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A novel hard decision decoding scheme based on genetic algorithm and neural network

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ABSTRACT

A novel hard decision decoding scheme based on a hybrid intelligent algorithm combining genetic algorithm and neural network, named as genetic neural-network decoding (GND), is proposed. GND offsets the reliability loss caused by channel transmission error and hard decision quantization by making full use of the genetic algorithm's optimization capacity and neural network's pattern classification function to optimize the hard decision outputs of received matched filter and restore a more likelihood codeword as the input of hard decision decoder. As can be seen from the theoretical analysis and computer simulation, GND scheme is close to the traditional soft decision decoding in error correction performance, while its complexity, compared with the traditional soft decision decoding, is greatly reduced because its decoding process does not need to use the channel statistical information.

1. Introduction

At present, error-correcting code technology has become an indispensable method to achieve the reliable and timely communication. However, the optimal decoding of error-correcting codes which is difficult to obtain good solutions in a reasonable time under the existing technical conditions, especially for the long code with complex structure, is in small range of application, due to its high computation complexity [1–3]. For today's high speed digital communication and information storage system are in great demand of high reliability and need to deal with large amount of data, the decoding problem has become a bottleneck of the development of error-correcting code's application.

Berlekamp had proven that the decoding of general error-correcting codes is essentially a class of NP (non-deterministic polynomial) complex problem, which can be equivalent to the processing of combinatorial optimization problem [4]. Intelligent algorithm as a kind of information processing technology that imitates adaptive optimization mechanism from the natural world to solve complex computational problem is introduced into the error-correcting code technique to solve decoding problem. From the point of view of information science, error-correcting decoding and intelligent algorithm are closely related in terms of theory, research methods and mathematical methods [5–8]. Therefore, it has the important theory significance and practical value to use adaptive intelligent optimization algorithm and fast parallel processing mechanism to solve the decoding technical problems of decoding of error-correcting code.

In this paper, two kind of intelligent algorithm: genetic algorithm (GA) and neural network (NN), are introduced into the traditional hard decision decoding technology to reduce the complexity of traditional soft decision decoding while ensuring the error correction performance. This novel decoding scheme is genetic neural-network decoding (GND).

2. Genetic algorithm and neural-network

2.1. Genetic algorithm

GA is a highly parallel, stochastic and adaptive optimization technique based on biological genetic evolutionary mechanisms. It simulates the natural process of genetic recombination and evolution, performing operations similar to natural selection, crossover and mutation to get the final optimization result after repeated iterations [9,10]. GA is with following main features:

(1) Parallelism: GA inherits the natural parallelism in the evolution process, that is 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, greatly enhancing the speed of problem solving.

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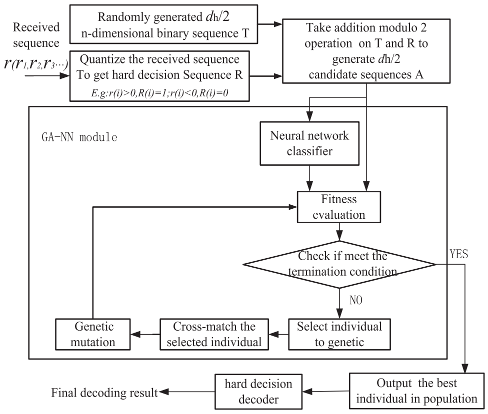

Fig. 1. GND decoding flow chart.

(2) Heuristic search: GA uses probabilistic transition rules to guide the search's direction, so individuals can change constantly to make sure the group move in the best direction of evolution, in a way of high quality of problem-solving.

When solving the optimization problem, GA needs to set its parameters according to the specific problems. These parameters include the size of individuals, crossover probability, mutation probability and genetic termination conditions.

2.2. Neural-network

NN is good at extracting meaning from complex or imprecise data, that is used to extract the complex patterns and detection which is difficult for human or other computer technology. Based on a certain learning algorithm, NN can adjust the state of the network according to the environment of the data. The learning algorithm described how neural network adjusts the state of network according to training data [11].

When given an input, a trained NN can provide a very similar prediction to target results. The characteristics of neural network include [12]:

(1) Adaptive learning: NN can learn from a given initial training or experience to complete the task of data.
(2) Self-organizing: NN can self-build their own structure or show the received information in the learning process.
(3) Real-time operation: NN can calculate in parallel and this ability can be taken advantage of in the design and production of special hardware equipment.
(4) Fault-tolerance: For some network, local destruction will lead to degradation of the corresponding performance. However, even with the main part of the neural network is damaged, the network can still use some functions.

3. GND decoding scheme

In the GND decoding scheme, NN is added into the fitness evaluation mechanism of GA, as shown in Fig. 1. Taking block codes (n, k) as an example, in the fitness evaluation mechanism, NN as a pattern classifier will classify genetic individual according to the Hamming distance between codeword represented by genetic individual and closest available codeword. Genetic individual with the some Hamming distance will be classified as a class.

The classification is operated by mapping syndrome sequence related to genetic individual into their corresponding coset leader's weight according to the one-to-one corresponding relation between syndrome sequence and coset leader in the decoding standard array. The neural network's output will serve as the compensation factor into the evaluation mechanism of genetic algorithms to further enhance the optimization performance of genetic algorithm.

3.1. Decoding scheme model

Taking linear block code (n, k) as an example, Implementation of GND decoding scheme can be described as following:

(1) Train neural networks: neural network in GND case is shown in Fig. 2. As a classifier, it consists of three layers, namely the input layer, hidden layer and output layer. The input layer consists of $(n-k)$ neurons; hidden layer consists of $(2/3)(n-k+t+1)$ neurons, where k is the number of bits of information code, t is the maximum number of error able to be corrected; output layer has 1 neuron. The train operation is conducted according to the following steps: the syndrome sequences are taken as input training patterns, while the weight of corresponding error patterns as the target output. When getting a syndrome sequence, the trained network will export the weight of corresponding error patterns. Syndrome sequences can be obtained by codeword R represented by genetic individual and parity-check matrix H, shown in following formula.

$$S = R \cdot H' \tag{1}$$

According to the minimum distance decoding, the larger the Hamming distance between a codeword and its closest available codeword is, the greater the weight of its corresponding coset leader in the decoding standard array will be, as well as the number of error bits and the output value of neural network.

(2) Generate a more likelihood codeword: by making the use of genetic algorithm to obtain a more likelihood codeword with received sequence, following these steps:
- Population initialization:
  Generate 2^t binary vectors with length n as the initial population.
  (a) First individual members P_1: the hard decision sequence $R(r_1, r_2, \ldots, r_n)$ as output of match filter is set to the first individual populations:

$$P_1 = R(r_1, r_2, \ldots, r_n), r_i = \begin{cases} 1, & q_i > 0 \\ 0, & q_i \le 0 \end{cases} \quad 0 < i < n \tag{2}$$

  $Q(q_1, q_2, \ldots, q_n)$ is the received real number sequence without quantized by matching filter.
  (b) Other $2^t - 1$ individual members P_i will be obtained by randomly generated uniform binary sequence $T(t_1, t_2, \ldots, t_{2t-1})$and hard decision sequence $R(r_1, r_2, \ldots, r_n)$, as shown in formula (3).

$$P_i = \mathrm{mod}(R + T, 2), \quad 2 \le i \le 2^t, \quad T = rand[0, 1] \tag{3}$$

- Individual fitness assessment:
  Calculate the fitness of individual populations according to the following formula.

$$\text{Fitness} = \lambda(P, Q) - \underbrace{\text{Weight}(\text{error} \quad \text{class}(\text{Indiv.}))}_{\text{Penalty}} \tag{4}$$

  (a) $\lambda(P,Q)$ is the correlation function, used to calculate the Euclidean distance between P_i and received real number sequence Q. The more similar the individual is to Q, the larger the value of λ will be.

$$\lambda(P, Q) = \sum_{i=1}^{n} p_i \cdot q_i \tag{5}$$