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Evaluating the Performance of LDPC Decoders Using the Sum-Product and Minimum-Sum Algorithms in 5G Communication Networks

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Abstract

In need to offer multiple services, wireless mobile communication demands a huge amount of data capacity. Peak throughput, low latency, and substantial speed are delivered by 5G networks. Wireless communications increasingly depend on channel coding. Channel coding for the 5G communication networks is facing a fresh difficulty and Sum product algorithm (SPA) is the significant breakthrough in this area. This research evaluates performance of LDPC of Sum product algorithm (SPA) and LDPC of Min-Sum algorithm (MSA) as in channel coding contenders for the 5G communication networks for different coding rates of ½ and 2/3 and at the same block length of 1024. The simulations are implemented using MATLAB R2018b. As the quality criterion of a channel code, FER and BER of the coding schemes is displayed versus SNR for the same block lengths (L=1024) and different code rates of 1/2 and 2/3 correspondingly. The evaluations and comparisons are conducted in terms of FER and BER for the same block length (L=1024) and differing code rates of 1/2 and 2/3. It is evident from the results that the SPA surpasses the other rival algorithm for nearly in all code rates. Also, there is no error floor in case of SPA. Therefore, choice for faster algorithm which are sought for the 5G communication networks because its characteristic of Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (URLLC), and Massive Machine Type Communications (mMTC). Although SPA has demonstrated their potential, faster decoding performance enhancement for tiny block lengths is still an unresolved subject. Channel coding for 5G is a dynamic investigation area as to tackle various outstanding tasks in future.

Keywords: LDPC, SPA, MSA, 5G, Communication Networks

I.INTRODUCTION

Wireless mobile communication demands a big quantity of data capacity to support diverse services. 5G networks deliver peak throughput, low latency, and substantial speed. Fifth-generation network scheduling accommodates varied organizational requirements and various use scenarios. Channel coding is increasingly vital for 5G communications, with characteristics like as coding gain, power, and area being crucial. Turbo codes and Low Density Parity Check (LDPC) codes are utilized for channel coding to meet the needs of 5G communications. (Patil, Pawar, and Saquib 2020),

The worldwide population expansion has been outpaced by the exponential growth rates of Internet of Things (IoT) devices, which demand technology that is rapid, supports high dependability, and enables huge connections. The most current generation of wireless technology is referred to as "International Mobile Telecommunications-2020" and "5G" by the Institute of Electrical and Electronics Engineering (IEEE) and the International Telecommunication Union (ITU) (Sun, Joung, Zhou, Tan, Adachi, & Ho, 2015, Kumar, Kedia, and Purohit (2023).

5G addresses ultra-high dependability, very low latency, and large-scale connections in addition to data rate enhancement. The fundamental rationale for adding three use cases for 5G technology is because each addresses these characteristics differently: Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (URLLC), and Massive Machine Type Communications (mMTC) (Patil et al., 2020 and Kumar et al., 2023).

LDPC refers to Low-Density Parity-Check codes, which have been extensively explored and applied to different sectors such as data storage, optical communications, and wireless communications. Shannon's 1948 article established the existence of a channel coding scheme capable of decreasing error rate while transmitting a signal across a noisy channel, however various coding strategies have been offered. Hamming's 1950 Hamming codes are a special form of linear block codes.

II. LITERATURE REVIEW

Channel coding, a method of transmitting signals across noisy channels, was established by Shannon in 1948. However, it did not provide practical methods for creating such codes. Numerous coding techniques have been proposed since then, including Hamming codes, cyclic coding, and LDPC codes. Hamming codes are a specific form of linear block codes, while cyclic codes allow codewords to be valid even after a specific degree of cyclic shift, making decoding easier. Quasi-cyclic codes, on the other hand, can be invalid after one time of cyclic shift but still valid after several times, lowering decoding difficulty.

LDPC codes were first researched using graph theory by Tanner in 1981, but their performance was considered too expensive for the technology at the time. The advent of turbo codes in 1993 stimulated researchers to revive belief propagation and iterative decoding, leading to the development of LDPC. In 1999, LDPC was used by WiMAX (IEEE 802.16e) and WiFi (IEEE 802.11n). In 2011, LDPC set a performance record, with codes designed by S. Y. Chung approaching the Shannon limit as close as 0.0045 dB. In 2004, LDPC was adopted by the second-generation digital TV broadcasting standards (DVB-S2) in Europe, and in 2016, quasi-cyclic LDPC (QC-LDPC) was chosen by 3GPP as the channel coding technique for physical traffic channels of 5G NR. (Chung, Forney, Richardson & Urbanke, 2001, Xiao, & Banihashemi, 2004, Casado, Griot, & Wesel, 2007, Xu et al 2023; Emad et al., 2024 and Kumar, Gaur, Chakravarthy & Nanthaamornphong, 2024).

Gallager's Ph.D. thesis provided a detailed performance-bound analysis of LDPC codes and presented two decoding schemes: (1) simple algebraic technique and (2) decoding based on probability theory (Gallager, 1962). Gallager believed that the low-density attribute of LDPC could minimize decoding complexity and increase efficiency of iterative decoding. However, LDPC was initially opaque due to its more sophisticated nature than basic algebraic decoding. The insufficient grasp of probability theory-based decoding, particularly its performance potential, contributed to the opaqueness of LDPC. Traditional channel decoding relied on the codeword distance criterion, which is more sophisticated than basic algebraic decoding. This led to a lack of accuracy in forecasting performance. The turbo decoding algorithm, published in 1993, brought about a large "fad" of probabilistic decoding that works on soft bits, rather than hard bits. Both turbo codes and LDPC codes can be represented by a factor graph in a uniform setting, and the iterative decoding technique is fundamentally similar to the belief propagation algorithm and message transmission algorithm widely used in artificial intelligence (Gallager, 1968 & Kumar et al., 2024).

A. Regular LDPC and Irregular LDPC

LDPC codes can be categorized into two types: regular LDPC and irregular LDPC. These codes are expressed using a bipartite graph. The word "bipartite" underlines the presence of two distinct groups of nodes in the graph: variable nodes and check nodes. Nodes of same kind should not be linked directly, meaning that direct communication is not allowed. However, nodes of the other type are permitted to send the information. Each link is frequently referred to as a "edge". The entirety of the connections is exclusively described by the parity check matrix. LDPC codes can be categorized into two basic categories: regular and irregular (MacKay, & Neal, 1997; Xu et al 2023; Emad et al., 2024 and Kumar et al., 2024). In a conventional LDPC code, nodes of the same type, such as variable nodes or check nodes, have similar degrees. The term "degree" in this case particularly means the count of edges. Figure 1 illustrates a bipartite network exhibiting a common Low-Density Parity-Check (LDPC) code. The network consists of nine variable nodes, marked as Yi, i, where i ranges from 1 to 9, and six check nodes, labelled as Ai, i, where i ranges from 1 to 6. Each bit node is paired with q=2 check nodes, e.g., the number of “1” elements in a column

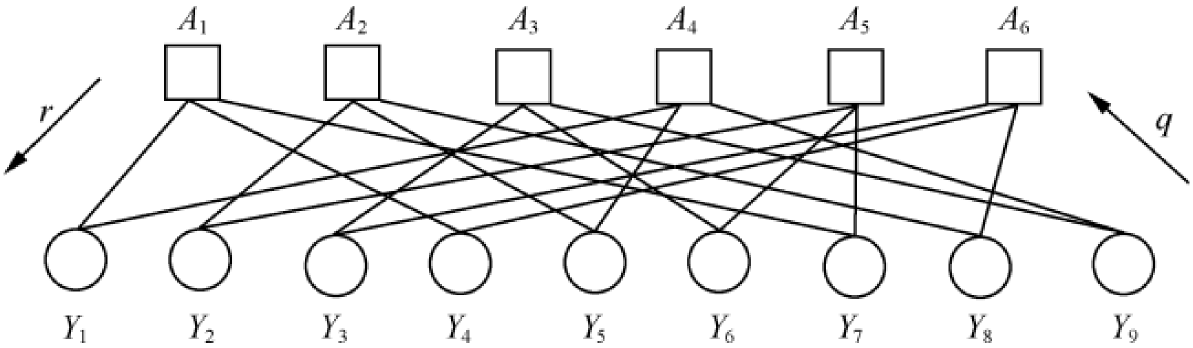

Figure 1: Bipartite graph of an examples of LDPC parity check matrix (Xu et al 2023)

is dv= 2, e.g., the column weight is 2. Each check node is connected to r= 3 bit nodes, and the number of “1” elements in a row is dc=3, e.g., the row weight is 3. It is seen that the column weight is the same for all the columns in this parity check matrix. So is the row weight. With respect to the whole 54 elements in this matrix, only 18 elements are non-zero. Hence, it can be regarded as scarce. The sparsity would become more obvious as the size of the parity check matrix rises (Xu et al., 2023; Emad et al., 2024).

The design of LDPC base matrices should establish a harmonious equilibrium between performance and throughput. Using smaller base matrices is helpful for permitting larger levels of parallel processing and better throughput, which is important to satisfy the requirement for peak data rates. Nevertheless, the smaller matrices have a lower number of elements, which might constrain design flexibility and create issues in optimizing and enhancing performance. In contrast, bigger base matrices possess a greater number of elements and give more freedom in design, allowing for greater potential in optimizing performance. However, this comes at the expense of diminished parallel processing capabilities and increasing difficulty in fulfilling peak rate requirements, albeit having the same hardware complexity as smaller base matrices (Xu et al 2023; Emad et al., 2024 and Kumar et al., 2024).

Another thing to consider is the quantity of base matrices (BGs) that will be introduced. Increasing the number of base matrices can undoubtedly boost the performance. Nevertheless, there is a growth in both the expenses connected with hardware and the quantity of effort required for standardization. On the other side, limiting the number of base matrices can minimize the cost of hardware and make the specification easier, yet it may make performance optimization more complicated.

The third design factor is that the mother code rate should not be unduly low for extended code blocks. There are three justifications for this. Firstly, while scheduling a transmission, prolonged code blocks are frequently coupled with good channel circumstances where the high code rate correlates to high data rate transmission. Secondly, for big blocks of information bits, if the mother code rate is low, the memory demand would be substantial and the hardware implementation would be problematic. Lastly, a very low mother code rate design needs big base matrices which increases the complexity of LDPC decoding (Xu et al 2023; Emad et al., 2024 and Kumar et al., 2024).

B. **LDPC Decoders**

(i) The Sum of Products method (SPA)

The Sum of Products method (SPA) is a soft decision message-passing method that involves LLR (intrinsic message) variable node operations to assist decoding decisions. The Sum of Products Algorithm (SPA) offers excellent decoding performance is primarily owed to its soft decision-making capabilities, iterative processing, and adaptability, which allow it to handle noisy channels and provide precise error correction effectively (Dhanorkar & Kalbande, 2017, Liu, Huang, Zhao, Wang, Chen, & Pan, 2025). However, it does come with its share of obstacles and inconveniences. These can include computational complexity due to the nonlinear operations conducted at the check nodes, which can be resource-intensive and time-consuming. Additionally, transmitting high-precision unnecessary messages between nodes demands significant computational effort. These factors contribute to the algorithm's computational load and can impact its real-time processing capabilities, making it less suitable for applications where low latency is critical.

Moreover, while the SPA delivers high-quality error correction, it may not be the most power-efficient solution, making it less suited for energy-constrained devices. (Subhi, Al-Doori, & Alani, 2023, Huo, X., Tian, Yang, Yu, Zhang, & Li, 2024, Liu et al, 2025).

(ii) The Min-Sum Algorithm (MSA)

The Min-Sum Algorithm (MSA) is a simplification of the SPA. the check node operation is streamlined to simplify the method. The MSA is easy to implement in hardware since it uses simple arithmetic and logic operations.

On the other hand, quantizing the soft input messages greatly affects how effectively the algorithm works (Zarubica, Hinton, Wilson, Hall, 2008). There are many MS algorithm modifications, such as "offset min-sum" (Xu, Wu, Zhang, 2010), "normalized min-sum" (Wu, Song, Jiang, Zhao, 2010), and "adaptive quantization in min-sum" (Kim, Sobelman, Lee, 2008). To increase the MS algorithm's BER performance, several adjustments are proposed. (Subhi et al., 2023, Huo et al., 2024, Liu et al, 2025).

III. **MATERIALS AND METHODS**

In this study, an assessment and appraisal analysis of LDPC Sum of Products Algorithm (SPA) and LDPC Min-Sum Algorithm (MSA) for the same block length (L=1024) and different code rates are implemented. The simulations are implemented using MATLAB R2018a. As the quality criterion of a channel code, FER and BER of the coding schemes is displayed versus SNR for the same block lengths (L=1024) and different code rates of 1/2 and 2/3 correspondingly. The evaluations and comparisons are conducted in terms of FER and BER for the same block length (L=1024) and differing code rates of 1/2 and 2/3. The messages are sent using QPSK modulation technique across an Additive White Gaussian noise (AWGN) channel, in which the modifications of the channel were evaluated using the SNR values. The simulations are done starting from 500 frames and continuing till the BER of 10-5 is attained. In the conclusion, decoding solution Sum of Products Algorithm (SPA) and LDPC Min-Sum Algorithm (MSA) for LDPC are implemented as the decoders.

IV. RESULTS

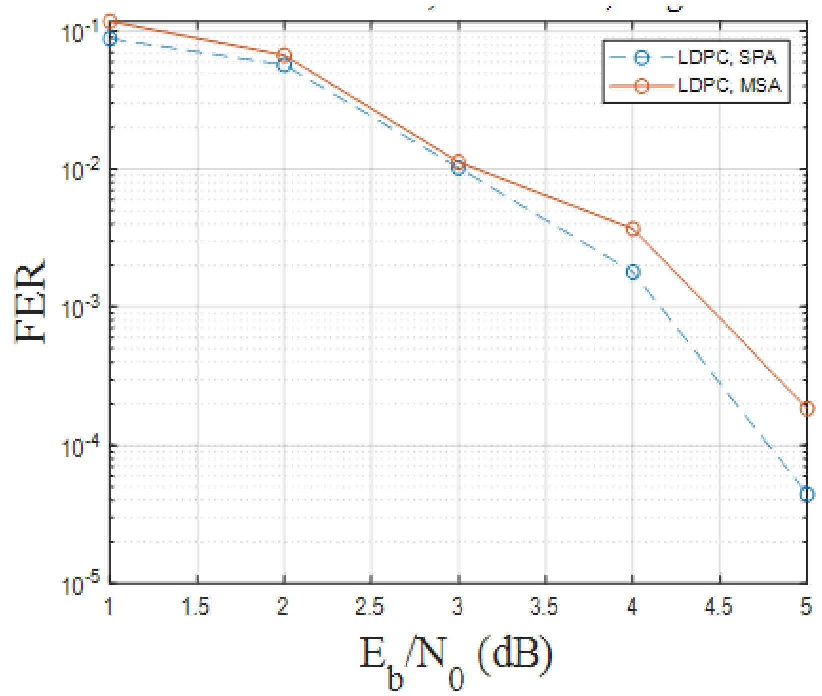

Figure 2: FER-SNR perforamnce of LDPC SPA and MSA coding rate of 1/2 and length of 1024.

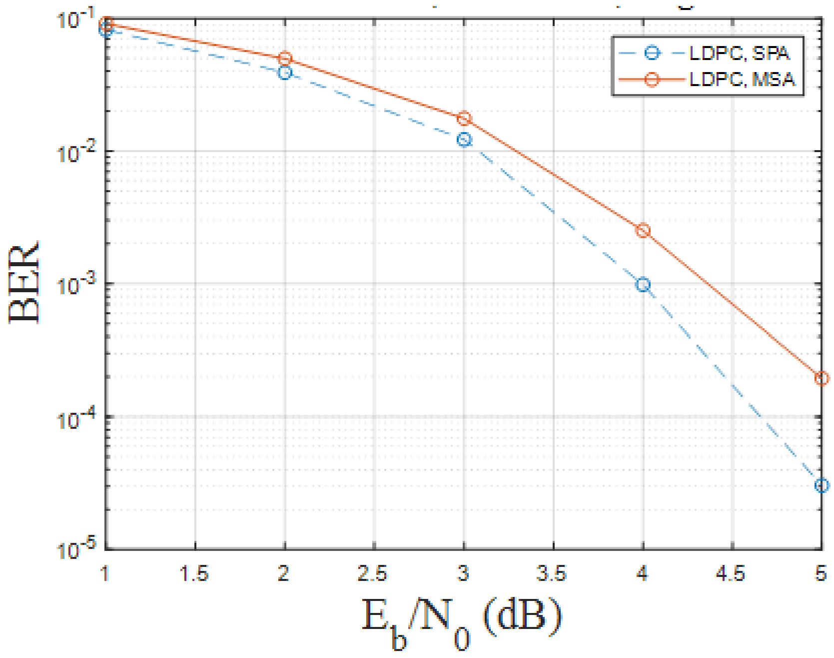

Figure 3: BER-SNR perforamnce of LDPC SPA and MSA coding rate of 1/2 and length of 1024.

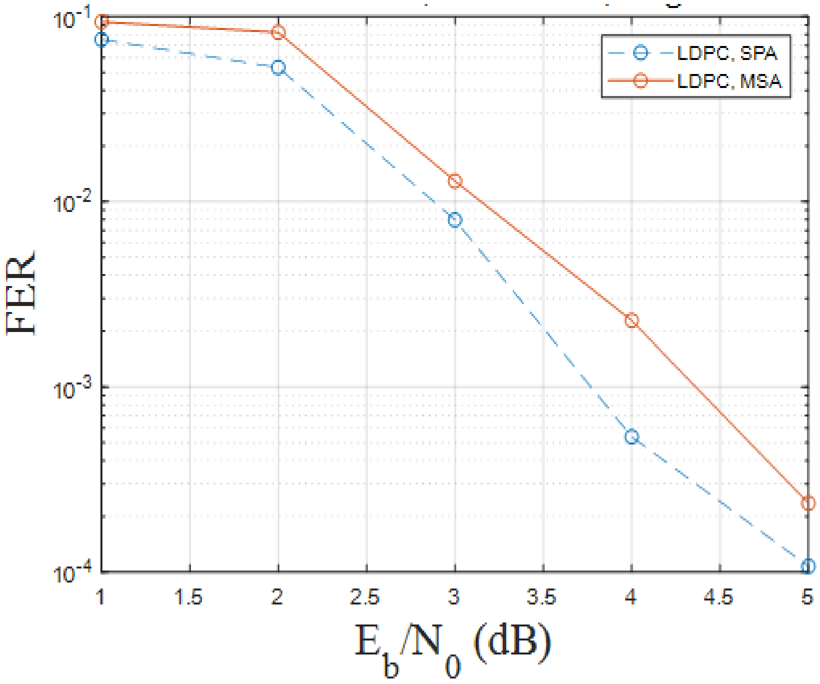

Figure 4: FER-SNR perforamnce of LDPC SPA and MSA coding rate of 2/3 and length of 1024.

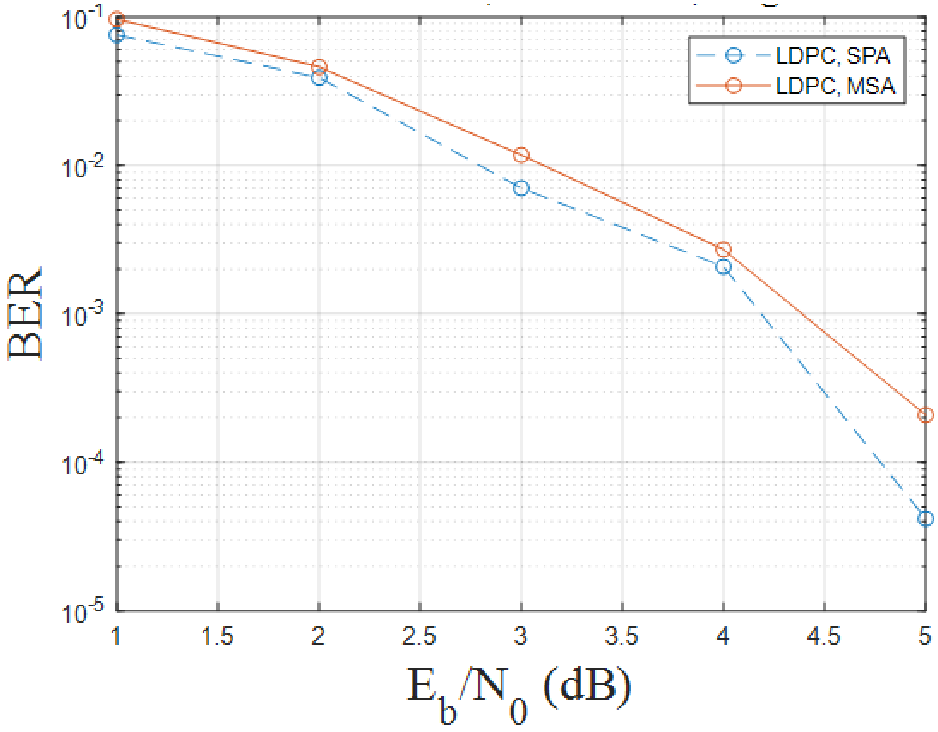

Figure 5: BER-SNR perforamnce of LDPC SPA and MSA coding rate of 2/3 and length of 1024.

DISCUSSION

From figure 2 to 5 show the evaluation of coding rate and bit error rate (BER) is achieved using two codes: Low Density Parity Check (LDPC) of Sum product algorithm (SPA) and Low Density Parity Check (LDPC) of Minimum-Sum algorithm (MSA). The LDPC of SPA with a code rate of 1/2 is the poorest and performs closely with the LDPC of SPA at the same code rate and SNR. Both LDPC of SPA and LDPC of Min-Sum algorithm (MSA) demonstrate performance gains of 5 dB and roughly 10^{-4} and 10^{-5} BER at the same code length of 1024. Despite high saturation in the low BER sector, potential improvement through improved construction is conceivable. BER lowers with the increasing of Eb/N0, and the LDPC of Sum product algorithm (SPA) offers larger error correcting potentials in low BER areas compared to the LDPC of Min-Sum algorithm (MSA). The adoption of LDPC of Sum product algorithm (SPA) and LDPC of Min-Sum algorithm (MSA) as channel coding techniques for 5G design heterogeneous network applications is justified according to the error correction capability required.

The assessment of coding rate and frame error rate (FER) is based on two distinct codes: Low density parity check (LDPC) of Sum product algorithm (SPA) and Low density parity check (LDPC) of Minimum-Sum algorithm (MSA). The LDPC of Minimum algorithm (MSA) with a code rate of 2/3 is the weakest, encountering some type of error floor. Both LDPC of Sum product algorithm (SPA) and LDPC of Min-Sum algorithm (MSA) experience performance gain of 5 dB and roughly value of 10^{-4} of FER at the same code rate of 2/3. The Sum product algorithm (SPA) with a code rate of 2/3 offers the best performance, obtaining dB = 5 at around 10^{-4} FER.

The LDPC of Sum product algorithm (SPA) surpasses the LDPC of Min-Sum algorithm (MSA) for the examined code rates of 2/3 in the 5G allowing heterogeneous network environment. Simulation results accept that LDPC of Sum product algorithm (SPA) gives bigger error correcting potentials in an evaluation with LDPC of Min-Sum algorithm (MSA) in low FER area, which is significant for delivering less control messages.

CONCLUSION

LDPC codes are an effective error correction tool in numerous applications. The recent improvements in the LDPC coding sector have considerably boosted these codes' performance and usefulness. This paper comprehensively explores the underlying concepts of LDPC and decoding systems, performance measurement, comparisons, and applications during the previous few years. Recent research areas include the design of low complexity LDPC decoding, the improvement of the min-sum algorithm, and the use of LDPC codes in new fields such as the Internet of Things (IoT) and the 5G wireless communication standard. The analysis highlights the requirement for continued research and empirical testing. Key computational factors, including hardware complexity, decoding stability, overhead, and convergence rates, warrant additional research. Also, further improvements to the min-sum algorithm are needed, including testing its power consumption, decoding speed in different implementations, and lowering implementation complexity. This drive for optimisation is vital as it directly effects the reliability of communication networks. Indeed, when the error correction algorithm's time increases, the reliability of the communication system declines, underlining the need of finding faster error correction methods.

In addition, this research studied modern technology, with a special focus on the implementation aspect, considering issues such as complexity and decoding time. It becomes evident that with an increase in the time required for error correction methods, the reliability of the communication system declines. Therefore, developing solutions to repair faults faster is vital for maintaining a dependable communication infrastructure. By its nature, increasing the speed of the decoder leads to an increase in complexity. Thus, establishing a delicate balance, a trade-off between speed and complexity, is a vital issue in constructing an optimal communication system. The use of LDPC of Sum product algorithm (SPA) and LDPC of Min-Sum algorithm (MSA) as channel coding techniques for 5G design heterogeneous networks applications has been justified according to error correction capability standard.

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