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Анализ передачи данных в двоичном симметричном канале связи с использованием БЧХ кодирования

Analysis of data transmission in a binary symmetric communication channel using BCH coding

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Аннотация. *В данной статье была составлена модель передачи данных по двоичному симметричному каналу связи в MATLAB Simulink. Исследована передача данных, закодированных БЧХ кодами, с различными вероятностями ошибки, а также проведен сравнительный анализ процентного соотношения исправленных ошибок при разной избыточности кода.*

Ключевые слова: БЧХ коды, помехоустойчивое кодирование, двоичный симметричный канал связи

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Abstract. *In this article, a data transfer model was compiled over a binary symmetric communication channel in MATLAB Simulink. The transmission of data encoded with BCH codes with different error probabilities was studied, as well as a comparative analysis of the percentage of corrected errors with different code redundancy was carried out.*

Keywords: BCH codes, error-correcting coding, binary symmetric communication channel

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Introduction. The problem of quickly transmitting large amounts of information and ensuring error-free information transfer when designing and using modern digital infocommunication systems in networks is of great importance. As a result, protecting information from errors and the harmful effects of interference is of great practical importance and is one of the serious problems of modern communication theory and technology. To transmit messages in digital information transmission systems, it is important to increase noise immunity, especially in channels with complex interference conditions. Any noise-resistant coding adds redundancy, which makes it possible to restore information in the event of partial data loss in the communication channel.

Noise-resistant codes must provide both detection and error correction, that is, encoding must be carried out in such a way that the signal corresponding to a sequence of symbols, after being exposed to interference expected in the channel, remains closer to the signal corresponding to a specific transmitted sequence of symbols than to signals corresponding to other possible sequences [1-4]. The use of a correction code cannot guarantee error-free reception, but it makes it possible to increase the likelihood of obtaining the correct result at the output. In error-correcting coding, the most common are linear cyclic codes, in particular from the family of Bose-Chaudhuri-Hocquengham codes (BCH codes) [5], for which, in addition to classical syndromic ones, effective norm [6-7] and polynomial-norm error correction methods have been developed [8-10].

Bose-Chowdhury-Hocquengham (BCH) codes are a class of cyclic codes that correct multiple errors, that is, two or more. The technique for constructing BCH codes differs from conventional cyclic codes, mainly in the choice of the defining polynomial *P(x).* BCH codes are constructed according to a given codeword length *n* and the number of corrected errors *S,* while the number of information bits *k* is not known until the defining polynomial is selected. BCH codes are important because for blocks whose length is on the order of several hundred bits, BCH codes are superior in quality to all other block codes with the same block length and coding degree. The most commonly used BCH codes use a binary alphabet and a codeword block [11].

Materials and research methods. Simulation of data transmission in a binary symmetric communication channel. A binary symmetric communication channel is a communication channel that uses two different symbols to transmit information. There may be two states, such as high and low voltage or two different frequencies. One of the basic principles of a binary symmetric communication channel is that each character that is transmitted over the channel can either be correctly recognized or misinterpreted. Binary symmetric communication channel is one of the most used types of communication in information technology. The importance of this type of communication lies in the fact that it ensures stable and reliable transmission of information even in conditions of high noise and other interference [12].

A binary symmetric communication channel can be described using probabilistic models. The probability of transmitting the correct symbol is denoted by p and is called the probability of success. The probability of transmitting an erroneous symbol is denoted by q and is called the probability of failure. This model can be represented using the Bernoulli formula:

$$P(k) = C(n,k) \cdot p^k \cdot q^{n-k} \qquad (1)$$

where *P(k)* is the probability that *k out of n* symbols will be transmitted correctly, *C (n, k)* is the number of combinations of *n* by *k, p* is the probability of successful transmission, *q* is the probability of unsuccessful transmission.

Also, to describe a binary symmetric channel, the concept of channel capacity is used - the maximum value of information capacity that can be transmitted over the channel per unit time. The channel capacity can be calculated using the formula:

$$C = B \cdot \log_2(1 + \frac{S}{N}) \qquad (2)$$

where *B* is the frequency bandwidth, *S* is the signal power, *N* is the noise power.

Thus, the use of probabilistic models and mathematical formulas makes it possible to more accurately describe and analyze the operation of a binary symmetric communication channel.

BCH (Bose-Chaudhuri-Hocquenghem) coding is an error correction method that allows you to correct data transmission errors in a binary symmetric communication channel. Of decisive importance in BCH coding is the polynomial that defines the codeword. Polynomials in BCH coding have the following form:

$$g(x) = (x - \alpha^1)(x - \alpha^2)(x - \alpha^3) \dots (x - \alpha^t) \qquad (3)$$

where $\alpha^1, \alpha^2, \alpha^3, \dots, \alpha^t$ are the roots of the polynomial, *t* is the number of roots.

An algebraic criterion is used to determine the correctness of the resulting code word. It is based on the fact that if the polynomial obtained during decoding has a lower degree than a given threshold, then the codeword was transmitted without errors. If the polynomial has a large degree, then the codeword contains errors. The algebraic criterion is formulated as follows: if a polynomial when divided by *g(x)* gives a remainder *r(x)* of lesser degree than *t*, then the codeword is transmitted correctly. If the remainder has a degree greater than or equal to *t*, then the codeword contains errors. Mathematical analysis of BCH coding makes it possible to calculate coding parameters, such as the number of check bits and the minimum distance between codewords, which can significantly increase the reliability of data transmission in a binary symmetric communication channel [13-15].

S imulink graphical programming environment, into which an error is introduced using a BSC (Binary symmetric channel) block. The BSC block transmits a binary input signal through a symmetrical binary channel having a specified error probability. The channel introduces a bit error and processes each input element independently. The information must be an array of binary numbers or a Galois array in *GF (2)*.

Research results and their discussion. To perform the simulation, the Simulink software module was selected, which is an application to the MATLAB R 2021 a package.

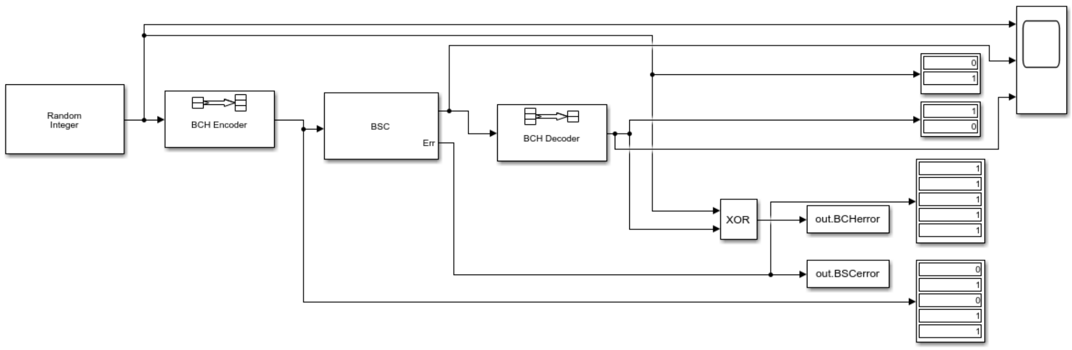

Figure 1. Model of message transmission using the BCH code. An example of how the model works when using the (5, 2) BCH code

To calculate the number of transmitted messages, the formula was used

$$N = \frac{t}{T} + 1, \qquad (3)$$

where *t* is the operating time of the model, *T* is the sampling time. For example, at *t* =2.5 s and *T* =0.001, using formula (3), we obtain *N* =2501 transmitted messages over a binary symmetrical communication channel.

Simulation results describing the percentage of errors before and after encoding using BCH codes for various error probabilities in a binary symmetric communication channel are presented in Tables 1-6. The codes are ordered in ascending order of redundancy.

Table 1. Results of modeling data transmission over a binary symmetric communication channel with BCH coding, sampling time 0.1

Probability of error, %	Code Options		Errors in BSC		Errors after decoding	
	$(n, k)-$code	Redundancy, %	Quantity	Percent, %	Quantity	Percent, %
0.01	(15, 11)	36	0	0	0	0
	(7, 4)	75	0	0	0	0
	(5, 2)	150	0	0	0	0
	(31, 11)	182	0	0	0	0
	(4, 1)	300	0	0	0	0
0.1	(15, 11)	36	0	0	0	0
	(7, 4)	75	0	0	0	0
	(5, 2)	150	0	0	0	0
	(31, 11)	182	0	0	0	0
	(4, 1)	300	0	0	0	0

1	(15, 11)	36	1	0.67	0	0
	(7, 4)	75	1	0.55	0	0
	(5, 2)	150	1	0.39	0	0
	(31, 11)	182	2	0.65	0	0
	(4, 1)	300	3	0.74	0	0
5	(15, 11)	36	10	6.67	7	6.36
	(7, 4)	75	13	7.14	4	3.85
	(5, 2)	150	17	6.68	2	1.96
	(31, 11)	182	19	6.13	0	**0**
	(4, 1)	300	26	6.44	2	1.98
10	(15, 11)	36	17	11.33	17	15.45
	(7, 4)	75	21	11.54	7	6.73
	(5, 2)	150	30	11.76	4	3.92
	(31, 11)	182	36	11.61	3	**2.73**
	(4, 1)	300	49	12.13	4	3.96
25	(15, 11)	36	37	24.67	31	28.18
	(7, 4)	75	45	24.73	29	27.88
	(5, 2)	150	63	24.71	17	16.67
	(31, 11)	182	76	24.52	34	30.91
	(4, 1)	300	105	25.99	17	16.83
50	(15, 11)	36	75	50.00	58	52.73
	(7, 4)	75	90	49.45	54	51.92
	(5, 2)	150	129	50.59	50	49.02
	(31, 11)	182	155	50.00	65	59.09
	(4, 1)	300	200	49.50	48	47.52
75	(15, 11)	36	118	78.67	87	79.09
	(7, 4)	75	142	78.02	80	76.92
	(5, 2)	150	195	76.47	70	68.63
	(31, 11)	182	234	75.48	84	76.36
	(4, 1)	300	307	75.99	79	78.22
90	(15, 11)	36	139	92.67	102	92.73
	(7, 4)	75	171	93.96	99	95.19
	(5, 2)	150	241	94.51	92	90.20
	(31, 11)	182	290	93.55	108	98.18
	(4, 1)	300	375	92.82	95	94.06

Table 2. Results of modeling data transmission over a binary symmetric communication channel with BCH coding, sampling time 0.01

Probability of error, %	Code Options		Errors in BSC		Errors after decoding	
	$(n, k) -$code	Redundancy, %	Quantity	Percent, %	Quantity	Percent, %
0.01	(15, 11)	36	0	0	0	0
	(7, 4)	75	0	0	0	0
	(5, 2)	150	0	0	0	0
	(31, 11)	182	0	0	0	0
	(4, 1)	300	0	0	0	0
0.1	(15, 11)	36	1	0.0007	0	0
	(7, 4)	75	1	0.0006	0	0
	(5, 2)	150	1	0.0004	0	0
	(31, 11)	182	1	0.004	0	0
	(4, 1)	300	1	0.0002	0	0

1	(15, 11)	36	16	1.17	0	0
	(7, 4)	75	19	1.08	0	0
	(5, 2)	150	30	1.20	0	0
	(31, 11)	182	35	1.24	0	0
	(4, 1)	300	49	1.22	0	0
5	(15, 11)	36	79	5.79	46	4.60
	(7, 4)	75	100	5.69	29	2.89
	(5, 2)	150	146	5.83	19	1.90
	(31, 11)	182	171	6.06	3	**0.30**
	(4, 1)	300	233	5.82	14	1.40
10	(15, 11)	36	142	10.40	118	11.79
	(7, 4)	75	178	10.13	66	6.57
	(5, 2)	150	265	10.58	42	4.19
	(31, 11)	182	305	10.81	36	**3.60**
	(4, 1)	300	427	10.66	41	4.10
25	(15, 11)	36	359	26.30	310	30.97
	(7, 4)	75	457	26.01	294	29.28
	(5, 2)	150	662	26.43	226	22.55
	(31, 11)	182	752	26.66	275	27.47
	(4, 1)	300	1065	26.60	195	19.48
50	(15, 11)	36	693	50.77	522	52.15
	(7, 4)	75	886	50.43	496	49.40
	(5, 2)	150	1267	50.58	519	51.80
	(31, 11)	182	1431	50.73	545	54.45
	(4, 1)	300	2033	50.77	520	51.95
75	(15, 11)	36	1012	74.14	731	73.03
	(7, 4)	75	1298	73.88	711	70.82
	(5, 2)	150	1872	74.73	687	68.56
	(31, 11)	182	2110	74.80	763	76.22
	(4, 1)	300	3016	75.32	779	77.82
90	(15, 11)	36	1232	90.26	896	89.51
	(7, 4)	75	1584	90.15	928	92.43
	(5, 2)	150	2262	90.30	844	84.23
	(31, 11)	182	2539	90.00	980	97.90
	(4, 1)	300	3600	89.91	922	92.11

Table 3. Results of modeling data transmission over a binary symmetric communication channel with BCH coding, sampling time 0.001

Probability of error, %	Code Options		Errors in BSC		Errors after decoding	
	$(n, k) -$code	Redundancy, %	Quantity	Percent, %	Quantity	Percent, %
0.01	(15, 11)	36	0	0	0	0
	(7, 4)	75	1	0.0006	0	0
	(5, 2)	150	2	0.0008	0	0
	(31, 11)	182	2	0.00007	0	0
	(4, 1)	300	7	0.0002	0	0
0.1	(15, 11)	36	11	0.0008	0	0
	(7, 4)	75	17	0.001	0	0
	(5, 2)	150	24	0.001	0	0
	(31, 11)	182	26	0.0009	0	0
	(4, 1)	300	43	0.0011	0	0

1	(15, 11)	36	167	1.22	20	0.2
	(7, 4)	75	214	1.22	10	0.001
	(5, 2)	150	282	1.13	6	0.0006
	(31, 11)	182	304	1.08	0	**0**
	(4, 1)	300	426	1.06	3	0.0003
5	(15, 11)	36	788	5.77	466	4.66
	(7, 4)	75	986	5.63	245	2.45
	(5, 2)	150	1349	5.39	129	1.29
	(31, 11)	182	1501	5.32	16	**0.16**
	(4, 1)	300	2068	5.17	105	1.05
10	(15, 11)	36	1492	10.93	1178	11.77
	(7, 4)	75	1881	10.74	757	7.57
	(5, 2)	150	2623	10.49	474	4.74
	(31, 11)	182	2931	10.39	243	**2.43**
	(4, 1)	300	4131	10.32	376	3.76
25	(15, 11)	36	3543	25.96	2922	29.19
	(7, 4)	75	4555	26.02	2774	27.73
	(5, 2)	150	6399	25.59	2112	21.12
	(31, 11)	182	7183	25.46	2425	24.23
	(4, 1)	300	10113	25.27	1820	18.19
50	(15, 11)	36	6844	50.14	5042	50.37
	(7, 4)	75	8779	50.15	5031	50.29
	(5, 2)	150	12532	50.12	5056	50.55
	(31, 11)	182	14133	50.10	5033	50.28
	(4, 1)	300	19981	49.93	4978	49.76
75	(15, 11)	36	10288	75.37	7249	72.42
	(7, 4)	75	13197	75.38	7391	73.88
	(5, 2)	150	18786	75.13	7053	70.52
	(31, 11)	182	21202	75.16	7638	76.30
	(4, 1)	300	30011	75.02	7716	77.15
90	(15, 11)	36	12320	90.26	9013	90.04
	(7, 4)	75	15781	90.14	9345	93.41
	(5, 2)	150	22511	90.03	8442	84.40
	(31, 11)	182	25396	90.02	9811	98.01
	(4, 1)	300	36005	89.98	9062	90.58

Table 4. Results of modeling data transmission over a binary symmetric communication channel with BCH coding, sampling time 0.0001

Probability of error, %	Code Options		Errors in BSC		Errors after decoding	
	$(n, k) -$ code	Redundancy, %	Quantity	Percent, %	Quantity	Percent, %
0.01	(15, 11)	36	14	0.0001	0	0
	(7, 4)	75	16	0.0001	0	0
	(5, 2)	150	22	0.0009	0	0
	(31, 11)	182	23	0.00008	0	0
	(4, 1)	300	42	0.0001	0	0
0.1	(15, 11)	36	126	0.0009	2	0.00002
	(7, 4)	75	164	0.001	3	0.0003
	(5, 2)	150	232	0.0009	0	0
	(31, 11)	182	269	0.001	0	0
	(4, 1)	300	376	0.0009	0	0

1	(15, 11)	36	1414	1.04	220	0.22
	(7, 4)	75	1811	1.03	80	0.0008
	(5, 2)	150	2593	1.04	56	0.0006
	(31, 11)	182	2878	1.02	0	**0**
	(4, 1)	300	4081	1.02	43	0.0004
5	(15, 11)	36	6973	5.11	3775	3.77
	(7, 4)	75	8956	5.1	2005	2.00
	(5, 2)	150	12641	5.06	1228	1.23
	(31, 11)	182	14193	5.04	83	**0.0008**
	(4, 1)	300	20196	5.05	934	0.93
10	(15, 11)	36	13836	10.15	10679	10.68
	(7, 4)	75	17743	10.14	6881	6.88
	(5, 2)	150	25139	10.06	4388	4.39
	(31, 11)	182	28283	10.04	1985	**1.98**
	(4, 1)	300	40259	10.06	3544	3.54
25	(15, 11)	36	34261	25.12	28047	28.05
	(7, 4)	75	44043	25.17	26340	26.34
	(5, 2)	150	62646	25.06	20513	20.51
	(31, 11)	182	70623	25.06	23791	23.79
	(4, 1)	300	10182	25.05	17934	17.93
50	(15, 11)	36	68473	50.21	49934	49.93
	(7, 4)	75	87771	50.15	50081	50.08
	(5, 2)	150	125050	50.02	49982	49.98
	(31, 11)	182	141008	50.03	50187	50.19
	(4, 1)	300	100182	25.05	17934	17.93
75	(15, 11)	36	102525	75.18	72243	72.24
	(7, 4)	75	131333	75.04	73918	73.92
	(5, 2)	150	187583	75.03	70576	70.57
	(31, 11)	182	211471	75.04	763701	76.37
	(4, 1)	300	299896	74.97	77326	77.33
90	(15, 11)	36	122733	90.00	89598	89.60
	(7, 4)	75	157429	89.96	93202	93.20
	(5, 2)	150	224917	89.97	84313	84.31
	(31, 11)	182	253558	89.97	98033	98.03
	(4, 1)	300	359764	89.94	90742	90.74

Table 5. Results of modeling data transmission over a binary symmetric communication channel with BCH coding, sampling time 0.00001

Probability of error, %	Code Options		Errors in BSC		Errors after decoding	
	$(n, k) -$ code	Redundancy, %	Quantity	Percent, %	Quantity	Percent, %
0.01	(15, 11)	36	143	0.0001	0	0
	(7, 4)	75	190	0.0001	0	0
	(5, 2)	150	268	0.0001	0	0
	(31, 11)	182	289	0.0001	0	0
	(4, 1)	300	402	0.0001	0	0
0.1	(15, 11)	36	1351	0.001	17	0.00002
	(7, 4)	75	1758	0.001	9	0.00001
	(5, 2)	150	2504	0.001	4	0.000004
	(31, 11)	182	2827	0.001	0	**0**
	(4, 1)	300	4044	0.001	4	0.000004

1	(15, 11)	36	13751	1.01	1977	0.20
	(7, 4)	75	17563	1.00	869	0.0009
	(5, 2)	150	25012	1.00	479	0.00005
	(31, 11)	182	28126	1.00	0	**0**
	(4, 1)	300	39934	1.00	415	0.0004
5	(15, 11)	36	68508	5.02	36696	3.67
	(7, 4)	75	87700	5.01	19525	1.95
	(5, 2)	150	125164	5.01	11555	1.16
	(31, 11)	182	140926	5.00	805	**0.0008**
	(4, 1)	300	200287	5.01	9332	0.93
10	(15, 11)	36	136503	10.01	103996	10.40
	(7, 4)	75	175031	10.00	66799	6.68
	(5, 2)	150	249809	9.99	42411	4.24
	(31, 11)	182	281382	9.98	18959	**1.90**
	(4, 1)	300	399935	10.00	35156	3.52
25	(15, 11)	36	340652	24.98	278307	27.83
	(7, 4)	75	436974	24.97	260812	26.08
	(5, 2)	150	624208	24.97	202398	20.24
	(31, 11)	182	703738	24.97	237562	23.76
	(4, 1)	300	1000091	25.00	179488	17.95
50	(15, 11)	36	681411	49.97	499728	49.97
	(7, 4)	75	874483	49.97	500153	50.02
	(5, 2)	150	1249607	49.98	499528	49.95
	(31, 11)	182	1408287	49.97	499926	49.99
	(4, 1)	300	1999572	49.99	499373	49.94
75	(15, 11)	36	1022208	74 , 96	721130	72 , 11
	(7, 4)	75	1311549	74.95	737869	73.79
	(5, 2)	150	1874033	74.96	702743	70.27
	(31, 11)	182	2112598	74.96	761634	76.16
	(4, 1)	300	2998943	74.97	773119	77.31
90	(15, 11)	36	1227440	90 , 01	896075	89 , 61
	(7, 4)	75	1574763	89.99	933072	93.31
	(5, 2)	150	2249394	89.98	841720	84.17
	(31, 11)	182	2535800	89.98	980891	98.09
	(4, 1)	300	3599504	89.99	906955	90.70

Table 6. Results of modeling data transmission over a binary symmetric communication channel with BCH coding, sampling time 0.000001

Probability of error, %	Code Options		Errors in BSC		Errors after decoding	
	$(n, k) -$code	Redundancy, %	Quantity	Percent, %	Quantity	Percent, %
0.01	(15, 11)	36	1361	0.00009	2	0.0000002
	(7, 4)	75	1774	0.0001	0	0.0000001
	(5, 2)	150	2516	0.0001	1	0.0000001
	(31, 11)	182	2849	0.0001	0	**0**
	(4, 1)	300	4077	0.0001	2	0.0000002
0.1	(15, 11)	36	13795	0.001	210	0.00002
	(7, 4)	75	17690	0.001	93	0.000009
	(5, 2)	150	25335	0.001	43	0.000004
	(31, 11)	182	28517	0.001	0	**0**
	(4, 1)	300	40221	0.001	33	0.000003

1	(15, 11)	36	136668	1.00	19444	0.19
	(7, 4)	75	175522	1.00	8707	0.0009
	(5, 2)	150	250471	1.00	4900	0.0005
	(31, 11)	182	282224	1.00	0	**0**
	(4, 1)	300	399836	1.00	3953	0.0004
5	(15, 11)	36	682095	5.00	365819	3.66
	(7, 4)	75	875376	5.00	194939	1.95
	(5, 2)	150	1250516	5.00	115606	1.16
	(31, 11)	182	1409518	5.00	8563	**0.0008**
	(4, 1)	300	1999160	5.00	94156	0.94
10	(15, 11)	36	1362994	10.00	1037672	10.38
	(7, 4)	75	1749178	10.00	669947	6.70
	(5, 2)	150	2499922	10.00	424227	4.24
	(31, 11)	182	2816847	10.00	191076	**1.91**
	(4, 1)	300	3998119	10.00	352762	3.53
25	(15, 11)	36	3408542	25.00	2781778	27.82
	(7, 4)	75	4373185	24.99	2614730	26.15
	(5, 2)	150	6248321	24.99	2030107	20.30
	(31, 11)	182	7041922	24.99	2381617	23.82
	(4, 1)	300	9994024	24.99	1795899	17.96
50	(15, 11)	36	6816686	49.99	4997597	49.98
	(7, 4)	75	8746236	49.98	4998222	49.98
	(5, 2)	150	12497530	49.99	4999139	49.99
	(31, 11)	182	14087676	49.99	4999615	50.00
	(4, 1)	300	19996270	49.99	4999375	49.99 _
75	(15, 11)	36	10226078	74.99	7215294	72.15
	(7, 4)	75	13123531	74.99	7383156	73.83
	(5, 2)	150	18749633	75.00	7032033	7032
	(31, 11)	182	21135182	75.00	7616404	76.16
	(4, 1)	300	29997512	74.99	7735725	77.36
90	(15, 11)	36	12271695	89.99	8959606	89.60
	(7, 4)	75	15749688	90.00	9332295	93.32
	(5, 2)	150	22498799	90.00	8422339	84.22
	(31, 11)	182	25361970	89.88	9809884	98.10
	(4, 1)	300	35996781	89.99	9072408	90.72

The presence of redundancy helps to increase the noise immunity of messages; the higher the redundancy, the better the code copes with finding and correcting errors. It can be seen from the tables that the (31, 11) code with 182% redundancy coped better than others with this task, including the (4, 1) code with 300% redundancy. With an error probability of 0.1% and a sampling time of 0.1 to 0.00001, all codes corrected errors completely. With the same error probability and sampling time of 0.000001, only the (31, 11) code managed to correct all errors; other codes were only close to this value. With an error rate of 1% and sample times ranging from 0.1 to 0.001, all of the codes examined were able to correct errors after decoding. With the same error probability and sampling time, the 0.0001 (5,2), (31,11) and (4,1) codes were able to correct all errors. Only the (31, 11) code was able to correct all errors with sampling times from 0.00001 to 0.000001. With an error probability of 5% and a sampling time of 0.1 (31, 11), the code also corrected all errors. Starting from sampling time 0.01, none of the codes considered was able to correct all errors. Only the (31, 11) code was able to correct all errors at 0.1% and 1% error probability at any sample time considered. The (31, 11) code showed the best results with an error probability of 5% to 25% for different sampling times.

Conclusion. Based on the simulation data, it was found that it is inappropriate to consider the error probability with a relatively small redundancy and code word length, since BCH codes cope poorly with correction with an error probability of more than 25%. It is logical to assume that the (31, 11) code, while not having the highest redundancy, coped with the task better than the (4, 1) code due to the fact that the length of the code word is higher, which makes this code the most efficient.

The study of the issue of efficiency of BCH codes is also considered in [1]. An important fact is that when correcting errors, it is theoretically possible to provide any degree of increase in reliability by increasing the code length n and the number of redundant elements $n - k$. However, the practical implementation of such codes would cause serious difficulties.

In further studies, BCH codes with a longer codeword will be considered to study and analyze their properties in order to ensure the rationality of using these codes with a high probability of error. Noise-resistant coding in the system of residual classes will also be studied to achieve greater noise immunity when transmitting data over a binary symmetrical data channel.

ЛИТЕРАТУРА

1. Коды Боуза-Чоудхури-Хоквингема [электронный ресурс]. URL: https://studfile.net/preview/7704440/page:35/ (дата обращения: 21.06.2023).
2. Кушнеров А. В, Липницкий В. А, Королёва М. Н. Обобщенные коды Боуза – Чоудхури – Хоквингема и их параметры. Вестник Полоцкого государственного университета. Серия С: Фундаментальные науки. 2018. № 4. С. 28–33.
3. Морелос-Сарагоса Р. Искусство помехоустойчивого кодирования. Методы, алгоритмы, применение. Афанасьев ВБ, переводчик. Москва: Техносфера. 2005. 320 с.
4. Sun Z, Zhu S, Wang L. A class of concyclic BCH codes. Cryptogr. commun. 2020;12:265–284.
5. Theodoridis S. Introduction to Error Correction Codes. Morgan & Claypool Publishers, 2009. 168 p.
6. Moon TK. Error Correction Coding: Mathematical Methods and Algorithms. Wiley-Interscience, 2005. 780 p.
7. Richardson T, Urbanke R. Modern Coding Theory. Cambridge University Press, 2008. 802 p.
8. Fossorier MPC, Wu H. Applied Algebra, Algebraic Algorithms and Error-Correcting Codes. Wiley-IEEE Press, 2003. 352 p.
9. Chen B, Lin S, Zhang G. Application of constancyclic codes to quantum MDS codes. IEEE Trans. inf. 2015, 1474-1484.
10. Fisher A. Channel Coding Theory: From Classical to Modern. Cambridge University Press, 2017. 300 c.
11. Kabatiansky G., Krouk E. Error-Correcting Coding and Security for Data Networks. CRC Press, 2014. 286 p.
12. Lin S, Costello JrDJ. Error Control Coding: Fundamentals and Applications. Pearson Education, 2004. 1276 p.
13. Raizer E. Algebraic Coding Theory. Springer, 2007. 440 p.
14. Adams SS, Galloway KG. An Introduction to Error Correcting Codes with Applications. Wiley-Interscience, 2017. 408 p.
15. Кудряшов Б. Д. Основы теории кодирования. Санкт-Петербург: БХВ-Петербург. 2016. 400 p.

REFERENCES

1. Kody Bouza-Choudkhuri-Khokvingema [elektronnyi resurs]. URL: https://studfile.net/preview/7704440/page:35/ (accessed: 21.06.2023).
2. Kushnerov AV, Lipnitskii VA, Koroleva MN. Obobshchennye kody Bouza – Choudkhuri – Khokvingema I ikh parametry. Vestnik Polotskogo gosudarstvennogo universiteta. Seriya S: Fundamental'nye nauki. 2018;4:28–33.
3. Morelos-Saragosa R. Iskusstvo pomekhoustoichivogo kodirovaniya. Metody, algoritmy, primenenie. Afanasev VB, perevodchik. Moskva: Tekhnosfera. 2005. 320 p.

4. Sun Z, Zhu S, Wang L. A class of concyclic BCH codes. Cryptogr. commun. 2020;12:265–284.
5. Theodoridis S. Introduction to Error Correction Codes. Morgan & Claypool Publishers, 2009. 168 s.
6. Moon TK. Error Correction Coding: Mathematical Methods and Algorithms. Wiley-Interscience, 2005. 780 p.
7. Richardson T, Urbanke R. Modern Coding Theory. Cambridge University Press. 2008. 80p.
8. Fossorier MPC, Wu H. Applied Algebra, Algebraic Algorithms and Error-Correcting Codes. Wiley-IEEE Press, 2003. 352 p.
9. Chen B, Lin S, Zhang G. Application of constancyclic codes to quantum MDS codes. IEEE Trans. inf. 2015;1474-1484.
10. Fisher A. Channel Coding Theory: From Classical to Modern. Cambridge University Press, 2017. 300 p.
11. Kabatiansky G, Krouk E. Error-Correcting Coding and Security for Data Networks. CRC Press, 2014. 286 p.
12. Lin S, Costello JrDJ. Error Control Coding: Fundamentals and Applications. Pearson Education, 2004. 1276 p.
13. Raizer E. Algebraic Coding Theory. Springer, 2007. 440 p.
14. Adams SS, Galloway KG. An Introduction to Error Correcting Codes with Applications. Wiley-Interscience, 2017. 408 p.
15. Kudryashov BD. Osnovy teorii kodirovaniya. Sankt-Peterburg: BKHV-Peterburg. 2016. 400 p.

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