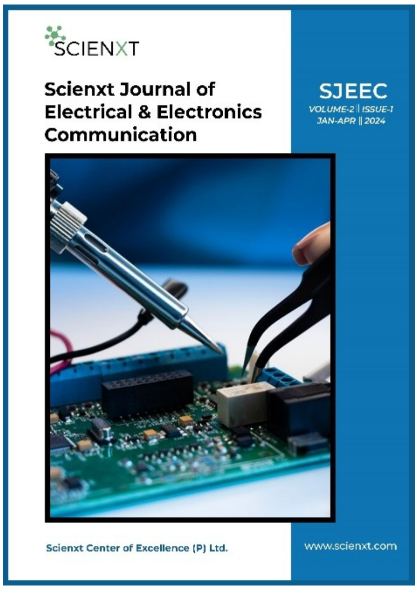

Scienxt Journal of Electrical & Electronics Communication
Volume-2 || Issue-1 || Jan-Apr || Year-2024 || pp. 1-8

Design of low-density parity check codes for 5G technology

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Abstract:

Channel coding plays a vital role in telecommunication. Low-Density Parity-Check (LDPC) codes are linear error-correcting codes. According to the 3rd Generation Partnership Project (3GPP) TS 38.212, LDPC is recommended for the Fifth-generation (5G) New Radio (NR) shared channels due to its high throughput, low latency, low decoding complexity and rate compatibility.

LDPC encoding chain has been defined in 3GPP TS 38.212, but some details of LDPC encoding chain are still required to be explored in the MATLAB environment. For example, how to deal with the filler bits for encoding and decoding. However, as the reverse process of LDPC encoding, there is no information on LDPC decoding process for 5G NR shared channelsin 3GPP TS 38.212. In this thesis project, LDPC encoding and decoding chains were thoughtfully developed with MATLAB programming based on 3GPP TS 38.212. Several LDPC decoding algorithms were implemented andoptimized. The performance of LDPC algorithms was evaluated using blockerror rate (BLER) v.s. signal to noise ratio (SNR) and CPU time.

Results show that the double diagonal structure-based encoding method is an efficient LDPC encoding algorithm for 5G NR. Layered Sum Product Algorithm (LSPA) and Layered Min-Sum Algorithm (LMSA) are more efficient than Sum Product Algorithm (SPA) and Min-Sum Algorithm (MSA). Layered Normalized Min-Sum Algorithm (LNMSA) with proper normalizationfactor and Layered Offset Min-Sum Algorithm (LOMSA) with good offset factor can optimize LMSA. The performance of LNMSA and LOMSA decoding depends more on code rate than transport block.

Keywords:

New radio (NR), Shared channel, Channel coding, Low-Density Parity-Check (LDPC) codes, Layered Normalized Min-Sum Algorithm (LNMSA), Layered Offset Min-Sum Algorithm (LOMSA)

1. Introduction:

Low-Density Parity-Check (LDPC) codes are linear error-correcting codes. According to the 3rd Generation Partnership Project (3GPP) TS 38.212[1], two channel coding codes, i.e., Polar codes and LDPC codes, are recommended for the Fifth-generation (5G) New Radio (NR). Polar codes are applied to 5G NR control channels. LDPC codes are suitable for 5GNR shared channels due to its high throughput, low latency, low decoding complexity and rate compatibility. LDPC codes can be used to different blocksizes with varying code rates because of the design of rate-compatible base graphs. Another advantage of 5G NR LDPC codes is that the performance of LDPC codes has an error floor around or below block error rate (BLER) 10−5for all code sizes and code rates [2]. So LDPC codes play an important role in channel coding for 5G communication.

TietoEVRY hosts this project in Karlstad, Sweden, with an interestin developing LDPC encoding and decoding chains and optimizing LDPC encoding and decoding algorithms for 5G NR based on 3GPP TS 38.212[1]. Therefore, the objective of current research is to study different kinds of LDPC encoding and decoding algorithms to seek the most efficient ones for implementation on 5G link level simulator 5G_lls.

2. LDPC codes:

Gallager invented LDPC codes in 1962. LDPC codes are linear block codes based on sparse parity- check matrix. It is forgotten for dozens of yearsbecause of the limited computation ability. In recent years, LDPC codes attract more attention because of their efficient decoding algorithms, excellent error-correcting capability, and their performance close to the Shannon limit for large code lengths. 5G needs to support high throughput up to20 Gbps and a wide range of block sizes with different code rates for thedata channels and hybrid automatic repeat request (HARQ). LDPC codes canfulfil the requirements. The base graphs defined in 3GPP TS 38.212 [1] are structured parity-check matrix, which can efficiently support HARQ and ratecompatibility that can support arbitrary amount of transmitted information bits with variable code rates.

3. Problem Formulation:

LDPC encoding chain has been defined in 3GPP TS 38.212 [1], but some details of LDPC encoding chain is still required to be explored in the MATLAB [3] environment. For example, how to deal with the filler for encoding and decoding. LDPC encoding process can be optimized to be more efficient. However, as the reverse process of LDPC encoding, there is no information on LDPC decoding process for 5G NR shared channels in 3GPP TS 38.212 [1]. The specific problems are illustrated as follows:

1. How to implement the LDPC encoding and decoding chains using MATLAB?
2. Which algorithm is more efficient to process LDPC encoding for 5G NR shared channels?
3. Which LDPC decoding algorithms are more efficient for 5G NR shared channels?

4. Proposed Methodology:

The LDPC encoding and decoding chains. Parameters, used in LDPC coding chain, were calculated based on transport block size and the length of transport block information bits according to 3GPP TS 38.212[1] specifications. The LDPC encoding chain is processed. If there is NULL value in the information bits when doing LDPC encoding, the NULL value is treated as 0 to calculate the parity bits. After the LDPC encoding chain, the encoded message is modulated before transmitting through the noise channel. Then, the message is demodulated before going to LDPC decoding chain, which is carried out. If there is NULL value in message bits before LDPC decoding, the NULL value is replaced by in f, which was done during rate de-matching. The NULL value is replaced by 0 for encoding, and the NULL value is replaced by in f for decoding because MATLAB is used to develop the coding chain, and NULL stays NULL no matter what operation used in MATLAB. 0 in information bits does not contribute to calculating parity bits, and in f almost does not influence decoding.

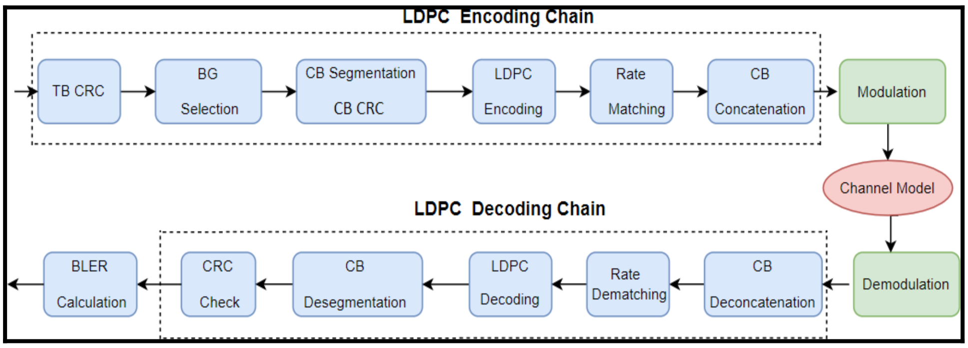

Figure. 1: LDPC encoding and decoding chains

5. Result and discussion:

The results and discussion are presented based on the test cases in Table. Performance can be evaluated using BLER v.s.SNR and CPU time. Parameters of all transport blocks in LDPC coding chain are shown in Table. 1.1.

Table. 1.1: Parameters of all transport blocks in LDPC coding chain

Transport block	Code rate	CRC type	Base graph	Lifting size	Code blocks
(2400,872)	0.36	CRC16	2	96	1
(2400,1608)	0.67	CRC16	2	176	1
(2400,1992)	0.83	CRC16	1	96	1
(7200,4824)	0.67	CRC24	1	224	1
(14794,9912)	0.67	CRC24	1	240	2

Itr4 with the plots of SPA itr30 and MSA itr30 in Figure. It only uses 6 decoding iterations for LSPA to get about 0.3 dB better performance than SPA using 30 iterations. For LMSA, it only uses 4 decoding iterations to get about 0.6 dB better performance than MSA using 30 decoding iterations

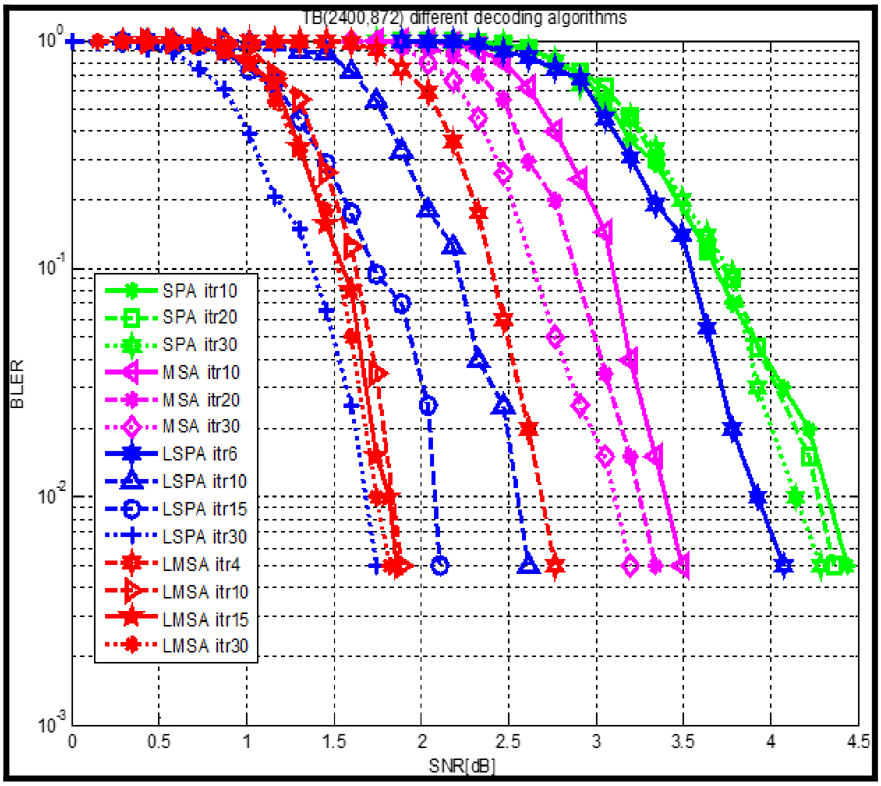

Figure. 2: Simulation results of Group 1 test cases

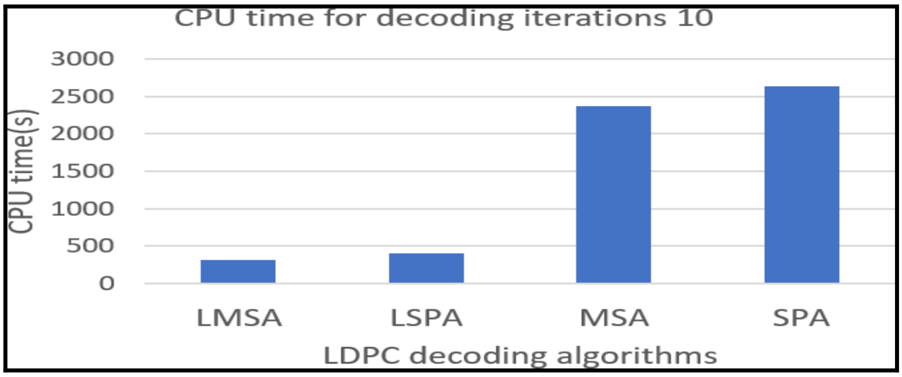

Figure. 3: CPU time for different LDPC decoding algorithms

6. Conclusion and future scope:

The LDPC encoding and decoding chains developed in this thesis project can work well on 5G_lls. When the LDPC encoding and decoding chains were developed using MATLAB, it is an excellent way to deal with the fillers by replacing the NULL value with 0 for encoding and in f for decoding.

Due to the special structure of base graphs defined in 3GPP TS 38.212, double diagonal structure- based encoding method is an efficient LDPC encoding algorithm for 5G NR.

Several decoding algorithms, SPA, MSA, LSPA, LMSA, LNMSA and LOMSA, were implemented using different transport blocks, modulations and channel models. The conclusions of LDPC decoding algorithms are summarized as follows.

1. Layered message passing algorithms, i.e. LSPA and LMSA, are efficient methods to implement LDPC decoding algorithms for 5G NR. LSPA and LMSA used less decoding iterations and less CPU time than SPA and MSA.

2. The performance of LMSA with different code rates shows that transport block with low code rate performs better than transport block with high code rate, which is expected due to the amount of redundant bits that helps to protect the message bits. The plots of BLER vs Eb/N0 show that high code rate can speed up convergence.

3. LNMSA with appropriate normalization factor and LOMSA with proper offset factor can optimize LMSA. In this thesis project, normalization factor 0.8 of LNMSA is good for transport blocks with all code rates. Offset factor 0.2 of LOMSA is a better choice for low code rate transport block (2400, 872), while LOMSA with offset factor 0.2 cannot optimize LMSA for higher code rate transport blocks (2400, 1608) and (2400, 1992).

4. The performance of LNMSA and LOMSA decoding depends more on code rate than transport block size.

5. There is a performance gap for LDPC decoding when different base graphs are used.

6. Channel model EPA with Doppler frequency 5Hz starts to decrease BLER earlier for lower SNR value than channel model AWGN for the same transport block. But Channel model EPA make the convergence much slower than AWGN channel model.

7. Future scope:

This section focuses on some of the remaining issues that should be addressed in future work.

It will be an exciting work to choose proper normalization factors for LNMSA and offset factors for LOMSA. Now AI-based methods, such as machine learning, is an excellent way to do optimization. In future work, Neural Networks can be used to choose normalization factors for LNMSA and offset factors for LOMSA.

LMSA performs better for transport block with lower code rate, while the simulation results of LNMSA and LOMSA using transport blocks with the same code rate show that the performance relies more on code rate than transport blocks. It is another exciting work to do more test cases simulations to explore the influencing factors of LDPC decoding algorithm Performance.

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