A new probability decoding scheme based on genetic algorithm for FEC codes in optical transmission systems*

YUAN Jian-guo(袁建国)******, **WANG Lin**(王琳), **HE Qing-ping**(何清萍), **LI Hao**(李好), **and WANG Yong**(王永)

Key Lab. of Optical Fiber Communications Technology, Chongqing University of Posts and Telecommunications, Chongqing 400065, China

(Received 4 May 2012)

Based on the genetic algorithm (GA), a new genetic probability decoding (GPD) scheme for forward error correction (FEC) codes in optical transmission systems is proposed. The GPD scheme can further offset the quantification error of the hard decision by making use of the channel interference probability and statistics information to restore the maximal likelihood transmission code word. The theoretical performance analysis and the simulation result show that the proposed GPD scheme has the advantages of lower decoding complexity, faster decoding speed and better decoding correction-error performance. Therefore, the proposed GPD algorithm is a better practical decoding algorithm.

Document code: A **Article ID:** 1673-1905(2012)05-0376-4

DOI 10.1007/s11801-012-2270-1

The forward error correction (FEC) technique has been used in optical transmission systems to compensate for the transmission quality degradation from noise and pulse distortion[1,2]. Since fiber channel has a high signal to noise ratio (SNR), it requires the channel output to have low bit error rate (BER) and high code rate[1-4]. So the research on the error correction decoding algorithm for FEC codes with low complexity, fast and efficient decoding performance is always a hot topic, and the operation speed and implementation complexity of the decoder have become the key to the application of FEC codes [2-10]. Currently, the genetic algorithm (GA) is a concerned optimization algorithm[11-13]. Refs.[12] and [13] studied the use of genetic algorithm in error correction code decoding scheme to accelerate the decoding speed.

A new genetic probability decoding (GPD) scheme based on GA for the FEC codes in optical transmission system is proposed in this paper. This algorithm can greatly reduce the complexity of probability decoding and improve the decoding speed by combining the efficiency and operability of GA with the accuracy of the probability decoding.

GA is an adaptive probabilistic optimization technique based on biological genetic evolutionary mechanisms to optimize complex systems. It simulates the natural process of genetic recombination and evolution, similar to natural selection, crossover and mutation to get the final optimization result after repeated iterations[9-11]. In a specific implementation process, GA imposes genetic manipulation on individuals in a group to achieve the restructuring of the iterative process within the group based on a fitness function[11,12]. In repeated iterations, individuals in a group (solution of the problem) are able to be optimized, and the generation is gradually approaching the optimal solution. The basic GA can be expressed as:

$$\mathrm{GA}=(C,E,P_0,M,\Phi,\Gamma,T,\Psi)\ , \tag{1}$$

where C stands for coding method for individual, E is the individual fitness evaluation function, P_0 is the initial group, M represents the size of groups, Φ is selection operator, Γ is crossover, Ψ is the mutation operator, and T is genetic termination condition.

GA inherits the natural parallelism in the evolution process, and a large number of species evolve forward independently through natural selection, crossover and mutation, allowing the GA to evaluate multiple solutions in the search space simultaneously and enhancing the speed of problem solving greatly. Moreover, the GA uses probabilistic transition rules to guide the search direction, so individuals can change constantly to make the group move in the best direction of evolution, which is called heuristic search with high quality of problem solving[12-15].

* This work has been supported by the National Natural Science Foundation of China (Nos.61071117 and 61003256), the Natural Science Foundation of Chongqing CSTC (No.2010BB2409), and the Science and Technology Foundation of Chongqing Municipal Education Commission (No.KJ110519).

** E-mail: yuanjg@cqupt.edu.cn

From the above description, we can see it will be very efficient to take advantage of the intrinsic parallel properties of GA to eventually restore the optimal transmitted code word. And decoding complexity will be reduced greatly due to the stable population size of search space, which is almost not affected by the number of symbols. Therefore, the new GPD based on GA is worthy of further study.

The flowchart of GPD algorithm is shown in Fig.1. The implementation process of the algorithm is described as follows:

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

(2) Generate $2^{d_h/2}$ correct sequences T with the same length as received sequence based on the corresponding location (p_1, p_2, p_3,...) of $d_h/2$ lowest credibility symbols in the credibility sequence α , where the location (p_1, p_2, p_3,...) of the correct sequence is replaced by 1 simultaneously or respectively;

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

(4) Use GA to generate a sequence with the most likelihood to the received sequence, according to the candidate sequence A, following these steps:

a. Population initialization: The candidate sequence A is set as GA initial population;

b. Individual fitness assessment: Take correlation function

$$\lambda(v,w)=\sum_{i=1}^{n} v\cdot w \tag{2}$$

as the genetic fitness function to calculate the fitness of individual populations to generate the initial population, where v represents the received sequence which hasn't been hard-decided and w represents the candidate sequences;

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

d. Crossover: Generate new individuals by cross-matching the selected individuals. Crossover methods include one-point crossover and multi-point crossover. In this study, one-point crossover is selected, and the crossover rate is set to 0.9 (Block diagram is shown in Fig.2.);

e. Genetic mutations: Select individuals randomly from the new individuals generated in process d to conduct mutation operation, namely, certain symbol in the individual will turn from 0 to 1 or 1 to 0 as shown in Fig.3. Mutation rate in this study is set to 0.025;

f. Genetic termination: When the genetic number of generations reaches the preset genetic termination value, the individual with highest fitness in the last generation will be taken as output of the GA; if not, jump to step c. The genetic number of generations in this study is set to 20;

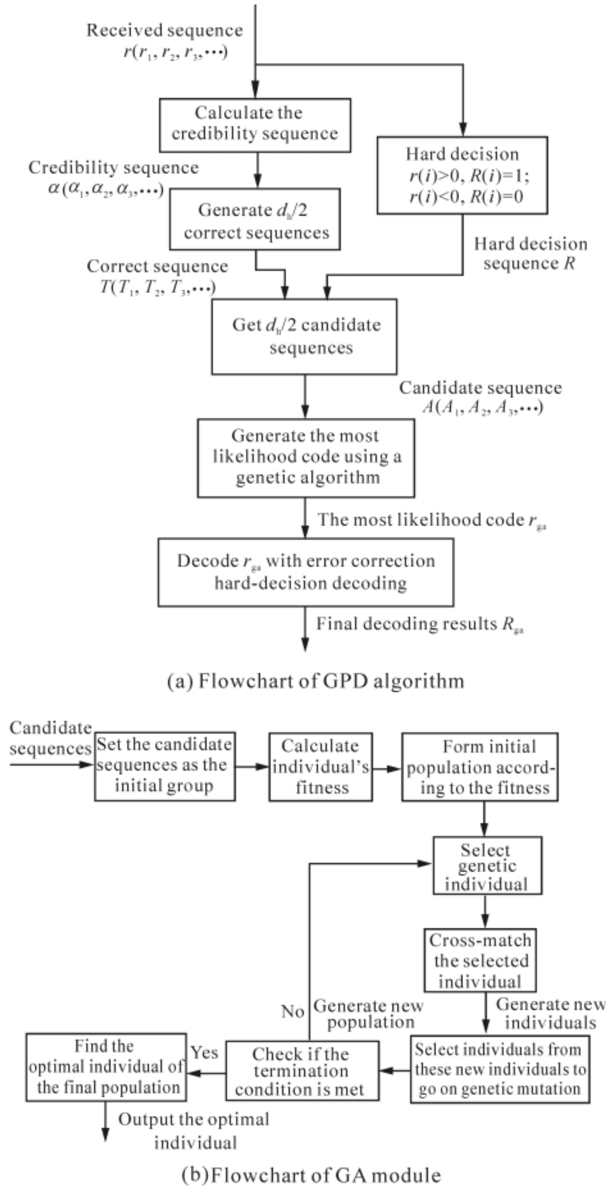

Fig.1 Flow diagram of probability decoding based on GA

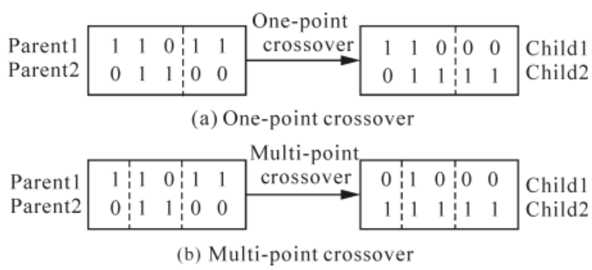

Fig.2 Block diagram of crossover

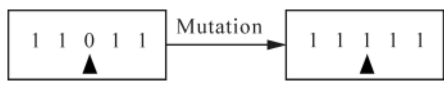

Fig.3 Schematic diagram of mutation

(5) To send the optimal output sequence of the GA into

the error correction hard decision decoder to conduct the error correction decoding, the final decoding result is got.

As can be seen from the above description of GPD algorithm, the GA's search space is only associated to population size which remains stable, whereas the population size is up to the minimum Hamming distance of code word, which means its search space won't expand exponentially with the code length. Although the GPD algorithm requires additional operations of selection, crossover and mutation, the computation of them can be ignored compared with the related operations of error-correction hard decision and probability decoding. As can be seen, the complexity of the GPD algorithm has a significant reduction compared with the traditional probability decoding algorithm, since the minimum Hamming distance is far less than the length of a code word. In this paper, the amount of computation of addition and multiplication needed in the algorithm is proposed to analyze the complexity of GPD algorithm. The complexity comparison of GPD, sub-optimal decoding algorithm (Chase2) and MLD related to linear block code (n, k, d_h, t) is shown in Tab.1, where *gen* means the genetic number, d_h is the minimum Hamming distance, and t is the error correction ability. Taking BCH code (63, 36, 11, 5) for example, the result is given in Tab.2.

Tab.1 Complexity comparison of GPD, Chase2 and MLD

Algorithm \ Complexity	MLD	Chase2	GPD
Multiplication calculation	$2^n n$	$2^{d_h/2}n+2nt(n+t)$	$2^{(d_h/2-1)}\times gen \times n+2t(n+t)$
Addition calculation	$2^n(n-1)$	$2^{d_h/2}(n-1)+n(2nt+2t^2-t)$	$2^{(d_h/2-1)}\times gen \times(n-1)+2t(n+t)-t+n$

Tab.2 Complexity comparison of GPD, Chase2 and MLD with BCH (63, 36)

Algorithm \ Complexity	MLD	Chase2	GPD
Multiplication calculation	5.8×10^{20}	44856	20840
Addition calculation	5.7×10^{20}	44509	20578

From the above analysis, we can see that the computation of the GPD algorithm is moderate, its complexity is much lower than that of the traditional probability decoding algorithm and is better than the traditional sub-optimal decoding algorithm.

Traditional probability decoding algorithms, such as MLD and Chase2, require to search object code word in the corresponding candidate code word space one by one, taking a lot of time, while the GPD algorithm inheriting the GA's parallel search capability can search the object code word independently and parallelly, which is very efficient. In addition, during the entire process, the GPD algorithm only needs one time of error correction hard-decision, which is supposed to take a lot of decoding time. As a result, the efficiency to achieve the target code word is greatly enhanced, so the overall decoding speed will be improved.

This section will discuss the decoding simulations of primitive BCH code (63, 36) under binary phase shift keying (BPSK) modulation and additive white Gaussian noise (AWGN) channel. For the purpose of performance comparison, the paper also simulates that with Chase2 and MLD decoding. In Fig.4, R represents the hard-decision result, BER is for the bit error rate, and EbN0 (dB) is on behalf of SNR.

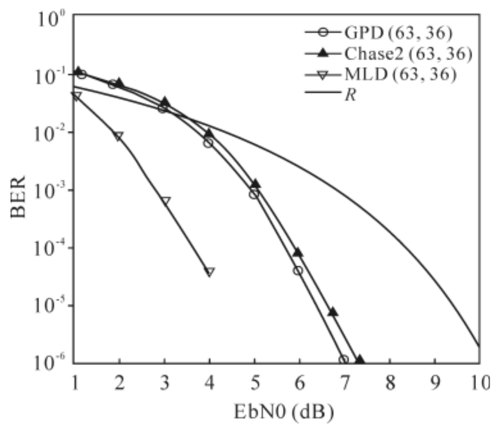

Fig.4 Simulation results on decoding performance of different algorithms for BCH (63, 36) code

From Fig.4 we can see bit error rate of the hard-decision output can be reduced in various degrees by operating different decoding algorithms on it. For example, when the bit error rate is 10^{-4}, MLD algorithm gains about 5.0 dB over the hard-decision output, GPD algorithm gains about 2.5 dB, and Chase2 algorithm gains about 2.3 dB. As can be concluded, MLD algorithm has the best error correction performance, followed by the GPD algorithm which is slightly better than Chase2 algorithm. Although the GPD algorithm can not obtain the gain as large as that of the MLD algorithm, MLD algorithm's calculation is too much to be suitable for practical application. What's more, the GPD algorithm can gain the same performance with traditional Chase2, while its complexity is only half of the latter. From the above analysis, it can be concluded that the GPD algorithm is an error correction decoding method with superior performance.

A new decoding algorithm of GPD for FEC code in optical transmission system based on GA is proposed. This algorithm takes full advantage of channel statistical information to further optimize the received sequence to restore the transmission information with high credibility. From the theoretical analysis and simulation results, the GPD algorithm presented in this paper is a lower-complexity decoding algorithm with high decoding speed and superior error correction performance. What's more, the GPD algorithm discussed in this paper is for block codes, which needs to predict the transmission code word's minimum Hamming distance. If the pattern is modified to generate the candidate code word according to the characteristics of other code, the GPD algorithm can be further extended to decoding for more types of codes.

References

[1] Nakazawa Masataka, Kikuchi and Tetsuya Miyazaki, High Spectral Density Optical Communication Technologies, New York: Springer, 2010.

[2] YUAN Jian-guo, YE Wen-wei and MAO You-ju, Journal of Optoelectronics • Laser **20**, 1450 (2009). (in Chinese)

[3] I. B. Djordjevic, W. Ryan and B. Vasic, Coding for Optical Channels, New York: Springer, 2010.

[4] YUAN Jian-guo, HE Qing-ping, LIANG Tian-yu and WANG Yong, Journal of Optoelectronics • Laser **23**, 1093 (2012). (in Chinese)

[5] W. C. Huffman and V. Pless, Fundamentals of Error-Correcting Codes, Cambridge University Press, 2003.

[6] Yuan Jian-guo, Wang Wang and Liang Tian-yu, Journal of Optoelectronics • Laser **23**, 906 (2012). (in Chinese)

[7] GUO Jian-zhong, Optoelectronics Letters **7**, 147 (2011).

[8] M. P. C Fossorier and S. Lin, IEEE Trans. Inform. Theory **IT-48**, 287 (2002).

[9] Aditi Koyhiyal, Oscar Y. Takeshita and Wenyi Jin, IEEE Trans. Commun. Lett. **9**, l067 (2005).

[10] Amal K. Ghosh, Optoelectronics Letters **6**, 325 (2010).

[11] J. H. Holland, Adaptation in Natural and Artifieal Systems, Ann Arbor: Miehigan University Press, 1975.

[12] Ahmed Azouaoui, Mostafa Belkasmi and Abderrazak Farchane, Journal of Electrical and Computer Engineering **10**, 1155 (2012).

[13] Hassan Berbia, Faissal Elbouanani, Rahal Romadi and Mostafa Belkasmi, World Academy of Science, Engineering and Technology **76**, 850 (2011).

[14] Chen Guoliang, Wang Xufa and Zhuang Zhenquan, Genetic Algorithm and its Application, Beijing China: Posts & Telecom Press, 2001.

[15] Kuk-Hyun Han and Jong-Hwan Kim, Genetic Quantum Algorithm and its Application to Combinatorial Optimization Problem, Proceedings of the 2000 Congress on Evolutionary Computation **2**, 1354 (2000).