An investigation of low-density parity-check codes and polar codes for future communication systems

Layla Mahdi Salih[1], Thuraya Mahmood Al-Qaradaghi[2], Jalal Jamal Hamad Ameen[2]
[1]Department of Electrical Engineering, College of Engineering, Kirkuk University, Kirkuk, Iraq
[2]Department of Electrical Engineering, College of Engineering, Salahaddin University, Erbil, Iraq

Article Info

Article history:

Received Jul 9, 2022
Revised Nov 15, 2022
Accepted Nov 21, 2022

Keywords:

5G
Bit error rate
Channel coding
Low-density parity-check codes
Polar code

ABSTRACT

In the fifth-generation (5G) era and future, mobile internet and internet of things (IoT) are the driving forces for mobile communications' development. The three main 5G usage scenarios: enhanced mobile broadband (eMBB), massive machine-type communication (mMTC), and ultra-reliable and low-latency communications (URLLC), require improvement in throughput, reliability, and latency as compared with the previous fourth generation (4G) system. In this paper, an investigation is done on the coding part of the wireless communication systems. Two channel coding types; low-density parity-check (LDPC) code which is used as the coding scheme for data transmission, and Polar code which is utilized for control in 5G are discussed. Moreover, simulations are performed to assess their performance. The simulation results revealed the superiority of polar code for transmitting short information messages and LDPC for transmitting long data messages. The use of LDPC and polar codes in 5G communication systems is justified by their ability to accommodate a wide range of data lengths and code rates, as well as their good bit error rate (BER) performance. Furthermore, the effect of the number of iterations on the BER performance of LDPC code and different decoding algorithms of polar code are considered.

This is an open access article under the CC BY-SA license.

Corresponding Author:

Thuraya Mahmood Al-Qaradaghi
Department of Electrical Engineering, College of Engineering, Salahaddin University
Erbil, Iraq
Email: thuraya.alqaradaghi@su.edu.krd

1. INTRODUCTION

The rising demand for mobile broadband services drives the development of wireless technologies of the fifth-generation (5G) [1]–[6]. Since mobile networks are currently essential to our society's "anywhere, anytime" connectivity, one key feature of 5G and beyond (B5G) mobile networks are the massive amount of data they handle, necessitating extremely high throughput per device (several Gbps) and per-area efficiency (bps/km^2) [7], [8]. As a result, 5G wireless networks prioritize enhancing quality of service (QoS), reliability of data transmission, and system security. The three main parameters that determine the ability of the system to provide good coverage with excellent performance are: a much higher data rate; low latency; and a large number of connections. Low energy consumption is achieved if all the aforementioned parameters are met [9]. To date, wireless systems have become so widespread that they have become an integral part of communications. The channel coding scheme is described as the backbone of a wireless communication system, as a result of that, it has a significant impact on throughput, reliability, and latency [10]–[16]. To make these systems more energy-efficient, forward error correcting (FEC) codes are used for channel coding. Lower rate codes can correct more channel errors, as a result of this, the channel consumes more energy. Higher rate codes, on the other hand, are more bandwidth efficient than lower rate codes. Therefore, selecting the coding rate necessitates a compromise between energy efficiency and bandwidth efficiency [17].

In 1948, Shannon showed and proved that when the system's transmission rate is lower than the channel capacity, channel noise-related errors can be minimized to an arbitrarily low level by utilizing appropriate encoding and decoding methods [18]. Since then, researchers are experimenting with various approaches for constructing error-correcting codes [19]. The main breakthrough happened when the turbo code was introduced in 1993 [20]. These codes perform near Shannon limits [21]. Another capacity-approaching channel code was introduced by Gallager [22] under the name LPDC code, but because of the technology state at that time they were impractical. They were rediscovered by MacKay and Neal and obtained interest since then [23], [24]. The previous channel codes are only channel-approaching codes, but the first that is proved capacity-achieving code with a low-complexity encoder and decoder is the polar code [11].

The contribution of this paper is to evaluate and compare the performance of low-density parity-check codes (LDPC) and polar codes in terms of BER vs signal to noise ratio (SNR) for different code block lengths and different code rates ranging from 1/3 to 9/10. Similar evaluations based on using LDPC and Polar codes were made in previous works like [25] and [26]. However, a limited number of code rates (1/2, 1/3, 2/3, 5/6) were examined in [25], and the decoding technique for LDPC codes was not considered in [26], which means it is a perfect solution and this can be defined as an impractical solution. Therefore, in this paper decoding solutions for LDPC and polar code are defined as offset min-sum and cyclic redundancy check-successive cancellation list (CRC-SCL) are utilized for practical environments.

This paper is structured as shown in: A short overview of the use cases of 5G is given in section 2. Section 3 describes the 5G channel coding schemes; LDPC and polar codes. Some physical channels used in 5G are presented in section 4. Simulation results for both codes are presented in section 5. In addition, the effect of various polar decoding algorithms and the number of iterations in LDPC codes on the performance of these codes have been investigated. Finally, section 6 concludes this paper.

2. USAGE SCENARIOS AND MINIMUM REQUIREMENTS IN 5G

The international telecommunication union (ITU) in its reports [27], [28] defines three main usage scenarios in 5G for different user requirements and the minimum requirements as:

- Enhanced mobile broadband (eMBB): It is the human-centric case in which enhancing the user experience and providing higher data rates are required. It covers a range of usage cases, including hotspots and wide-area coverage. The minimum requirementsfor this scenario: for downlink (DL) peak data rate is set to 20 Gbps and 10 Gbps for uplink (UL), user experienced DL data rate is 100 Mbps, user experienced UL data rate is 50 Mbps, and user plane latency of 4 ms.
- Ultra-reliable low-latency communication (URLLC): Delay-sensitive applications such as tele-surgery, industrial manufacturing processes automation, intelligent transportation, and smart grids should be supported by URLLC. The minimum requirements: user plane latency is set to 1ms with $1\text{-}10^{-5}$ reliability for 32 bytes packet size and control plane latency of 20 ms. The selected channel code for URLLC must perform well in terms of error rate over a wide variety of block lengths and code rates; low computing complexity, low latency, and cheap cost [29].
- Massive machine type communication (mMTC): Traditionally, wireless communication networks are built to accommodate a small number of high-speed devices. This is in contrast to mMTC which should support a very large number of simultaneously connected devices. These devices normally send a small amount of non-delay sensitive data and must be low-cost with long battery life. The minimum requirement: it should support a connection density of one million devices/ km^2 [28]. mMTC are used in applications such as public safety and supervision, environmental and utility service monitoring, monitoring of electric energy distribution and power plants [30].

In comparison to a 4G system, these usage cases necessitate increased throughput, low energy, low latency, high reliability, large spectral efficiency and low decoding complexity [31], [32]. Furthermore, 5G channel codes should allow variable code lengths and code rates for both user data and control information, in addition to hybrid automatic repeat request (HARQ) for user data, similar to a 4G system [31]. It is expected from 5G to enable high mobility users up to 500 km/h (high speed trains) with acceptable QoS [27]. As a result, the main key performance indicators (KPI) of 5G network are: high peak data rates for eMBB, million connected devices/km^2 for mMTC, and less than 1 ms latency for URLLC communications.

3. CHANNEL CODING SCHEMES IN 5G

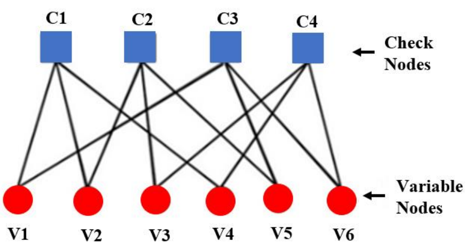
The 3^{rd} generation partnership project (3GPP) as a standardization body, has developed a series of new radio (NR) standards to address the requirements of the 5G [33]. 3GPP NR employs channel coding for error detection and correction. During the development of 3GPP NR, the channel coding for user data was examined separately from the control information. Various channel coding schemes were compared especially, turbo codes, LDPC codes, and Polar codes. The 3GPP RAN1-86b meeting compared flexibility, error-correcting capability, HARQ support, implementation complexity, decoding latency, and other factors for these possible channel coding schemes. Research into the selection and implementation of appropriate channel coding techniques is critical because there is no single channel coding candidate that can meet all 5G requirements. In addition, selecting an improper channel coding technique can result in poor performance of the mobile network in terms of data rates, coverage, capacity, and QoS [34]. The 3GPP designed the functionality of the new radio LDPC (NR-LDPC) code for data channels and the Polar code for control channels [35]. However, this technical specification enplanes only the encoding process performed in transmitting user equipment (UE) or the base station (BS), without any discussion of the decoding process performed on the receiver side [34]. Other wireless standards, such as IEEE 802.11, advanced television system committee (ATSC), and the digital video broadcast (DVB), have previously adopted LDPC codes. The extensive requirements of 5G NR necessitate some LDPC design innovation. A flexible architecture is required to enable incremental-redundancy HARQ (IR-HARQ), as well as a wide range of block sizes and coding rates. The 802.11 codes, on the other hand, are made up of 12 different codes, each with its description. Because the number of possible codes for 5G NR is in the thousands, it is necessary to combine multiple codes into a single description [36].

3.1. LDPC code

LDPC codes are linear error correction block codes with a sparse parity check matrix (PCM). It also can be described by the Tanner graph, which is a bipartite graph with two sets of nodes; the variable nodes (VNs) correspond to the codeword bits (columns of the PCM), and the check nodes (CNs) correspond to the parity checks (rows of the PCM). An edge e_{ji} connects the VN_j with the CN_i if the corresponding entry in the PCM is nonzero. An iteration is a round of messages passing from the CNs to VNs where the VNs process these messages and return their decisions to the CNs [37]. Figure 1 shows a PCM H with its corresponding Tanner graph, where the Figure 1 is divided into Figure 1(a) shows a PCM H of size 4x6 of an LDPC code, and Figure 1(b) shows Tanner graph corresponding to the PCM H where each VN is connected to two CNs and each CN is connected to three VNs.

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

(a)



(b)

Figure 1. The representation of LDPC code by (a) an example of parity check matrix H and (b) its Tanner graph representation

Even though LDPC codes are mature, the NR-LDPC code has a refined structure that differs significantly from earlier standards. In general, the encoder and decoder of an LDPC code can be uniquely described by its PCM. The NR-LDPC code, in particular, can be thought of as a combination of a core LDPC code and an extended low-density generator matrix (LDGM)-based code [38], [39]. The NR-LDPC codes are quasi-cyclic (QC) codes that can be represented by two base graphs (BGs) with similar structures: BG1, is designed for larger blocks with length $(500 \le K \le 8448)$, code rates $\left({}^{1}/_{3} \le R \le {}^{8}/_{9}\right)$, and the mother code rate is 1/3, whereas; BG2, is designed for shorter block lengths $(40 \le K \le 3840)$, code rates $\left({}^{1}/_{5} \le R \le {}^{2}/_{3}\right)$, and the mother code rate is 1/5. Each BG has eight sets of lifting sizes (Z) defined as $Z = a.2^j$ Where $a \in \{2, 3, 5, 7, 9, 11, 13, 15\}$ and $0 \le j \le 7$ [35].

The most common method of encoding LDPC codes is Gaussian elimination [40]. To overcome the encoding complexity, an LDPC encoding method with a computational complexity that is roughly linear suggested in [41]. The forward substitution-based encoding method is used to encode the QC-LDPC codes used in Wi-Fi 802.11n/ac/ax. The 5G applications necessitate a significant degree of LDPC encoder flexibility; there are 102 codes generated by lifting each of the 51 lifting sizes from BG1 and BG2 matrices. The standard also includes the shortening of BG matrices, resulting in a ten-fold increase in the number of potential codes, as a result, the Forward Substitution-Based method is used for encoding NR-LDPC codes [42]. Decoding methods for LDPC are mainly iterative. The belief-propagation algorithm (BPA) is the basis for the majority of these techniques [37]. To reduce the decoding complexity, the min-sum algorithm (MSA) was introduced [43]. Although the MSA can minimize computational complexity, it causes error performance degradation. To overcome this problem, normalized MSA (NMS) and offset MSA (OMS) were introduced [44].

3.2. Polar codes

Polar codes were invented by Arikan based on the idea of channel polarization. They are the first codes to have an explicit proof for achieving channel capacity. In channel polarization, an N independent and identical copies of the original channel of capacity I(W) are translated into N synthesized channels $W_N^i : 1 \leq i \leq N$ with variable capacities either close to one or zero. I(W) number of these synthesized channels will become noiseless channels that are used for data transmission and the rest are the noisy channels with foreknown input bits (usually zero). The Polar code construction task is to find the set of the noisiest channels which is called the frozen set [11]. Polar codes (N, K) are linear codes defined using a generator matrix. Its basic binary version is defined in terms of a generator matrix $\boldsymbol{G_N}$. For encoding K- information bits with code rate R, the length of the polar code will be N= K/R. The encoding is done using a length-N encoder. The maximum possible code lengths in 5G Polar codes is $N = 2^n \; for \; 5 \leq n \leq 10$ for UL transmission while $7 \leq n \leq 9$ for DL transmission [31]. The binary vector $\boldsymbol{u} = \{u_1, u_2, \ldots, u_N\}$, which consist of K information bits and (N-K) frozen bits, is encoded using (1) to the codeword vector x:

$$\boldsymbol{x} = \boldsymbol{u} * \boldsymbol{G_N} \tag{1}$$

where $G_N = B_N * F_2^{\oplus n}$ is the generator matrix, B_N represents the bit-reversal permutation matrix, $F_2^{\oplus n}$ denotes the n[th] Kronecker power of F_2, and F_2 is the kernel matrix defined by (2).

$$\boldsymbol{F}_2 = \begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix} \tag{2}$$

Decoding of polar codes can be performed using several ways. Arikan’s fundamental decoder was the successive cancellation (SC) decoder. To improve the block-error probability of SC decoders, a successive cancellation list (SCL) decoder was proposed. The SCL decoder activates L number of the best decoding paths. After finishing the decoding, the path with the minimum Path Metric is chosen. A further improvement to the SCL decoder is the cyclic redundancy check (CRC) aided SCL (CRC-SCL) decoder. In the CRC-SCL decoder, the message is first encoded with a CRC code then the result is polar encoded [45].

4. NR PHYSICAL CHANNELS

Channel is a frequency band that is used to transmit different types of data through radio signals. Depending on the direction of the communication, the channels are classified into DL channels (from the BS to the UE) and UL channels (from the UE to the BS). Channel classification can also be depending on the data type they carry; user channels , and control channels [34]. To transmit data, the transport channels (TrCHs) are first mapped to their corresponding physical channels, then the data is transmitted using these physical channels. The coding schemes used with different types of TrCHs are shown in Table 1 [35].

Table 1. Physical channels and their corresponding coding schemes

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

4.1. Downlink channels

As shown in Table 1, there are three different types of physical DL channels:

- Physical downlink shared channel (PDSCH): it carries user data. It also carries paging information, some UE-specific control messages that are coming from the upper layers, and different types of system information blocks (SIBs). 5G supports up to eight layers to a particular single user on the DL transmission. NR uses the same modulation schemes as LTE on the DL: from quadrature phase shift keying (QPSK) through 256 quadrature amplitude modulation (QAM) [46], [47].

- Physical downlink control channel (PDCCH): this channel is responsible for transmitting DL control information (DCI). It uses QPSK for modulation and Polar codes as a coding scheme [34], [46].
- Physical broadcast channel (PBCH): it is responsible for transferring the system information portion that is required for connecting the UE with the network. The UEs can obtain the master information block (MIB) using this channel. In combination with the control channel, PBCH can support the time and frequency synchronization that assists in acquiring, selecting, and re-selecting the cells. It uses QPSK for modulation and Polar codes as a coding scheme [46], [34].

There are several common coding steps among the physical downlink channels, as depicted in Figure 2 [48], [49]:

- CRC attachment: the parity bits are calculated and appended to the TB. The length of the CRC bits depends on the payload size. For TBs > 3824 bits, 24-bit CRC is applied, otherwise a 16-bit CRC is applied.
- Code block (CB) segmentation and CB-CRC attachment: for PDSCH where LDPC is used, the maximum CB size is 8448 bits for BG1 and 3840 bits for BG2. For TBs greater than maximum CB size, the TBs are segmented into multiple CBs, each with its own CB-level CRC attached. For PDCCH where Polar code is used, after attaching CRC, bits are scrambled with a suitable radio network temporary identifier (RNTI) coding.
- Channel coding: the LDPC code is used to encode user data, while polar code is used for encoding control data.
- Rate matching: it is necessary to select the appropriate number of bits to be transmitted depending on the channel condition. For LDPC codes, every CB is individually rate matched and for polar codes, every CB is rate matched using interleaving, shortening, puncturing, or repetition [31], [50].
- CB concatenation: it is the final step in which a sequential concatenation of the rate matched outputs for the different CBs is done.

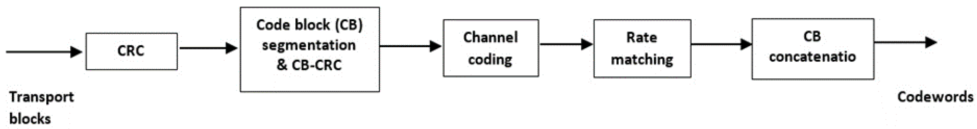


Figure 2. Common coding steps

At the receiver, the processing steps comprise the counterpart operations to the transmitter end, which include [7]:

- Rate recovery: it includes the inverse of the CB concatenation, bit interleaving, and the bit selecting stages.
- Channel decoding: it depends on the channel coding technique used.
- CB desegmentation: CRC bits are deducted from each CB segment and all the segments are grouped to one block.
- TB CRC decoding: this step checks the input block for CRC error. If no errors are obtained, the block can be considered as being successfully decoded.

4.2. Uplink channels

Physical UL channels have the same processing steps as the physical DL channels. There are two kinds of physical UL channels:

- PUSCH: it is used for transmitting shared data. It supports π/2 binary phase shift keying (BPSK), QPSK through 256 QAM modulation schemes.
- PUCCH: it carries the UL control information (UCI) like channel state information (CSI), radio resource control (RRC), HARQ acknowledgments (HARQACK). It uses either BPSK or QPSK modulation scheme.

The processing chain includes the following steps:

- CB segmentation and CRC attachment: for PUSCH if the payload size (A) is greater than 3824 bits, the CRC length is 24 bits, otherwise, it is 16 bits long. For PUCCH where polar code is used:
- If $A \leq 11$ no CRC bits are appended.
- If $12 \leq A \leq 19$, 6 CRC bits are appended.
- If $A \geq 20$, 11 CRC bits are appended.

- Channel coding: LDPC code is used for PUSCH, while Polar code is used for the PUCCH.
- Rate matching.
- CB concatenation.
- Multiplexing of the data and control information.
- Channel interleaver: it implements a time-first and frequency-first mapping of the control and data modulation symbols onto the transmit waveform.

5. SIMULATION RESULTS AND DISCUSSION

In this paper, an evaluation and comparison analysis of LDPC and Polar codes for different message lengths and code rates are performed. The simulations are performed using MATLAB R2021a. The evaluations and comparisons are made in terms of BER for different message lengths (64, 128, 256, 512) bits and different code rates (1/3, 2/5, ½, 3/5, 2/3, ¾, 4/5, 5/6, 8/9, 9/10). The messages are transmitted using QPSK modulation scheme over an additive white Gaussian noise (AWGN) channel, in which the variances of the channel were estimated from the SNR values. The simulations are performed starting from 500 frames and continued till the BER of 10^{-5} is achieved. Ultimately, decoding solution OMS for LDPC and CRC-SCL for Polar codes are used in the receiver side.

5.1. LDPC codes

In general, Figure 3 shows the BER performance for different data lengths and code rates in case of LDPC coding in UL direction (similar results are obtained for DL direction). Figures 3(a)-(d) illustrate typical curves: as the SNR increases, the BER decreases, which is matched with our investigation in this paper. In addition, the required SNR monotonically increases, as expected, as the code rate increases. The results show that for higher code rates more SNR values are required to get lower BER, because a decoder has fewer parity bits to confirm the message bits values. Although higher code rate consumes more energy, but it transmits more information in one codeword. It can be noted that the error correction requirements of a desired BER value might be reached at lower SNR values for longer messages. If the channel has noise/interference or the signal strength is poor, a lower coding rate is required for the decoder to successfully detect then correct all received errors. Furthermore, by increasing the block length size, the SNR value is decreased, and by performing the lower code rate, the required power for transmitting the data block will be less. That confirms that the offset min-sum decoder performs better for longer codes than for short codes.

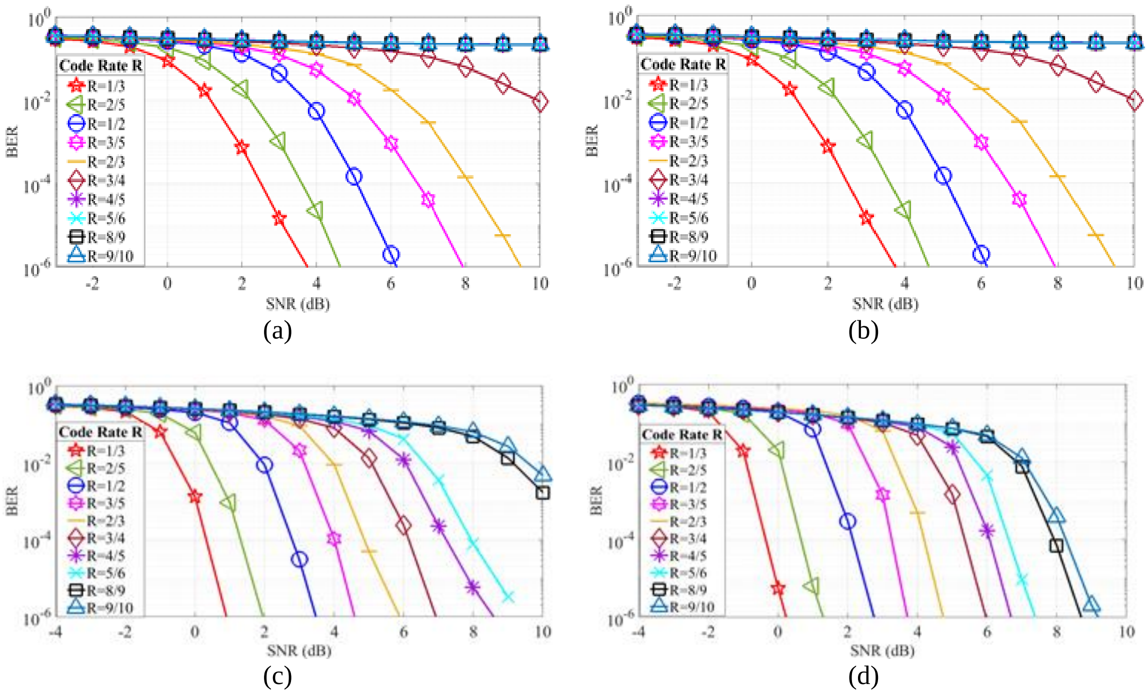


Figure 3. BER performance of LDPC code for: (a) 64 message bits, (b) 128 message bits, (c) 256 message bits, and (d) 512 message bits and variable code rates in uplink direction

In this work, the offset min-sum decoding algorithm with the maximum number of iterations (25) was considered. We examined the effect of the number of iterations on the BER performance for message length 64 bits and code rate ½. Given the results shown in Figure 4, it is clear that extending beyond 32 iterations does not bring that much gain, especially if we consider the longer simulation time it requires. In each iteration, the messages which represent the probability distributions related to each bit are passed along the edges. The CNs and the VNs process these messages and update their decisions about the bit. The decoding process continues until a predefined stopping criterion is satisfied, or it reaches the maximum number of iterations.

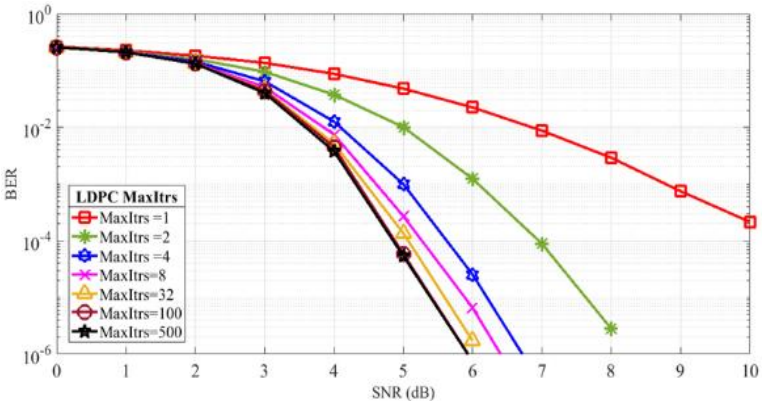
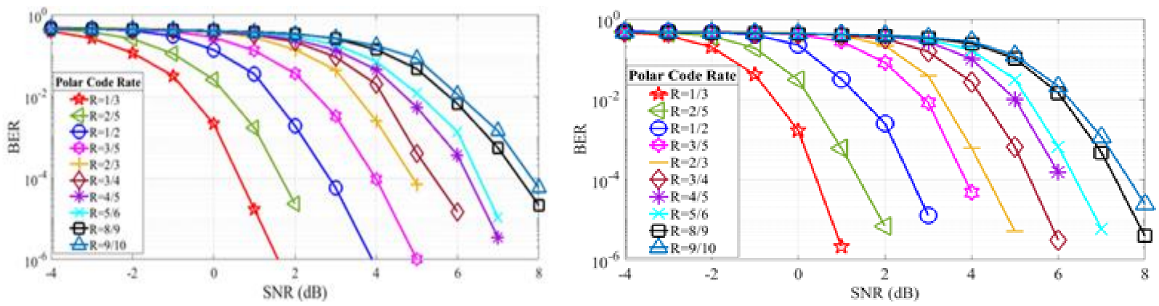


Figure 4. LDPC BER performance for 64 bits message long, code rate=½ and different maximum iterations

5.2. Polar codes

Results of the Polar code are based on using a CRC-SCL decoder with a list size of 8. Figure 5 shows the BER performance for two data length sets in the DL direction because the maximum data length for PDCCH cannot exceed 164 bits (including CRC bits). Figure 5(a) shows the BER performance for 64 bits data length, and Figure 5(b) shows the BER performance for 128 bits data length. In the UL direction, the maximum input message length is 1023 bits as defined in [26]. The results show that higher code rates, where the decoder has fewer parity bits to confirm the values of the information bits, result in worse performance. Hence, for higher code rates, we will need to push the SNR higher than the required for the lower code rates to get high accuracy. Figure 6 shows the BER performance for different data lengths and code rates in the UL direction. Figure 6(a) shows the BER performance for 64 bits data length, Figure 6(b) shows the BER performance for 128 bits data length, Figure 6(c) shows the BER performance for 256 bits data length, and Figure 6(d) shows the BER performance for 512 bits data length all in the UL direction. It is obvious that the BER decreases as the SNR increases, and the required SNR increases monotonically as the code rate increases. Furthermore, the higher the code rate, the lower the number of parity bits in the codeword and the more difficult for the decoder to decode. Finally, by increasing the block length size the SNR value increases for the same code rate. That justifies the utilization of Polar codes for control channels.



(a) (b)

Figure 5. BER performance of Polar code for: (a) 64 bits and (b) 128 bits and variable code rates in downlink direction

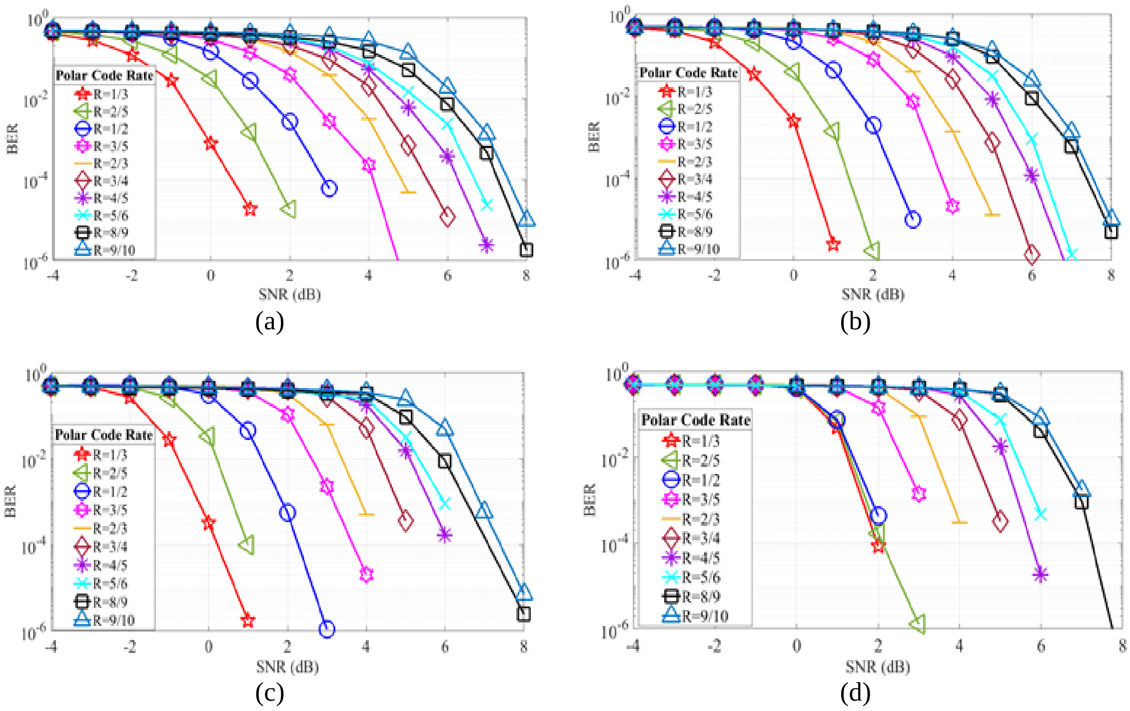


Figure 6. BER performance of Polar code for: (a) 64 bits, (b) 128 bits, (c) 256 bits, and (d) 512 bits with variable code rates in uplink direction

For an algorithm that uses predetermined parameters, it is important to select the best parameters for the implementation. Therefore, the CRC-SCL decoding algorithm was used with a list size of 8. Figure 7 shows the BER performance for different list sizes {1, 2, 4, 8, 16, 32} in the case of 64 bits messages and a code rate of ½. Clearly, increasing the list size of the CRC-SCL decoder improves Polar coding performance, but there is a diminishing-returns impact because it needs a longer simulation time.

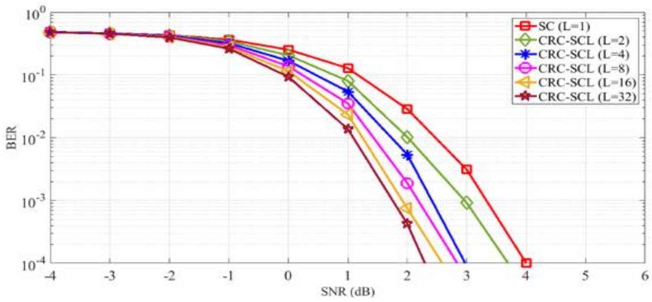


Figure 7. BER performance of Polar code for different list sizes in DL direction

A comparison analysis between the LDPC and the polar codes based on the same message length but for several code rates in terms of BER are performed as shown in Figure 8. Figure 8(a) shows the BER performance comparison of LDPC vs Polar codes for 64 bits data length in the UL direction, Figure 8(b) shows the BER performance comparison of LDPC vs Polar codes for 512 bits data length in the UL direction, and Figure 8(c) shows the BER performance comparison of LDPC vs Polar codes for 64 bits data length in the DL direction. Obviously, Polar codes outperform LDPC code in the case of short data message (64 bits in our study) for both UL and DL transmission and that justifies why Polar codes are used in control channels. For longer data messages (512 bits in our study), LDPC code outperforms the polar code. Clearly from Figure 8(b), for lower code rates, the size of the rate-matched output is longer and the LDPC code outperforms the Polar code. For higher code rates, the desired code length decreases, and Polar code performs better than the LDPC codes at higher SNR values.

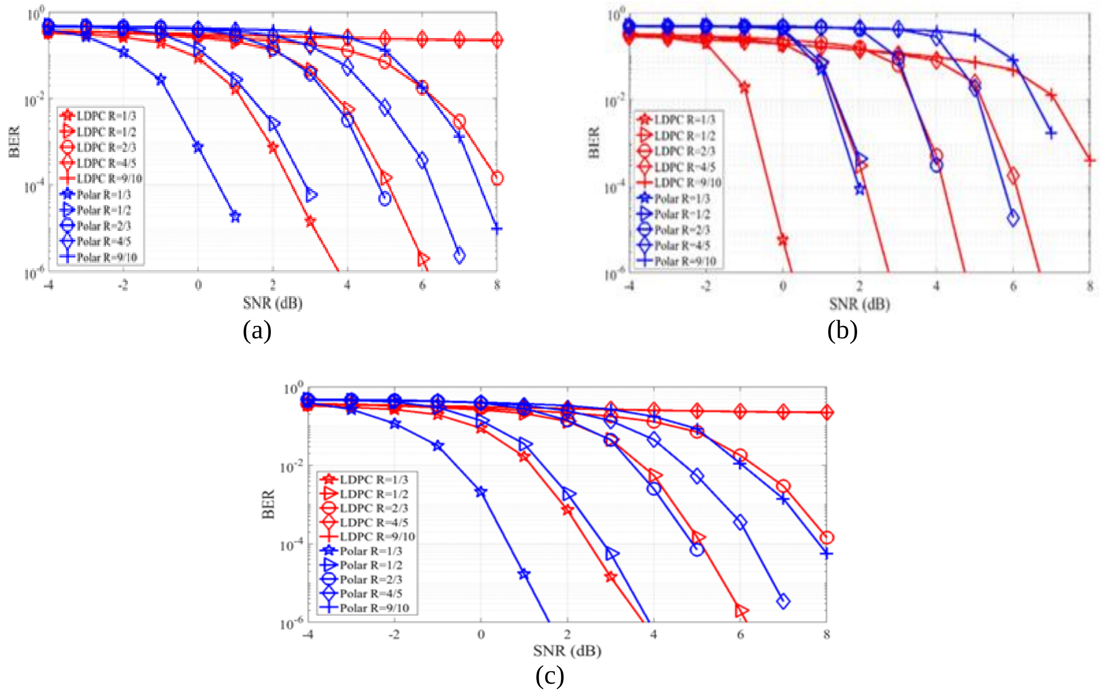


Figure 8. BER performance comparison LDPC vs Polar for variable code rates: (a) 64 bits UL, (b) 512 bits UL and (c) 64 bits DL directions

6. CONCLUSION

The main objectives of current and future wireless communication systems are higher data rate, reliability, higher energy-efficient, higher bandwidth, higher spectrum efficiency, and all that at lower latency. Channel coding plays an important role in wireless communications because it reduces the errors in the received data. The NR-LDPC and Polar codes are used in 5G applications, but none of them meet all the 5G requirements. Selecting the proper channel coding is crucial to achieving secure and efficient data transmission. A good channel coding scheme should support a wide range of data lengths and code rates. To demonstrate the effect of selecting the suitable channel coding scheme, transmission of variable message lengths (64, 128, 256, 512) bits over PDSCH, PDCCH (DL direction), PUSCH, and PUCCH (UL direction) at various code rates (1/3, 2/5, ½, 3/5, 2/3, ¾, 4/5, 5/6, 8/9, 9/10) was evaluated. The KPI was the BER as a function of the SNR. From the simulation results, it can be noted that the decoder's capability to detect and correct all received errors depends on the channel condition and the code rate used. Lower code rates were used for the bad channel, where more parity bits were added to combat the channel impairments. The results show that using offset min-sum decoder for NR-LDPC have BER performance in order of $\leq 10^{-5}$. The BER results revealed Polar codes' superiority for transmitting short data messages and LDPC codes' superiority for transmitting longer messages. This justifies the reason for using Polar codes in the control channels and LDPC codes in the data channels. The focus of the upcoming work will be on analyzing the maximum possible throughput for both UL and DL transmission over different channel models.

REFERENCES

[1] G. K. Prayogo, R. Putra, A. H. Prasetyo, and M. Suryanegara, "Evaluation of LDPC code and polar code coding scheme in 5g technology-massive machine type communication," *Proceedings of 2018 10th International Conference on Information Technology and Electrical Engineering: Smart Technology for Better Society, ICITEE 2018*, pp. 170–174, 2018, doi: 10.1109/ICITEED.2018.8534937.

[2] S. Chen, K. Peng, Y. Zhang, and J. Song, "Near capacity LDPC coded MU-BICM-ID for 5G," *IWCMC 2015 - 11th International Wireless Communications and Mobile Computing Conference*, pp. 1418–1423, 2015, doi: 10.1109/IWCMC.2015.7289290.

[3] A. Aljanabi, O. Alluhaibi, Q. Z. Ahmed, F. A. Khan, Waqas-Bin-Abbas, and P. Lazaridis, "Low complexity single carrier frequency domain detectors for internet of underwater things (IoUT)s," *Wireless Personal Communications*, vol. 125, no. 3, pp. 2443–2461, 2022, doi: 10.1007/s11277-022-09667-1.

[4] M. Li, H. Yuan, C. Maple, Y. Li, and O. Alluhaibi, "Security outage probability analysis of cognitive networks with multiple eavesdroppers for industrial internet of things," *IEEE Transactions on Cognitive Communications and Networking*, vol. 8, no. 3, pp. 1422–1433, 2022, doi: 10.1109/TCCN.2022.3179431.

[5] T. T. B. Nguyen and H. Lee, "Low-complexity multi-mode multi-way split-row layered LDPC decoder for gigabit wireless communications," *Integration*, vol. 65, no. April, pp. 189–200, 2019, doi: 10.1016/j.vlsi.2018.12.004.
[6] C. Sisavath and L. Yu, "Design and implementation of security system for smart home based on IOT technology," *Procedia Computer Science*, vol. 183, no. 1, pp. 4–13, 2021, doi: 10.1016/j.procs.2021.02.023.
[7] A. Morgado, K. M. S. Huq, S. Mumtaz, and J. Rodriguez, "A survey of 5G technologies: regulatory, standardization and industrial perspectives," *Digital Communications and Networks*, vol. 4, no. 2, pp. 87–97, Apr. 2018, doi: 10.1016/j.dcan.2017.09.010.
[8] El. Abderraouf, A. Bassou, and M. R. Lahcene, "Higher performance and lower complexity turbo decoding scheme for 4G-LTE using unpunctured turbo trellis-coded modulation," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 18, no. 1, pp. 351–360, 2019, doi: 10.11591/ijeecs.v18.i1.pp351-360.
[9] M. H. Alsharif and R. Nordin, "Evolution towards fifth generation (5G) wireless networks: Current trends and challenges in the deployment of millimetre wave, massive MIMO, and small cells," *Telecommunication Systems*, vol. 64, no. 4, pp. 617–637, 2017, doi: 10.1007/s11235-016-0195-x.
[10] W. Ji, Z. Wu, K. Zheng, L. Zhao, and Y. Liu, "Design and Implementation of a 5G NR System Based on LDPC in Open Source SDR," *2018 IEEE Globecom Workshops, GC Wkshps 2018 - Proceedings*, pp. 1–6, 2019, doi: 10.1109/GLOCOMW.2018.8644263.
[11] E. Arikan, "Channel polarization: A method for constructing capacity-achieving codes for symmetric binary-input memoryless channels," *IEEE Transactions on Information Theory*, vol. 55, no. 7, pp. 3051–3073, 2009, doi: 10.1109/TIT.2009.2021379.
[12] M. Maksimovi and M. Forcan, "Application of 5G channel coding techniques in smart grid : LDPC vs . polar coding for command messaging," *7th International Conference on Electrical, Electronic and Computing Engineering*, pp. 746–751, 2020.
[13] H. Wu and H. Wang, "Decoding latency of LDPC Codes in 5G NR," *2019 29th International Telecommunication Networks and Applications Conference, ITNAC 2019*, pp. 0–4, 2019, doi: 10.1109/ITNAC46935.2019.9077972.
[14] G. A. Hussain and L. Audah, "BCH codes for 5G wireless communication systems over multipath fading channel," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 17, no. 1, pp. 310–316, 2019, doi: 10.11591/ijeecs.v17.i1.pp310-316.
[15] S. Belhadj, A. M. Lakhdar, and R. I. Bendjillali, "Performance comparison of channel coding schemes for 5G massive machine type communications," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 22, no. 2, p. 902, 2021, doi: 10.11591/ijeecs.v22.i2.pp902-908.
[16] P. Chen, Z. Xie, Y. Fang, Z. Chen, S. Mumtaz, and J. J. P. C. Rodrigues, "Physical-Layer network coding: an efficient technique for wireless communications," *IEEE Network*, vol. 34, no. 2, pp. 270–276, 2020, doi: 10.1109/MNET.001.1900289.
[17] M. C. Valenti and J. Sun, "Turbo codes," *Handbook of RF and Wireless Technologies*, pp. 375–399, 2003, doi: 10.1016/B978-075067695-3/50014-8.
[18] C. E. Shannon, "A mathematical theory of communication," *Bell System Technical Journal*, vol. 27, no. 3, pp. 379–423, 1948, doi: 10.1002/j.1538-7305.1948.tb01338.x.
[19] G. Liva, S. Song, L. Lan, Y. Zhang, S. Lin, and W. E. Ryan, "Design of LDPC codes: A survey and new results," *Journal of Communications Software and Systems*, vol. 2, no. 3, pp. 191–211, 2006, doi: 10.24138/jcomss.v2i3.283.
[20] C. Berrou, A. Glavieux, and P. Thitimajshima, "Near SHANNON limit error-correcting coding and encoding: Turbo-codes (1)," *IEEE International Conference on Communications*, no. 1, pp. 1064–1070, 1993, doi: 10.1109/icc.1993.397441.
[21] A. Goldsmith, *Wireless communications*. Cambridge university press, 2005.
[22] R. Gallager, "Low-density parity-check codes," *IRE Transactions on information theory*, vol. 8, no. 1, pp. 21–28, 1962.
[23] D. J. C. MacKay and R. M. Neal, "Near Shannon limit performance of low density parity check codes," *Electronics Letters*, vol. 32, no. 18, pp. 1645–1646, 1996, doi: 10.1049/el:19961141.
[24] D. J. C. Mackay and R. M. Neal, "Good codes based on very sparse matrices," *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, vol. 1025, no. 1025, pp. 100–111, 1995, doi: 10.1007/3-540-60693-9_13.
[25] B. Tahir, S. Schwarz, and M. Rupp, "BER comparison between convolutional, turbo, LDPC, and polar codes," in *Proceedings of the 24th International Conference on Telecommunications: Intelligence in Every Form, ICT 2017*, 2017, pp. 1–7, doi: 10.1109/ICT.2017.7998249.
[26] D. Čarapić and M. Maksimović, "A comparison of 5G channel coding techniques," *Ijeec - International Journal of Electrical Engineering and Computing*, vol. 4, no. 2, pp. 71–82, 2020, doi: 10.7251/ijeec2002071m.
[27] ITU-R M.2083, "Itu-R M.2083," *Itu-R M.2083-0*, vol. 0, p. https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M, 2015.
[28] International Telecommunication Union, "ITU-R, M.2410 - Minimum requirements related to technical performance for IMT-2020 radio interface(s)," *Working Party 5D*, vol. November, no. Report ITU-R M.2410-0, pp. 1–11, 2017.
[29] Y. Liu, P. M. Olmos, and D. G. M. Mitchell, "Generalized LDPC codes for ultra reliable low latency communication in 5G and beyond," *IEEE Access*, vol. 6, no. c, pp. 72002–72014, 2018, doi: 10.1109/ACCESS.2018.2880997.
[30] I. Jovović, I. Forenbacher, and M. Periša, "Massive machine-type communications: an overview and perspectives towards 5G," in *Proceedings of The 3rd International Virtual Research Conference In Technical Disciplines*, Nov. 2015, vol. 3, pp. 32–37, doi: 10.18638/rcitd.2015.3.1.73.
[31] J. H. Bae, A. Abotabl, H. P. Lin, K. B. Song, and J. Lee, "An overview of channel coding for 5G NR cellular communications," *APSIPA Transactions on Signal and Information Processing*, vol. 8, 2019, doi: 10.1017/ATSIP.2019.10.
[32] A. A. Mahmood and A. A. Kadhim, "Joint polar with physical layer network coding and massive multi-input multi-output: performance analysis," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 26, no. 3, pp. 1469–1476, 2022, doi: 10.11591/ijeecs.v26.i3.pp1469-1476.
[33] 3GPP, "5G; Study on scenarios and requirements for next generation access technologies (3GPP TR 38.913 version 14.2.0 release 14," *3rd Gener. Partnersh. Proj. (3GPP), Tech. Rep 38.913, V 16.0.0*, vol. 0, p. 41, 2017, [Online]. Available: http://www.etsi.org/standards-search.
[34] Z. B. Kaykac Egilmez, L. Xiang, R. G. Maunder, and L. Hanzo, "The development, operation and performance of the 5G Polar codes," *IEEE Communications Surveys and Tutorials*, vol. 22, no. 1, pp. 96–122, Jan. 2020, doi: 10.1109/COMST.2019.2960746.
[35] TSGR, "TS 138 212 - V16.2.0 - 5G; NR; Multiplexing and channel coding (3GPP TS 38.212 version 16.2.0 Release 16)," vol. 0, p. 100, 2020, [Online]. Available: https://portal.etsi.org/TB/ETSIDeliverableStatus.aspx.
[36] T. Richardson and S. Kudekar, "Design of low-density parity check codes for 5g new radio," *IEEE Communications Magazine*, vol. 56, no. 3, pp. 28–34, 2018, doi: 10.1109/MCOM.2018.1700839.
[37] K. D. Rao, *Channel coding techniques for wireless communications*. 2015.
[38] H. Yasotharan and A. C. Carusone, "A flexible hardware encoder for systematic low-density parity-check codes," *Midwest Symposium on Circuits and Systems*, pp. 54–57, 2009, doi: 10.1109/MWSCAS.2009.5236155.
[39] D. Theodoropoulos, N. Kranitis, and A. Paschalis, "An efficient LDPC encoder architecture for space applications," in *2016 IEEE 22nd International Symposium on On-Line Testing and Robust System Design, IOLTS 2016*, Jul. 2016, pp. 149–154, doi: 10.1109/IOLTS.2016.7604689.

[40] T. T. B. Nguyen, T. N. Tan, and H. Lee, “Efficient QC-LDPC encoder for 5G new radio,” *Electronics (Switzerland)*, vol. 8, no. 6, Jun. 2019, doi: 10.3390/electronics8060668.

[41] T. J. Richardson and R. L. Urbanke, “Efficient encoding of low-density parity-check codes,” *IEEE Transactions on Information Theory*, vol. 47, no. 2, pp. 638–656, 2001, doi: 10.1109/18.910579.

[42] V. L. Petrović, D. M. El Mezeni, and A. Radošević, “Flexible 5g new radio ldpc encoder optimized for high hardware usage efficiency,” *Electronics (Switzerland)*, vol. 10, no. 9, 2021, doi: 10.3390/electronics10091106.

[43] M. P. C. Fossorier, M. Mihaljevic, and H. Imai, “Reduced complexity iterative decoding of low-density parity check codes based on belief propagation,” *IEEE Transactions on Communications*, vol. 47, no. 5, pp. 673–680, 1999, doi: 10.1109/26.768759.

[44] J. Chen and M. P. C. Fossorier, “Density evolution for two improved BP-based decoding algorithms of LDPC codes,” *IEEE Communications Letters*, vol. 6, no. 5, pp. 208–210, 2002, doi: 10.1109/4234.1001666.

[45] K. Niu and K. Chen, “CRC-aided decoding of polar codes,” *IEEE Communications Letters*, vol. 16, no. 10, pp. 1668–1671, 2012, doi: 10.1109/LCOMM.2012.090312.121501.

[46] E. Dahlman, S. Parkvall, and J. Sköld, *5G NR: The Next Generation Wireless Access Technology*. Academic Press, 2018.

[47] M. Roggero and H. Zarrinkoub, “Technical principles and simulations of the 5G NR Physical Layer Standard,” *embeddedworld2020*, 2020.

[48] KT:5G-SIG, “TS 5G.212: Multiplexing and channel coding,” *KT 5th Generation Radio Access*, vol. 3, 2016.

[49] X. Lin *et al.*, “5G new radio: unveiling the essentials of the next generation wireless access technology,” *IEEE Communications Standards Magazine*, vol. 3, no. 3, pp. 30–37, 2019, doi: 10.1109/MCOMSTD.001.1800036.

[50] Z. R. M. Hajiyat, A. Sali, M. Mokhtar, and F. Hashim, “Channel coding scheme for 5g mobile communication system for short length message transmission,” *Wireless Personal Communications*, vol. 106, no. 2, pp. 377–400, 2019, doi: 10.1007/s11277-019-06167-7.

BIOGRAPHIES OF AUTHORS

Layla Mahdi Salih received the B.Sc. and M.Sc. degrees in Electronics and Communications Engineering from University of Salahaddin, Erbil, Iraq in 1991 and 2010 respectively. From 2010, she is Lecturer at Electrical Engineering Dept./College of Engineering/Kirkuk University/Kirkuk/Iraq. She is currently pursuing the Ph.D. degree in Communication Engineering with the University of Salahaddin. Her research areas are wireless communication, multi-antenna communication systems, digital signal processing, biometrics, and pattern recognition. She can be contacted at email: layla-salih@uokirkuk.edu.iq.

Dr. Thuraya Mahmood Al-Qaradaghi is Assistant Professor at the Electrical Engineering Dept./Salahaddin University. She received the B.Sc. and M.Sc. degrees from University of Technology/Baghdad in 1979 and 1990 respectively. She received her Ph.D. in Communication Engineering from University of Technology/Baghdad with co-operation of Monash University/Melb-Australia in 2009. She was a visiting academic at the school of ECE at the Monash University in Melbourne- Australia during 2007-2008. She worked as a lecturer with foundation of technical institutions until 1997 in Electrical and Computer Dept. In 1997 she joined the Dept. of Electrical Engineering at the University of Salahaddin. From June 2009 to July 2014, she was the Local Manager of CISCO Academy/College of Engineering-University of Salahaddin. Her research interests include Digital Communications, Coding Techniques, MIMO Systems and Wireless Communication. She can be contacted at email: thuraya.alqaradaghi@su.edu.krd.

Assistant Prof. Dr. Jalal Jamal Hamad Ameen received the B.Sc. degree in Electronics and Communications Engineering, University of Salahaddin, Erbil, Iraq, 1991, M.Sc. degree in Communications Engineering, University of Technology/Baghdad in 2004, PhD in school of Electrical and Electronics, University Sains Malaysia (USM) 2012 in Wireless and Mobile Systems. From 1992 to 2002 a lecturer in Communications lab. From 2004 to 2008 a Lecturer of communications engineering in Electrical Engineering Dept./University of Salahaddin. a lecturer as PhD in Electrical Engineering Dept./Salahaddin University and continue. Research interests: (Wireless, Mobile, CDMA, Fiber optic) systems. Also, very good practical skill in the field of communications specially, satellite, mobile, microwave and optical communications systems. He can be contacted at email: jalal.hamadameen@su.edu.krd.