A novel BTC decoding algorithm based on the genetic algorithm in optical communication systems*

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Combining the advantages of both the genetic algorithm (GA) and the chase decoding algorithm, a novel improved decoding algorithm of the block turbo code (BTC) with lower computation complexity and more rapid decoding speed is proposed in order to meet the developing demands of optical communication systems. Compared with the traditional chase decoding algorithm, the computation complexity can be reduced and the decoding speed can be accelerated by applying the novel algorithm. The simulation results show that the net coding gain (NCG) of the novel BTC decoding algorithm is 1.1 dB more than that of the traditional chase decoding algorithm at the bit error rate (BER) of 10^{-6}. Therefore, the novel decoding algorithm has better decoding correction-error performance and is suitable for the BTC in optical communication systems.

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It becomes necessary to develop a novel more powerful super forward error correction (SFEC) code type to meet the rapid development of optical communication systems[1-5]. Therefore, the study of a novel more powerful super forward error correction (SFEC) code has become a new proposition[6-8]. ITU-T has constituted the recommendation G.975.1[9] that describes the eight code types to have more powerful error-correction performance than RS(255,239) code[10]. However, there is no block turbo code (BTC) constructed by subcode of turbo code that uses linear block code in the eight code types. The performance of BTC code can avoid "error-floor" effect, and has better decoding performance at high code rate[11]. At the same time, the construction of the BTC code uses the row-column interleaver, so the BTC can increase the code spacing and play an important role in the noise optimization and can correct the random and burst error patterns[11-13]. As a result, the study of more powerful FEC encoding/decoding based on BTC code is a very important work to extensively develop the ITU-T G.975.1[9].

In this paper, a novel improved decoding algorithm of the BTC based on the genetic algorithm (GA) is proposed in order to reduce the computation complexity and accelerate the decoding speed.

The decoding of binary linear block code $c(n,k,d_h)$ in the condition of the additive white Guassian noise (AWGN) channel is considered and used in this paper. In this case, the decoded binary 0 and 1 bit flows will be first mapped into -1 and +1 information flows and then transmitted through the AWGN channel. Let $x=\{x_1,x_2,\cdots,x_n\}$ be the code vector to be sent out. After the code vector is transmitted through AWGN channel, we can obtain the monitoring vector of $r'=x+e$, in which $r'=\{r'_1,r'_2,\cdots,r'_n\}$, $e=\{e_1,e_2,\cdots,e_n\}$, $e_i(1\le i\le n)$ are the sampling values of AWGN whose mean is 0 and variance is σ^2. In the case of greater signal-to-noise ratio (SNR), the optimum codeword d of multicast listener discovery (MLD) always falls with the very high probability in the ball, of which the center is at $r=\{r_1,r_2,\cdots,r_n\}$ and the radius is (d_h-1). Among them $r_i=[1+\mathrm{sgn}(r'_i)]/2$, and r'_i denotes the i th vector element of the channel monitoring vector. Consequently, in the inequation $|r'-c^i|^2\le|r'-c^j|^2$, it only needs to consider the codeword in the ball whose central point is at r and radius is (d_h-1). The decoding process is as follows[14].

(1) Use r' to determine the site of the $p=(d_h/2)$ binary elements which are most unreliable in r, and the reliability of the element r_i in r is defined as its Log likelihood ratio (LLR)[12]:

$$L(r_i)=L(r'_i\,|\,x)=\ln\left[\frac{p(r'_i\,|\,x=+1)}{p(r'_i\,|\,x=-1)}\right]=\frac{2}{\sigma^2}r'_i\,. \qquad (1)$$

(2) Take the values of 0 and 1 for the p most unreliable sites of the n-dimensional vector and then the number of

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test sequences (q=2^p) can be got. At the same time, take the value of 0 for all other sites. By this way we can obtain the q testing modes (T^q).

(3) Construct the testing sequence $Z^q = r \oplus T^q$, in which $z_i^q = r_i \oplus t_i^q, (1 \le i \le n)$, and decode r and the testing sequence Z^q by applying algebraic decoder to generate the set Ω containing the q observation codes.

(4) Limit the observation codes in the subset Ω, and find out the optimum decision-making vector $d = c^i$ of the transmitted code vector x by applying the judging inequation $|r' - c^i|^2 \le |r' - c^j|^2, c^i, c^j \in \Omega$.

A novel improved decoding algorithm of the BTC with the advantages of the genetic algorithm is proposed in order to further reduce the computation complexity and accelerate the decoding speed of chase decoding algorithm in this paper. The BTC will produce a series of candidate sequences by using chase decoding algorithm. The novel BTC decoding algorithm is that the genetic algorithm will recover a sequence similar to the received sequence by using these candidate sequences; finally, the decoding results will be obtained after the hard decision of the similar sequence that is sent as the input of the error correction decoder.

The implementation process of this novel decoding algorithm is described as follows.

(1) Get a credibility sequence a and a hard decision sequence R from the received sequence r;

(2) Generate the $2^{d_h/2}$ correct sequences T with the same length as the received sequence based on the corresponding locations (p_1, p_2, p_3,$\cdots$) of the $d_h/2$ lowest credibility symbols in the credibility sequence a, and the locations (p_1, p_2, p_3,$\cdots$) of the correct sequence are replaced by 0 simultaneously or respectively;

(3) Generate the candidate sequences A on the basis of the hard decision sequence R and the correct sequence T;

(4) Make use of genetic algorithm to generate a sequence with the most likelihood to received sequence, according to the candidate sequence A, and its steps are described as follows:

a. Population initialization: The candidate sequence A is set as the genetic algorithm initial population;

b. The assessment for the individual fitness: The correlation function[15] $\lambda(v,w) = \sum_{i=1}^{n} v \cdot w$ is taken as the genetic fitness function to calculate the fitness of individual population to generate the initial population, where v represents the received sequence which hasn't been hard-decided and w represents the candidate sequence;

c. Natural selection: Select the appropriate individuals to genetic algorithm based on the individual's fitness with roulette wheel selection or other methods from the initial population. The higher the fitness of individuals is, the greater the selected probability will be;

d. The paired crossover generates new individuals by cross-matching the selected individuals. The methods of the paired crossover include one-point crossover and multi-point crossover;

e. Genetic mutations: Select individuals randomly from the new individuals generated in process d to conduct mutation operation, namely, a certain symbol in the individual will turn from 0 to 1 or 1 to 0;

f. Genetic termination: When the genetic number of generations reaches the preset genetic termination value, the individual with the highest fitness in the last generation will be taken out as output of the genetic algorithm, otherwise jump to the step c to continue genetic process;

(5) Send the optimal output sequence of the genetic algorithm into the error correction hard decision decoder to conduct the error correction decoding, and then the final decoding result is got.

As the genetic algorithm's search space is only associated with population size which remains stable, whereas the population size is up to the minimum Hamming distance of codeword, its search space won't expand exponentially with the code length. Although the novel BTC decoding algorithm requires additional operations of selection, crossover and mutation, the computational overhead of it can be ignored compared with chase decoding algorithm. The optimization module of GA requires g generations of genetic process, each generation deals with $2^{d_h/2-1}$ individuals, and each process needs to have n^2 multiplication operations and (n-1)n addition operations, where d_h is the minimum Hamming distance and t is the number of correction-errors. Therefore, there are $2^{d_h/2-1} \bullet g \bullet n^2$ multiplication operations and $2^{d_h/2-1} \bullet g \bullet n(n-1)$ addition operations in total. The module of hard-decision needs to have $2 \bullet n^2 t + 2nt^2$ multiplication operations and $2 \bullet n^2 t + 2nt^2 - nt$ addition operations. Considering the hard-decision as addition operation, the novel BTC decoding algorithm needs to have $2^{d_h/2-1} g \bullet n^2 + 2 \bullet n^2 t + 2nt^2$ multiplication operations and $2^{d_h/2-1} gn(n-1) + 2nt(n+t) - nt$ addition operations. The complexity comparison of the novel BTC decoding algorithm and chase decoding algorithm is shown in Tab.1. A BCH(n,k)×BCH(n,k) code, namely, BTC(n,k)×(n,k), is taken as an example.

Tab.1 The comparison between the novel BTC decoding algorithm and the chase decoding algorithm

Algorithm	Multiplication operation	Addition operation
Chase decoding	$2^{d_h/2} n^2 +$ $2n^2 t(n+t)$	$2^{d_h/2}(n-1)n +$ $2n^3 t +$ $2n^2 t^2 - n^2 t$
The novel BTC decoding	$2^{d_h/2-1} gn^2 +$ $2n^2 t + 2nt^2$	$2^{d_h/2-1} gn(n-1) +$ $2nt(n+t) - nt + n^2$

Then a BCH(63,51)×BCH(63,51) code, namely, BTC (63,51)×(63,51), is taken as an example. The complexity comparison of the novel BTC decoding algorithm and chase decoding algorithm for this code is shown in Tab.2.

Tab.2 The comparison between the novel BTC decoding algorithm and chase algorithm for BTC(63,51) ×(63,51)

Algorithm	Multiplication operation	Addition operation
Chase decoding	1047816	1039626
The novel BTC decoding	413280	410823

In terms of Tab.1 and Tab.2, the computation complexity of the novel BTC decoding algorithm has a significant reduction compared with the traditional chase decoding algorithm.

Next, we will discuss the decoding simulations of BTC(63,51)×(63,51) under the conditions of binary phase shift keying (BPSK) modulation and AWGN channel. Bit error rate (BER) is for the bit error rate, and EbN0 (dB) is on behalf of signal-to-noise ratio (SNR). Simulation results of two decoding algorithms are shown in Fig.1.

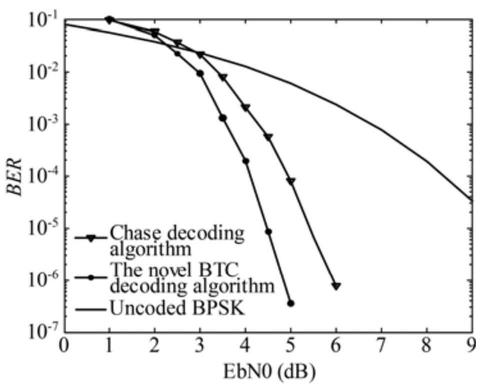

Fig.1 The simulation results on the decoding performance of the novel BTC decoding algorithm and chase decoding algorithm for BTC(63,51)×(63,51)

From Fig.1, it can be seen that the SNR of the novel BTC decoding algorithm gains about 4.8 dB and that of chase decoding algorithm gains about 5.9 dB at the BER of 10^{-6}. Therefore, the net coding gain (NCG) of the novel BTC decoding algorithm is 1.1 dB more than that of the traditional chase decoding algorithm. Because it has optimized the results of hard-decision again, the novel decoding algorithm has better decoding correction-error performance and is more practicable for the BTC in optical communication systems.

Based on the analyses of chase decoding algorithm and the genetic algorithm, a novel improved decoding algorithm for the BTC with the advantages of the two algorithms is proposed in this paper. Compared with the traditional chase decoding algorithm, the computation complexity can be reduced and the decoding speed can be accelerated by applying the novel algorithm. The NCG of the novel BTC decoding algorithm is 1.1 dB more than that of the traditional chase decoding algorithm at the BER of 10^{-6}. Therefore, the novel decoding algorithm has better decoding correction-error performance and is more practicable for the BTC in optical communication systems.

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