Survey on Spectrum Prediction Methods via Back Propagation Neural Network

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Abstract. Spectrum prediction is one of the key technologies of cognitive radio. With the development of electronic warfare, the concept of cognitive electronic warfare has been put forward. At the moment, as one of the key technologies of cognitive electronic warfare, spectrum prediction is also very important. In reality, it is difficult to predict the use of licensed spectrum, and it is more difficult to predict the enemy's spectrum in enemy operations. In this paper, the existing spectrum prediction research is introduced. According to their shortcomings, a method of spectrum prediction is proposed, which improves the BP neural network by using tabu search algorithm.

Keywords: BP neural network · Spectrum prediction · Tabu search

1 Introduction

With the development of communication technology, people are demanding more and more electronic warfare, expecting electronic warfare to have the same thinking and learning ability as people, so people put forward the concept of cognitive electronic warfare. The emergence of cognitive electronic warfare is an inevitable development of electronic warfare technology. In the electronic warfare technology, equipment with a digital, software based on the ability to continue to cognitive (or intelligent) is a matter of course [20]. In the cognitive warfare, the spectrum prediction of the enemy is a prerequisite for interference with enemy communications.

As one of the key technologies of cognitive radio, today's spectrum prediction is mainly to minimize the interference caused by unauthorized users to authorized users, and to find spectrum holes (That is, some bands or timeslots that are not fully used by unauthorized users) to allow unauthorized users use. In this way, the spectrum utilization can be improved. Therefore, in recent years, spectrum prediction has received extensive attention in the field of communication.

At present, the commonly used spectrum prediction method can be attributed to neural network prediction method, regression analysis based forecasting method, based on Markov chain prediction method and data mining

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method [11]. Among them, the neural network method has a good non-linear mapping ability, has been applied to the field of cognitive radio. Spectrum prediction played a very good role.

2 Fundamentals

Back Propagation (BP) neural network is a feed-forward artificial neural network model. It can establish a proper mapping relation between input data set and output data set [21]. BP neural network learning process is divided into two processes: positive and reverse transmission. When propagating forward, the input data is passed from the input layer of the network, through the hidden layer, and finally to the output layer. When the output data of the output layer is not equal to the expected value, the reverse propagation of the error is performed. The reverse propagation process of error is that the error is transmitted through the hidden layer to the input layer, the error is distributed in the hidden layer, and the error is distributed to each unit. In the process of forward propagation and backward propagation, we continuously adjust the weights and thresholds to get a better BP neural network.

In the BP neural network model, the application of the single hidden layer network (three layer feed forward network) as shown in Fig. 1 is the most common. It mainly includes input layer, hidden layer and output layer.

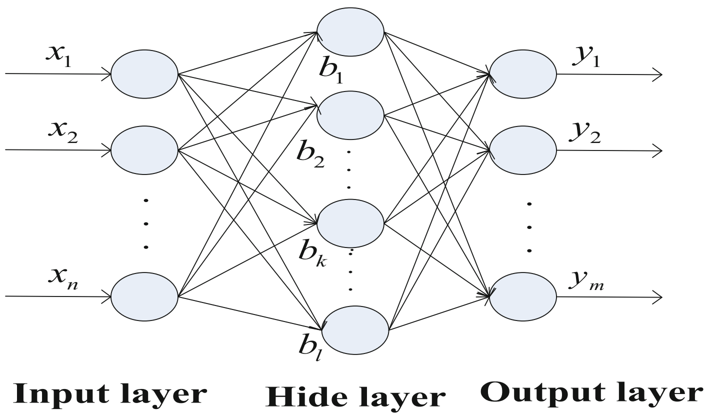

Fig. 1. BP neural network. Three layers of BP neural network, the eigenvalues $x_1, x_2, ..., x_n$ are input by the input layer, through the hidden layer, and finally to the output layer.

In this 3-layer BP neural network, there are n input neurons, m output neurons, l hidden neurons. The input of each layer is only related to the output of the previous layer. The input of the input layer is $X = (x_1, x_2, ..., x_i, ...x_n)^T$, The output of the output layer is $Y = (y_1, y_2, ..., y_j, ...y_m)^T$. Assume that the connection weights between the ith neurons of the input layer and the kth neurons of the hidden layer is v_{ik}, it is assumed that the connection weight between the kth neuron of the hidden layer and the jth neuron of the output layer is w_{kj}.

It is well known that the ideal activation function is a step function, but the step function is not smooth, discontinuous and other shortcomings, in practice commonly used sigmoid function as an activation function, Sigmoid function mathematical expression:

$$Sigmoid\,(x) = \tfrac{1}{1+e^{-x}} \tag{1}$$

Assuming that the neurons of the hidden layer and the input layer use the Sigmoid function as the activation function, the training sequence (x_k, y_k), we can give the formula:

$$\tilde{y}_j^k = f(\beta_j - \theta_j) \tag{2}$$

Among them, β_j $(\beta_j = \sum_{k=1}^{l} w_{kj} b_k)$ is represents the input received by the jth neuron of the output layer. θ_j is the threshold of the jth neurons in the output layer. Thus, the mean square error can be expressed as:

$$E_f = \tfrac{1}{2}\sum_{j=1}^{l}(\tilde{y}_j^f - y_j^f) \tag{3}$$

In the above BP neural network, $(m + n + 1)k + m$ parameters are determined. On the Eq. (3) in the error E_f, we give the learning rate η, there is:

$$\varDelta\omega_{kj} = -\eta\tfrac{\partial E_f}{\partial \omega_{kj}} \tag{4}$$

ω_{kj} first affect the jth output neuron input value β_j, and then affect its output value $\tilde{y}_j^k$, and finally affect E_f, so

$$\tfrac{\partial E_f}{\partial \omega_{kj}} = \tfrac{\partial E_f}{\partial \tilde{(y)}_j^k} \cdot \tfrac{\partial \tilde{(y)}_j^k}{\partial \beta_j} \cdot \tfrac{\partial \beta_j}{\partial \omega_{kj}} \tag{5}$$

And because the Sigmoid function has the following properties:

$$f'(x) = f(x)(1 - f(x)) \tag{6}$$

According to Eqs. (2) and (3) calculated:

$$\begin{aligned} g_j &= -\tfrac{\partial E_f}{\partial \tilde{(y)}_j^k} \cdot \tfrac{\partial \tilde{(y)}_j^k}{\partial \beta_j} \\ &= \tilde{(y)}_j^k(1 - \tilde{(y)}_j^k)(y_j^k - \tilde{(y)}_j^k) \end{aligned} \tag{7}$$

After the calculation, we get the weight between the hidden layer and the output layer. The formula is:

$$\varDelta\omega_{kj} = \eta g_j b_h \tag{8}$$

Similarly, we can deduce:

$$\Delta\theta_j = -\eta g_j \tag{9}$$

$$\Delta v_{ik} = \eta e_k x_i \tag{10}$$

$$\Delta\gamma_k = -\eta e_k \tag{11}$$

Among them, γ_k represents the threshold of the kth neurons in the hidden layer. In the formulas 10 and 11, e_k is:

$$\begin{aligned} e_k &= -\frac{\partial E_f}{\partial b_k} \cdot \frac{\partial b_k}{\partial \alpha_k} \\ &= -\sum_{j=1}^{m} \frac{\partial E_f}{\partial \beta_j} \cdot \frac{\partial \beta_j}{\partial b_k} f'(\alpha_k - \gamma_k) \\ &= \sum_{j=1}^{m} \omega_{kj} g + j f'(\alpha_k - \gamma_k) \\ &= b_k(1 - b_k) \sum_{j=1}^{m} \omega_{kj} g_j \end{aligned} \tag{12}$$

The goal of the BP neural network is to minimize the cumulative error on the entire training set.

$$E = \frac{1}{n} \sum_{f=1}^{n} E_f \tag{13}$$

So, we have to continue to train the data, adjust the network weights and thresholds [23].

3 Spectrum Prediction and Analysis

In recent years, spectrum prediction is mainly in the field of cognitive radio. The spectrum prediction technology in cognitive radio system mainly includes four aspects: channel state prediction, authorized user activity prediction, radio environment prediction and transmission rate prediction [14]. There is little research on the prediction of spectrum in enemy operations. In the context of the information age, with the development of cognitive electronic warfare technology, the prediction of the enemy spectrum is also particularly important.

In 2005, Zhang et al. conducted a statistical analysis of the wireless signals in the district. Based on the analysis method of Box-Jenkins, Auto Regression (AR), Moving Average (MA) and Autoregressive Integrated Moving Average (ARIMA) models were used to simulate and predict the measured data, and then the model data were analyzed by using the time series analysis method. An error analysis was performed [7]. In 2008, they used SPSS statistical tools and Box-Jenkins modeling method in time series to establish the AR, MA, ARMA (Auto-Regressive and Moving Average) and ARIMA models respectively to analyze and forecast the measured data, and can predict the trend of the wireless signal in the short term [6]. It is possible that they were the first to propose and study spectrum prediction. Since then, the spectrum predicted to enter people's field of vision.

In order to achieve the purpose of improving the spectrum utilization, some people have proposed the use of Markov's method. In 2012, Tang et al. proposed a hybrid spectrum switching algorithm combining passive spectrum switching with active spectrum switching. The algorithm is based on the continuous time Markov chain model of the main user channel, predicts the future state information of the channel, and periodically performs active spectrum switching on the cognitive user who is communicating in accordance with the prediction result. Hybrid spectrum switching algorithm can significantly improve the spectrum utilization of cognitive wireless networks [14]. In 2014, In order to improve the prediction complexity and reduce the prediction complexity, Liu proposes a spectral forecasting method combining the hidden Markov model with the context variable Markov model. This method can eliminate the influence of the spectrum detection error on the prediction performance. Based on the spectral data generated by the queuing model, the validity of the variable-length Markov method based on the context tree is verified in a stable environment and a non-stationary environment, respectively. In this paper, we use the data of the spectrum generated by the queuing model and the discrete time Markov model to verify the validity of the algorithm of the hidden Markov model and the context tree variable length Markov model in the presence of detection error [15]. In 2011, Liu et al. also proposes a dynamic cognitive radio spectrum access technology based on joint probability channel prediction (HMCP) based on hidden Markov model (HMM). The technical scheme can effectively improve the spectrum utilization rate of the cognitive users while reducing the interference of the cognitive users to the authorized users [16].

In the field of spectrum prediction of cognitive radio, the neural network method is often used by people. In 2011, Chen proposed a spectral model combined with the M/M/N queuing model, proposed a method of learning and forecasting the spectral cavity information by using the back propagation neural network, and by using the spectrum analyzer to collect the actual spectrum data as the simulation data, Which verifies the effectiveness of the method [9]. In 2014, Xu et al. proposed a cognitive radio spectrum prediction method based on SVM (Support Vector Machine), which significantly reduced the energy consumption of spectrum sensing, improved the spectrum utilization rate and had a good application prospect in cognitive radio prediction [11]. In 2011, Wang proposed a neural network prediction method. The spectrum of the cognitive radio is predicted by the network and the optimal spectrum is selected for the predicted results [12]. In 2014, Lan et al. Designed a three-step advanced spectrum prediction framework based on the neutral network. The genetic algorithm is used to optimize the neural network. Finally, this method is more suitable for the prediction of cognitive radio than Multi-layer Perceptron (MLP) [5]. In 2015, Huk and Mizera-Pietraszko made an experiment to analyze the predictive performance of Sigma-if neural network and Multi-layer Perceptron (MLP) network. The results show that Sigma-if neural network predicts better performance [4]. In 2011, Xian et al. proposes a chaotic neural network prediction mechanism for the remaining time of the channel state, and uses the chaos prediction to analyze and forecast the remaining time of the channel. The experimental results show that the prediction accuracy can reach more than 90%, which verifies the effectiveness of the prediction mechanism [17]. In 2016, Chen et al. proposed a spectrum support algorithm for weighted support vector machines, which changes the weights of key parameters in support vector machines based on signal reception signal-to-noise ratio and sampling time. The algorithm can improve the accuracy of the support vector in the cognitive radio prediction results [18]. In 2013, Li proposed a neural network spectrum prediction method based on DE-BP. The standard differential evolution (DE) algorithm and the BP algorithm are combined to introduce the neural network-based spectrum prediction, which saves the perception time and reduces the impact of unauthorized users on authorized users [22].

Neural networks have their own advantages in solving non-linear predictive problems, but there are some other ways. In 2014, Xing studied the problem of cooperative spectral state prediction in cognitive radio networks, and proposed a new cooperative spectral state prediction method to improve the accuracy of spectral state prediction [8]. In 2016, Eltholth uses wavelet neural network (WNN) to predict future channel occupancy. And the simulation of 100–200 MHz band is carried out to verify the effectiveness and accuracy of WNN in spectrum prediction [1]. In 2015, Bai et al. proposed the use of genetic algorithm and momentum algorithm to improve the BP neural network, customer service BP neural network shortcomings, and finally, verify the theory [2]. After 2016, Yang et al. also proposed a genetic algorithm to improve the BP neural network model for the field of spectrum prediction [3]. In 2016, Zang has improved the available time prediction algorithm for existing channels, and proposed two kinds of spectrum switching strategies based on the channel available time prediction. Compared with the traditional random passive switching strategy, it can greatly reduce the collision probability between the cognitive user and the authorized user, and can verify its validity [10]. In 2009, Yang et al. proposed a new access mechanism to predict future spectrum activity based on past and current spectrum activity of the primary user, so that the secondary user can access the band with high availability and reduce the possibility of collision with the primary user. It can be seen from the simulation experiment that compared with the traditional access mechanism and the access mechanism without threshold, the proposed scheme can effectively reduce the collision rate between primary and secondary users [13]. In 2012, Li et al., in order to find the airspace and energy domain conditions needed to satisfy the electromagnetic compatibility between the main user network and the cognitive radio network, consider the influence of distance, atmospheric loss and visual distance on the interdiffusion intensity and work efficiency, This method is of great significance for more efficient use of spectrum resources [19].

Cognitive radio spectrum prediction technology has been quite mature, we can learn from these spectrum prediction means, applied to cognitive electronic warfare, lay the foundation for the development of electronic warfare.

4 Conclusion

Although the artificial neural network has developed rapidly in recent years, the artificial neural network is only a simple simulation of the human brain. By summing up the above research results, although there are also neural network algorithm applications, but there is no real solution to some of the problems of neural networks. In this regard, according to the research progress summarized in this paper, we can think of spectrum prediction is expected to be applied in the future Cognitive electronic warfare. By improving the BP neural network by the tabu search algorithm, the BP neural network can improve the convergence rate slowly and easily fall into the local minimum. So as to realize the spectrum prediction in the field of cognitive electronic warfare.

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