

Performance comparison of channel coding schemes for 5G massive machine type communications

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ABSTRACT

Channel coding for the fifth generation (5G) mobile communication is currently facing new challenges as it needs to uphold diverse emerging applications and scenarios. Massive machine-type communication (mMTC) constitute one of the main usage scenarios in 5G systems, which promise to provide low data rate services to a large number of low power and low complexity devices. Research on efficient coding schemes for such use case is still ongoing and no decision has been made yet. Therefore, This paper compares the performance of different coding schemes, namely: tail-biting convolutional code (TBCC), low density parity check codes (LDPC), Turbo code and Polar codes, in order to select the appropriate channel coding technique for 5G-mMTC scenario. The considered codes are evaluated in terms of bit error rate (BER) and block error rate (BLER) for short information block lengths ($K \leq 256$). We further investigate their Algorithmic complexity in terms of the number of basic operations. The Simulation results indicate that polar code with CRC-aided successive cancelation list decoder has better performance compared with other coding schemes for 5G-mMTC scenario.

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1. INTRODUCTION

Wireless communication is a fast-growing field, which has significantly advanced through research and innovations [1]. The 5th generation (5G) wireless communication system has been designed recently with the ambition to support a multitude of emerging applications and services. The international telecommunications union has classified these services into three major usage scenarios with radically different objectives, namely: massive machine-typ communications (mMTC), enhanced mobile broadband (eMBB), and ultra-reliable low-latency communication (URLLC) [2]. According to its usage; mMTC provides wireless connectivity to a massive numbers of devices, eMBB requires high data rates and very high traffic capacity, while URLLC requires communication with very low latency and high reliability [3].

Channel coding is a crucial technology component of any wireless communication system. With the use of channel coding, the number of errors which occur during transmission can be controlled and kept to a desirable amount; this is done by adding redundancies in a controlled manner to the information bits on the transmitter side by means of an encoder and exploiting it by the corresponding decoder on the receiver side. In the context of 5G, channel coding is facing novel challenges as to meet the requirements of URLLC, mMTC, and eMBB scenarios [4]. For eMBB, LDPC codes and polar codes are adopted for data channel and

control channel, respectively [5]. Whereas, no decision has been taken yet on coding schemes for mMTC and URLLC use cases [6].

In particular, massive machine type communication scenario requires careful selection of channel coding technique. The key requirements for mMTC scenario are mainly to provide efficient connectivity to a massive number of low-costs and ultra-low power consumption machine-type devices [7]-[8]. This implies that the selected channel code should be able to support short block size information with low order modulation schemes to satisfy low power requirements [9]-[10]. In addition, the complexity of the encoder and decoder should be as low as possible to address the strict low cost requirements.

Although several modern capacity-achieving codes provide excellent performance at long block lengths, most of those do not exhibit consistently good performance when short packets have to be transmitted, as the mMTC demands. Turbo and LDPC codes are powerful channel coding schemes that are commonly employed in numerous wireless communication systems. However, its performance starts to degrade when the code length becomes shorter [11]. It should be noted, that the power consumption of the LDPC codes is far lower than that of Turbo code [12]. The TBCC code is one of the efficient coding techniques in such conditions, and it is used in LTE system due to its good performance for short block lengths [13]. Recently, Polar codes [14] have emerged. with CRC-SCL decoding algorithm, polar codes can be a fierce competitor with other modern coding techniques, such as turbo codes and LDPC codes [15]-[16].

The candidates coding schemes considered for 5G are Turbo, TBCC, LDPC and polar code [5]. In this paper, we consider these coding schemes as a starting point to find a suitable scheme for mMTC scenario and we compare their error correction performances in terms of BLER and BER. We also compare their decoding complexity. Similar partial comparisons were made in previous publications, such as [17]-[18]. However, none of these works provide the complexity of the considered codes. Furthermore, the comparisons were made only for polar and LDPC codes.

The remaining part of the paper is organized as follows. Section 2 provides a brief overview of the channel coding techniques considered in the paper. While BER and BLER simulations results besides the algorithmic complexity of the discussed codes are provided in Section 3. Finally, we draw the conclusion in Section 4.

2. CHANNEL CODING SCHEMES

The coding schemes considered in this paper are briefly reviewed. Throughout the paper K and N , denote message length and the code length, respectively.

2.1. Convolutional codes

Convolutional codes (CC) were discovered by P. Elias in 1955 [19]. These codes are commonly used in many communication systems. Unlike block codes, convolutional encoder contain a finite number m of memory and the N encoded bits at any time unit are a function of, not only the current set of input K but also some previous input bits. The decoding of the convolution code can be done by various decoding techniques; viterbi algorithm is one of the practical techniques that uses the trellis diagram to compute the path metric value [20].

Although terminated convolutional codes represent a promising candidate solution for short block lengths, they are not recommended because of their rate loss introduced by the zero tail termination. To deal with this problem. The TBCC are used to avoid this rate loss [21]. However, the amount of computation of decoding a TBCC code is $S = 2^m$ times of decoding a terminated CC. For the purpose of comparison in this paper, the considered convolutional code has the parameters determined in LTE standards [22]. More specially, it is a tail-biting convolutional code with memory order $m = 6$.

2.2. Turbo codes

Turbo codes [23] are an important family of error correcting codes that have proved to give a performance near to Shannon's limit. The turbo encoder is building by concatenating two identical convolutional encoders, connected in parallel and separated by an interleaving function. The concept is that the first encoder operates on the information sequence directly whereas the second encoder operates on the interleaved version of the information sequence.

The turbo decoding is performed iteratively by two maximum-a-posteriori (MAP) decoders connected via an interleaver. As the MAP algorithms are computationally complex and too complicated to be implemented in real systems. Some simplified versions, such as log-MAP algorithm and the sub optimal max-log-MAP algorithm were proposed as practical decoding algorithms [24]. Similar to the TBCC code, the turbo code considered in this paper is based on LTE standards [22] and we use max-log-MAP decoding algorithm with 8 iterations.

2.3. LDPC codes

In 1962, R. Gallager introduced a family of forward error correction codes, called low-density parity check (LDPC) codes [25]. As the name implies, they are characterized by a sparse parity check matrix H , where sparse means that most of the elements are zero. The encoding of LDPC code is performed in a similar way as in linear block codes and the decoding can be implemented by using message passing algorithm also known as iterative decoding algorithm. Sum-product (SP) [26] is an iterative decoding algorithm for LDPC codes and min-sum algorithms (MSA) [27] are the reduced complexity version of SP algorithm.

In recent years, quasi-cyclic (QC) LDPC code has gained considerable attention among researchers. The 5G LDPC code belongs to the class of QC-LDPC code, where two base graphs are defined [28]. For the purpose of comparison in this paper, we have considered LDPC code based on the 5G specifications [29]. The Min-sum decoder algorithm is used.

2.4. Polar Codes

Polar code [14], invented by Arikan in 2008, is a special class of error correcting codes that can provably achieve the channel capacity. Polar codes exploit a novel concept called channel polarization, which includes two phases: channel splitting and channel combining. The idea is that when the code length tends to infinity the input channels will become polarized [14].

The decoding of polar code is done by successive cancellation (SC) decoding algorithms. Although polar code with SC algorithm achieves the capacity asymptotically, their performance is unsatisfactory at short blocklengths. To solve this issue, a successive cancellation list (SCL) algorithm is proposed [30]. The performance of the SCL decoder can be further enhanced by concatenating them with a cyclic redundancy check (CRC) codes (CRC-SCL), where CRC is used to determine a valid codeword within the list of candidates at the end of the SCL decoding process [31]. For the purpose of comparison in this paper, the polar code was decoded using SC algorithm and CRC-SCL algorithm, with list size $L=8$ and CRC of length 16.

3. RESULTS AND DISCUSSION

3.1. Performance comparison

The different channel coding schemes described in Section 2 are compared here for different short information block lengths using binary phase shift keying (BPSK) modulation scheme and, the additive white gaussian noise (AWGN) channel. A summary of utilized parameters is provided in Table 1.

Table 1. Simulation parameters

Parameters	Specifications			
Channel	AWGN			
Modulation	BPSK			
Information block length (bits)	32, 64, 128, 256			
Code rate	1/3			
Coding schemes	TBCC	Turbo	LDPC	Polar
Decoding algorithm	Viterbi	MAX-Log-MAP (8 iterations)	min-sum (25 iterations)	SC, CRC-SCL 8

The following Figures 1-4 show the simulation results in terms of BLER and BER versus signal-to-noise ratio (SNR). It is obvious from Figures 1 to Figures 3, that the performance of Polar code with CRC-SCL decoder surpasses almost all the remaining coding schemes, while polar code with SC decoding algorithm performs the worst and this is because the SC decoder is poor at finite blocklengths. It is also observed from Figure 1 that, TBCC code performs better than turbo code, LDPC and polar code with SC but as the information block length increases, it suffers from severe performance degradation. In contrast, the performance of other coding schemes keeps improving.

From Figure 4, it is observed that the performance of Turbo and LDPC codes comes close to the performance of polar code with CRC-SC decoding algorithm at information block length $K=256$ bits. Figure 4 also shows that turbo code and LDPC code have slightly better BER performance than polar code with CRC-SCL algorithm.

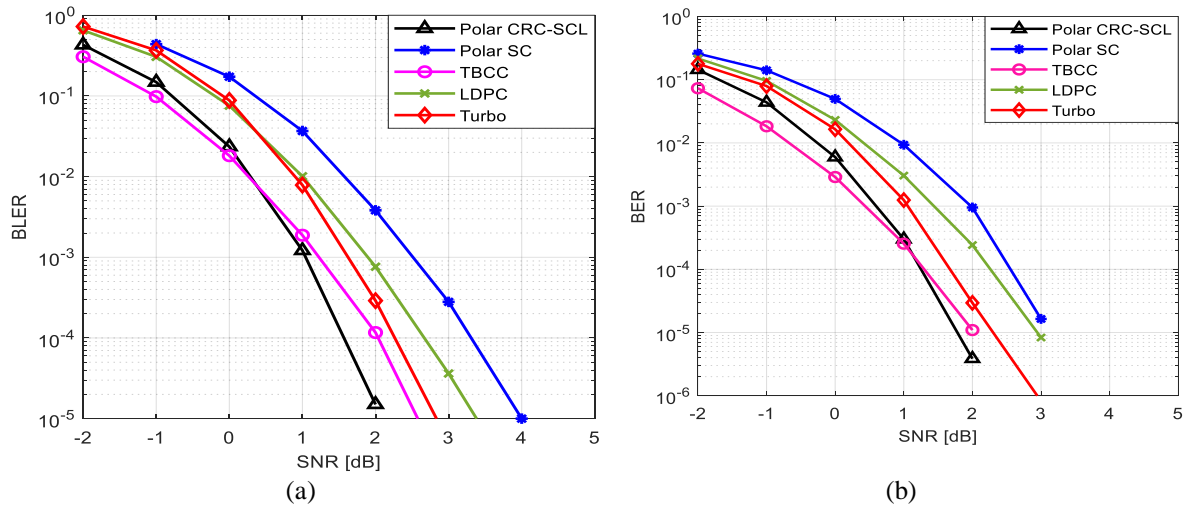


Figure 1. The performance comparison between different channel codes for K = 32 bits: (a) BLER, (b) BER

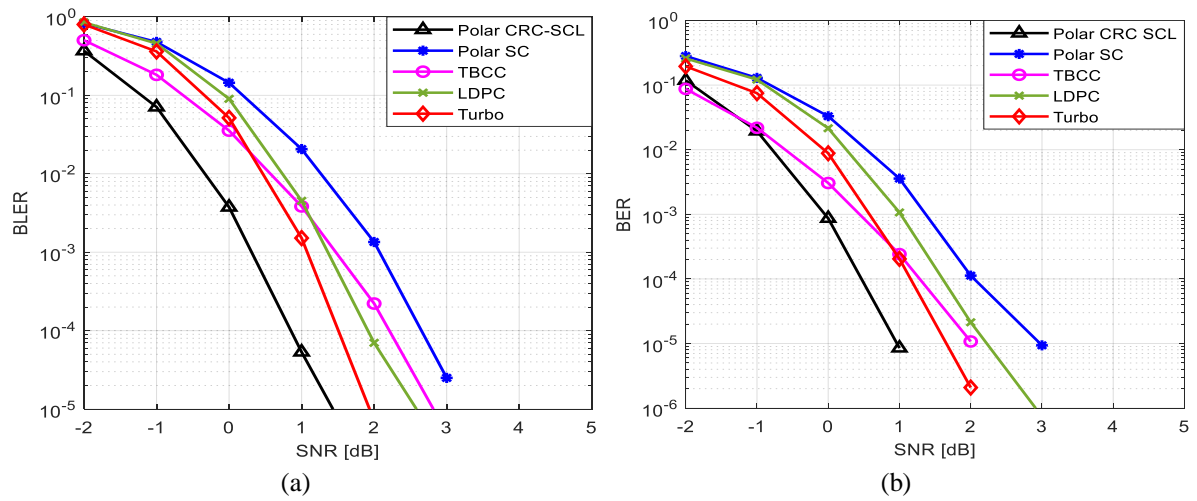


Figure 2. The performance comparison between different channel codes for K = 64 bits: (a) BLER, (b) BER

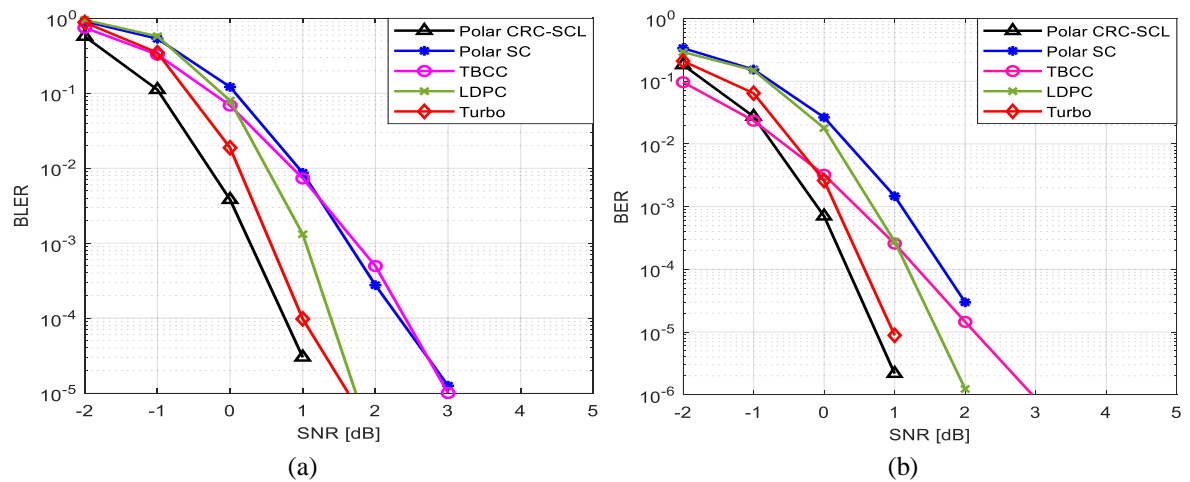


Figure 3. The performance comparison between different channel codes for K = 128 bits: (a) BLER, (b) BER

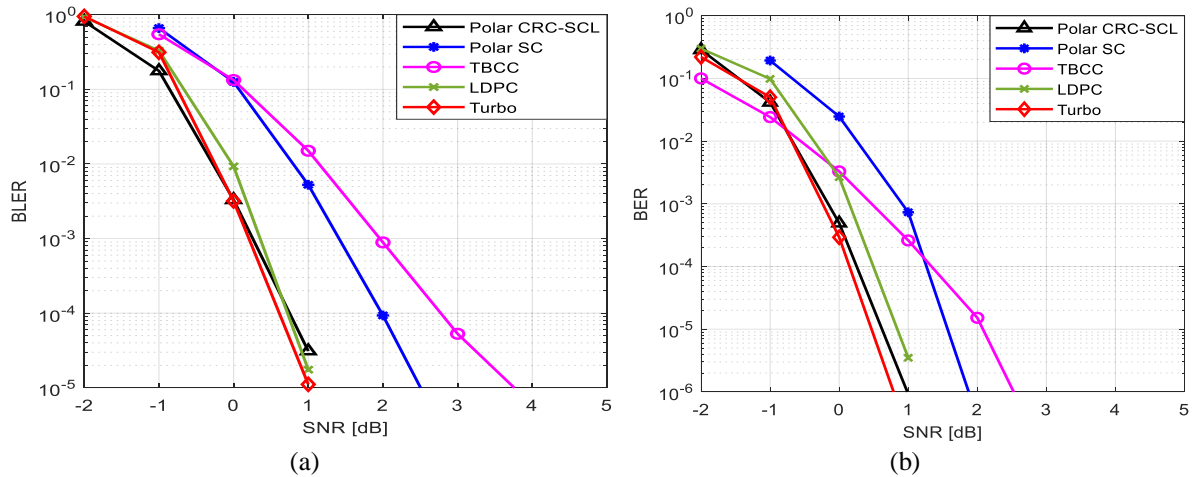


Figure 4. The performance comparison between different channel codes for K = 256 bits: (a) BLER, (b)BER

3.2. Algorithmic complexity

As already pointed out in the introduction of this paper, the complexity of coding scheme is very critical for mMTC usage scenario since lower complexity can directly minimize the cost and power consumption of the system. Evaluating the complexity of channel codes is a difficult task because it depends on many factors [32]. In this paper, we only focus on the number of basic operations to evaluate the complexity of decoding algorithms. The detailed analysis of algorithmic complexity is provided in Table 2. In the table, we use d_c and d_v to denote the average check and variable degrees in H matrix of LDPC code, respectively. Additionally, M is the number of parity bits and I_{max} is the maximum number of iterations.

The computational complexity of the decoders used for the afore-mentioned coding techniques (TBCC, LDPC, Turbo, and polar codes) is obtained for different short information lengths and at the code rate $R=1/3$. From Figure 5, it is clear that the complexity of polar code with SC decoding algorithm is lower than other coding schemes because the computational complexity of SC decoder is a function of block length N only. On the opposite side, TBCC with Viterbi decoder show the highest complexity due to the starting and ending state are unknown at the receiver.

Table 2. The complexity for different decoders

Channel Code(Decoding Algorithm)	Additions	MAX process/comparison
TBCC (Viterbi)	$4.R.N.S^2$	NA
Turbo(MAX-Log-MAP)	$I_{max}.16. R.N.S$	$I_{max}.8.R.N.S$
LDPC (min-sum)	$I_{max}.(2.N.d_v + 2.M)$	$I_{max} .(2.d_c-1).M$
Polar (SC)	$N.Log_2N$	NA
Polar (SCL)	$L.N.Log_2N + (N-M) .L. Log_22L$	NA

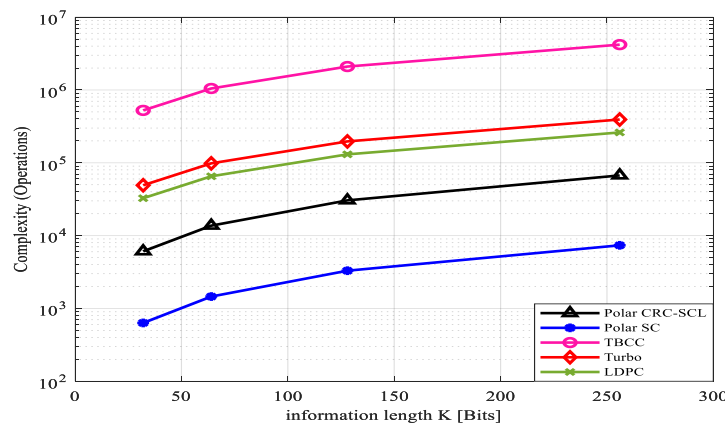


Figure 5. Computational complexity of the decoders for different coding schemes at $R=1/3$

4. CONCLUSION

This paper has presented the performance comparison of TBCC, LDPC, turbo and polar codes with coding parameters applicable to mMTC scenario. Also, the complexity of their decoders was evaluated. The results indicate that polar code with SC algorithm has very low computational complexity but the corresponding performance is poor than other coding schemes. In general, polar code with CRC-SCL decoding algorithm outperforms TBCC, LDPC and Turbo codes in both error correction performance and computational complexity. Therefore, it can be expected that polar code (CRC-SCL) is more flexible than other channel coding schemes for the tradeoff between computational complexity and performance in 5G-mMTC. Hence, Polar codes seem to be a perfect choice in such scenario.

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