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Evaluation of Correcting Ability of LDPC Code in 5G Networks

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ABSTRACT: The models and methods for evaluating the noise immunity of the LDPC code are considered. A simple method for evaluating the corrective power of LDPC code is proposed. The probability of incorrect reception of a codeword is determined at various encoding rates and interference levels in the radio channel. The selection of effective modulation-coding schemes (MCS) of the 5G network is based on the allowable value of the probability of codeword error.

KEY WORDS: LDPC code, noise immunity code, correcting ability code, coding speed, 5G network, modulation-coding scheme (MCS), MCS efficiency.

I.INTRODUCTION

One of the key tasks solved by the developers of promising mobile communication systems is the task of detecting and correcting errors. Error correction functions in 5G networks are implemented at three levels - the physical layer, the MAC layer, and the RLC layer [1-3].

At the physical layer of a 5G network, two basic coding schemes are used. For coding control information blocks — polar codes (Polar coding), for coding user information — codes with a low density parity check — LDPC (Low density parity check codes), proposed by Gallager [4]. The coding rate varies from 120/1024 to 948/1024 depending on the current radio conditions and the modulation-coding scheme (MCS) [1].

LDPC codes are characterized by a relatively high decoding speed, which led to their choice for use on high-speed traffic channels of 5G networks. LDPC codes replaced the turbo encoders used to encode traffic channels in 4G-LTE networks. This is mainly due to the fact that turbo encoders, in comparison with LDPC, have a higher decoder implementation complexity and a lower speed of its operation. In addition, LDPC allows the use of lower-speed encoding schemes and, therefore, has great potential for recovering distorted signals.

The transmission of the MAC (Media Access Control) layer is based on the HARQ (Hybrid Automatic Repeat Request) protocol, which is a combination of (Hybrid) methods for error detection with packet retransmission and error-correcting coding (LDPC code). Upon receipt of a packet containing errors that were not corrected by the channel decoder, the receiver discards the received packet and requests its retransmission (HARQ retransmission). In the presence of significant radio interference or a high level of interference, the number of retransmissions of data packets may be unacceptably large. To limit the resulting time delays, HARQ is usually configured to limit the maximum number of retransmissions, after which the packet is recognized as irreparably damaged and discarded. At the same time, at a higher level of the receiver protocol stack (RLC - Radio Link Control level), a problem can be detected and a lost packet is re-requested using the basic scheme of the ARQ protocol (Automatic Repeat Request) [3].

II. SIGNIFICANCE OF THE WORK

The performance of the HARQ and ARQ protocols is highly dependent on the noise immunity of the LDPC code. The evaluation of the number of correctable bit errors in the LDPC codeword is necessary to select the optimal MCS and HARQ protocol parameters. Therefore, the task of assessing the corrective ability of the LDPC code and choosing the optimal MCS is relevant.

III. EXISTING WORK

The noise immunity study of the LDPC code was carried out in numerous works. Below are some works that are close to the problem under consideration.

Studies were conducted to evaluate the noise immunity of the LDPC code during transmission over a radio channel with additive white Gaussian noise (AWGN - Additive Wite Gaussian Noise) [5], Rayleigh fading [6] and Weibull fading [7].

Estimation of the error coefficient by bits of the LDPC code are determined using various decoding methods [7] and modulation [8]. The spectral efficiency of the LDPC code with various modulation methods was considered in [9].

A quasi-cyclic LDPC code for the 5G network [10], a modified decoding algorithm [11], a new method for constructing a check matrix of the LDPC code [12], and empirical formulas for estimating the number of correctable bits in the LDPC codeword [13, 14] are proposed.

In order to improve system performance, an approach is proposed for combining M-QAM modulation, LDPC coding, and multiple access methods [15]. In [16], a study of error-correcting codes was carried out according to the requirements of a 5G network. The simulation results are presented and the noise immunity of the LDPC code is evaluated. The analysis of the parameters of the LDPC code to achieve the characteristics of a 5G network.

In the considered works, the noise immunity of the LDPC code and the MCS efficiency are estimated by simulation. In this paper, based on processing the results of simulation, we propose a simple method for the analytical assessment of the correcting ability of the LDPC code and the efficiency of MCS.

IV. EVALUATION OF CORRECTING ABILITY OF LDPC CODE

The following methods of multi-position modulation are implemented in 5G networks: QPSK, QAM16, QAM64 and QAM256. When using multi-position modulation, one symbol can transmit $log_2 M$ bits of information, where M is the number of possible signal values. In QPSK, M = 4, so 2 bits are transmitted in one character. In one character, QAM16 transmits 4 bits, in QAM64 6 bits and in QAM256 8 bits.

The probability of error per bit with QPSK and AWGN is determined by the formula [17]

$$P_b = Q\left(\sqrt{\frac{2E_b}{N_o}}\right), \qquad (1)$$

where $\frac{E_b}{N_o}$ is the ratio of the average signal power to the average noise power (SNR), normalized to the bandwidth and bit rate; Q (x) is called the Gaussian error integral and is given in a table.

The probability of error per bit with QAM-M is determined by the formula [17]

$$P_b \approx \frac{2(1-M^{-1})}{log_2 M} Q\left[\sqrt{\left(\frac{3log_2 M}{M^2-1}\right)\frac{2E_b}{N_o}}\right] \qquad (2)$$

Thus, the transmission method using multiposition modulation effectively uses the frequency resource, since the spectral efficiency of bit/Hz increases, with a constant signal duration. At the same time, it is impossible to infinitely increase the number of bits per multi-position modulation symbol to increase the information transfer rate. The noise immunity of multiposition modulation decreases with decreasing E_b/N_o ratio and increasing the number of bits per symbol, since the distance between the points of the constellation of multiposition modulation decreases.

One of the methods to improve the noise immunity of signals (further reducing the probability of error per bit P_b) is error-correcting coding. LDPC - the code, like all linear codes of length n bits, consists of k information bits and $(n-k)$ test bits. Test bits are generated by modulo 2 addition of certain information bits. An LDPC is represented as a (n, J, K) code with a verification matrix H of dimension $(n-k) \times n$, in which each column contains J units $(J \ll (n-k))$, and each row contains K units $(K \ll n)$. Each bit of the codeword is involved in J parity checks, and K bits of the codeword are involved in each parity check. In regular LDPC codes, J and K are constant values, and in irregular ones they are not constant. The encoding and decoding algorithms of the LDPC code are described in detail in [18–20].

In the theory of error-correcting coding, the expression $r_k = k/n$ is called the code rate [17], i.e. the average number of information bits k in a codeword of length n. Since in the regular code $K(n-k) = Jn$, the transmission rate of the LDPC code is given by

$$r_k = \frac{k}{n} = 1 - \frac{J}{K}. \qquad (3)$$

For LDPC codes, there is no exact analytical expression for determining their correcting ability t as a function of codeword length n and coding rate r_k. In [9, 10], many numerical experiments were performed to study the noise immunity of an LDPC code with check matrices for a code with lengths n (50,100,200,500,1000 bits) and a hard decoding algorithm with 50 iterations. Based on the approximation of the simulation results, the following empirical formula for determination of corrective ability

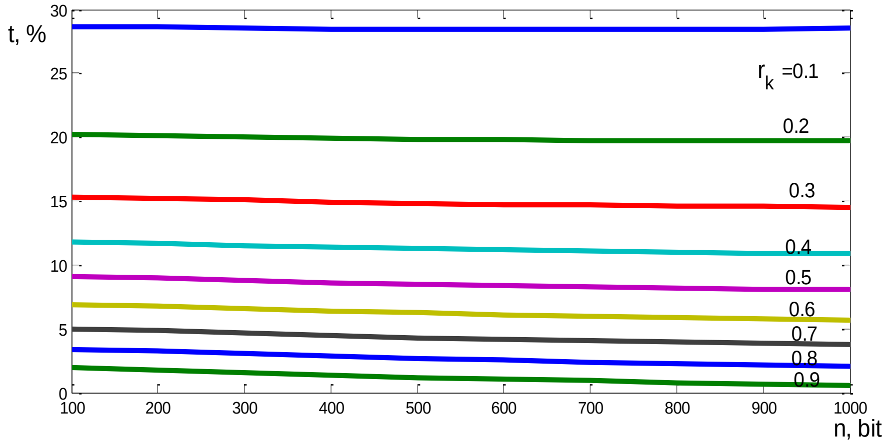
$$t = \frac{n(r_k - 0.0342\ln n - 0.7101}{-0.73\ln n - 0.2951}. \qquad (4)$$

Formula (4) is valid only for the considered code lengths, and for the remaining code lengths, the calculation results do not coincide with the simulation results obtained for large code lengths ($n > 1000$).

The analysis of the known results of experimental studies shows that there is a pattern of dependence of the correcting ability of the code t on the encoding speed r_k, regardless of the length of the code n. This pattern is shown in Figure 1.

From Figure 1 it follows that the fraction of corrected bits of the code length at various coding rates is an almost constant value. The simulation results obtained for the maximum length of the LDPC code of 64800 bits also confirm the revealed pattern.

Based on Fig1, the table shows the average fractions of error correction versus code length at various encoding rates.



Coding rate	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
The average proportion of correctable bits of the length of the code,%	28	20	15	12	8	6	4	3	2

Fig1. Dependence of correcting ability of LDPC code on code length and coding rate

Table1. Corrective power of LDPC code

If the correcting ability of the code t is known, then the probability of erroneous reception of the code word is determined by the formula

$$P_c = \sum_{i=t+1}^{n} C_n^i P_b{}^i (1 - P_b)^{n-i}. \qquad (5)$$

The probability of correctly receiving a code word is

$$Q_c = 1 - P_c. \qquad (6)$$

V. EVALUATION OF THE MCS EFFECTIVENESS

The signal-code constructions (MCS) have the following requirements for its performance: high coding rate (r_k), high probability of correct reception of the code word Q_c, and high spectral efficiency of the modulation method ($log_2 M$). All of these requirements are contradictory, because improving one performance indicator leads to a deterioration of another indicator. Therefore, we will evaluate the effectiveness of MCS according to the following criterion, which is a product of all performance indicators

$$E = r_k Q_c log_2 M. \qquad (7)$$

You must select the MCS with the maximum value of E, depending on the indicator of the quality of the radio channel E_b/N_o.

For example, Fig2 shows the values of E for several relations E_b/N_o.

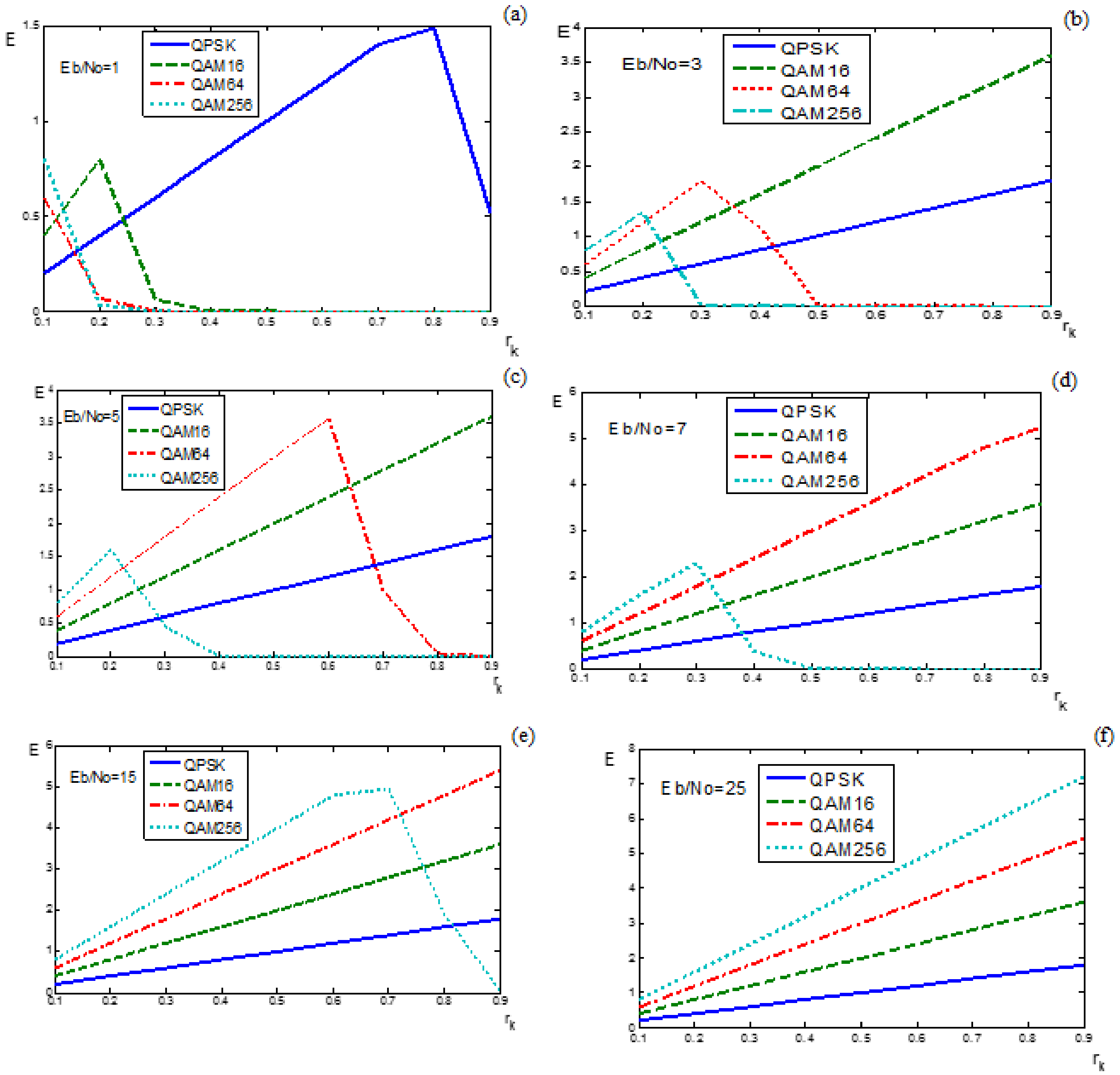


Fig2. Graphs of the dependence of the MCS efficiency on the coding rate for various values of E_b/N_o

Some applications set limits on the probability of correct (or erroneous) reception of a code word. Suppose the probability of the correct reception of the codeword Q_c should be equal to and greater than the permissible value Q_c^* ($Q_c \geq Q_c^*$). Then, from the set of MCS variants satisfying the condition $Q_c \geq Q_c^*$, the MCS variant with maximum efficiency is selected.

Table2. MCS options with maximum efficiency and satisfying the condition $Q_c \geq 0.999$

$\frac{E_b}{N_0}$, db	MCS Parameters	
	Modulation method	LDPC Encoding Rate
1	QPSK	0.7
2	QAM16	0.5
3	QAM16	0.7
4	QAM16	0.8
5	QAM16	0.9
6	QAM64	0.5
7	QAM64	0.6
8	QAM64	0.7
9	QAM64	0.8
10	QAM64	0.9
15	QAM256	0.6
20	QAM256	0.8

VI.CONCLUSION

In existing works, the tasks of studying and evaluating the noise immunity of an LDPC code are solved mainly with the help of simulation. Based on the analysis of the simulation results, the regularity of the correcting ability of the LDPC code is determined depending on the encoding speed. This allowed us to analytically evaluate the noise immunity of the LDPC code and the efficiency of MCS. In the following works, the results obtained will be used to study and select the optimal parameters of the HARQ protocol with MCS.

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