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A Comparison of 5G Channel Coding Techniques

LPDC and Polar Codes

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Abstract— **The rapid, reliable, and secure data transmission in everyday life and numerous applications is one of the crucial demands of modern society. Mobile wireless communications have advanced significantly in recent decades. From the first (1G) to fifth-generation (5G) of mobile communications, the realization of fast and secure communication has always been challenging as data transfer happens in an imperfect channel environment where noise due to amplification, distortion, and other impairments is present. Channel coding is key to establishing fast communication with low error probability, implying that choosing the proper channel coding scheme is a challenging and crucial task. Higher flexibility and reliability, and low computational complexity, latency, and costs are desired coding technique characteristics. This paper focuses on two 5G channel coding techniques, Low-Density Parity-Check (LDPC) and Polar codes. These codes have been examined in the case of variable message sizes and for a wide range of code rates. In addition, different Polar decoding algorithms have been investigated. Simulations results have confirmed that there is no single channel coding scheme able to meet all 5G requirements as well as the superiorities of LDPC codes in case of long messages and Polar codes for short messages. The ability to support a wide range of code lengths and code rates and excellent Bit Error Rate (BER) performances, justify the utilization of LDPC and Polar codes in 5G communication systems.**

Keywords - 5G, LDPC codes, Polar codes, BER, SNR

I. INTRODUCTION

Mobile communication has undergone dramatic changes over the past few decades, experiencing five generations of technological evolution. The first generation of mobile networks, introduced in the 80s of the last century, was based on analog transmission. 1G was restricted to voice transmission only and, for the first time in history, mobile networks were available to all. At the beginning of the 1990s, the second generation of the mobile network appeared, introducing for the first time digital transmission via radio link which improved both capacity and security. While the most important service remains voice transmission, the use of digital transmission has also provided novel services like text messaging, conference calls, call hold, internal roaming, and more. Initially, there were several different second-generation technologies, such as the Global System for Mobile Communication (GSM), which was developed jointly by several European countries. The third generation of the mobile network, also called the 3G network, emerged in the early 2000s. The 3G network enables faster wireless Internet access and for that time, this was a big step towards a high-quality mobile broadband network. Improving data capacity services and data transmission, tasks like browsing, multimedia content sharing, video downloading, performing video calls, running video games, and participation on social media platforms have become possible. All this has been achieved through the evolution of 3G - HSPA (High-Speed Packet Access). In 2009, the fourth generation (4G) of the mobile telecommunications network was launched, along with LTE technology. LTE technology is based on HSPA, which offers greater efficiency and improved wireless Internet access in order to allow higher data rates to the end-user. This is achieved by a transmission that is based on Orthogonal Frequency-Division Multiplexing (OFDM), and the main benefits are to allow wider bandwidths and advanced technologies that use multiple antennas. 4G has resulted in higher data rates, higher quality, enhanced security, and reduced costs. Further development goes beyond communication services between people and makes possible human-to-machine and machine-to-machine communication. This refers to the Internet of Things (IoT). Hence, 5G wireless networks focus on improving the quality of service (QoS), the reliability of data transmission, and the security of the systems. Three key parameters influence the provision of good coverage with very good performance: the first is a far better data rate; the second is low latency and a third parameter is a large number of connections. If all of the above parameters are met, it results in low energy consumption. In order to achieve greater bandwidths, improved capacity, and energy efficiency, the 5G relies on spatial multiplexing, massive multi-user multiple-input-multiple-output (MIMO) techniques utilization with millimeter-waves (mm-waves) in small cell geometries [1-4].

In order to ensure fast and reliable transmission of data, channel coding, or forward error control coding (FEC) plays an important role in the network. Since errors occur during the transmission of data, due to a number of factors in mobile communications, such as noise or signal attenuation, their detection and correction are of immense importance. In previous generations of mobile networks (3G and 4G), turbo codes were used because they performed well and were reliable. In 5G, the 3rd Generation Partnership Project (3GPP) decided to use Low Density Parity Check (LDPC) codes and a relatively novel type of channel coding – Polar codes. The reason for this change in channel coding methodology was a significant coding delay due to numerous processing iterations required for turbo codes. They were therefore challenging to use in 5G, where high speeds and low delays were paramount. Since no type of code can satisfy all the strict requirements of the 5G, it was decided to use these two code types. In summary, LDPC and Polar codes have been chosen due to their excellent Bit Error Rate (BER) performance and fast encoding and decoding procedures [5]. Polar codes are a fairly simple method of encoding and decoding and are able to reach channel capacity. However, they introduce a little higher latency. LDPC codes, in addition to lower latency, also use the available bandwidth better than Polar codes [6].

Having in mind that there is no single channel coding candidate able to meet all 5G requirements and that not choosing channel coding technique correctly lead to poor mobile network performances in terms of coverage, data rates, capacity, and QoS [7, 8], the research devoted to the selection and implementation of appropriate channel coding techniques is crucial. Hence, this paper is organized as follows. A short overview of 5G is given in Section II. Section III presents 5G channel coding schemes while simulation results (BER vs Signal-to-Noise Ratio (SNR) graphs for both, LDPC and Polar codes, in the function of variable code block lengths and code rates) are shown in Section IV. In addition, the influence of different Polar decoding algorithms on BER performance have been investigated. A summary of the performed research and directions for future research are provided in the Conclusion.

II. AN OVERVIEW OF 5G

The 5G New Radio (NR) is being developed by the 3GPP as a new technology for radio access in the fifth generation of mobile networks. The original time frame for developing the standard was set in March 2017 at RAN#75. There are two releases, Release-15 and Release-16, while Release-17 is expected in 2021. The first set of specifications, Release-15, was finished in June 2018, while the second release was completed on July 3rd, 2020, slightly delayed by the pandemic [9-11]

This network as a base uses the LTE network to offer even higher throughputs and significantly higher wireless internet efficiency. Since LTE has served as a foundation for 5G NR, there are similarities between LTE and 5G NR. New radio networks are structured so that they are compatible with LTE, but with the aim of enabling higher spectral efficiency, shorter response time for the user plane, and greater traffic capacity.

Protocol architecture used in 5G NR is given in Fig. 1 and consists of user-plane protocols, for transfer of user data, and control-plane protocols, for transporting control signaling information [12, 13]:

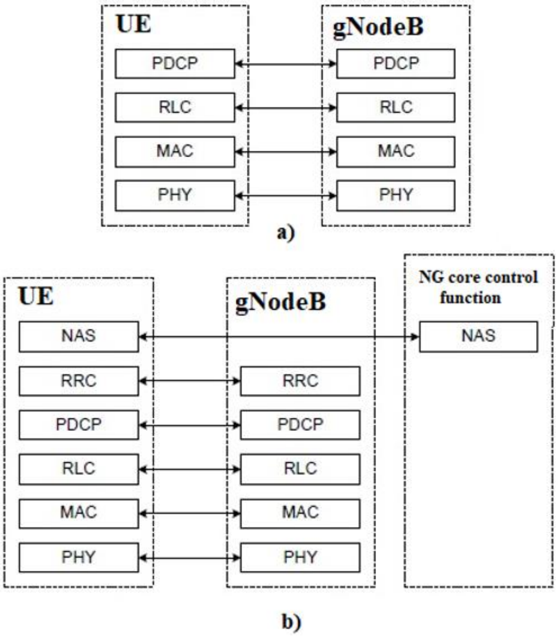


Figure 1. 5G protocol architecture: a) 5G user-plane protocol stack; b) 5G control-plane protocol stack

- The Non-Access Stratum (NAS) layer exists within the 5G control plane protocol stack and it manages and maintains communication sessions to persist as the user moves across the network (e.g., registration, authentication, location update, and session management).
- Radio Resource Control (RRC) has several functions: broadcast of AS and NAS system information, paging, signal and data radio bearers' setup and maintenance, mobility functions, radio failure detection, recovery, etc.
- Service Data Adaptation Protocol (SDAP) has two main functions:
  - a mapping between data radio bearer and QoS flow, and
  - to mark the QoS ID of the uplinked and downlinked packets.
- Packet Data Convergence Protocol (PDCP) primarily improves the efficiency of the radio interface by compressing and decompressing IP data thus reducing total overload.
- Radio Link Control (RLC) transports upper layer Protocol Data Units (PDUs), corrects errors using Automatic Repeat Request (ARQ) methods, segments and re-segments Service Data Units (SDUs), etc.
- Media Access Control (MAC) is responsible for mapping between logical and transport channels,

scheduling information reporting, correcting errors using Hybrid Automatic Repeat Request (HARQ), priority handling of UEs via dynamic scheduling, multiplexing and demultiplexing of upper layer PDUs, priority handling between logical channels of one UE and so on.

- Physical layer transports all information coming from the MAC layer over the air.

5G network applications can be divided into three fundamental categories [7, 14, 15]:

- Enhanced mobile broadband (eMBB) - represents a service improvement initially introduced by 4G LTE networks that allow higher data rates over a larger area. Such a network will provide a larger capacity for peak data rates for bigger crowds and moving users. This group of applications remains the most important as it is oriented towards communication between people. These types of applications are further challenged by the 5G network. For instance, hot spots require a higher data rate, a greater number of potential users, and the need for greater capacity. Furthermore, extensive coverage is required to allow mobility and a positive user experience.
- Massive machine-type communications (mMTC) - this group comprises device-related applications and its specificity is a large number of interconnected devices communicating intermittently while exchanging small amounts of data. High data rates are not necessarily needed for such applications. However, they should be able to support asynchronous access (intermittent network access), high device density (about 200,000 per square kilometer, low data rates (between 1 and 100 kbps), cost-effective IoT endpoints with substantial battery life (over 10 years), cost-effectiveness, extended availability and low energy consumption [16].
- Ultra-reliable and low latency communications (URLLC) - this group of applications includes human-initiated communications as well as critical machine communications that require communication with the least possible delay, ultra-reliability, and high availability. Typically, URLLC applications include applications related to 3D games, autonomous cars, critical applications in remote healthcare, and wireless control of industrial machines.

As a result, there are three main key performance indicators for a 5G network:

- peak data rates for enhanced mobile broadband (eMBB) should be greater than 10 GB/s,
- for massive machine-type communications (mMTC) more than 1 million/km2 connections are needed, and
- latency for ultra-reliable low-latency communications (URLLC) must be under 1ms.

The actual specific minimum requirements for the 5G network are indicated in Table I [9].

TABLE I. REQUIREMENTS FOR 5G NETWORK [9]

Metric	Requirement
Peak data rate	DL: 20GB/s UL: 10GB/s
Peak spectral efficiency	DL: 30b/s/Hz (assuming 8 streams) UL: 15b/s/Hz (assuming 4 streams)
User experienced data rate	DL: 100MB/s UL: 50MB/s
Area traffic capacity	Indoor hotspot DL: 10Mb/s/m2
User plane latency	eMBB: 4ms URLLC: 1ms
Control plane latency	20ms (encouraged to consider 10ms)
Connection density	1 million devices per km2
Reliability	99.9999% success prob.
Bandwidth	> 100 MHz; up to 1 GHz in > 6 GHz

III. 5G CHANNEL CODING SCHEMES

In short and simplest terms, a communication system is anything that can transport information between two entities. This process of transport is called communication. In our specific case, we are dealing with a digital telecommunications system which means that information is transferred in digital form over a telecommunications network consisting of different transmission systems, relay stations, and terminal equipment [17]. One of the main obstacles to this type of communication has to do with the physical problems associated with the transmission of radio waves. Such a way of carrying information suffers from fading and interference. Fading occurs when a receiver receives several versions of the same signal that have crossed different paths (multipath propagation), or the signal is shadowed by obstacles on its way. In multipath propagation, different versions of the same signal have undergone different attenuations, delays, and phase offsets that can amplify or weaken the signal [18]. All this results in communication errors so that the data sent is not the same as the data received.

In 1948, Shannon demonstrated that error-free communication over a channel with noise is possible if the rate of transmission of information is less than or equal to the channel capacity boundary [19]. After that, scientists from around the world were trying to introduce a new method of transmission that would approach the maximum possible capacity presented by Shannon's theory. Reaching the maximum channel capacity boundary is possible by using channel coding, along with encoding and decoding. In that case, the communication system looks like in Figure 2.

Coding makes communication better because it adds redundancy to the data. Although additional information is appended, the relative number of valid transmitted alternatives is smaller. This implies that it is more easygoing for the receiver to discriminate between transmitted alternatives since the distance between valid codewords has increased. When a not valid codeword is received, the receiver can reasonably safely decode to the closest valid codeword. In terms of distance measurements, two common types are Hamming distance and Euclid distance.

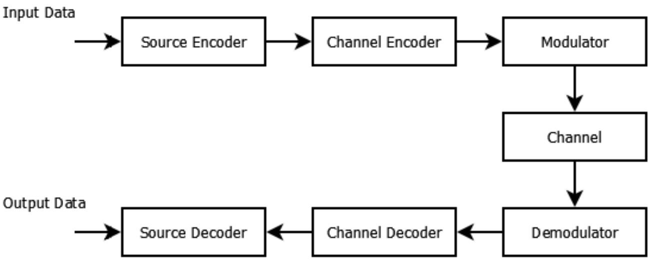


Figure 2. Channel coding position in a communication system

As a result, channel coding offers the following advantages:

- it reduces the energy requirements on both sides of the communication channel. For a mobile device, this is particularly important because it is powered by a battery.
- less latency introducing retransmissions occurring on receipt of data that cannot be corrected,
- increased link capacity as more noise from more data transmitted via a link can be tolerated, and
- an effective channel coding system makes it possible to obtain higher data rates.

In this paper, two types of coding schemes used in the 5G network are presented: LDPC and Polar codes. LDPC codes are mainly used for user data whereas Polar codes are used for downlink and uplink transmission of control information.

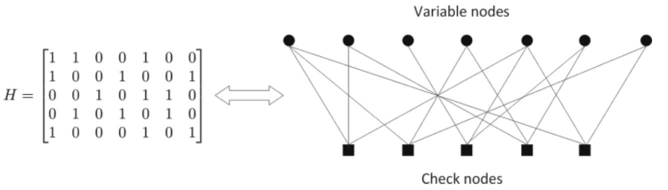
A. LDPC code

The LDPC code was originally introduced in 1962 by Gallager [20] in his doctoral dissertation. At that time, it was too computationally complex for all practical applications, so it remained relatively unknown for a long time afterward. Mackay [21] re-discovered the Gallager codes in 1997 and demonstrated that their performance is very close to the Shannon boundary. Furthermore, the researchers have produced new LDPC codes, known as generalizations of Gallager's LDPC codes, that perform better than the original ones [22].

LDPC code is based on a sparse parity check matrix,

$$H = n \times m, \tag{1}$$

which consists of low-density ‘1’s. As a result, coding and decoding are less complex and more reliable. In addition, the parity check matrix can be shown as a Tanner graph where each row corresponds to the check node (CN_n) and each column corresponds to the variable node (VN_m). Relations between CNs and VNs depend on the number of ‘1’s in the matrix (Fig. 3). The three main characteristics of the parity check matrix H are: base graph, lifting size and cyclic shifts which are applied to the edges of the graph [8]. In the case of NR, two base graphs are defined [23]: Base graph 1, whose size is 46 x 68, and Base graph 2, with a size of 42 x 52.



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

Figure 3. Tanner graph [23]

Information bits in base graphs correspond to the first 22 columns of base graph 1 and 10 first columns of base graph 2. Selecting the base graph depends on the code rate and the length of the message sent.

Besides base graphs, there are eight sets of lifting sizes, which correspond to a large number of code rates and information block sizes. For a base graph, there are eight sets of parity check matrices, which define eight sets of cyclic shifts, one per set of lifting sizes [8].

There are two methods of LDPC encoding [24]. First, the preprocessing method, which uses the generator matrix G which corresponds to the parity check matrix H. This method is used for encoding vector of size 1 x q where q is the number of bits of the random message. The second method is even simpler than the previous one since the parity check matrix H is used directly which makes this type of method more effective.

In addition, there are two types of decoding algorithms [24]. In case of hard decision, a bit-flapping algorithm is used and in case of the soft decision, the channel will use a Sum-Product Algorithm (SPA). The second one is often called the message-passing algorithm. It is based on passing messages between CNs and VNs in each iteration until the decoding process is completed. This kind of processing causes this algorithm to be an iterative decoding algorithm.

B. Polar codes

The polar codes were revealed for the first time in 2009 [25] by Arikan Erdal at Bilkent University in Ankara, Turkey. The reason they were accepted so rapidly is their ability to achieve maximum channel capacity. Moreover, the encoding and decoding processes are much less complex. The codes are based on the concept of channel polarization [15], where polarization increases with longer blocks [26]. The main idea is to split the channel of capacity I(W) into N channels with capacity zero or one. I(W) number of channels will become perfect channels with no noise and the rest, 1 – I(W) will become completely noisy. This is obtained by applying the polarization transformation recursively. Noiseless channels are then employed for data transmission [15]. Inputs of channels that are completely noisy are frozen to one or zero.

If the length of polar codes is N and code rate R, there will be K=N×R information bits. The encoding is done with the encoder whose length is N as well. N – K positions are frozen bits. The maximum code length is 2^n, where n is different for uplink and downlink. For the uplink, n ranges from 5 to 10, and for the downlink, n ranges from 7 to 9, including limit values [23]. The encoder is given by Kernel (2) [24]:

$$F = \begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix} \quad (2)$$

and it represents a polarization transform. If N is larger, the input is described as the Kronecker product of the above Kernel matrix with itself. If length is 2^n, then the encoder is given as:

$$G = F^{\otimes n}, \quad (3)$$

where G is a Kronecker product.

Polar codes in 5G NR are replacements for Convolutional Codes in LTE. One of the disadvantages of Polar codes is the insufficient testing of the practical application, as it has been discovered recently [26].

There are plenty of ways to decode Polar codes. In 2009, Arikan proposed the Successive Cancellation (SC) decoding algorithm [15]. Besides SC, there are also Successive Cancellation List (SCL) decoding, Cyclic Redundancy Check - Aided Successive Cancellation List (CRC-SCL) decoding, and Adaptive Successive Cancellation List (Adaptive-SCL) decoding [27].

Some other algorithms were initially considered, but 3GPP decided to use an SC-based decoder due to better error correction performance. The first issue that emerged was the issue of hardware implementation since soft information was given as likelihoods. The resulting instability was reduced by log-likelihood and ultimately it was eliminated with log-likelihood ratios (TLRs) [27]. Although the above issue has been solved and the algorithm applies to hardware and software applications, error correction performance is not ideal for medium lengths.

For this reason, a list-based decoding algorithm is applied. The main idea is to combine several SC decoders, which operate in parallel. Each path metric is calculated to choose more likely codeword candidates at every leaf node. Prior to this, the bit will be assessed as 1 and 0 at the same time, so that the number of codeword candidates doubles. The discarding of less probable candidates will limit the number of paths [27].

C. Channel coding and decoding steps

Channels are frequency bands used to transmit various kinds of data via radio signals. There are different types of channels. The direction of communication is the first criterion, so depending on whether the data is transmitted from the user equipment (UE) to the NR base station (gNodeB) or vice versa, channels are classified into uplink and downlink channels [7]. Moreover, the channels can be differentiated depending on the type of data they transport. As a result, the channels are divided into data channels and control channels according to the type of data they transmit. User channels transfer user data, whereas control channels transport data used to establish and maintain user connections and their bearers.

Transport channels are mapped into proper physical channels. At the physical level, a signal is mapped to fitting physical time-frequency resources. The actual transmission of the data is going to be through those physical channels. There are three downlink and two uplink physical channels as listed in Table II.

TABLE II. PHYSICAL CHANNELS AND CORRESPONDING CODES

Physical Channel	Channel Coding
Physical Downlink Shared Channel (PDSCH)	LDPC
Physical Uplink Shared Channel (PUSCH)	
Physical Downlink Control Channel (PDCCH)	Polar codes
Physical Broadcast Channel (PBCH)	
Physical Uplink Control Channel (PUCCH)	

1) Downlink channels

As indicated in Table II, three types of physical downlink channels exist:

- Physical Downlink Shared Channel (PDSCH) carries different types of data to the UE, including user data itself, but is also responsible for carrying paging information, some of the UE-specific control messages coming from the upper layers, system information blocks, as well as some random access response messages. Channel capacity is split as a function of time and frequency. Coding and data rate are flexible due to the use of flexible coding schemes and adaptive modulation format that depends on current conditions such as SNR. PDSCH supports the Quadrature Phase Shift Keying (QPSK), 16 Quadrature Amplitude Modulation (QAM), 64QAM, and 256QAM modulation schemes [2, 28, 29].
- Physical Downlink Control Channel (PDCCH) is responsible for the transmission of Downlink Control Information (DCI), which are mainly scheduling decisions for PDSCH reception and grants for scheduling to enable data transmission on PUSCH. Its modulation format is QPSK and the coding scheme is Polar coding [2, 7, 28, 29].
- Physical Broadcast Channel (PBCH) transfers a portion of the system information required by the UE to connect to the network. It is a part of the synchronization signal block. The UEs obtain the Master Information Block (MIB) via this channel. With the control channel, PBCH supports time and frequency synchronization, which assists in the acquisition, selection, and re-selection of cells. The data format is fixed where one block extends over a Transmission Time Interval (TTI) of 80 ms. PBCH uses QPSK modulation. In addition, a cell-specific demodulation reference signal is transmitted over this channel which may assist in beam-forming [2, 7, 28].

Channel coding schemes for each of the physical downlink channels have few common coding steps as it is depicted in Figure 4 [30-32]:

- The calculation of the CRC is used to detect errors. To enable forward error correction, CRC is first appended to a transfer block. It is calculated based on payload size and number of parity bits and then, in the next step, is attached to the code block. It may be 16 bits long when the transport block size exceeds 3824, or 24 bits long for shorter transport blocks [33].

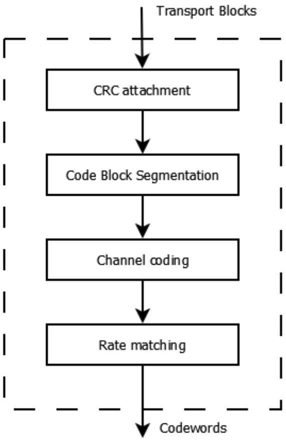


Figure 4. Common coding steps

- Code block segmentation and code block CRC attachment process are dependent upon the coding scheme:
    - For PDSCH, where LDPC code is used, maximum code block size depends on the LDPC base graph (base graph 1 – 8448 and base graph 2 – 3840) and the total number of code blocks is estimated based on [33].
    - For PDCCH, where Polar code is used, after CRC attachment, bits are scrambled with the suitable RNTI (Radio Network Temporary Identifier) coding.
    - For PBCH, prior to CRC attachment to the transport block, it is necessary to generate the payload and then scramble.
- Channel coding depends on the type of coding techniques used. LDPC code design has been done with high throughput in mind and a strong ability to correct errors. Code rate can vary. When LPDC codes are involved, code blocks are carried to the channel coding block. Polar codes are used to encode control information due to their good performance with short blocks. With Polar codes, information bits are transferred to the channel coding block [23].
- Rate matching functionality is needed to allow an appropriate number of transmitted bits to be selected whenever the amount of available transmission resources changes. This is because of the nature of a cellular system in which conditions change frequently. Rate matching is a step that takes place after channel coding. Every code block is individually rate matched for LDPC codes and in the case of Polar code, every code block is rate matched through interleaving, puncturing, shortening, or repetition [23, 34].
- Code block concatenation is the sequential concatenation of the rate matching outputs for the various code blocks.

At the receiver side, the steps are the opposite of the steps explained [34]:

- Rate recovery is the process of preparing for decoding. It includes reverse code block concatenation and rate matching procedures.
- The decoding depends on the type of channel coding technique used; the same type of decoding will be carried out.
- Code block desegmentation – Each code block segment has CRC attached. Before concatenation, CRC is deducted from the segment and then all segments are grouped into one block.
- Transport block CRC decoding checks input block for CRC error. In the absence of errors, the block is regarded as having been successfully decoded.

2) *Uplink channels*

In the case of physical uplink channels, the processing steps are similar to those used in the physical downlink channels. In this case, the physical uplink channel receives the uplink shared channel codeword. There are two types of physical uplink channels, depending on the type of data passing through them:

- Physical Uplink Shared Channel (PUSCH) is used for transmission of shared data on the uplink (by a UE) and ½ layer control information. PUSCH supports pi/2-Binary Phase Shift Keying (BPSK), QPSK, 16QAM, 64QAM, and 256QAM modulation schemes.
- Physical Uplink Control Channel (PUCCH) main purpose is to serve as an Uplink Control Information (UCI) carrier (i.e., HARQ Acknowledgements (HARQACK), Scheduling Requests (SRs), Radio Resource Control (RRC) signaling messages and Channel State Information (CSI)). The PUCCH uses BPSK or QPSK depending on the PUCCH format and the number of bits

As well as with the downlink signals, coding schemes of uplink signals depend on the applied coding mechanism [2, 7, 8, 31, 32]:

- Code block segmentation and code block CRC attachment:
    - For PUSCH, the number of parity bits is dependent upon the size of the payload (A):
        - if A>3824, CRC length is 24 bits,
        - otherwise, CRC is 16 bits long.
    - For PUCCH, where Polar coding is used:
        - if 12≤A≤19, the length of CRC is fixed to 6 bits,
        - if A≥20, CRC length is 11, and
        - if A≤11 no CRC bits are included.

- Channel Coding – as previously stated, the PUSCH will use the LDPC code, while the Polar code is applied to PUCCH,
- Rate matching,
- Code block concatenation,
- Multiplexing of data and control information - ensures that control and data information are mapped to different modulation symbols.
- Channel interleaver - implements a time-first mapping of control modulation symbols and frequency-first mapping of data modulation symbols onto the transmit waveform.

At the receiver side, the processing stages of PUSCH and PUCCH correspond to those at the transmitter side.

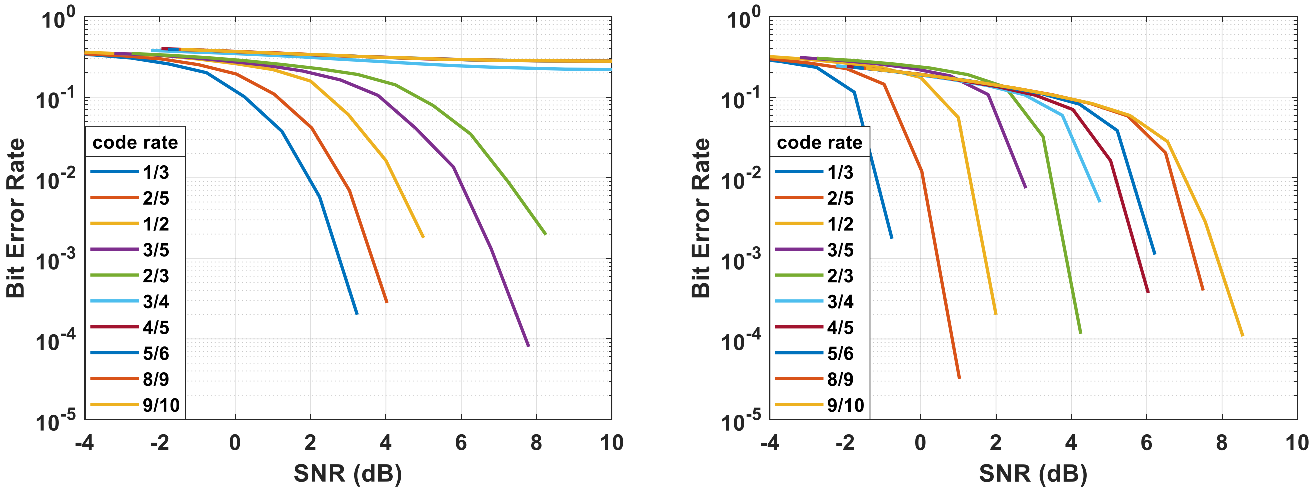
IV. 5G CHANNEL CODING SCHEMES SIMULATIONS

In this paper, a comparative analysis of LDPC and Polar coding schemes for different message lengths and code rates was performed. For simulation purposes, the Additive White Gaussian Noise (AWGN) channel model serves as a noise channel. It has been chosen as it is able to imitate the naturally occurring noise that exists all around us. This noise model is used to simulate the influence of some natural signals, also referred to as background noise on a signal. The fundamental characteristics of the AWGN are stated in its name [15]:

- Additive - The signal on the receiver side corresponds to the sent signal to which the noise has been added.
- White - The unique power across the entire frequency range, which does not change with different frequencies, is the basic idea that noise represents.
- Gaussian – Values close to zero are more likely to appear because AWGN follows the Gaussian normal distribution, which means that positive and negative values are possible.
- Noise – Signal interferences.

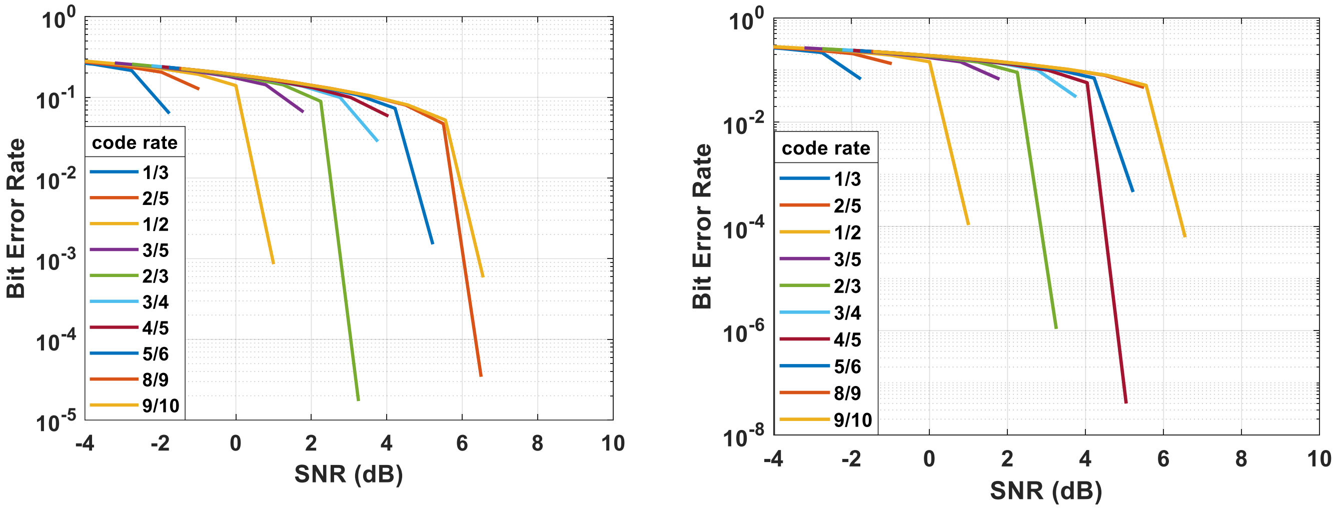
The simulations are carried on considering different message lengths and variable code rates. Shorter messages are typical in IoT application scenarios while long messages are associated with broadband data applications. On the other side, low code rates are practiced in rural areas due to the sparse distribution of base stations, while in urban regions high coding rates have been used (due to the ultra-dense population) [34]. All simulations have been performed using MATLAB [31]. As the quality criterion of a channel code, BER of the coding schemes is plotted against SNR for different message lengths (50, 500, 5000, and 50000 bits) and different code rates {1/3, 2/5, ½, 3/5, 2/3, ¾, 4/5, 5/6, 8/9, 9/10}. Message transmission has been performed using QPSK over the AWGN channel model which variances are estimated from SNR values. The transmission parameters were set according to the 5G numerology. Each simulation was performed for 500 frames and continued until the BER of 10^{-5} is achieved.

Figures 5. and 6. show the LDPC coding of the message of different lengths in downlink and uplink directions, respectively, and obtained BER performances for variable code rates. Both figures illustrate a typical curve - BER decreases with the increase of SNR. In addition, it can be noted that for the longer messages, error correction requirements of desired BER values can be reached at lower SNR values, which confirm the LDPC superiority in case of longer message lengths.



a) LDPC, DL, 50 bits

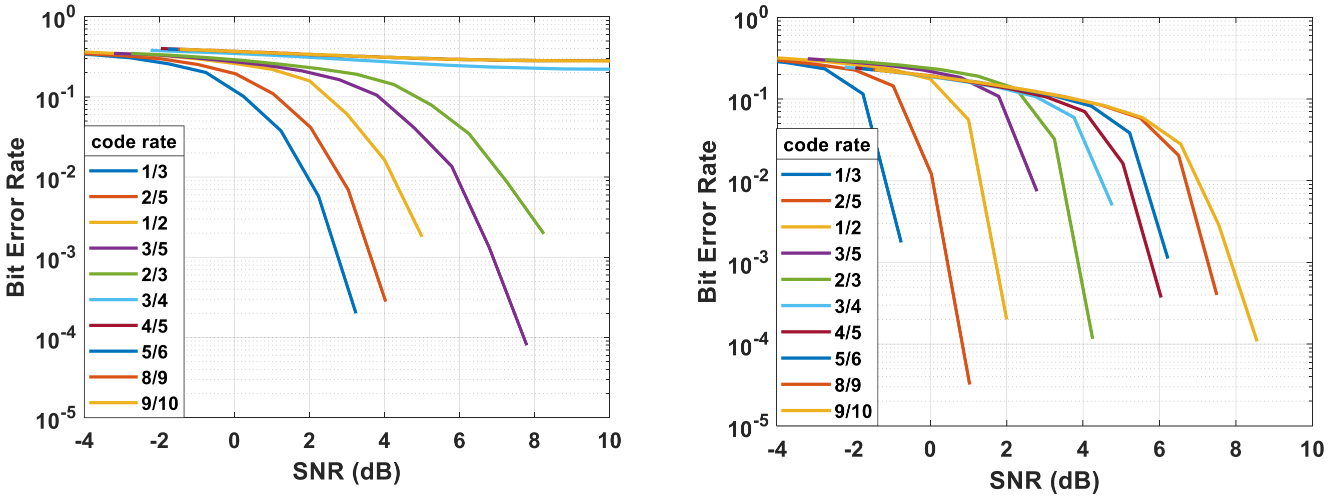
b) LDPC, DL, 500 bits



c) LDPC, DL, 5000 bits

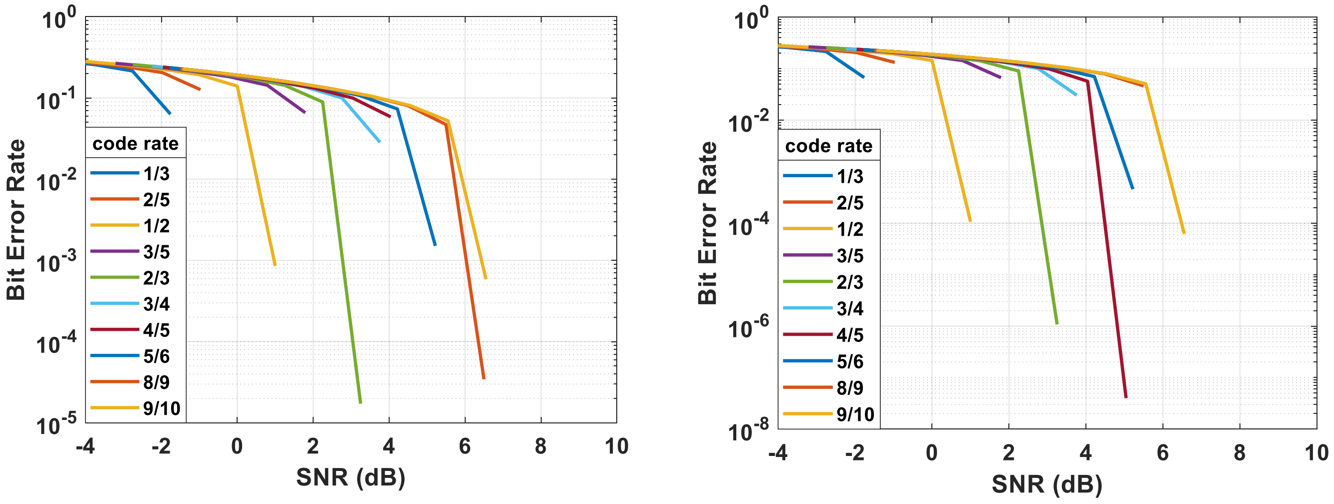
d) LDPC, DL, 50000 bits

Figure 5. LDPC, downlink - BER performance for variable code rates and different message lengths



a) LDPC, UL, 50 bits

b) LDPC, UL, 500 bits



c) LDPC, UL, 5000 bits

d) LDPC, UL, 50000 bits

Figure 6. LDPC, uplink - BER performance for variable code rates and different message lengths

In the case of Polar coding, this coding scheme cannot be applied for downlink transmission of 500-, 5000-, and 50000-bits long messages because they exceed the maximum input length for PDCCH that must be less than or equal to 164 (140 information bits + 24-bit CRC). Therefore, BER performance simulation can be done only for a 50 bits long information message (Fig. 7). Simulations have been performed using the CRC-SCL algorithm with the decoder list size L=8.

Fig. 8. shows the simulation results for variable list sizes {1, 2, 4, 8, 16, 32} in the case of 1/2 code rate. Evidently, a larger list size of the CRC-SCL decoder means enhanced Polar coding performance but with a diminishing-returns effect (larger L value means lower error rate, but longer simulation time).

In the uplink directions, the maximum size of input length is 1023 bits which imply that simulations of BER performances can be executed only for 50- and 500 bits long messages (Fig. 9).

From the performed simulations, it is evident that Polar codes are not applicable in the case of long information messages what justifies their use for UCI and DCI transmissions. Figures 7-9. show that BER follows a typical curve - decreases with the higher values of SNR.

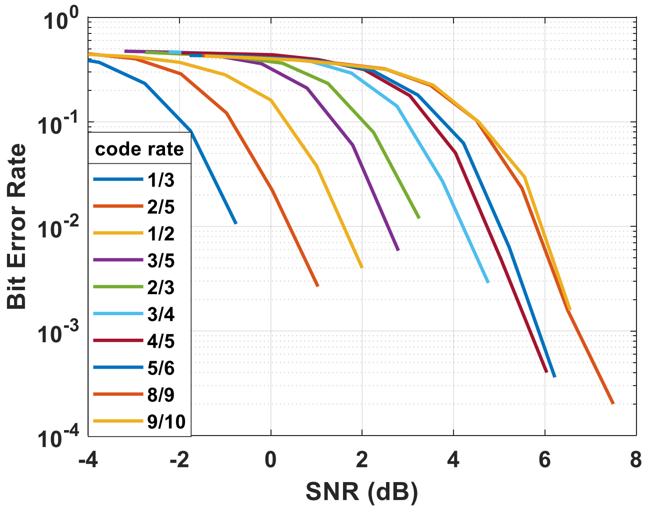


Figure 7. Polar coding, downlink – BER performance for 50 bits long message for variable code rates

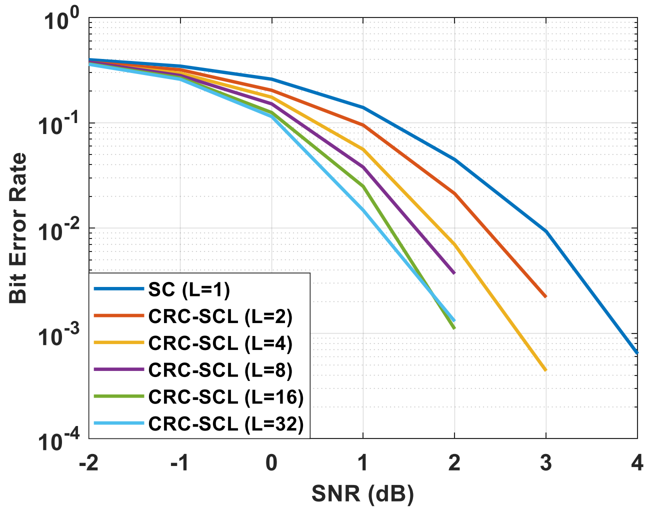
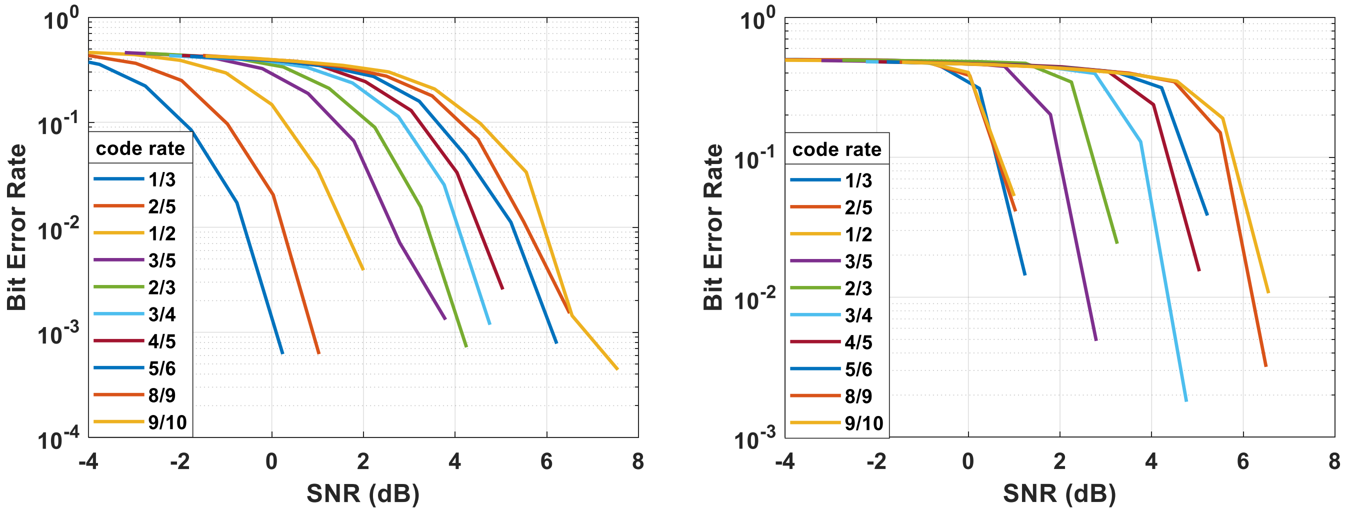


Figure 8. Polar coding, downlink – BER performance for 50 bits long message for ½ code rates and variable list sizes L



a) Polar coding, uplink, 50 bits

b) Polar coding, uplink, 500 bits

Figure 9. Polar coding, uplink – BER performance for variable code rates and different message lengths

Since both coding techniques can be applied for 50 bits long uplink message and 50- and 500 bits long downlink messages, a comparative analysis of LDPC and Polar coding techniques in terms of the BER for several code rates is performed (Fig. 10 and 11). In the case of a short information message, 50-bits long, Polar code outperforms LDPC code in both cases, uplink and downlink transmission (Fig. 10. and Fig. 11. a)). From the waterfall regions (regions where BER falls clearly after a certain SNR) for both coding schemes, it can be seen that the error correction requirements of desired BER in the case of a Polar code application can be achieved at lower SNRs in comparison with LDPC code application. Good error floor performance is another advantage of Polar codes compared to LDPC codes. The error floor region is the region where the BER does not fall as quickly as it used to. It is important to note that LDPC codes with good waterfall characteristics are most affected by the error floor problem. Fig. 10. and Fig. 11. a) clearly present that Polar code outperforms the LDPC code for all investigated code rates of {1⁄3, 1⁄2, 2⁄3, 4/5 8/9}, in the case of transmitting the short message in both directions.

For the longer message, 500 bits, LDPC shows superiority over Polar code (Fig. 11. b)). From the graph, it can be seen that when the code rate is lower, rate-matched output length (desired code length) is higher and LDPC outperforms Polar codes. For the higher code rates, desired code length decreases, and Polar codes will perform better at higher SNR values. However, as a longer message is, the LDPC codes have better performance than Polar codes.

The simulation results justify the proposition to use LDPC codes in data channels and Polar codes in control channels.

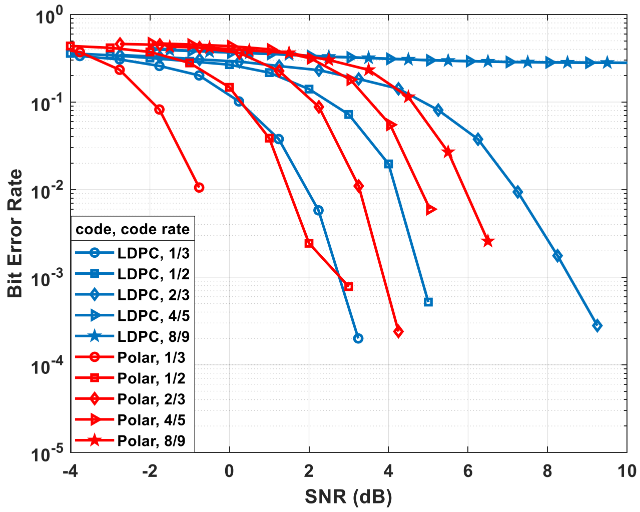
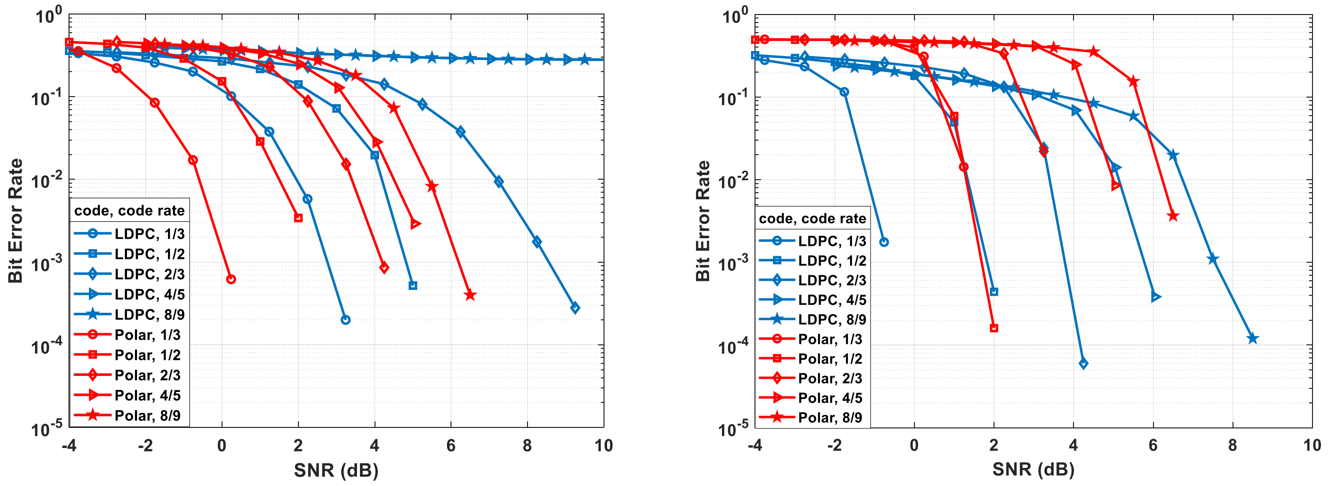


Figure 10. BER performance for variable code rates: LDPC vs Polar coding, downlink, 50 bits



a) 50 bits

b) 500 bits

Figure 11. BER performance for variable code rates: LDPC vs Polar coding, uplink

V. CONCLUSION

To achieve fast communication with a minimum of errors across a wide range of 5G applications, channel coding techniques play an immense role. Two channel coding schemes, LDPC and Polar codes have been suggested for use in 5G communication systems. None of them can meet all 5G requirements and the selection of proper channel coding technique is crucial for the achievement of efficient and secure data transmission. The type of application, underlying hardware, and decoding algorithm affect the choice of proper channel code. A good channel code should support a wide variety of data block lengths and data code rates. In this manner, it is possible to avoid using unnecessary data bits and undesirable code rates that have a negative influence on throughput, latency, energy consumption, and error correction capability.

To demonstrate the selection of the appropriate channel coding scheme, the transfer of variable length messages via PDSCH, PDCCH, PUSCH, and PUCCH (from UE to gNodeB and vice versa) for different code rates has been investigated. The BER results obtained using QPSK for communication over AWGN, as a function of the SNR, demonstrate superior Polar codes BER performance in comparison with LDPC codes when shorter messages are being transmitted. The simulation results regarding the choice of appropriate Polar decoding algorithm have shown that the larger list size L is, the lower errors are achieved. For longer messages, the LDPC code outperform the

Polar codes. The simulation results have confirmed the selection of Polar codes for use in control channels, via short messages are being transmitted, and LDPC code utilization in data channels over long messages are being transferred.

Future work will be focused on the further evaluation of the performances and complexity of the LDPC and Polar codes. The different decoding algorithms and fading channels present a focus of upcoming work.

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