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Coding Schemes in 5G Networks for Error-free Communication

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***Abstract*—The fifth-generation mobile communication network (5G) technology is a significant topic in today`s mobile communication industry. However, due to difficulties in the wireless channel generally, error-free communication is a big challenge. Thus, channel coding is a technology incorporated in the 5G mobile systems for achieving reliable and error-free two-way connections. In terms of data rate, capacity, coverage, latency, energy consumption, and cost, the fifth-generation (5G) communication systems must outperform previous fourth-generation (4G) systems. In this paper, we attempt to compare and evaluate the main characteristics of 5G channel and the performance of channel coding candidates. Low-density parity-check (LDPC) codes and polar are two capacity-achieving channel coding schemes that we concentrated on here. Block error rate (BLER), bit error rate (BER), computational complexity, and flexibility are all considered while analyzing the system. The results indicate that polar codes outperform the LDPC code systems, although LDPC is reasonable compared to other code systems.**

Keywords*—*5G, bit error rate, block error code, channel coding, LDPC code, polar code.

I. Introduction

The emergence of new technology demands and the need for the use of an increased number of various digital devices in our everyday lives brings the necessity to adopt new communication methods. High-speed computer-based systems allow practical and convenient work with advancements, and every year, leaders of the digital market introduce new networking and data transfer methods. The fifth-generation wireless connection, abbreviated as 5G, is one of these innovations. Previous generations have undeniable advantages; however, the new framework performs better and has more modern functionality. 5G intends to offer very high-speed connections, guarantee service quality, and serve mobile end-users as much as possible depicted in Fig. 1. The network behind this technology is wireless. This means there are unstable, unreliable and noiseless channels. To deal with the channel issue, a well-known technology channel coding is introduced. The study of efficient coding techniques is still ongoing and represent an open problem. Many different coding schemes today are present and already in use within the new technology networks. By incorporating them in the 5G network generally, this technology can provide considerable benefits in terms of increased capacity and coverage areas, data rates, dependability, availability, and low latency rates.

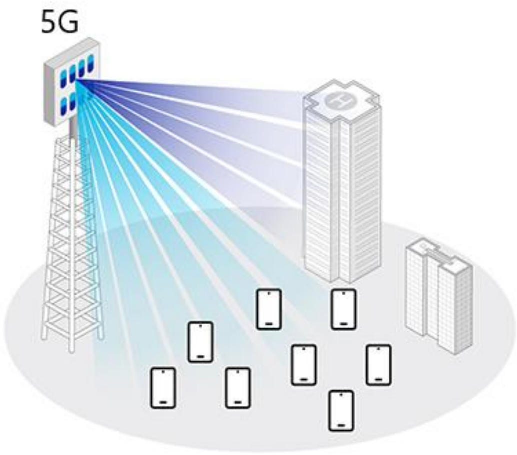

Fig. 1. 5G Networking

This paper will use two different coding schemes for analyzing the channel performance in 5G, a Low-Density Parity Check (LDPC) and Polar code. The Polar code schemes that we simulated in this work is a Polar code with consecutive cancellation decoding and successive cancellation list decoding. The LDPC code scheme is tested for two different parity-check matrices. The simulations are done by matching the parameters and characteristics of a 5G environment.

The rest of the paper is organized as follow: Section II gives the description of the related concepts and briefly gives the description of the 5G. Section III provides the characteristics of the coding schemes. Section IV presents the simulation stage and the preparation and modulation in terms of frame error rate (FER) and bit error rate (BER). The results from their comparison are presented in Section V and Section VI conclude this article.

II. Related Concepts

5G wireless technology is meant to deliver higher multi-Gbps peak data speeds, ultra-low latency, more reliability, massive network capacity, increased availability, and a more uniform user experience to more users. Higher performance and improved efficiency empower new user experiences and connect new industries. For proper functioning 5G systems incorporate different access technologies into a single, seamless experience. The convergence and interoperability of terrestrial and satellite communication systems is one significant trend. Reference [1] considers the cognitive approach using an Adaptive Coding and Modulation protocol for the second user to ensure entering in a primary user frequency band. The assumption here is that the cognitive receiver will need to recognize the start of the frame together with the code rate recognition point. Wireless caching technology also gaining popularity in 5G, especially in ultra-dense networks where many devices try to access different network services while being restricted by latency, energy efficiency, and bandwidth. The cache efficiency increases by using the concept of femtocaching, and addressing for file allocation [2]. Another way to guarantee a functional 5G network is to have successful New Radio Access Technology (NRAT). NRAT aims to examine the user channels and apply appropriate coding schemes to fit the wide range and diverse applications. According to the European research centre [3] when focusing on short message length ($k < 512$), the most appropriate coding schemes that are considered are Turbo, Polar, binary and non-binary LDPC and tail-biting convolutional codes.

One popular coding scheme intended for 5G is the Polar code [4], which provides excellent error-correcting efficiency. The turbo code was chosen as the primary channel code schemes in the previous network standards (3G and 4G). Still, the experience showed that this would not be the case in the 5G due to bandwidth and energy usage, latency, and complexity limitations. This conclusion comes from the simulation performed by Maunder er al. in [5], [6], and it can be concluded that they need to be replaced by (LDPC) code because of the benefits which are coming in the down-link, ultra-low latency, wide range, Internet of Things (IoT) and cloud computing. Focusing on block error results performed in the physical layer reference [7] showed that Turbo, LDPC, and polar codes give promising results on a wide range of coding rates and code lengths. Specifically, LDPC works fine even without using the CRC (Cyclic redundancy check), and the Polar codes do not have an error flow, but the code construction needs to be based on the channel, so they are not yet flexible. The major drawback of polar codes compared the LDPC codes is the increasing complexity and functionality and the dependence on the parity check matrix design [8]. Paper [9] demonstrated that the output from those codes is highly dependent on the duration of the related input and that larger block lengths (132 bits) need fewer repetitions of the code. When the coding length is 1024, the performance of LDPC and turbo codes are similar to each other, with the turbo code having an advantage at lower coding speeds [10], [11].

Another topic that needs to be mentions is the sub-layer for mobile video Streaming/Downloading in the cellular network, which is implemented to ensure secure and good video transmission. According to the previous work [12] perfect candidate is Random Linear Network Coding, which provides flexible input source blocks, source block length, source/encoded packet length, coding coefficient field size and many generated numbers of encoded packets.

There are many challenges regarding lower latency implementation, such as reliability, higher bandwidth, high spectrum efficiency, higher data rate. But the main focus stays on acquiring reliability and security simultaneously, as elaborated in [13]. Replacing of convolutional and Turbo codes with polar and low-density parity-check (LDPC) is done in 5G. Compared with polar codes, LDPC codes are part of the QC-LDPC code family, which can be explained using the protograph code principle. Protograph codes can be represented as a graph by adding several copies of the protograph and then permuting edges across them. Lifting is the method of adding several copies of the protograph and permuting their edges given in [14]. This method found wide commercial adoption and is represented with IEEE 802.11 standards. The reinforcement of this framework is the Q-learning algorithm [15], which enables the base station to choose suitable modulation and coding schemes that will maximize spectral efficiency while keeping a low block error rate. The previous works [16], [17] have assessed three different incarnations of successive cancellation list decoders for polar codes with different trade-offs between performance, latency, and complexity using the Extrinsic Information (EXIT) chart tool that evaluates the output of near limit channel codes. The results would help in the selection of a channel code for 5G and higher systems.

III. Underlying Theories

This section gives a brief description of both coding schemes, Polar and LDPC. Channel coding has been the transmission chain's first processing block, dedicating error correction and detection capability to the transmitted signal. Convolutional, turbo, LDPC and polar codes are among the four coding schemes supported by the model. Due to their outstanding performance and low complexity assert implementation, 3GPP (3rd Generation Partnership Project) chose these schemes as contenders for 5G. The previous standard follows the turbo and convolutional codes, but for the 5G new radio (NR) standards, we introduce the LDPC code. The LDPC decoder includes a layered design that incorporates the column message-passing schedule. In terms of decoding iterations, this provides for quicker convergence. The decoder for polar codes is based on log-domain successive cancellation (SC) and its extensions List-SC and CRC-aided List-SC.

The parameters of the codes are given in Table I, and then the encoding and decoding processes are elaborated, which later are used in the simulation program.

A. Polar code

Polar codes in detail are introduced in [11]. In general polar coding represents a channel polarization method where the channel is polarized into N channels (bit channels) that together with the duration of the codeword ($N \rightarrow \infty$) forms a new efficient channel that is entirely noise or noiseless. In these coding schemes, the number of bit channels is restricted. Thus, based on the code rate $R = \frac{K}{N}$ a good channel K from N channel in terms of bit error rate must be chosen. Polar code creation is the process of selecting a bit channel (W).

B. LPPC code

Gallager discovers LDPC code explained in [17]. Those codes for the encoding process use the concept of a sparse parity-check matrix H following the condition where the number of "1" bits need to be less than the number of bits of "0". All of this is represented using the Tanner graph, which is mainly a matrix divided into parts (bits nodes and check nodes).

C. Encoding Scheme of Polar Code and LDPC code

The LDPC code coding scheme used in this paper starts with creating the matrix H using Mackay random construction [12], permutation matrix H using the min-prod technique, encoding using the triangular factorization process, and decoding using the message passing algorithm (MPA) and the min-sum product algorithm (SPA) [14].

This paper`s Polar code encoding scheme starts with code construction using the Bhattacharya algorithm [4] to locate frozen bits. Then, the encoding and decoding of the Polar code is done by using successive cancellation (SC) and successive cancellation list (SCL) [2].

D. Decoding Scheme of Polar Code with Successive Cancellation (SC) and Successive Cancellation List (SCL)

The Successive cancellation (SC) decoder process, which can be represented as a binary tree search, starts with providing the codeword bit with a remark on channel output and using the previous codeword bit. On the other side, with the Successive cancellation list (SCL), we are using the list parameter to encode a codeword by seeing his decoding directory [8]. The algorithm estimates a bit considering both its possible values 0 and 1.

Parameters	***Specifications***
nbRM	Total number of codeword bits generated
K	Number of message bits
nL	List size
FER	Frame error rate
BER	Bit error rate
BLER	Block error rate
Nblkerrs	Number of block errors
Nbiterrs	Number of bit errors
Nblocks	Number of blocks

TABLE I. PARAMETERS AND SPECIFICATIONS OF CHANNEL CODING FOR SIMULATION SCENARIO

IV. SIMULATION

Simulations of the LDPC and Polar code encoding schemes are done to be determined the output in terms of block error rate (BLER) and frame error rate (FER). The simulation conditions, as well as the scenario predictions, are represented separately.

Step 1: Preparation stage or Setup and Code Construction Starting with the polar code, we set the parameters: the block length $n=1024$, $rate = \frac{1}{2}$. Next, we choose the SC decoding where $k=512$, but if we choose the SC list, we must specify the length of the message $l=500$ and specify the CRC $length = 11$. Now for the LDPC we have two options (base graph 1 and base graph 2). If we have the first case Base graph 1 then $k=22z$ and $rate = \frac{1}{2}$ and the *codeword bit transmitted* $= 44z$. The variable z represents the expansion factor. According to Base graph 1 we have parity check matrix (46 × 68) where the first 22 rows are reserved for the message, then the remanding 46 are parity. So, for the proposed rate, showed in Fig. 2, we need to take 24 parity (from the parity part) because later those are used for the decoding part. Next thing we take the block length, but because we have fixed value for the z this will have base matrix 24. The process is similar for Base graph 2 in Fig. 3, but here the length of the parity check matrix is (42 × 52), so $k=10z$, codeword *transmitted* $= 20z$ (and from here $z \approx 50$).

Step 2: Preprocessing Stage There is preprocessing stage before the bits of information are transmitted. That stage in LDPC is the construction and permutation of matrix H, whereas the phase in polar code is done only construction. The wight of the column is essential if matrix formation is of dimension $M \times N$. Next, matrix H is examined to avoid the occurrence of length cycles, which would result in increasing the decoding difficulty. Then, the permutation of matrix $H = [H1 \mid H2]$ seeks to turn the matrix $H1$ into a non-singular matrix. The Polar code is prepared using the SNR 0 design and the Bhattacharya algorithm in successive cancellation decoding. The Polar code creation algorithm is also utilized in successive cancellation list decoding, but with a value of $\varepsilon = 0.32$.

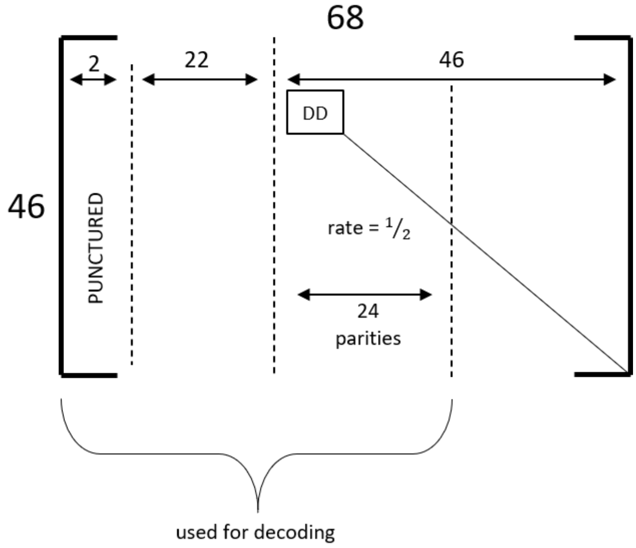

Fig. 2. LDPC, Basegraph1 – parity chech matrix

Step 3: Modulation Stage

Before we proceed to the next part, first, we must provide enough errors. After that, in the end, we are printing and putting in one matrix the results from frame error rate and bit error rate simulations, number of block errors, number of bit errors, number of blocks. In order to choose which data needs to be taken, we must perform this stage multiple times by reducing the numbers of the blocks until we get some errors, and then slowly to start with increasing. Last, we must provide the plotting details where x axis will keep the *log y* in liner scale and then y axis to semi *log y*.

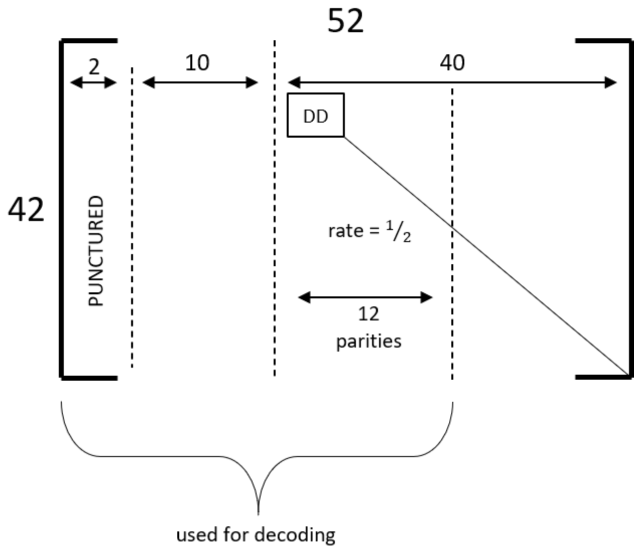

Fig. 3. LDPC, Basegraph2 – parity chech matrix

V. Performance Comparison

This section elaborates the performance among both codes, Polar and LDPC. The comparison is made regarding the coding rate and the number of bit or block errors during the data transmission time. Under all examinations, four different codes are considered: Polar code with successive cancellation, Polar code with successive cancellation list, LDPC based on Basegraph 1 and LDPC based on Basegraph 2. Fig. 4 calculates the achievable bit error rate of each code construction. The figure depicts that the polar code with successive cancellation decoder is the poorest one. As it is noticeable is located on the right side where for *3dB*, the value for FER goes to 10^{-3}. On the other side, the polar code with successive cancellation list decoding gives the best result, i.e., for 10^{-3} FER we get $dB \approx 2.1$. With the list size increasing to eight, the curves go more to the left and give good results. The LDPC with Base graph 1 and Base graph 2 are relatively equivalent with same size of block length, although we must consider the choice of parameters i.e., the quantization. In general, we can see that the polar code and the LDPC code are quite effective at these comparable block lengths, and they perform pretty well when quantized and simulated.

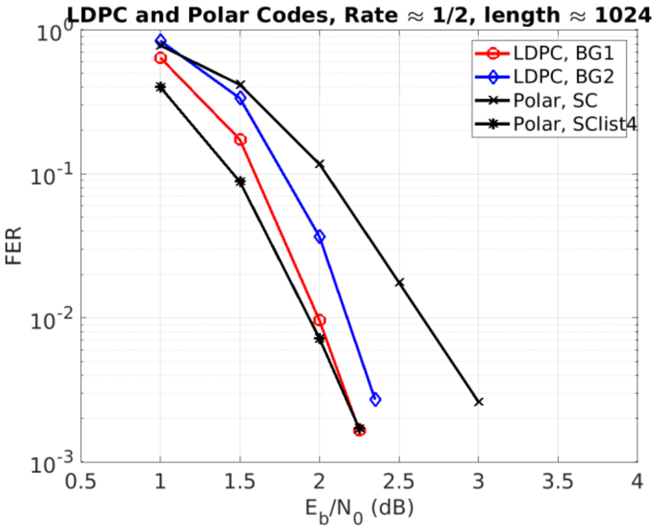

Fig. 4. LDPC and Polar Codes, Rate ≈ ½ , length ≈ 1024

Fig. 5 shows the number of bit errors compared to the value of the number of blocks. From the graphs can be understood that they all have similar results at the beginning of the x-axis, which in some way they perform close to each other, especially at the higher number of blocks. As expected, the polar code with SC gives the most bit errors at the beginning for smaller values. However, as the number of blocks increases, the Polar successive cancellation code outperforms the other ones. Still, it has the most significant value for errors, which is not the case with others. At the end of the x-axis, the improvement of the Polar with SC is slightly increased, and all other gives a constant increase.

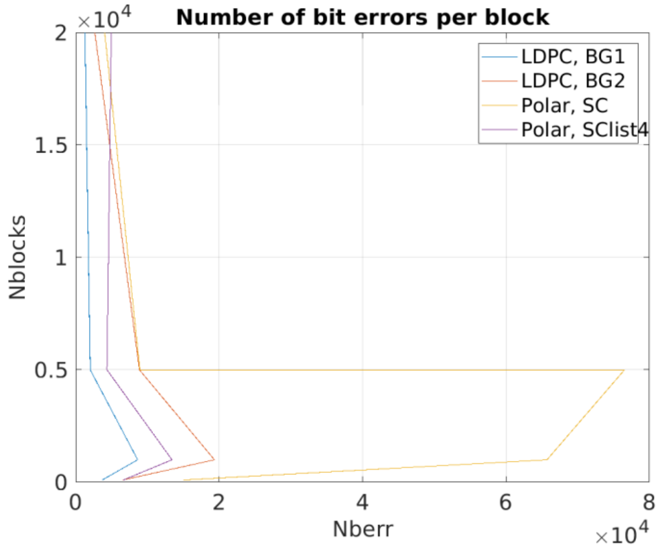

Fig. 5. Number of bit errors vs block

Fig. 6 compares the number of block errors vs the number of blocks. As shown in Fig. 6, it can be examined that in the situation where the number of blocks is greater than 1×10^4, the result is similar to each other for most of the coding schemes. They perform well, but it must be mention that the best performance gives the Polar with successive cancellation with list=4 where it meets the lowest parameters for the number of blocks errors compared to the number of blocks. On the other side, when the value for the number of blocks is below 1×10^4, the worst performance is given by Polar with SC which provides around 600 block error just for 0.5×10^4 blocks.

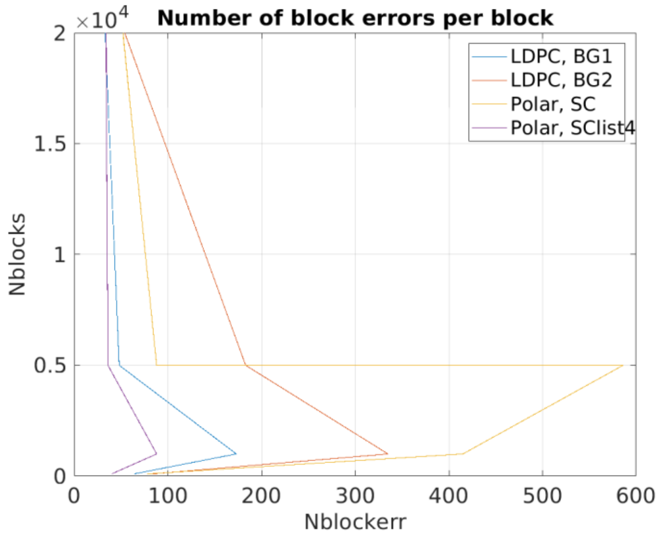

Fig. 6. Number of block errors vs block

VI. Conclusion

This work compares and estimates the efficiency of the Polar and LDPC codes as candidates for coding in the 5G networks. To different codes and four variations of them are considered in the simulations, the polar code with successive cancellation (SC), the polar code with successive cancellation list (SCL) decoding, LDPC code Base graph 1 and LDPC code Base graph 2 decoding. All coding schemes have a uniquely critical role in providing high throughput and low latency. To increase the value of block length, we must decrease the $\frac{E_b}{N_o}$, and by this, we have a demand for less power consumption. Although the successive cancellation decoder for polar codes has the lowest complexity, the CRC-assisted successive cancellation list decoder outperforms LDPC and turbo codes. Due to a lack of implementations, the actual costs of these types of decoders are unknown. Many other considerations must be addressed when choosing a coding scheme, such as encoding and decoding delay, energy efficiency, and space efficiency. The polar code with successive cancellation list has the best performance with *2dB* related to other schemes in order to achieve FER 10^{-3}. In conclusion, polar codes with SCL become the best candidate as an effective encoding scheme for this concrete situation.

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