Development of Dynamic Channel Coding Strategy for Multi-User MIMO -NOMA 5G Downlink Communication by Concatenation of Coding Method

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The aim of this work is to develop a dynamic coding strategy for a Multi user MIMO NOMA 5G downlink communication by means of concatenation of coding methods. The ultimate motive behind 5G technology is to deliver data at an ultra-high speed of multi - Gbps rate with extremely low latency, being highly reliable, offering huge network capacity, readily available channels and a much stable user experience accommodating multiple simultaneous users. This in turn demands a highly flexible and an effective channel coding method as it helps out the communication to be almost error free by reducing the bit errors of the transmitted data by saving it from the channel noise and the available interference in the channel. This paper provides an efficient approach based on the concatenation of Polar codes that is suited for a multi user mimo NOMA system that meets the criteria of the 5G standard. To compare the performance of mimo NOMA systems with that of concatenated PDCCH (Physical Downlink Control CHannel) polar codes E_s/N_0 *(Symbol Energy to Noise Ratio) versus BLER (BLock Error Rate) simulations have been performed. The results show that the suggested approach performs better in terms of Sum Rate Capacity versus SNR in multiuser mimo NOMA system.*

Povzetek: Cilj pristopa je razviti dinamično kodirno strategijo za Multi-user MIMO NOMA 5G, s konkatenacijo Polar kod za visoko učinkovitost.

1 Introduction

The maximum possible rate achievable by a communication link at which a reliable transfer of information takes place is termed as Channel Capacity. Shannon's coding theorem for a noisy channel is given by, say if C is the Channel Capacity. C is the rate at which information could be transmitted over a noisy channel such that it is not possible to achieve even more with no errors as well. In practice, there is a concept called Error correcting codes, that exists in any communication link aiding in the successful transmission of data at the rate little lesser than the C but with preferably at a small BER value. Channel coding technique is the methodology of including intentional redundancy to the source coded data bits to reduce the error rate aiming at a lower BER transmission. The formation of the channel codes should be dynamic such that the coding method should adopt itself to the dynamic nature of the channel to enhance the Forward Error Correction (FEC) enabling the reduction in the error rate with better data transfer. The dynamic nature of channel could be modeled using Gilbert Model based on a Two-State Markov process scheme [1].

2 Related works

The key requirements of a 5G network in short includes extremely high rates of data transmissions almost 1000 times greater than a 4G network, extremely low latency (< 1ms), a completely efficient spectrum resulting in a high spectrum efficiency coefficient and a highly energy efficient network almost 100 times better than a 4G network to be more precise. Channel polarisation is a method for creating code sequences that may operate at the symmetric capacity I(W) of any particular discrete memoryless channel with binary input (BDMC) W. The speed of channel polarisation has a limit stated. As a result, a prior constraint on the likelihood of mistake for polar coding is enhanced [2, 3]. In 3GPP, the NR, multiplexing and channel coding has specified [4]. The primary concepts of the polar codes and the decoded algorithms are explained and the concatenation of polar codes are simulated in [5]. The algorithm includes searching through many potential design-SNRs. comparing the effectiveness of various building algorithms using several simulations. If the design-SNR is improved, the authors discover that all polar code generation methods produce equally excellent polar codes in an AWGN channel [6]. The authors provide two approximation techniques that "sandwich" a deteriorated and an enhanced version of the original bit-channel. Both estimates are easily computed and, in reality, prove to be very close [7]. The performance of polar codes and concatenated codes built on them may be precisely predicted using the Gaussian approximation for density evolution [8]. As a theoretical framework for investigating the rapid creation of polar codes based on a recursive structure of universal partial order (UPO) and polarisation weight (PW) algorithms, the authors of [9] devised the -expansion, a number theory concept. In each recursive phase, a large number of polynomial equations can be constantly solved in order to create the polar codes from UPO. Both encoders and decoders must be aware of relative reliabilities: in multi-mode systems with numerous code lengths and code rates supported, storing relative reliabilities can lead to considerable implementation complexity. The authors discovered patterns in code reliabilities and suggest an approximation computing approach for representing the reliabilities of numerous codes using a small number of variables and update rules [10]. The article introduces a novel SC decoder variant known as the SC flip decoder [11]. The authors describe the successive-cancellation list decoder for polar codes, which is an extension of Arikan's classic successive-cancellation decoder. Up to L decoding paths are taken into account concurrently at each decoding stage of the proposed list decoder [12]. The authors show how to improve the efficiency of the full concatenated polar code's belief propagation (BP) decoding. The performance of multiple polar code architectures is examined in an additive white Gaussian noise (AWGN) channel. This research suggests a novel form of punctured polar coding. The codes are formed by setting constraints on both puncturing patterns and frozen sets, so that the decoder knows what the punctured bits are worth. They proposed polar codes using a CRC adaptable SC (Successive Cancellation)-List decoder. Before this adaptive SC-List decoder increases the list size, at least one survival path must pass CRC [13, 14, 15, 16]. Having said so, the channel coding method used should be of extremely efficient resulting in no latency, reduced complexity, enabling higher data rates with less or no re-transmission of data at the cost of less energy consumption as well. The channel coding methods namely convolution codes or block codes method, turbo codes method, LDPC based coding method and polar codes have been evaluated by the 3GPP standard and it has been found that polar codes have been found capable of meeting up higher rates of data and the requirements of satisfying a diverse scenario of typical 5GNR (5G New Radio) namely eMBB (enhanced Mobile Broadband), mMTC (massive Machine Type Communication) and uRLLC (ultra Reliable Low Latency Communication) [17, 18, 19]. Polar codes have been chosen up by the 3GPP standard for the control channels of eMBB

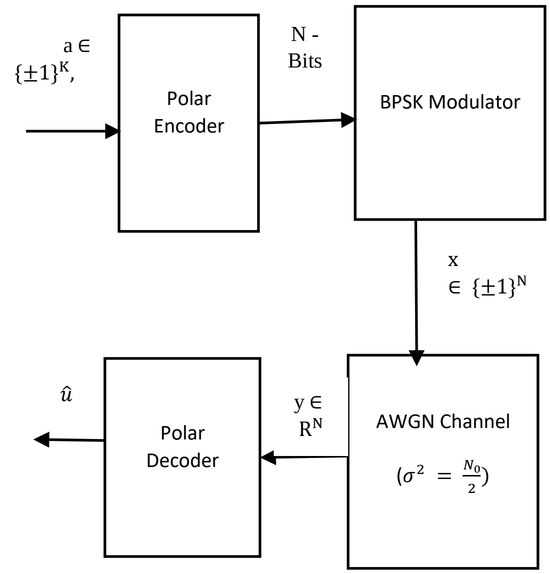

Figure 1: A polar coder

as in 5G/NR technology. This polar code technology could be further improvised by means of Concatenated coding method and by employing a decoding scheme based on combined methods as proposed.

The paper is organized further like the next section 2 briefs about proposed model of Polar codes - introduction, need for it and construction, followed by section 3 explaining the simulation results and discussions followed by section 4 concluding the work and the paper closes with the valuable references made to come up with this work successfully.

2 Proposed modelling

Channel codes play a very vital role in information theory, wherein Polar codes have started gaining a very great power of attraction as it is the only provable channel code that achieves the Shannon capacity. It was introduced by Erdal Arikan lately in 2009 and belong to the linear block code type of error correction codes [1]. A simple polar coder block diagram is shown below figure (1).

A polar code is constructed by recursive process of concatenation over a short code typically called a kernel code, which actually tries to modify the real channel into multiple possible virtual channels. With the increase in the recursive additions, the virtual channel either tries to polarize or get sparse. In other terms, the channel either becomes highly reliable (Good State) or unreliable (Bad State) virtually. This reliability factor helps to transfer data via the highly reliable channels for that matter making the transmission towards error free communication. It has been proven by Erdal Arikan in his work that the polar codes help achieving a reliable capacity for various channels with a complexity for a given code length say N is of the order of 0(N log N). The lesser complexity and the nature of being of good spectral efficiency has pushed polar codes into limelight in the field of digital communication. Basically polar codes were constructed to work with code lengths of the order of 2^n, where n is an integer and it is usually termed as the Mother kernel code. The mother code of dimension say K is given by (N_m, K_m) for a given code length of $N_m=2^n$. The matrix form of representing Polar codes based on the transformation matrix by means of the application of the product called Kronecker product onto the kernel is given by, $\tau_{N_m} = \tau_2^{\otimes n}$. The kernel matrix is represented as $\tau_2$and its value is generally given by, $\tau_2 = \begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix}$. The frozen bit set is given by $\mathrm{F} \subseteq \{1, \ldots, \mathrm{N_m}\}$, whose dimension is said to be $N_m - K_m$. The frozen set of bits are framed in such a way that it helps in minimizing the probability of errors aiding the process of successive cancellation method of decoding done at the receiving end in general. The frozen bits are usually positioned at the given $N_m - K_m$bit locations preferably having the possible least re-liabilities as computed. The computation of the possible reliability associated with the bits is generally done by means of methods like variance calculation, mutual information, tracking of the mean value, Gaussian approximation and by means of analysing the Bhattacharyya parameter of the Gaussian L – densities.

Encoding is the process of coding the information bits with code words. If the information bits are assumed to be a $\in \mathbb{F}_2^{\mathrm{K_m}}$ say, then the codewords they are encoded into is given by x $\in \mathbb{F}_2^{\mathrm{K_m}}$. If the encoding process is represented as a vector form for the frozen and actual bits, then it takes up the form of v $\in \mathbb{F}_2^{\mathrm{K_m}}$. To be in detail v has two sub vectors namely, $v_{\mathbb{I}} =$ = a and v_F = 0. The computed codeword is given as, $\mathrm{x} = \mathrm{v}.\tau_{\mathrm{N_m}}$. The encoding process here is performed in terms of permutation of Bit - reversal done over a length say N_m and given as $B_{N_M}.\tau_{N_M}$. The permutation of bit reversal is actually a procedure in which at first, indexing is done to the number sequence starting from 0 until $N_m - 1$. Then the sequence having indexed is reversed in terms of its binary equivalent of each number as in the sequence. At times, the Cyclic Redundancy Check (CRC) is also added. If the number of channels is assumed to be N, the matrix used in generation of polar codes is given by M_N. The generation of polar codes is given by,

$$M_N = B_N \tau^{\otimes n} = P_N(I_2 \otimes B_{N/2})\tau^{\otimes n} \tag{1}$$

Where, the B represents the bit reversal function, P represents the permutation function, $\otimes$ stands for the Kronecker product of the I matrix.

The encoded bit generation in total is given by,

$$g_1^N = a_1^N M_N \tag{2}$$

Where, the term $a_1^N$is the information bit.

The initial conventional method of decoding the polar codes was based on the Successive Cancellation (SC) method. The method of Successive Cancellation is actually a very simple yet an efficient method as well. But probably it suffers from decoding errors as well. This was improvised by the new method called Successive Cancellation List (SCL) method of decoding aiming at the betterment of Block errors. The encoder at the transmitter, generates a coded data bits from the original information data bits and then pass it via the polarized channel distinguishing them like active bits through reliable channels and frozen bits through noisy channels. At the decoder in the receiving end, the frozen bits are actually frozen to fixed values and based on the knowledge of the frozen bit value saya_{A^c} aand the code word vector say Z_1^N , an estimated value of the information is computed to get the value of $\hat{a}_1^N$ along with the help of the vector A. The successive cancellation method of decoding is made use of to compute the estimated value$\hat{a}_1^N$, given by

$$\hat{a}_i \triangleq \begin{cases} a_i, & if\ i \in A^c \\ Di(z_1^N, \hat{a}_1^{i-1}), & if \in A \end{cases} \tag{3}$$

The value of the function D is the decision made over the value of the bits to be computed.

The conditional decision making function of D is given by,

$$Di(z_1^N, \hat{a}_1^{i-1}) = \begin{cases} 0 & if\ \frac{C_i^N(z_1^N, \widehat{a_1}^{i-1} | 0)}{C_i^N(z_1^N, \widehat{a_1}^{i-1} | 1)} \\ 1 & else \end{cases} \tag{4}$$

The level of polarization of the virtual channels formed by means of Polar encoding is actually denoted by the values 0 and 1 in the equation above. From the above discussion, it would be inferred that the computation of the estimated value involves complexity along with inaccuracies as well. To out-beat the shortcomings, a new level of approach called Belief Propagation mechanism of decoding is suggested at the receiving end to decode the polar coded information bits aiming at its successive recovery.

In the Belief Propagation based decoding process, a new concept called Factor Graph is introduced. A Factor Graph is obtained from the generated Polarization matrix say G_N. The factor graph takes up the form of n - stages, wherein the value of n is given by $\mathrm{n} = \log \mathrm{N}$ and the corresponding number of factor graph nodes is given by, $(\mathrm{n}+1)\mathrm{N}$. The factor graph is constructed such that each stage of the n-stages involved is provided with $N/2$ number of elements for processing. Every node present in the corresponding stages of the factor graph, helps evaluating two types of

LLRs each. Two LLRs are being evaluated in such a way that one LLR is looked up along the flow from left to right and the other LLR is looked up in the vice versa direction, giving up evaluated message values say $R_{i,j}^{(t)}$ and $L_{i,j}^{(t)}$ respectively. If for instance, BPSK modulation is considered to map the input bits, x $\in \{0,1\}^{N}$to $\in \{+1,-1\}^{N}$, then the left to right denotation of the evaluated message is given by,

$$R_{1,j}^{(0)} = \begin{cases} 0, & if\ j \in A \\ +\infty, & if\ j \in A^{c} \end{cases} \quad (5)$$

The LLR or the Log Likelihood of the given polar code is computed by means of the equation given by,

$$L_{n+1,j}^{0} = \ln \frac{Pr(x_j = +1/r_j)}{Pr(x_j = -1/r_j)} \quad (6)$$

The modulated and the received codewords are given by x_j and r_j, respectively. The LLR value computed gets updated with each iterative propagation based on certain specific regulatory conditions. The conditional equations are summarized as below.

$$\begin{aligned} L_{i,j}^{(t)} &= g(L_{n+1,j}^{(t-1)}, L_{n+1,j}^{(t-1)}, L_{i+1,j+N/2}^{(t-1)} + R_{1,j+N/2^{i}}^{(t)}) \\ L_{i,j+n/2^{i}}^{(t)} &= g(L_{n+1,j}^{(t-1)}, R_{i,j}^{(t-1)} + L_{i+1,j+N/2}^{(t-1)}) \\ R_{i+1,j}^{(t)} &= g\left(R_{i,j}^{(t-1)}, L_{i+1,j+N/2^{i}}^{(t-1)}\ L_{i+1,j+N/2^{i}}^{(t)}\right) \\ R_{i+1,j+N/2^{i}}^{(t)} &= g(R_{i,j}^{(t)}, L_{i+1,j}^{(t-1)} + R_{i,j+N/2^{i}}^{(t)}) \end{aligned} \quad (7)$$

The g(x,y) function as in the above 7 expressions stands for the operation called the box plus function given in detail as,

$$g(x,y) \triangleq In \frac{1+e^{x+y}}{e^{x}+e^{y}} \quad (8)$$

The computation of the$\hat{a}_j$ and $\hat{x}_j$ namely the value of the information bit and the code word bit estimated respectively is done from the calculated LLR value after the successive

completion of the maximum possible iterations.If the calculated value of the LLRs is represented by Γ_j^{a} and Γ_j^{x}respectively corresponding to the information a_jand the code word x_j, then the value of Γ_j^{a} is given b$\Gamma_j^{a} = R_{1,j}^{(T)} + L_{1,j}^{(T)}$y. And the value of Γ_j^{x} is equal to $R_{n+1,j}^{(T)} + L_{n+1,j}^{(T)}$. The simplified condition for decision making is given by,

$$\hat{a}_j = \begin{cases} 0, & if\ \Gamma_j^{a} > 0 \\ 1, & otherwise \end{cases} \quad (9)$$

The factor graph of code length N=8 is given below figure (2).

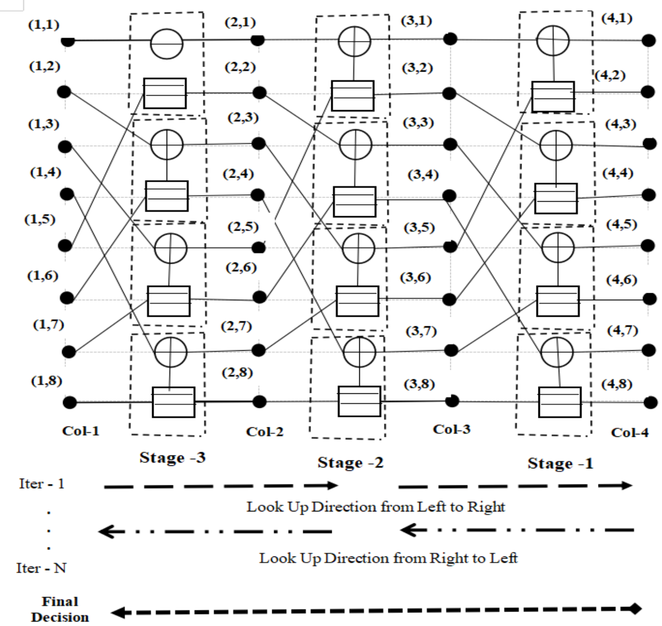

Figure 2: Factor Graph for N=8 Length

The Factor Graph is drawn indicating the flow of Look Up direction in the process of the LLR value computation, which in turn helps in the decision making of the value in the process of data bits estimation.

3 Simulation results and discussion

The above discussed system model based on the processing of polar coded control signals, whose role is highly commendable in the effective functioning of a MIMO - NOMA based 5G NR system was simulated taking up some essential parameters of assumptions and approximations as well. ased on the above simulation parameters listed, the suggested system model is simulates and the resulting plots have been discussed below in terms of the system performance namely its SNR (in dB) Vs BER, Capacity (in Mbps) Vs SNR (in dB), BLER Vs Es/No (in dB). The tabulation below lists the parameters considered for the simulation done.

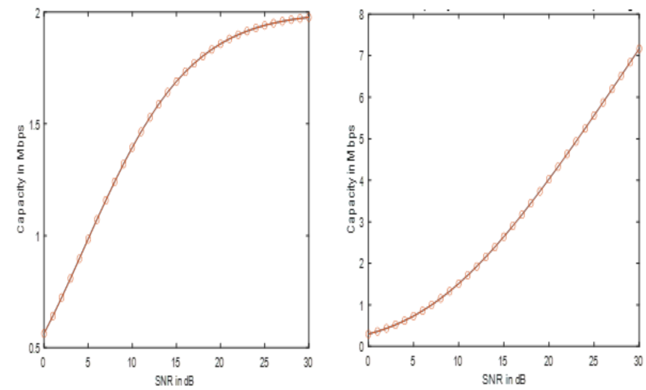

Fig 3 (a and b). Capacity vs SNR performance of an uplink and downlink MIMO-NOMA system.

The above Figure 3 (a and b) depicts the capacity in Mbps vs. the SNR in dB of a MIMO - NOMA system in the Uplink and Downlink. The control information used in the functioning of a typical 5G NR system is generally said to be UCI abbreviated from Uplink Control Information and DCI abbreviated from Downlink Control Information. The UCI is taken care of by the physical channel termed as PDCCH, expanded to be Physical Downlink Control CHannel and at times the duty of communicating the control information is done by PDSCH also. Where, PDSCH is the Physical Uplink Shared CHannel, which carries both data and control information. The DCI on the other hand is taken care only by means of PDCCH called as the Physical Downlink Control CHannel, solely dedicated for downlink control information alone. The PDSCH (Physical Downlink Shared CHannel) does not support the communication of control signals through it and supports only the transfer of data.

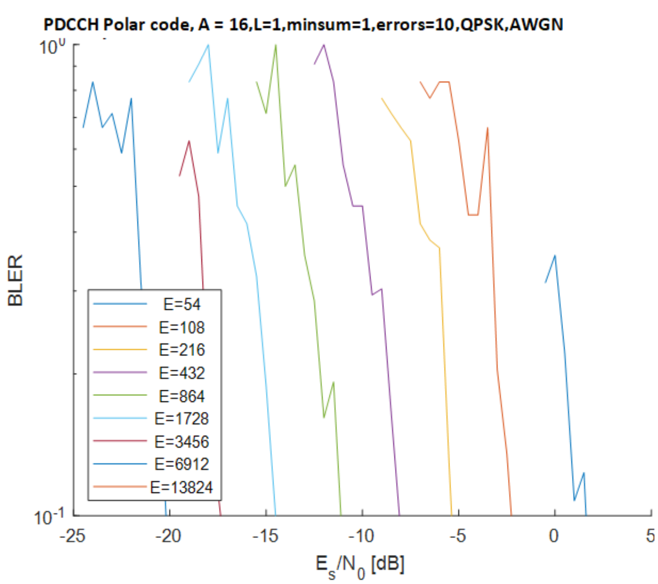

Figure 4: BLER versus $\left(\frac{E_S}{N_0}\right)$ (in dB) for A = 16 Bits

Table 1: Simulation parameters used

Parameter	**Values Assumed**
Number of users	2 per cluster
Number of clusters	3
Order of the MIMO system	2X2
Modulation Method	QPSK
Number of Errors	10,100
Size of the Successive Cancellation List	1
Input data bit length (A)	16,32,64,128,256,512 and 1024
Bit selection length (E)	54,108,216,432,864, 1728,3456,6912 and 13824

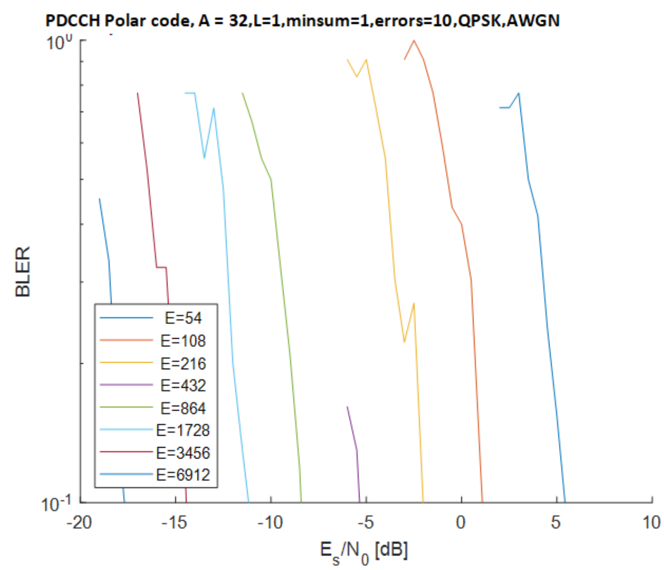

Figure 5: BLER versus $\left(\frac{E_S}{N_0}\right)$ (in dB) for A = 32 Bits

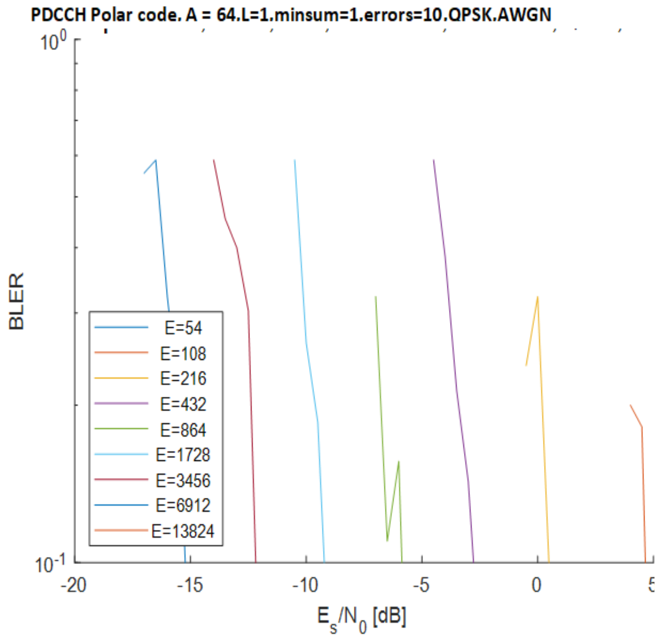

Figure 6: BLER versus $\left(\frac{E_S}{N_0}\right)$ (in dB) for A = 64 Bits

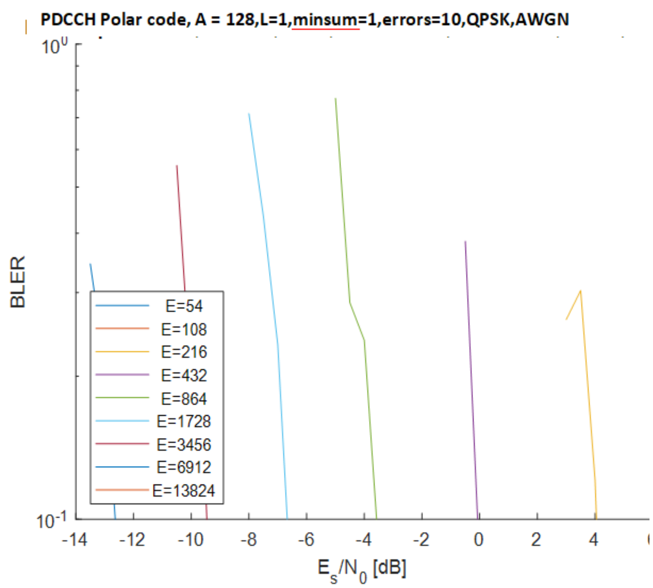

Figure 7: BLER versus $\left(\frac{E_S}{N_0}\right)$ (in dB) for A = 128 Bits

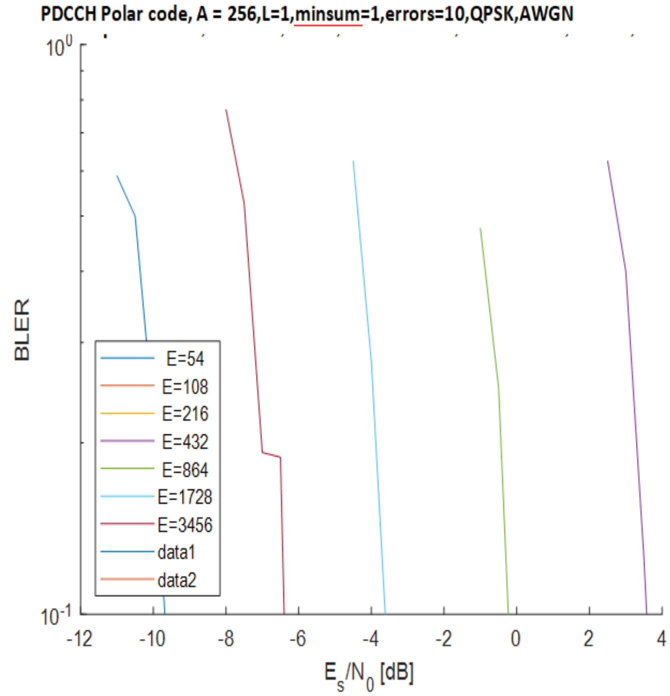

Figure 8: BLER versus $\left(\frac{E_S}{N_0}\right)$ (in dB) for A = 256 Bits

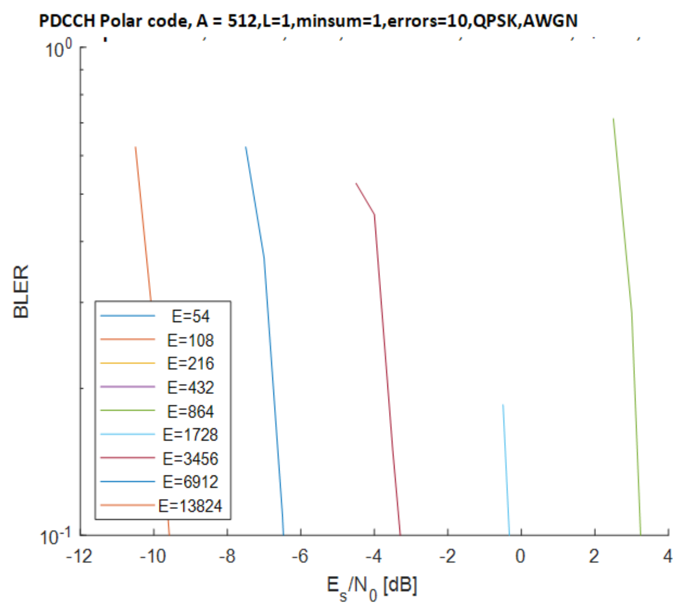

Figure 9: BLER versus $\left(\frac{E_S}{N_0}\right)$ (in dB) for A = 512 Bits

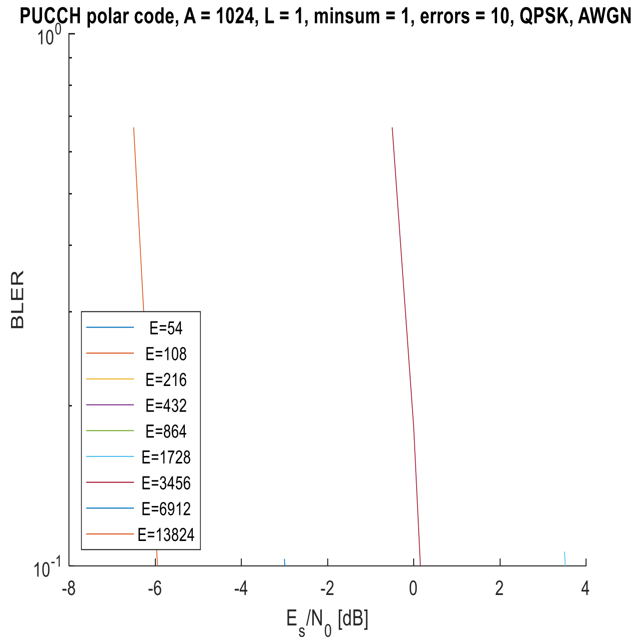

Figure 10: BLER versus $\left(\frac{E_S}{N_0}\right)$ (in dB) for A = 1024 Bits

BLER stands for Block Error Rate. The actual target of BLER at the 5G NR is 10%. It means, 90% of the data grouped in blocks are error free and a 10% being erroneous is acceptable. The BLER is a crucial parameter of discussion at the receiving end of a 5G NR system. The BLER is computed as the ratio of the number of blocks received with errors to the total number of blocks received. The PDCCH polar codes of input data bit length A (16, 32, 64, 128, 256, 512, and 1024) with the bit selection length E (54, 108, 216, 432, 864, 1728, 3456, 6912, and 13824) shown in figures (4-10) indicate that the BLER is lowered as the input bit length increases with regard to E_s/N_0.This computation is done after de - interleaving the received data at the physical layer and performing the decoding operation by means of CRC verification done on every block of data being received. The throughput of a given system keeps increasing with the decreasing value of the BLER value.

Table 2: Simulation Parameters considered for channel encoded MIMO NOMA system

CHANNEL CODING	LTE TURBO CODE	5G LDPC CODE	5G POLAR CODE
Input data bit length	1024	1024	1024
Information bit length	512	512	512
Code Rate	1/2	1/2	1/2
Performance evaluation parameters	BLER, SNR, Sum Rate Capacity	BLER, SNR, Sum Rate Capacity	BLER, SNR, Sum Rate Capacity
Speed achieved (x 10^6 Mbps)	1.3 (at max 20 dB SNR)	1.0 (at max 20 dB SNR)	1.9 (at max 20 dB SNR)

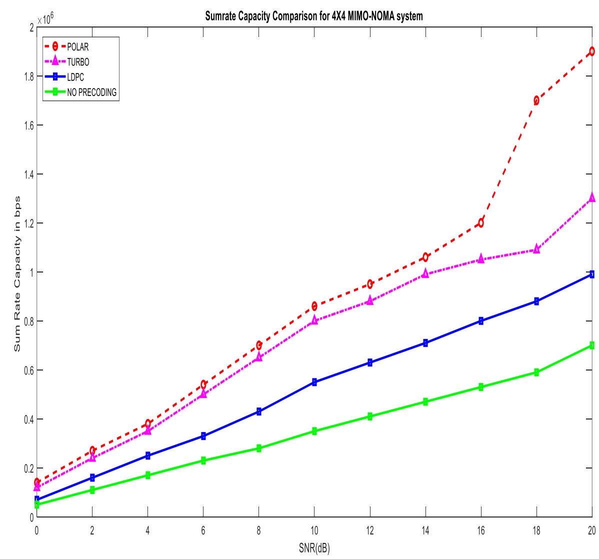

Figure 11: Comparison of SNR Vs BLER for 4 x 4 MIMO NOMA

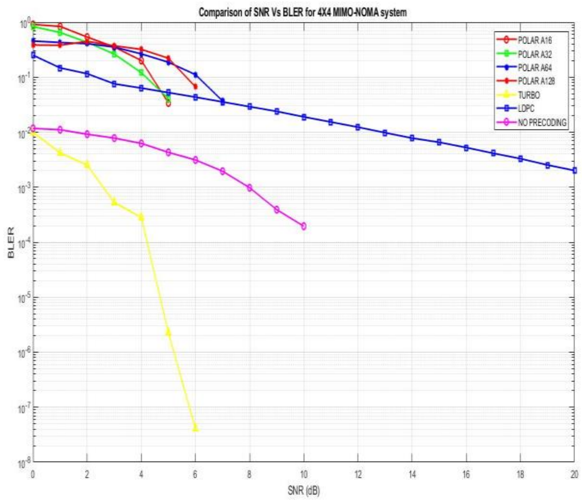

Figure 12: SNR versus Sum Rate Comparison for 4 x 4 MIMO NOMA

Figures 11 and 12 demonstrate a comparison of polar code, turbo code, and LDPC codes, as well as the no coding condition, when applied to a 4 x 4 MIMO NOMA system. Figure 11 depicts a gain of around 0.5 dB over LDPC and Turbo codes, with a corresponding block error rate (BLER) of 10^-2 for polar codes with input data bit lengths A of A16, A32, A64, and A128. The polar codes in figure 12 outperform the system when compared to the Turbo and LDPC codes (red line). Sum rate capacity ranging from 0 to 2 x 10^6 Mbps and SNR ranges of 0 to 20 dB illustrate the higher performance of polar codes has gain the speed of approximately 0.6x10^6 Mbps at the maximum of 20 dB SNR.

4 Conclusion

In a 5G NR system, a channel code's goal is to be extremely dynamic and assist the system in achieving almost error-free communication in a dynamic fashion without driving up the system's cost or increasing the complexity of the structure. In that case, the suggested polar codes outperform the existing channel coding methods and helps the system to be very effective in terms of error combating and the ease of its implementation complexity as well. The comparative analysis of SNR Vs BLER and SNR Vs Sum rate analysis of various typical coding schemes including no coding condition, LDPC code, Turbo code and the suggested Polar code of different block lengths (A = 16,32,64 and 128), shows the highlighted performance of the polar coding method in precise. In figure 11, the detailed analysis of Polar codes shows that they perform better than LDPC and turbo codes, and their performance increases as the length of the Polar code utilized increases. The figure 12, shows the comparative performance of various channel codes in terms of SNR Vs Sum rate wherein the suggested polar code method gives a better performance when being applied to a typical 4 x 4 MIMO NOMA system.

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Conflict of Interest

The authors declare that there are no conflicts of interest.

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