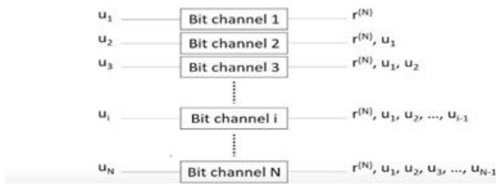

Figure 5 Bit Encoder

XI. Encoding

The information set I along with the channel transformation matrix GN = G2 ⊗n define a (N, K) polar code. The code's generator matrix is provided by GN sub-matrix made up of the rows with indices recorded in I. However, by adding an extra input vector u of the length N, GN’s recursive structure makes it possible to lower encoding complexity. Conveying ui=0 if i ∈ F as well as storing the information bits in remaining entries creates this input vector, u=[u0, u1,..., uN−1]. Next, d = u · GN is computed for the codeword d = [d0, d1,..., dN−1]. Encoding complexity may be minimized to O(log2(N)) by processing several G2 matrix multiplications in parallel to accomplish this matrix multiplication. GN's recursive structure really makes it possible to decode in log2(N) stages, each of which is made up of N/2 identical fundamental polarization kernels. The polarization and bit channels of polar coding are displayed in Figure 4.2. The encoder structure “for a polar code of length N=8 has been illustrated in Fig. 4.3. It also provides information on frozen set F={0, 1, 2, 4} that is collected for a code of dimension K=4, as well as erasure probabilities of the synthetic BECs when the code is built for a BEC of erasure probability δ=1/2. With the help of the input vector u=[0, 0, 0, 1, 0, 0, 1, 1], this structure is utilized to encode message c=[1, 0, 1, 1] in n=3” stages, yielding codeword d=[1, 0, 1, 0, 0, 1, 0, 1].

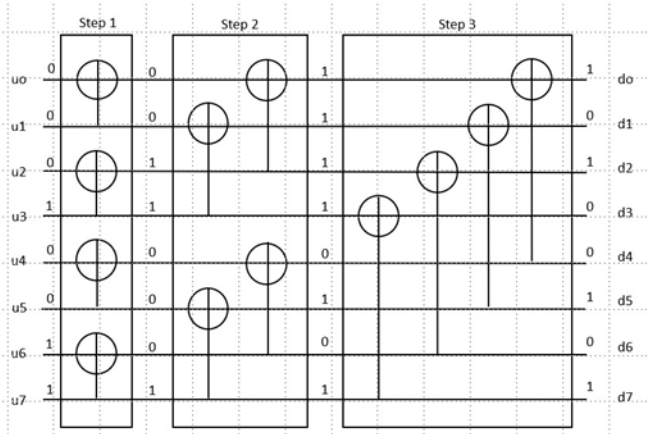

Figure 6: The Encoder Structure

XII. Result And Analysis

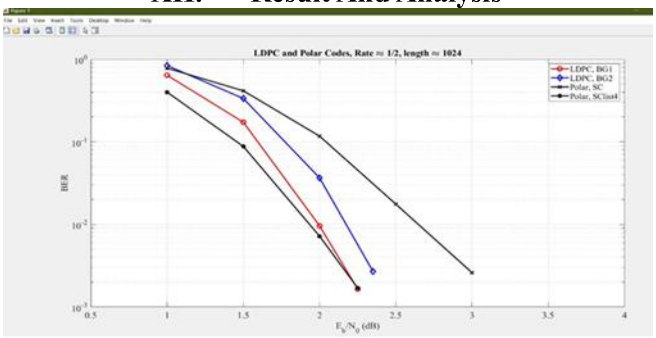

Figure 7: Simulation Result Of BER V/S SNR For Various Ases Of LDPC And Polar Codes

From the graph obtained in Figure 7, we can conclude that both LDPC and polar codes can achieve very low BERs at low Eb/No. However, polar codes have a lower BER than LDPC codes at all Eb/No values. This is because polar codes are capacity-approaching codes, that indicate, for a particular channel, they can attain error-correction performance that is extremely close to theoretical maximum.

Although LDPC codes are more robust to channel faults than polar codes, they are not capacity-approaching codes. This is because LDPC codes have a larger codeword size, which means that they have more degrees of freedom when trying to correct errors. The particular application determines which code must be employed. If robustness to channel errors is important, then LDPC codes are a good choice. If simplicity and low complexity are important, then polar codes are a good choice. In 5G, polar codes are typically utilized for user data, while LDPC codes are typically utilized for control information. This is because LDPC codes are more appropriate for situations where robustness to channel defects is crucial, whereas polar codes are better suited for high-speed communication.

XIII. Conclusion And Future Scope

Although LDPC codes have simpler decoding process, it has a relatively complex encoding process, as per belief propagation. This makes them well-suited for applications where decoding complexity is a major concern, such as mobile devices. Additionally, at high code rates, LDPC codes perform well in error correction, which makes them a good choice for applications where bandwidth is limited.

LDPC and Polar codes are both promising error correcting codes with a wide range of applications. Their future scope is bright, and they are likely to be used in a diversity of new communication systems in coming years. There are currently numerous applications for LDPC codes, including 4G LTE and 5G NR cellular networks, satellite communications, and optical communications. They are also being considered for use in next-generation wireless technologies, such as 6G and beyond. Future utilization of LDPC codes is probably going to continue because of their low decoding complexity, good error correction performance, and ease of implementation.

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