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# Performance Analysis of Different Flexible Decoding Algorithms for NR-LDPC Codes

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## ABSTRACT

Channel coding technique is a fundamental building block in any modern communication system to realize reliable, fast, and secure data transmission. At the same time, it is a challenging and crucial task, as the data transmission happens in a channel where noise, fading, and other impairments are present. The Low-Density Parity-Check (LDPC) codes give substantial results close to the Shannon limit when the complexity and processing delay time are unlimited. In this paper, the performance of the LDPC decoding with four algorithms was investigated. The investigated four algorithms were Belief Propagation (BP), Layered Belief Propagation (LBP), Normalized min-sum (NMS), and Offset min-sum (OMS). These algorithms were examined for code rates ranging from 1/3 to 9/10 and message block lengths (64, 512, 1024, and 5120) bits. The simulation results revealed the flexibility of these decoders in supporting these code rates and block lengths, which enables their usage in a wide range of applications and scenarios for fifth-generation (5G) wireless communication. In addition, the effect of the maximum number of decoding iterations on the error correction performance was investigated, and a gain of 5.6 dB can be obtained by using 32 decoding iterations at BER=2*10-3 instead of one decoding iteration. The results showed that the decoders performed better for longer message blocks than for short message blocks, and less power was required for transmitting longer messages. Finally, the comparison results of their performance in terms of bit error rate (BER) under the same conditions showed a gain of 0.8 dB using LBP at BER= 10-5 compared with the NMS decoding algorithm.

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# تحليل أداء خوارزميات فك التشفير المرنة المختلفة لرموز NR-LDPC

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## الخلاصة

تعد تقنية تشفير القناة لبنة أساسية في أي نظام اتصال حديث لتحقيق نقل بيانات موثوق وسريع وآمن. وهي في نفس الوقت مهمة صعبة وحاسمة حيث يحدث نقل البيانات في قناة يوجد بها ضوضاء وخبو وأضرار أخرى. تعطي رموز فحص التماثل منخفض الكثافة (LDPC) نتائج جوهرية قريبة من حد Shannon عندما يكون التعقيد ووقت تأخير المعالجة غير محدود. في هذا البحث، قمنا بالتحقيق في أداء فك تشفير LDPC بأربعة خوارزميات، وهي: نشر المعتقدات (BP)، ونشر المعتقدات الطبقية (LBP)، والمحصلة الدنيا الطبيعية (NMS)، والمبلغ الأدنى للإزاحة. (OMS) تم فحص هذه الخوارزميات لمعدلات الشفرة التي تتراوح من 1/ 3 الى 9 10/واطوال كتل الرسائل (64, 512, 1024, 5120) بت. كشفت نتائج المحاكاة عن مرونة أجهزة فك التشفير هذه في دعم معدلات الشفرة وأطوال الكتل، مما يتيح استخدامها في مجموعة واسعة من التطبيقات والسيناريوهات للاتصالات اللاسلكية من الجيل الخامس. (G5) بالإضافة إلى ذلك، تم التحقيق في تأثير الحد الأقصى لعدد مرات تكرار فك التشفير على أداء تصحيح الخطأ ويمكن الحصول على كسب قدره 5.6 dB باستخدام 32 تكرارًا لفك التشفير عند BER = 2 * 10-3 بدلاً من تكرار واحد لفك التشفير. تُظهر النتائج أن أجهزة فك التشفير تعمل بشكل أفضل مع كتل الرسائل الأطول مقارنةً بمجموعات الرسائل القصيرة، وأن هناك حاجة إلى طاقة أقل لإرسال الرسائل الأطول. أخيرًا، تُظهر نتائج المقارنة لأدائهم من حيث معدل خطأ البتات (BER) في نفس الظروف كسبًا قدره 0.8 ديسيبل باستخدام LBP عند BER = 10-5 مقارنة بخوارزمية فك تشفير NMS.

**الكلمات الدالة: تشفير القناة، كود LDPC، انتشار المعتقدات، معدل الخطأ في البتات، الجيل الخامس.**

## 1. INTRODUCTION

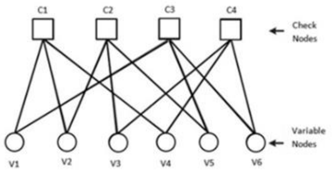
Wireless communication, in particular, mobile communication is widely spread and has become an essential part of communications [1, 2, 3]. A communication channel is prone to errors because of impairments such as random noise, fading, and interference. These impairments corrupt the original data, therefore, channel coding is employed to repair such faults [4]. It is clear that choosing an appropriate channel coding scheme is important for reliable and rapid data transmission. Channel coding has a significant impact on the system's reliability, throughput, and latency [5, 6, 7]. To make these wireless systems more energy-efficient and bandwidth-efficient, forward error-correction (FEC) codes are utilized. More channel errors can be corrected with lower code rates, as a result, more energy is consumed by the channel. While higher code rates are used to exploit the bandwidth efficiently. Hence, selecting an appropriate coding rate necessitates a good comparison between the bandwidth and the energy consumed by the system [8]. The establishment of channel coding and information theory originate from Shannon's paper in 1948 [9]. Shannon showed and proved that by transmitting the data at a rate that is less than the channel capacity, errors caused by the channel can be minimized by using suitable encoding and decoding methods [9]. Since then, many researchers have been experimenting with various approaches to construct error correction codes [10]. However, only after the invention of the Turbo code, Shannon's channel limits could be significantly approached [11]. The LDPC code is another channel capacity-approaching code that was introduced by Gallager in 1962, but it was impractical because of the technology state at that time [12]. After the invention of the Turbo codes, MacKay and Neal rediscovered the LDPC codes and found that these codes had a decoding performance close to the channel capacity using iterative decoding algorithms for large code lengths [13, 14]. While Turbo codes are used in the third-generation (3G) and the fourth-generation (4G) mobile communication systems, the LDPC codes are adopted in many wireless communication standards as channel coding such as IEEE 802.16e (WiMAX), IEEE 802.11n, and Digital Video Broadcast/ satellite second generation (DVB-S2) [10, 15, 16]. The LDPC and the Turbo codes are only channel-approaching codes, whereas the Polar code is the first proven channel-achieving code with low-complexity encoding and decoding methods [17]. The hardware implementation of the LDPC decoder can be dictated by the services and the nature of the applications that the system support. Since the current and future wireless communication systems should support a wide range of services and applications, the user data blocks will vary in length. Therefore, the channel decoder must be flexible and support different code rates and block lengths to enable its usage in a wide range of situations. Decoder flexibility will minimize the usage of wasteful encoded bits that degrade spectrum efficiency, latency, and system throughput [10, 18]. The contribution of this paper is to provide an evaluation and comparison of four different decoding algorithms for the new radio (NR) LDPC codes, namely Belief Propagation (BP), Layered Belief Propagation (LBP), Normalized min-sum (NMS), and Offset min-sum (OMS) decoding algorithms. The evaluation is made in terms of the bit error rate (BER) as a function of the signal-to-noise ratio (SNR). First, the effect of the number of decoding iterations on the BER performance was examined. Then the performance of these algorithms for different code rates ranging from 1/3 to 9/10 was evaluated. Further, a comparison of different code block lengths' impact on the BER performance was considered. This paper is structured as follows: section two describes some of the NR-LDPC encoding and decoding algorithms. Section three describes the methodology used in this paper. Section four presents the simulation results with a discussion of the results. Finally, section five concludes the outcomes of the present investigation.

## 2.LDPC CODES

LDPC Codes are a class of linear error-correcting block codes. LDPC Codes can be described by a sparse parity check matrix (PCM). The sparsity property facilitates low-complex encoding and decoding. LDPC codes can also be represented by the Tanner graph, which contains two sets of nodes; variable nodes (VNs) and check nodes (CNs) corresponding to the columns and rows of the PCM. An edge $e_{ij}$ in the Tanner graph is a nonzero entry in the PCM that connects the $VN_i$ with the $CN_j$. An iteration is defined as the round of messages passed from CNs to VNs where the VNs process these incoming messages and return their soft decisions to the CNs. Usually, the LDPC decoding process is run until it reaches a predefined maximum number of iterations or a prescribed stopping criterion is meet [19-20]. Fig. 1 shows an example of a PCM **H** and its corresponding Tanner graph.

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

**(a)**



**(b)**

**Fig.1** (a) An example of PCM and (b) its Tanner graph representation.

Radio communication sector of the International Telecommunication Union (ITU) in its report [21] defined three different service classes: enhance mobile broadband (eMBB), ultra-reliable and low-latency communications (URLLC), and the massive machine-type communication (mMTC). Among these different classes, eMBB is human-centric communication, which deals with high mobile data rate demands. The third Generation Partnership Project (3GPP) has developed many NR standards in order to address the 5G requirements. This standardization body adopted the New Radio LDPC (NR-LDPC) code for data transmission and Polar codes for control information transmission for eMBB. The NR-LDPC codes have a refined structure that significantly differs from previous standards. The NR-LDPC codes are quasi-cyclic (QC-LDPC) codes that can be described by two base graphs (BGs) that have a similar structure. BG1 is designed for large blocks of lengths ($500 \le k \le 8448$) and code rates R $\left(1/3 \le R \le 8/9\right)$. The mother code rate of BG1 is 1/3, whereas; BG2 is designed for short blocks of lengths ($40 \le k \le 3840$) with lower rates $\left(1/5 \le R \le 2/3\right)$ and the mother code rate is 1/5. There are eight sets of lifting sizes (Z) for each BG that is defined as $Z = a.2^j$ where $a \in \{2, 3, 5, 7, 9, 11, 13, 15\}$ *and* $0 \le j \le 7$ as shown in Table 1.[22]

**Table 1.** Sets of LDPC lifting sizes

| Set index ($i_{LS}$) | Lifting size set |
|---|---|
| 0 | $Z=2x2^j$, j= 0, 1, 2, 3, 4, 5, 6, 7 |
| 1 | $Z=3x2^j$, j= 0, 1, 2, 3, 4, 5, 6, 7 |
| 2 | $Z=5x2^j$, j= 0, 1, 2, 3, 4, 5, 6 |
| 3 | $Z=7x2^j$, j= 0, 1, 2, 3, 4, 5 |
| 4 | $Z=9x2^j$, j= 0, 1, 2, 3, 4, 5 |
| 5 | $Z=11x2^j$, j= 0, 1, 2, 3, 4, 5 |
| 6 | $Z=13x2^j$, j= 0, 1, 2, 3, 4 |
| 7 | $Z=15x2^j$, j= 0, 1, 2, 3, 4 |

### 2.1.Encoding of LDPC Codes

The Gauss-Jordan elimination is the most common algorithm for encoding LDPC codes. In this method, the information bits vector ($\boldsymbol{s}$) is multiplied by the generator matrix **G** to obtain the codeword vector ($\boldsymbol{c}$) given in Eq. (1) as:

$$\boldsymbol{c} = \boldsymbol{s} * \boldsymbol{G} \quad \dots(\mathbf{1})$$

For LDPC codes, the PCM (**H**) is the design parameter not the generator matrix **G.** The matrix **H** is the generator of the dual code with all rows of **H** are codewords. The generator matrix **G** and the PCM (**H**) are related by Eq. (2) [23] :

$$\boldsymbol{GH}^T = 0 \dots(\mathbf{2})$$

Therefore, for a systematic code the unknown **G** can be derived from **H** which is defined using Eq. (3):

$$\boldsymbol{H} = [\boldsymbol{A} \quad \boldsymbol{I}_M] \quad \dots(\mathbf{3})$$

Where $\boldsymbol{A}$ is a binary matrix of order M * K, $\boldsymbol{I}_M$ is an (M = N-K) identity matrix, K is the message length, and N is the codeword length. The generator matrix **G** can be obtained by Eq. (4):

$$\boldsymbol{G} = [\boldsymbol{I}_K \quad \boldsymbol{A}^T] \quad \ldots(\mathbf{4})$$

This method has a complexity of the order $O(N^2)$ [decoding complexity based on operations count determines the number of multiplication and addition operations the algorithm requires. The amount of time the computer will take to implement the algorithm is estimated based on the operations count] and the derived generator matrix **G** could most unlikely to be sparse [24, 25]. To reduce the encoding complexity, the RU method was proposed, in which the PCM was transformed into a lower triangular form, and the computation complexity was roughly linear [26]. Non-flexibility and non-systematic were the main disadvantages of the RU encoding method. The Forward Substitution encoding method was used for encoding the QC-LDPC codes utilized in Wi-Fi 802.11 n/ac/ax. Such an encoding method enables a flexible encoder and decoder which supports multiple message lengths and code rates. Therefore, it was adopted for encoding the NR-LDPC codes [25, 27].

### *2.2. Decoding of LDPC Codes*

Different methods can be applied for decoding LDPC codes. BP algorithm is the basic soft decision decoder proposed by Gallager, which is based on passing messages between the CNs and the VNs. First, for the transmitted LDPC encoded codeword **c**, where **c** = (c₀, c₁, …, c$_{N-1}$), the log-likelihood ratio (LLR) values received from the channel are fed as input to the decoder as given in Eq. (5):

$$L(c_i) = \log\frac{P_r(c_i = 0|\, y_i)}{P_r(c_i = 1|y_i)} \quad \ldots(\mathbf{5})$$

where $L(c_i)$ is the LLR input value to the decoder, P$_r$ is the probability that the i$^{th}$ codeword bit (c$_i$) =0 given the channel output is $y_i$for that c$_i$ bit, $y_i$ is the i$^{th}$ bit of the received vector $\boldsymbol{y} = (y_0, y_{1,} \ldots, y_{N-1})$. The VNs operation is given in Eq. (6):

$$L(r_{ji}) = \log\frac{r_{ji}(0)}{r_{ji}(1)} = 2tanh^{-1}\left(\prod_{i' \in V_{j\backslash i}} \tanh\left(\frac{1}{2}\, L(q_{i'j})\right)\right) = \left(\prod_{i' \in V_{j\backslash i}} \alpha_{ij}\right)\varphi\left(\sum_{i' \in V_{j\backslash i}} \varphi(\beta_{i'j})\right) \ldots(\mathbf{6})$$

where: L$(r_{ji})$ is the estimated LLR value of the sum of the messages from CNs to each VN, $i' \in V_{j\backslash i}$ represent indices $i'$ $(1 \le i' \le N)$ the set of VNs except i connected to j CN, $j\,(1 \le j \le M)$ $\alpha_{ij} \equiv sign\left(L(q_{i'j})\right)$ *and* $\beta_{i'j} \equiv |L(q_{i'j})|$ *and* $\varphi(x) \equiv \log\frac{e^x+1}{e^x-1}$.

The CNs operation is given in Eq. (7):

$$L(q_{ij}) = L(c_i) + \sum_{j' \in C_{i\backslash j}} L(r_{j'i}) \ldots(\mathbf{7})$$

$$L(Q_i) = L(c_i) + \sum_{j' \in C_i} L(r_{j'i}) \quad \ldots(\mathbf{8})$$

where: L$(q_{ij})$ is the estimated LLR value of the sum of the messages from VNs to each CN, $j' \in C_{i\backslash j}$ represent indices $j'$ $(1 \le j' \le M)$ the set of CNs except $j$ connected to VN $i$ , $i$ $(1 \le i \le N)$, $L(Q_i)$ is the updated soft estimate LLR value of the transmitted bit $c_i$ at the end of each iteration. If the value of $L(Q_i)$< 0, then the hard-decision output of $c_i = 1$ . Otherwise, the output of $c_i = 0$ [28]. The sequence in which all CNs update their messages, then the VNs, can affect the performance of the decoder. This parallel message updating is called Flood Schedule. An improvement in the decoder performance can be achieved by performing serial scheduling, which is called Layered Belief Propagation (LBP) [20]. LBP decoding loop iterates on subsets of layers (rows) of the PCM. For each row, m, and bit index, j, in the layer, the updating of the LLR values is based on Eq. (9-13)

$$L\,(q_{mj}) = L\,(q_j) - R_{mj} \quad \ldots(\mathbf{9})$$

$$A_{mj} = \sum_{\substack{n\, \in N(m)\\ n \neq j}} \Psi\left(L\,(q_{mn})\right) \ldots(\mathbf{10})$$

$$s_{mj} = \prod_{\substack{n\, \in N(m)\\ n \neq j}} sign\left(L\,(q_{mn})\right) \ldots(\mathbf{11})$$

$$R_{mj} = -\,s_{mj}\,\Psi(A_{mj}) \quad \ldots(\mathbf{12})$$

$$L\,(q_j) = L\,(q_{mj}) + R_{mj} \quad \ldots(\mathbf{13})$$

where $\Psi(x) \equiv \log\left(\left|\tanh\left({}^{x}/_{2}\right)\right|\right)$ and $L\,(q_j)$ represents the output LLR for the decoded bit. If the value of $L\,(q_j) \ge 0$, then the hard-decision output of $c_i = 0$. Otherwise, the output of $c_i = 1$. The message passing in the LBP can accelerate the convergence time because the CNs operations can be processed whenever the VNs operations in a layer are done, rather than waiting for all the VNs operations in the whole PCM. The VNs and the CNs operations in each layer are the same as BP, but the difference is in the updated LLR value of each layer. The current layer input LLR value is the previous layer output LLR value, and the last layer output LLR value is the final output LLR value of the decoder, which is used for making a decision. The input LLR value of the current layer can be updated by Eq. (14):

$$l_{layer_{k+1,i}} = L_{layer_{k,i}} - l_{layer_{k+1,i'}} \quad \dots \textbf{(14)}$$

where $l_{layer_{k+1,i}}$ is the layer (k+1) updated input LLR, $L_{layer_{k,i}}$ is the previous layer output LLR, $l_{layer_{k+1,i'}}$ is the layer (k+1) old input LLR [20].
The NMS and OMS are algorithms that are used to reduce the computation complexity at a cost of some error performance degradation. The NMS uses Eq. (9-13) for updating the LLR values, with Eq. (10) replaced by Eq. (15):

$$A_{mj} = \min_{\substack{n \in N(m) \\ n \neq j}} (|L\,(q_{mn})| . \alpha) \quad \dots \textbf{(15)}$$

where $\alpha$ is the scaling factor in the range (0, 1]. While OMS uses Eq. (9-13) with Eq. (10) replaced by Eq. (16):

$$A_{mj} = \max \left( \min_{\substack{n \in N(m) \\ n \neq j}} (|L\,(q_{mn})| - \beta) \ \ , 0 \right) \dots \textbf{(16)}$$

where $\beta \ \geq 0$ is the offset factor [29, 30].

## 3.SYSTEM DESIGN

In the 5G NR standard, data are transmitted from the Medium Access Control (MAC) layer to the physical (PHY) layer in units called transport blocks (TBs). A transport block undergoes the following processing steps in the LDPC encoding and decoding chains, as shown in Fig. 2 [22].

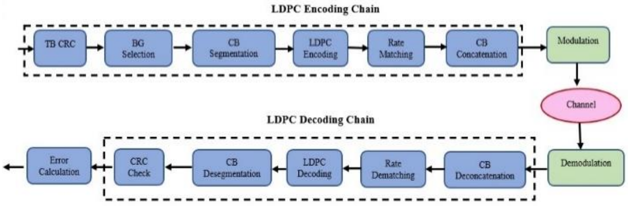


**Fig.2** NR-LDPC encoding and decoding chains.

Cyclic Redundancy Check (CRC) bits, which are parities used for error detection, are calculated depending on the payload size (A). If TB > 3828 bits, then 24 CRC is applied. The maximum code block (CB) size for BG1 is 8448 bits and 3840 bits for BG2. If the size of the TB is greater than the maximum CB size, then it is segmented into multiple CBs each with its CRC attached. The selection of the BG is based on the TB size $A$ and the code rate R. If $A \leq 3824, or\ A \leq 292\ and\ R \leq 0.25\ or\ R \leq 0.67$, then BG2 is used. Otherwise, BG1 is used.The NR-LDPC code is utilized for encoding user data. Number of transmitted bits depends on the channel conditions; hence each CB is independently rate-matched. The final step is a sequential concatenation of the rate-matched CBs which will be transmitted by the physical channel. The codewords are transmitted over the channel. At the receiver side, counterpart operations are processed (demodulation, rate recovery, channel decoding, CB de-segmentation, and TB-CRC decoding). If there are no errors obtained, then the TB can be considered successfully decoded.

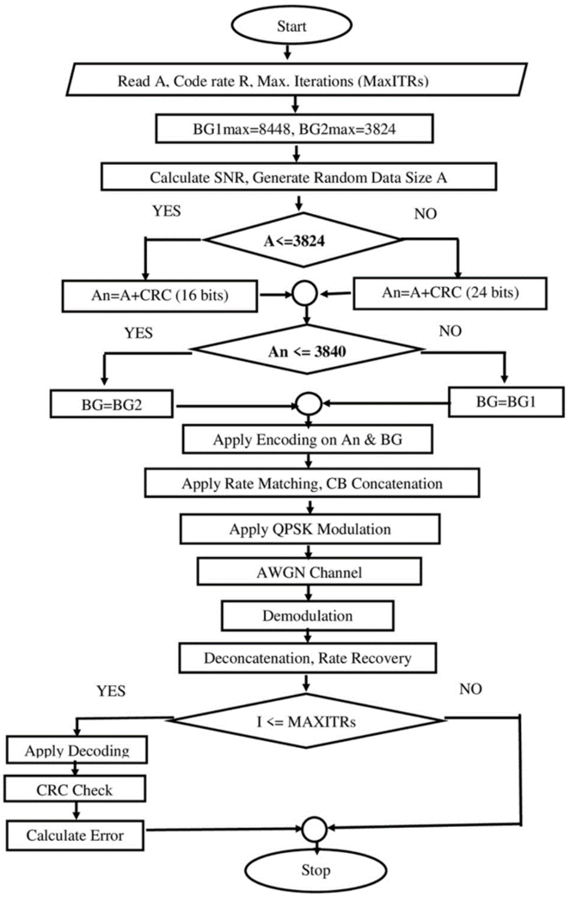


**Fig.3** Flowchart for calculating BER using NR_LDPC codes.

The flowchart in Fig.3 shows the order of the required steps to achieve a full encoding / decoding processes using NR_LDPC codes.

## 4.SIMULATION RESULTS AND DISCUSSION

In this paper, simulations are performed using MATLAB R2021a. Three test cases are implemented. The LDPC decoding algorithms are iterative, therefore, selecting the optimum predetermined parameter is important for implementation. The first test case was to find the optimum number of decoding iterations that gave a trade-off between BER performance and simulation time. The messages were transmitted using Quadrature Phase Shift Keying (QPSK) modulation over an Additive White Gaussian Noise (AWGN) channel. The simulations were performed starting from 500 frames and then continued to reach BER of $10^{-5}$. Figs. (4-a, 4-b, 4-c, 4-d) show the BER performance for the different maximum number of decoding iterations.

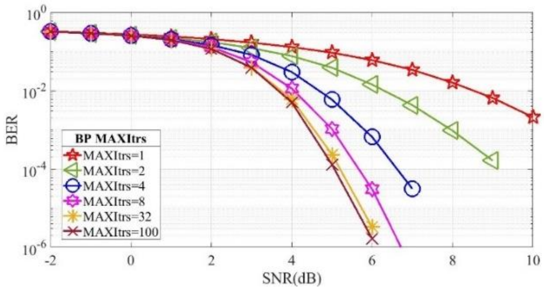


**Fig.4 (a)**

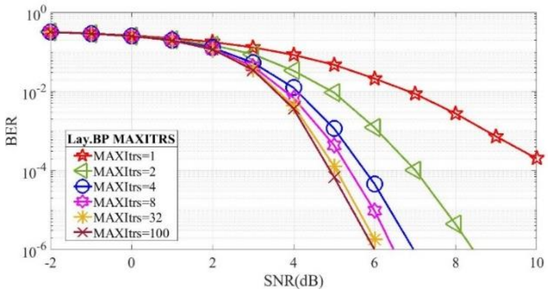


**Fig.4 (b)**

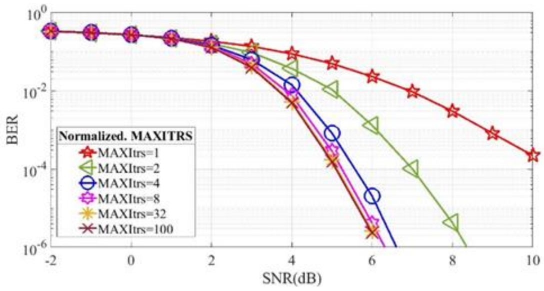


**Fig.4 (c)**

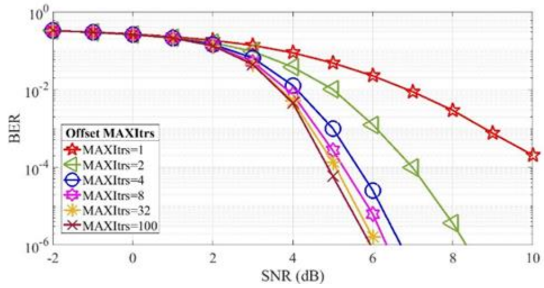


**Fig.4 (d)**

**Fig.4** LDPC BER performance for 64 bits messages, code rate= ½ for: (a) BP decoding, (b) LBP decoding, (c) NMS decoding, and (d) OMS decoding.

Figs. (4-a, 4-b, 4-c, 4-d) show that there was an insignificant improvement in going beyond 32 iterations, especially if it was taken into account the longer simulation time. Consider Fig.4-a as an example of how the BP algorithm was deployed. There was a gain of about 5.6 dB when 32 decoding iterations were used instead of one decoding iteration at BER=2*10$^{-3}$, and a gain of almost 0.2 dB when 100 decoding iterations were used instead of 32 decoding iterations at 3*10$^{-6}$. Therefore, using 32 decoding iterations resulted in some performance loss, while processing 100 decoding iterations took more processing time. As a result, larger SNR values were needed for the same BERs for fewer iterations.

The second test cases were conducted, taking 25 iterations for all decoding algorithms in regard. To investigate the effect of the code rate on the BER performance, the second test cases were performed. A message of 64 bits in length was transmitted with different code rates (1/3, 2/5, ½, 3/5, 2/3, ¾, 4/5, 5/6, 8/9, 9/10) and different decoding algorithms as shown in Figs. (5-a, 5-b, 5-c, 5-d).

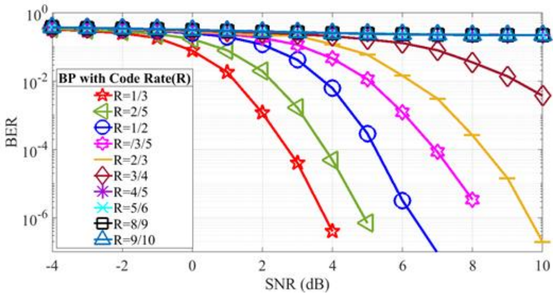


**Fig.5 (a)**

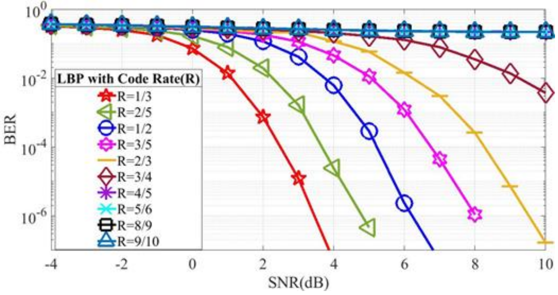


**Fig.5 (b)**

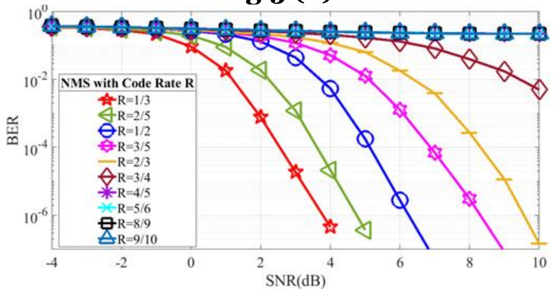


**Fig.5 (c)**

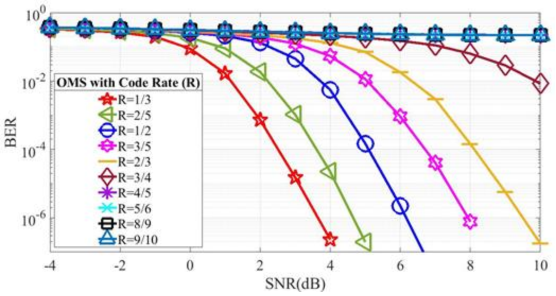


**Fig.5 (d)**

**Fig.5** BER performance for 64 bits and different code rates using: (a) BP algorithm, (b) LBP algorithm, (c) NMS algorithm, and (d) OMS algorithm.

Figs. (5-a, 5-b, 5-c, 5-d) show typical curves, where the BER decreased as the SNR increased. Further, the required SNR values monotonically increased as the code rate increased. The results clearly showed that higher code rates required larger SNR values to achieve lower BER because decoders had fewer parity bits available to check message values. Lower code rates are desirable when the channel is noisy or the signal is poor so that the decoder might correctly identify and fix any received error. The next test cases were to examine the impact of the message length on the BER performance. Messages of lengths (64, 512, 1024, and 5120) bits were transmitted with different code rates (1/3, 2/5, ½, 3/5, 2/3, ¾, 4/5, 5/6, 8/9, 9/10) and different decoding algorithms as shown in Figs. (5-a, 5-b, 5-c, 5-d), (6-a, 6-b, 6-c, 6-d), (7-a, 7-b, 7-c, 7-d), and (8-a, 8-b, 8-c, 8-d).

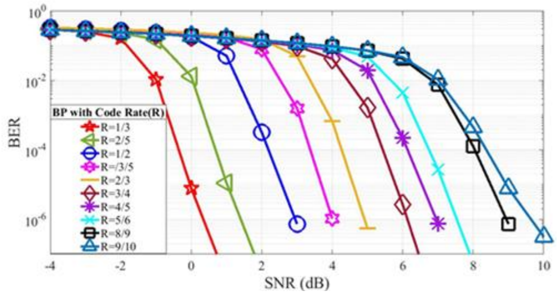


**Fig.6 (a)**

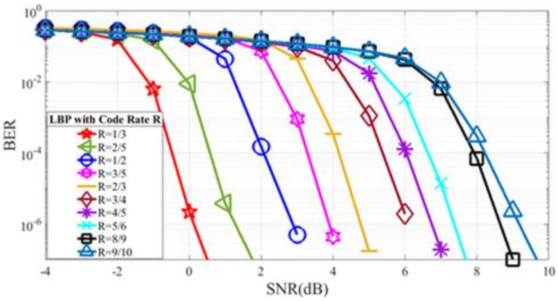


**Fig.6 (b)**

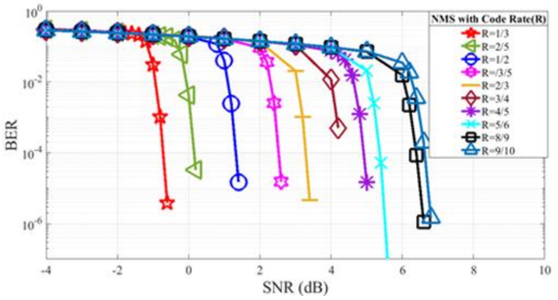


**Fig.6 (c)**

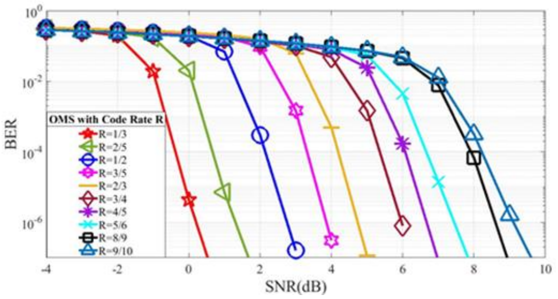


**Fig.6 (d)**

**Fig.6** BER performance for 512 bits and different code rates using: (a) BP algorithm, (b) LBP algorithm, (c) NMS algorithm, and (d) OMS algorithm.

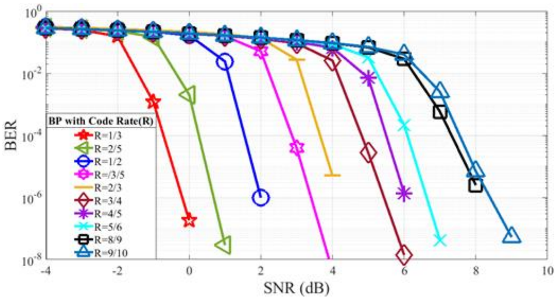


**Fig.7 (a)**

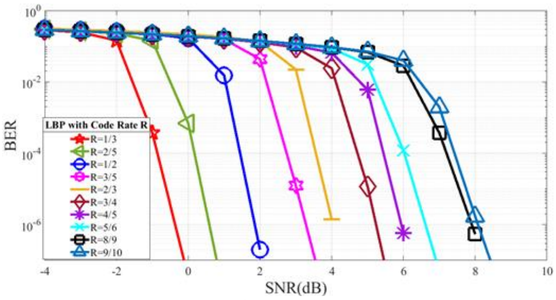


**Fig.7 (b)**

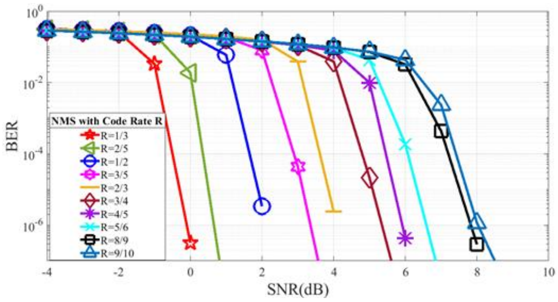


**Fig.7 (c)**

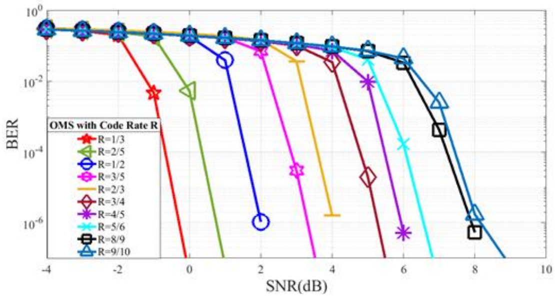


**Fig.7 (d)**

**Fig.7** BER performance for 1024 bits and different code rates using: (a) BP algorithm, (b) LBP algorithm, (c) NMS algorithm, and (d) OMS algorithm.

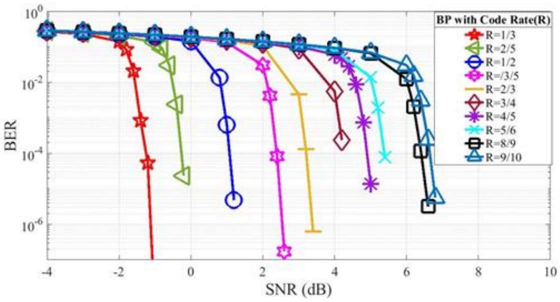


**Fig.8 (a)**

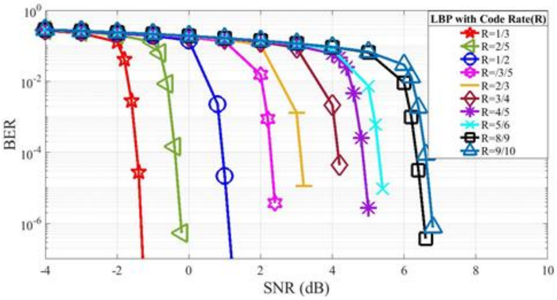


**Fig.8 (b)**

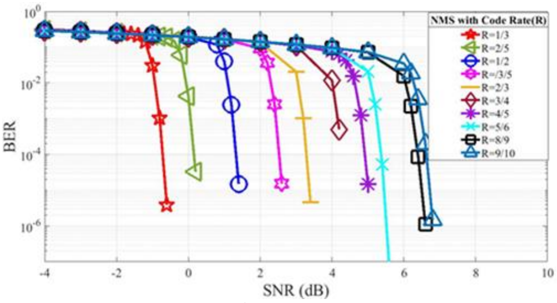


**Fig.8 (c)**

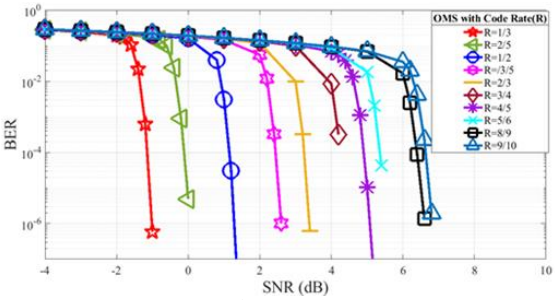


**Fig.8 (d)**

**Fig.8** BER performance for 5120 bits and different code rates using: (a) BP algorithm, (b) LBP algorithm, (c) NMS algorithm, and (d) OMS algorithm.

It can be noted from Fig. 9 for the same decoding algorithm (LBP was used for Fig.9) that the BER performance (error correction performance) degraded by decreasing message lengths. Fig.9 shows the admirable performance of LDPC codes for large data block sizes and the resilience of these codes to low levels of the channel SNR. There was a gain of about 5 dB at BER=$10^{-6}$ when a block of length 5120 bits was used compared with a block of length 64 bits for the same code rate 1/3, which was considered the channel's worst case. Furthermore, since the SNR values had decreased as a result of longer messages and lower code rates, less power was required for message transmission, which justifies the reason behind adopting the LDPC code for user data transmission in eMBB. The BER performance for the different decoding algorithms under the same conditions (data block length =5120 bits, code rate =1/3) is shown in Fig.10 Judging from the different decoding performances in Fig.10, the LBP algorithm was the best decoding algorithm and NMS decoding algorithm was the worst. It can be noted that LBP was the best with BER= 2.7565e-05, BP with BER= 0.00084609, OMS with BER= 0.021706, and NMS with BER =0.21052, all at SNR = -1.4 dB. Compared to the SNR gain, LBP gained approximately 0.8 dB at BER= $10^{-5}$ in comparison with the NMS decoding algorithm.

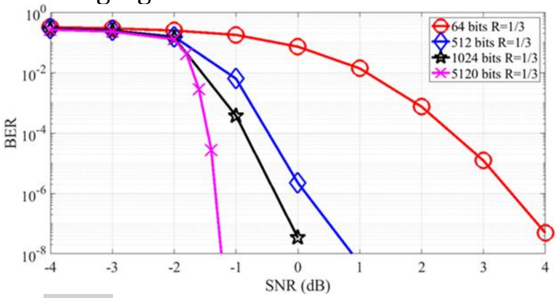


**Fig.9** BER performance comparison for different block lengths.

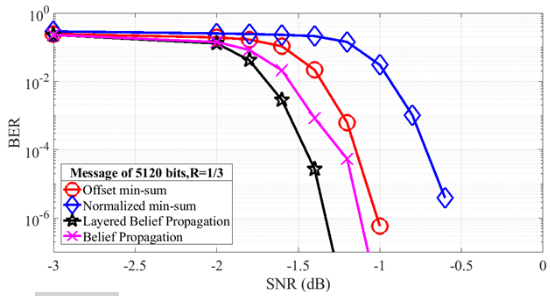


**Fig.10** BER performance comparison for different decoding algorithms.

## 5.CONCLUSIONS

The main requirements of modern communication systems are high throughput, low complexity, reliability with acceptable error correction performance, and flexibility to work with different code rates and block lengths. Therefore, the channel coding technique has become a crucial part of all modern communication systems. The decoding of an LDPC code can be deployed with a high degree of parallelism, which is essential to achieve high throughput and low complexity. In this paper, four decoding algorithms for NR-LDPC codes were provided to prove their flexibility with different code rates (1/3, 2/5, ½, 3/5, 2/3, ¾, 4/5, 5/6, 8/9, 9/10) and different block lengths (64, 512, 1024, and 5120) bits. Simulation results showed the importance of selecting a suitable number of decoding iterations because the error performance of the NR-LDPC codes can be improved by increasing the number of iterations. As a result, a gain of 5.6 dB can be obtained by using 32 decoding iterations at BER=$2*10^{-3}$ instead of one decoding iteration. In addition, performance improvement can be achieved by increasing the block length and a gain of about 5 dB at BER=$10^{-6}$ was obtained when a block of length 5120 bits was used compared with a block of length 64 bits for the same code rate 1/3 and decoding algorithm. Finally, comparing the BER performance of the decoders revealed the superiority of LBP with a gain of approximately 0.8 dB at BER= $10^{-5}$ compared with the NMS decoding algorithm.

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