A novel concatenated code based on the improved SCG- LDPC code for optical transmission systems*

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Based on the optimization and improvement for the construction method of systematically constructed Gallager (SCG) (4, *k*) code, a novel SCG low density parity check (SCG-LDPC)(3969, 3720) code to be suitable for optical transmission systems is constructed. The novel SCG-LDPC (6561,6240) code with code rate of 95.1% is constructed by increasing the length of SCG-LDPC (3969,3720) code, and in a way, the code rate of LDPC codes can better meet the high requirements of optical transmission systems. And then the novel concatenated code is constructed by concatenating SCG-LDPC(6561,6240) code and BCH(127,120) code with code rate of 94.5%. The simulation results and analyses show that the net coding gain (NCG) of BCH(127,120)+SCG-LDPC(6561,6240) concatenated code is respectively 2.28 dB and 0.48 dB more than those of the classic RS(255,239) code and SCG-LDPC(6561,6240) code at the bit error rate (BER) of 10^{-7}.
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With the development of technology, the optical communication system tends to be with larger capacity, longer transmission and higher speed, and the fiber transmission effects, e.g., dispersion, nonlinear effects and amplified spontaneous emission (ASE) noise, continue to accumulate, which greatly affect the communication quality of the optical transmission systems[1-3]. Thus it is imminent to search for an efficient forward error correction (FEC) code. As low density parity check (LDPC) code has advantages in the numerous FEC codes type, for example, high flexibility of prepared coding, low error floor, low complexity of decoding and superior error-correction performance, it becomes a hot spot in the research field of optical transmission systems[4,5].

As a code pattern of FEC technology, the concatenated code has widely been used in optical transmission systems[1,6,7]. In essence, the concatenated code is a special product code[6,8], which has a strong ability to correct burst errors and random errors, and can achieve the code limit given by the channel coding theorem[8-10]. Eight schemes of the super FEC codes used in optical transmission systems were given in the standard recommendations of the ITU-T G.975.1, six schemes of which were with the concatenated code[11].

Based on the construction method of systematically constructed Gallager (SCG) code[12], the SCG-LDPC code, which is suitable for optical transmission system, is optimized and improved. Furthermore, the corresponding concatenated code for optical transmission systems is researched.

Daniel Hösli and Erik Svensson[12] proposed a construction method for regular LDPC codes on the basis of Gallager[13], i.e.,

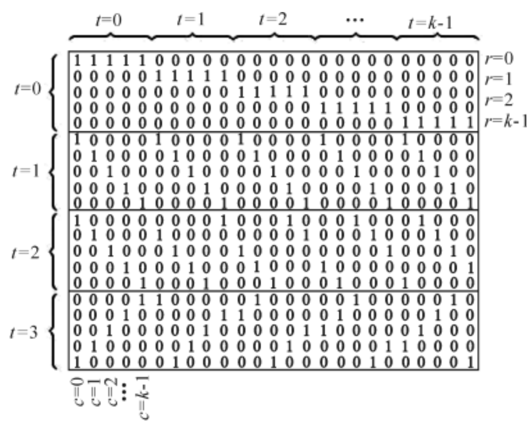

Fig.1 Check matrix of the SCG(4,5) code constructed by Daniel Hösli and Erik Svensson

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SCG(j, k) code[12], which is shown in Fig.1, where $j\in\{2, 3, 4\}$ shows the number of sub-matrices and the column weight of parity check matrix, and k is the line weight of parity check matrix.

According to the channel coding theorem, the error probability in the decoding process can tend towards zero at the exponent mode with the increase of the codeword length[14]. Therefore, the longer codeword must be used so as to improve the error-correction performance of the FEC code. However, the code rate can decrease with the increase of the codeword length, and thus the complexity and calculated amount of the decoding devices increase, which is difficult to be implemented. The concatenated code was firstly presented by Forney in 1966 so as to solve this contradiction correspondingly[14]. The encoding process in this coding scheme is divided into the two inner-outer serial stages, by which the requirement of the codeword length for the channel error-correction can be met, and the error-correction performance and high coding gain of the concatenated code can be the same as those of the used longer codeword without increasing the complexity of the encoding/decoding process as well[14]. A theoretical block diagram of the concatenated code is shown in Fig.2[14].

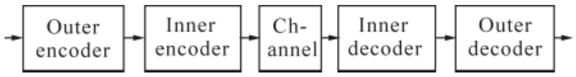

Fig.2 Theoretical block diagram of the concatenated code presented by Forney[14]

Take the first sub-matrix of the original SCG(4, k) code parity check matrix as the first sub-matrix of the new constructed one. Let each square-matrix, i.e., unit matrix, of the second sub-matrix do a center mirror symmetry transformation, and take the sub-matrix after transformation as the second sub-matrix of the new constructed parity check matrix. The first small square matrix of the third sub-matrix is the same as the first square matrix of the new constructed second sub-matrix. However, the other square matrix comes from each square-matrix of the second sub-matrix after a left shift. The fourth sub-matrix is obtained by the center mirror symmetry transformation from the third sub-matrix of the new constructed SCG(4, k). Fig.3 shows the improved sub-matrix of SCG(4,5) constructed by this method.

From Fig.3, it is obviously seen that the girth-4 phenomenon does not exist in the check matrix, and it is validated by MATLAB program. The improvement of the new constructed check matrix starts from the second sub-matrix. Let the second sub-matrix of the original check matrix do a mirror symmetry transformation to increase the girth length of the check matrix, and thus the decoding performance of the code is optimized. The third sub-matrix is constructed by the circular permutation matrix with some advantages, such as the little computing amount, fast computing speed and fast encoding speed, due to using the shift register to process the encoding. The fourth sub-matrix is obtained by the mirror symmetry transformation of the third sub-matrix, so the storage space can be saved to some extent.

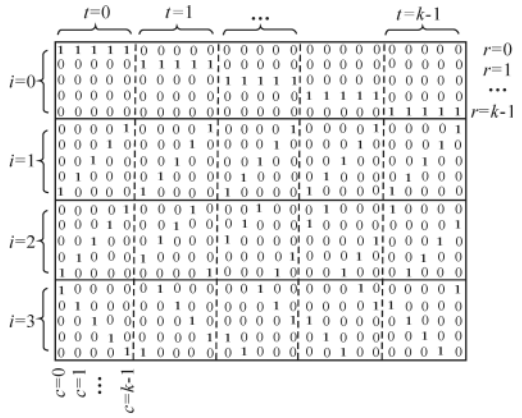

Fig.3 An improved sub-matrix of SCG(4,5)

Based on the optimization and improvement for the construction method of SCG, SCG-LDPC(3969,3720) code is constructed. The novel SCG-LDPC(6561,6240) code with code rate of 95.1% is constructed by increasing the length of SCG-LDPC(3969,3720) code. Row-column (RC) constraint validation is done by programming using MALAB software. It can be learned that the new constructed SCG-LDPC(6561, 6240) code does not have the girth-4 phenomenon.

The technology of concatenated codes is applied in order to make LDPC codes more suitable for optical transmission systems. And then the novel BCH (127,120) +SCG-LDPC(6561,6240) concatenated code is constructed by concatenating SCG-LDPC(6561,6240) code and BCH(127,120) code with code rate of 94.5%.

During the simulation, the setting of the parameters is shown as Tab.1. The simulation is done in MATLAB simulation platform with the Galois binary fields (GF(2)), binary phase shift keying (BPSK) modulation and the additive white Gaussian noise (AWGN) channel model.

Tab.1 Simulation parameters of MATLAB system

Parameter name	Parameter setting
Code mode	SCG-LDPC(6561,6240) RS(255,239) BCH(127,120)+SCG-LDPC (6561,6240)
Simulation environment	GF(2)
Modulation mode	BPSK
Channel model	AWGN
Decoded mode	Belief propagation decoding algorithm (The maximum of iteration times is 16.)

First, the code is simulated and analyzed with the classic RS(255,239) code[15] which is widely used in optical transmission systems and the SCG-LDPC(6561,6240) code constructed by SCG method. The error-correction performance is shown in Fig.4.

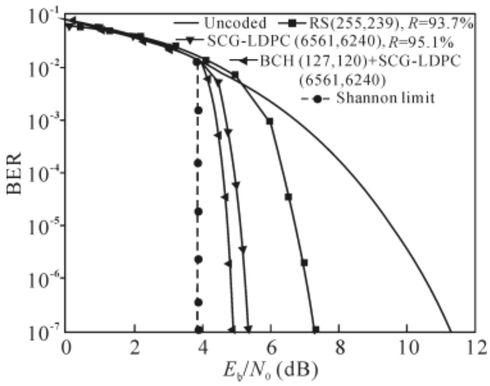

Fig.4 Error-correction performance of simulation for different codes

It can be seen from Fig.4 that at the bit error rate (BER) of 10^{-7}, the net coding gain (NCG) of BCH(127,120)+SCG-LDPC(6561,6240) concatenated code is about 1.0 dB away from Shannon limit, and 2.28 dB more than that of the classic RS(255,239) code. It is obvious that the convergence performance of the new constructed BCH (127,120)+LDPC (6561,6240) concatenated code is better than that of RS(255, 239) code with the error code ratio (E_b/N_0) increasing. Thus the error-correction performance of the new constructed BCH (127,120)+LDPC(6561,6240) concatenated code is significantly better than that of the RS(255,239) code.

In order to further demonstrate the superiority and reasonability of the novel code pattern, the error-correction performance of the new constructed BCH (127,120)+SCG-LDPC(6561,6240) concatenated code is compared with that of the novel SCG-LDPC(6561, 6240) code based on the construction method of the SCG code. Fig.4 shows that the error-correction performance of the new constructed BCH(127, 120)+SCG-LDPC(6561,6240) concatenated code is still significantly better than that of the SCG-LDPC(6561,6240) code based on the SCG construction method. At the BER of 10^{-7}, the NCG of the new constructed BCH(127,120)+SCG-LDPC (6561,6240) concatenated code is 4.92 dB, which is nearly 0.48 dB more than that of the SCG-LDPC(6561,6240) code based on the SCG construction method. On the whole, the new constructed BCH(127,120)+SCG-LDPC(6561,6240) code with better error-correction performance is more suitable for optical transmission systems.

A new SCG-LDPC(3969,3720) code is constructed based on the optimization and improvement for the construction method of SCG(4, *k*) code. The novel SCG-LDPC(6561, 6240) code with code rate of 95.1% is constructed by increasing the length of SCG-LDPC(3969,3720) code in order that the code rate of LDPC codes better meets the high requirements of optical transmission systems. And then the novel BCH(127,120)+SCG-LDPC(6561,6240) concatenated code is constructed by concatenating SCG-LDPC(6561,6240) code and BCH(127,120) code with code rate of 94.5%. The simulation results and analyses show that the NCG of BCH (127,120)+SCG-LDPC(6561,6240) concatenated code is respectively 2.28 dB and 0.48 dB more than those of the classic RS(255,239) code and SCG-LDPC(6561,6240) code at the BER of 10^{-7}. Therefore, the novel concatenated code is more suitable for optical transmission systems.

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