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NR LDPC CODES IN 5G MOBILE COMMUNICATION SYSTEM

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Abstract. In order to meet the new communication requirements and achieve low latency, high speed and high reliability connections between mobile devices, the Fifth-Generation (5G) mobile communication system. The fifth-generation (5G) mobile communication system introduces new error correction coding techniques in the data channel and control channel. Low-Density Parity-Check (LDPC) codes have been identified as the standard for 5G due to their excellent performance.has been identified as the data channel coding scheme in the 5G standard due to its excellent performance. In this paper, we introduce the construction method of LDPC code in 5G standard and simulate its decoding performance.

Keywords: 5G mobile communication, LDPC code, confidence propagation decoding.

Introduction

So far, four generations of mobile communication systems have been developed. System has a peak downlink rate of 1 Gb/s and a peak uplink rate of 500 Mb/s. The first four generations of mobile communication systems have met most of the needs of human-to-human communication. However, with the rapid development of mobile Internet, IoT and Telematics, in addition to the demand for high data rate, the demand for low latency, low power consumption and high reliability has become a new challenge for 5G mobile communication systems. The International Telecommunication Union Radiocommunications Standardization Sector has identified three major application scenarios for future 5G networks: Enhanced Mobile Broadband (eMBB), Ultra-Reliable LowLatency Communications (URLLC), and Massive Machine Communication (MMC). Machine Type Communications (mMTC).

Machine Type Communications (mMTC) [1-3]. Compared to 4G LTE (Long Term Evolution) network, the transmission rate of 5G network is 10~100 times higher; the user experience rate is 0,1~0,1. The user experience rate reaches 0,1~1 Gb/s; the latency is reduced by 5~10 times; the connected device density is increased by 10~100 times. Equipment density to improve 10 to 100 times, reaching millions per square kilometer; traffic density to improve 10 to 1000 times, to reach every square kilometer 10 ~ 1000 times, to reach tens of terabits per second per square kilometer; mobility The mobility should reach more than 500 km/h to achieve a good user experience in the high-speed railway environment.

Advantages of LDPC codes in 5G

In order to meet the needs of 5G communication, 5G New Radio (NR) adopts many new transmission technologies such as non-orthogonal multiple access, large-scale array antennas, and new channel coding techniques. Compared with 4G mobile communication system, 5G mobile communication system adopts a new pair of data channel and control channel respectively. The 5G mobile communication system adopts a pair of new channel coding techniques for the data channel and control channel, respectively. Specifically, low-density parity Low-Density Parity-Check (LDPC) code replaces the Turbo code for the data channel and the Polarization code.

Turbo codes for the data channel and polarization codes for the control channel instead of the bite-tailed convolutional codes. LDPC codes were originally proposed by Dr. Gallager, but did not receive much attention at that time due to hardware constraints. The LDPC code was originally proposed by Dr. Gallager, but did not receive much attention at that time due to hardware limitations. It was not until the mid-1990s, with the rapid development of hardware technology, that LDPC codes were again introduced. The LDPC code was originally proposed by Dr. Gallager, but did not receive much attention at that time due to hardware limitations. Currently, the LDPC codes have been adopted by several IEEE standards, such as IEEE 802.16e, IEEE 802.11n, IEEE 802.11ac, etc. Compared with Turbo codes in 4G LTE networks, 5G NR LDPC codes have the following advantages:

1. Better area throughput efficiency and higher peak throughput.

2. Short decoding delay due to low decoding complexity and highly parallelized implementation. The advantage is more obvious at high code rates.

3. Better decoding performance for all code lengths and rates, with an error

The Frame Error Rate (FER) [4-5] is close to or below 10-5 for all code lengths and rates.

These advantages of NR LDPC codes are particularly suitable for the ultra-high throughput of 5G networks (20 Gb/s peak downlink rate and 10 Gb/s peak uplink rate) and URLLC requirements.

NR LDPC code structure in 5G

The NR LDPC coding process in 5G is shown in Figure 1. The whole NR LDPC coding chain includes code block partitioning, Cyclic Redundancy Check (CRC), LDPC coding, number-rate matching and system bit-first interleaver. First, the CRC), LDPC coding, number rate matching and system bit-first interleaver are performed. First, the large transmission block is sliced and divided into several small data blocks suitable for processing by the LDPC coder. The CRC checksum combined with the inherent error detection capability of the Parity Check Matrix (PCM) of the LDPC code can achieve a very low probability of error miss. The CRC checksum combined with the inherent error detection capability of the LDPC Parity Check Matrix (PCM) can achieve a very low probability of error misses. Again, the data block is encoded with LDPC. Then, in order to match the carrying capacity of the channel and achieve the required bit rate, a rate matching process is performed; including punching and finally, the data block is retransmitted after a system bit that enables more reliable transmission of the system bits than the checksum bits. Finally, the final encoded bits are obtained by a system bit-first interleaver that enables more reliable transmission of system bits than check bits.

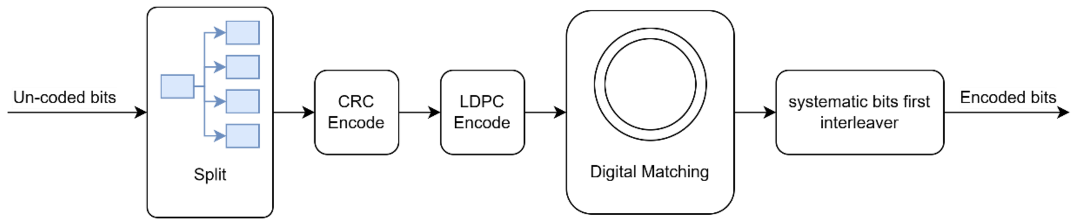

Figure 1. 5G NR LDPC encoding flow chart

NR LDPC code is a quasi-cyclic LDPC code, whose PCM is constructed by a small basic matrix. Z denotes the sub-block size and each element of the basic matrix represents a square matrix of size $Z \times Z$. Z denotes the sub-block size and each element of the basic matrix represents a square matrix of size $Z \times Z$. This square matrix can be an all-zero matrix of $Z \times Z$, or a unitary matrix of $Z \times Z$. This matrix can be a $Z \times Z$ all-zero matrix or a $Z \times Z$ unitary matrix cyclically shifted to the right by a number of bits. The number of cyclic right shifts is determined by the corresponding shift factor in the basic matrix.

Two basic matrices of NR LDPC codes

In 5G networks, the data channel can support two basic matrices, and to ensure In order to ensure good performance and low decoding delay, the standard gives the range of message block length and code rate for the two basic matrices. In order to ensure good performance and low decoding delay, the standard gives the range of message block length and code rate for the two basic matrices, and the specific parameters are shown in Table 1. Basic matrix 1 is mainly for large message blocks and high code rate, as can be seen from Table 1, the maximum message block length of basic matrix 1 can reach 8448, and the highest code rate can be 8448. Basic matrix 2 is designed for small message blocks and low code rates. The minimum block length is only 308 and the minimum code rate is only the minimum block length is only 308 and the minimum code rate is only 1/5, which is much lower than the Turbo code in LTE. Because NR LDPC codes can use very low code rate to obtain additional coding gain, NR LDPC codes can be used in scenarios requiring high reliability. in scenarios that require high reliability.

Table 1. **Basic matrix parameters of NR LDPC codes**

Matrix parameters	Basic Matrix 1	Basic Matrix 2
Range of design code rates	$1/3 \sim 8/9$	$1/5 \sim 2/3$
Number of rows of the basic matrix	46	42
The number of columns of the basic matrix	68	52
Range of design code lengths	308 ~ 8448	40 ~ 3840
Number of non-zero elements	316	197

From Table 1, it can be seen that there is a clear overlap in the information block size and code rate of both basic matrices, which means that both basic matrices can be used in this range matrices. However, the two basic matrices have different performance for the same block size and code rate. We generally use the best fundamental matrix with different performance.

From the decoding complexity point of view, for a given block size of information, using the basic matrix2 works better for a given block size because it is more compact. Usually, the decoding delay is proportional to the number of non-zero elements in the base the number of non-zero elements in the matrix is usually proportional to the number of non-zero elements in the matrix. As can be seen from Table 1, for a given code rate, the number of non-zero elements in the basic matrix 2 is much smaller than that of the basic matrix 1, e.g. at code rate 1/3, the number of non-zero elements of basic matrix 2 is about 0,38 of that of basic matrix 1. This means that the decoding delay of basic matrix 2 has a significant decrease compared to basic matrix 1.

Table 1 shows the regional ranges of code rates and message block sizes corresponding to the two basic matrices. Typically, basic matrix 2 is used for low code rates and basic matrix 1 for high code rates. The information block size is represented by the parameter K and the code rate is represented by the parameter R. When $K \le 308$, only the basic matrix 2 can be used because in this information block size range, the basic matrix 2 has better decoding performance at all code rates compared to the basic matrix 1. When $308 \le K \le 3840$, since the code rate range of basic matrix 2 is, basic matrix 2 can reach $2/3$ in this information block range. for basic matrix 2, code rates higher than $2/3$ can be achieved by punching, but at code rates, basic matrix 1 has better decoding performance. When $K > 3840$ and, the decoding performance of basic matrix 2 is better. basic matrix 1 needs to be combined with repetitive coding to achieve the code rate, so basic matrix 2 is chosen.

5G NR LDPC code performance simulation

In order to compare the performance of NR LDPC codes composed of two basic matrices, we have performed extensive simulations for different code lengths and code rates. The decoding algorithm used in this paper is a soft-judgment decoding algorithm in a binary additive Gaussian white noise channel, Belief Propagation (BP) algorithm. The Belief Propagation algorithm updates the state information of each node by passing information from node to node, and this algorithm is an iterative approach. After several iterations, the information of all nodes no longer changes, and then the final result is obtained by judgment.

Assume that the original message symbol is $S = \{s_1, s_2, \ldots, s_k\}$, After the LDPC encoder produces n LDPC coded symbols are generated and the coded symbols are modulated with BPSK $(0 \to 1, 1 \to -1)$, Get the symbol to be sent $X = \{x_1, x_2 \ldots, x_n\}$, then after the Gaussian channel is transmitted, and the final symbol received at the receiver is:

$$y_i = x_i + n_i . \quad (1)$$

The x_i is the symbol after modulation $x_i \in \{-1,1\}$, n_i is a Gaussian random variable, $n_i \sim N(0,\sigma_n^2)$ and $\sigma_n^2 = N_0/2$, $N_0/2$ is the bilateral power spectral density of Gaussian white noise. The transmitted information is measured by the Log Likelihood Ratio (LLR). The encoding process of LDPC code is to continuously establish a linear relationship between the information symbols and the encoding symbols. This linear relationship can be expressed in terms of the encoding matrix, which is also known as the basic matrix. Suppose that after l iterations, $L^l_{v_i \to c_j}$ denotes the information passed from check node j to variable node i, $L^l_{v_i \to c_j}$ denotes the variable node i to the check j node. The specific steps of the decoding process are as follows: First, the LLR value from the channel is calculated and the LLR value of the channel is used as the initial value of the iteration of the variable node:

$$L(x_i \mid y_i) = \ln[\frac{P(x_i = +1 \mid y_i)}{P(x_i = -1 \mid y_i)}] = \frac{2}{\sigma^2} y_i \,. \tag{2}$$

The external messages are continuously exchanged between the variable node and the check node, and the message update rule from the check node to the variable node is shown in equation (3). The message update rule from the check node to the variable node is shown in equation (3), where denotes the set of all denotes the set of all variable nodes connected to the check node *j*; the message update rule from the variable node to the check node is shown in Eq. The message update rule from the check node to the variable node is shown in equation (4), where similarly denotes the set of all check nodes connected to the variable node *i*. denotes the set of all check nodes connected to variable node *i*.

$$L^l_{c_j \to v_i} = 2\tanh^{-1}\{\prod_{i' \in N(j) \setminus j} \tanh[\frac{1}{2} L^{l-1}_{v_i \to c_j}]\}, \tag{3}$$

$$L^l_{v_j \to c_j} = L(x_i \mid y_i) + \sum_{j' \in N(i) \setminus j} L^l_{c_j \to v_j} \,. \tag{4}$$

The soft information output of all variable nodes is calculated and adjudicated according to equation (5). If $q_i > 0$, then $v_i = 0$; otherwise $v_i = 1$. The decoding ends when the maximum number of iterations is reached or the checksum constraint is satisfied in advance.

$$q_i = L(x_i \mid y_i) + \sum_{j \in N(i)} L^l_{c_j \to v_i} \,. \tag{5}$$

Comparing the two decoding algorithms, we give some simulations as in Figure 2 and 3. Assuming the channel is a Gaussian white noise channel, using BPSK modulation, with a maximum number of 50 iterations and the energy is fully normalized and the signal-to-noise ratio is defined as in dB. It can be seen from the figure that the decoding performance of the BP algorithm is better than that of the MS algorithm.

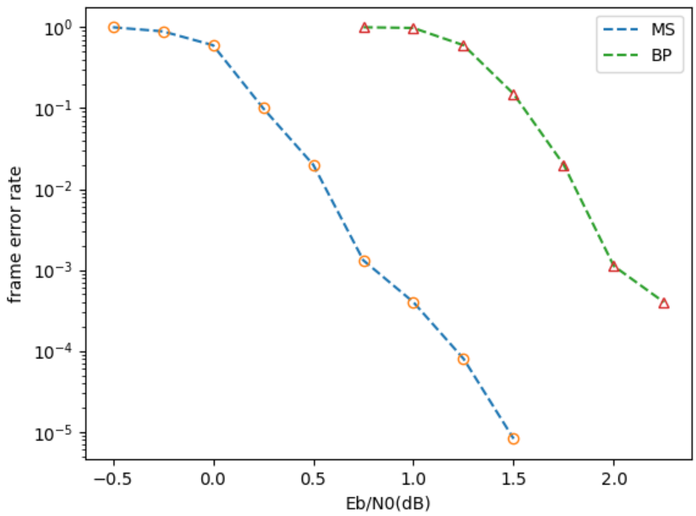

Figure 2. Simulation diagram of basic matrix 1

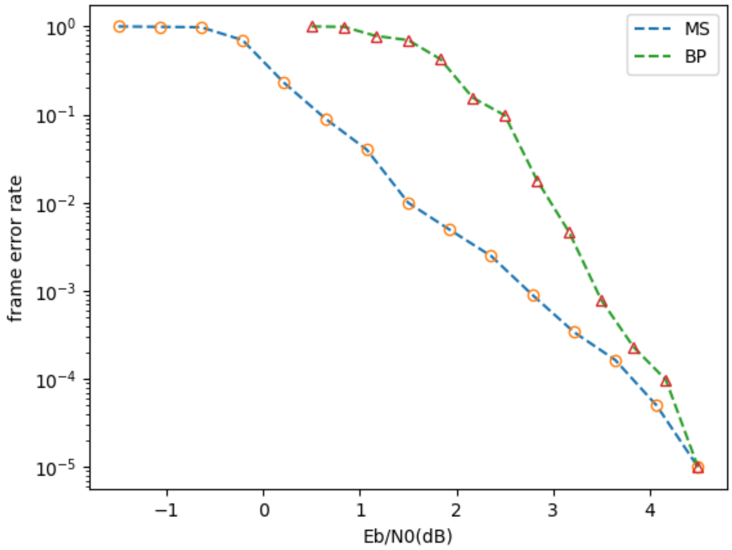

Figure 3. Simulation diagram of basic matrix 2

For example, gain for $FER = 10^3$, the dB of the BP algorithm is greater than that of the MS algorithm, which can withstand stronger noise interference, so the BP algorithm performs better than the MS algorithm.

Conclusion

In this paper, we introduce a new channel coding scheme, namely NR LDPC code in 5G. First, we give the whole flow of NR LDPC coding, and describe the uses and related operations of the key steps in the whole flow. Then, we compare the various parameters of the two basic matrices in 5G data channels. Then, we compare the various parameters of the two basic matrices in the 5G data channel; finally, we introduce in detail the decoding algorithms of the two LDPC codes, BP and MS. Finally, two decoding algorithms for LDPC codes, BP and MS, are introduced in detail.

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