Channel and Modulation Selection Based on Support Vector Machines for Cognitive radio

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Abstract

Channel and modulation selection strategy is an import factor for cognitive radio. In many conditions there are some different channels and modulation methods for the radio to choose. The strategy based on Support Vector Machines is proposed for cognitive radio. The cost of each chosen method grade by a fuzzy function is the input data and the algorithm can decide witch method is the best one, as the expert system. This algorithm is the computational intelligence application in cognitive radio.

Keywords: cognitive radio, support vector machines, fuzzy function

1. Introduction

It is commonly believed that there is a spectrum scarcity at frequencies that can be economically used for wireless communications. This concern has arisen from the intense competition for use of spectra at frequencies below 3 GHz. The Federal Communications Commission's (FCC) frequency allocation chart indicates overlapping allocations over all of the frequency bands, which reinforces the scarcity mindset. On the other hand, actual measurements are believed to indicate low utilization, especially in the 3-6 MHz bands [1]. This view is supported by recent studies of the FCC's Spectrum Policy Task Force who report [2] vast temporal and geographic variations in the usage of allocated spectrum with utilization ranging from 15% to 85%. In order to utilize these spectrum 'white spaces', the FCC has issued a Notice of Proposed Rule Making(NPRM-FCC 03-322 [3]) advancing Cognitive Radio (CR) technology as a candidate to implement negotiated or opportunistic spectrum sharing.

Wireless systems today are characterized by wasteful static spectrum allocations, fixed radio functions, and limited network coordination. Some systems in unlicensed frequency bands have achieved great spectrum efficiency, but are faced with increasing interference that limits network capacity and scalability. Cognitive radio systems offer the opportunity to use dynamic spectrum management techniques to help prevent interference, adapt to immediate local spectrum availability by creating time and location dependent in "virtual unlicensed bands", i.e. bands that are shared with primary users. Unique to cognitive radio operation is the requirement that the radio is able to sense the environment over huge swaths of spectrum and adapt to it since the radio does not have primary rights to any pre-assigned frequencies. This new radio functionality will involve the design of various analog, digital, and network processing techniques in order to meet challenging radio sensitivity requirements and wideband frequency agility.

Computational intelligence has its potential application in cognitive radio. The development of wireless communication should have the intelligence ability to change its working model and face the changing environment. The adaptive channel and modulation selection is a basic ability for CR to choose the best channel and modulation that the primary user keeps silence.

Support vector machine, as a powerful computational intelligence theory, is widely used in quadratic programming (QP) problems. Many expert systems organized based on SVM. In this paper, we describe the adaptive channel and modulation selection system in CR as an expert system, which based on SVM too.

2. SVM Models of CR Channel and Modulation Selection

2.1 Linear Programming Base on SVM

SVM is used to solve the programming problems. Support the training serials $T=\{(\mathbf{x}_1,y_1),\ldots(\mathbf{x}_N,y_N)\}$, where $\mathbf{x}_i=(x_{i1},\ldots x_{il},)$ is the input vector, $y_i\in\pm1$. The aim of the linear programming is to design an FIR filter **w** and constant value b, to get the decision function:

$$f(x)=\operatorname{sgn}((\mathbf{wx})+b) \quad (1)$$

In cognitive radio application, the input vector $\mathbf{x}_i$ contains the channel environment and modulation information. For instance, the frequency band, signal to noise rate (SNR) or the noise energy, different modulation model, and other CR user's information, etc. The output $y_i\in\pm1$ is the result that whether this combination of frequency band and modulation model is workable.

Minimize the cost function of the programming problem [4]:

$$J(\alpha)=\frac{1}{2}\sum_{i=1}^{N}\sum_{j=1}^{N}y_i y_j \alpha_i \alpha_j \langle \mathbf{x}_i \cdot \mathbf{x}_j \rangle - \sum_{j=1}^{N}\alpha_j \quad (2)$$

subject to $\sum_{i=1}^{N} y_i \alpha_i = 0$, (3)

$0 \le \alpha_i \le C$, i=1,…N

where C is a penalty value, $\langle \cdot \rangle$ is the immultiply, and $\boldsymbol{\alpha}=(\alpha_1,\ldots\alpha_N)^T$ is the positive Lagrange multipliers that according to the Karush-Kuhn-Tucker (KKT) conditions [4]:

$$\nabla_x J(\mathbf{x},\boldsymbol{\alpha},\boldsymbol{\beta}) = \nabla f(\mathbf{x}) + \sum_{i=1}^{p}\alpha_i \nabla c_i(\mathbf{x}) + \sum_{i=p+1}^{p+q}\beta_i \nabla c_i(\mathbf{x}) = 0$$

$$c_i(\mathbf{x}) \le 0 \quad i=1,\ldots,p$$

$$c_i(\mathbf{x}) = 0 \quad i=p+1,\ldots,p+q$$

$$\alpha_i \ge 0 \quad i=1,\ldots,p$$

$$\alpha_i c_i(\mathbf{x}) = 0 \quad i=1,\ldots,p$$

where $f: R^n \to R$ and $c_i: R^n \to R \quad (i=1,\ldots p)$ are differentiable quadratic functions and $c_i \quad i=p+1,\ldots,p+q$ are linear functions.

Calculate $\mathbf{w} = \sum_{i=1}^{N} y_i \alpha_i \mathbf{x}_i$ (4)

choose a positive α_j less than C from $\boldsymbol{\alpha}$, then calculate

$$b = y_j - \sum_{i=1}^{N} y_j \alpha_j \langle \mathbf{x}_i \cdot \mathbf{x}_j \rangle \quad (5)$$

we can get the decision function (1).

In the SVM based channel and modulation selection system, the measure of different cognitive radio information is important, which determined the performance of the output y_i.

The most difficult work is to correspond with the information and data values. Noise energy can be measured by cooperating between communicators. Different frequency band has different performance for different communication operation, and also different modulations. The ability of the cognitive radio itself is also an important constrain, for example, the calculate ability, the size of the ROM and RAM, and the length of equalizer. And the CR network's information is also important for decision function.

Many papers and academic works [5] have established some channel models, which are very useful for the CR applications. Input vector $\mathbf{x}_i$ can be expressed as: $\mathbf{x}_i$ ={frequency band$_i$, noise energy$_i$, modulation model$_i$, other CRs impact$_i$, CR ability, CR network information}. In fact, $\mathbf{x}_i$ is the parameter vector of the environment and CR itself.

To determine the value of this parameters, we need a grade criterion to quantitative them. Frequency band is not the data value of the frequencies but the channel characters for different communication operations. For example, 800 MHz band is better than 3 GHz band for cell phone. Different modulation models fit for different channel characters. Quaternary phase shift keying (QPSK) fit for the serious SNR circumstance; but quadrature amplitude modulate (QAM) has a high work efficiency. Communicate with other CRs, the compute speed and memory size should be the real value. CR network could provide other CR's working information, as the numbers of them and their priority.

Training process is needed for SVM, as common intelligence system. Basic strategy can be trained theoretically and as some basic rules for CR before practical application. Some appointed training process can make those basic rules.

Take basic combination as the input vector $\mathbf{x}_i$, and the appointed result $y_i \in \pm 1$ into SVM algorithm. Minimize the cost function (2), finally we get the decision function (1). In practical application, input the environment information vector, the SVM algorithm will give the result by (1) $y_i \in \pm 1$, to determine whether this channel and modulation model makes a good performance.

2.2 Regression Programming Based on SVM

In many applications, the output of SVM is only +1 or − 1 brings some problems, for instance, if the output of y_i has more than one +1, which channel and modulation model could CR select? So the soft decision function based on regression programming is more useful than the linear programming decision function.

Output of regression programming problem is any real number, not only ± 1. Soft decision has its predominance for CR, which can use the most appropriate combination of channel and modulation model.

Suppose the known training serial, $T=\{(\mathbf{x}_1,y_1),\ldots(\mathbf{x}_N,y_N)\}$, where $\mathbf{x}_i=(x_{i1},\ldots x_{il},)$ is the input vector, $y_i \in \mathbf{R}$, i=1,…,N. Choose the appropriate positive value ε and C; and the kernel $\mathbf{K}$(x,x'). Then minimize the cost function [4]:

$$\frac{1}{2}\sum_{i,j=1}^{N}(\alpha_i^* - \alpha_i)(\alpha_j^* - \alpha_j)K(\mathbf{x}_i,\mathbf{x}_j) + \varepsilon\sum_{i=1}^{N}(\alpha_i^* - \alpha_i) - \sum_{i=1}^{N} y_i(\alpha_i^* - \alpha_i) \quad (6)$$

subject to $\sum_{i=1}^{N}(\alpha_i - \alpha_i^*) = 0$ (7)

$0 \le \alpha_i, \alpha_i^* \le \frac{C}{N}$ i=1,2,…,N

the optimal result $\boldsymbol{\alpha}=(\alpha_1, \alpha_1^*,\ldots,\alpha_N, \alpha_N^*)^T$.

Then the decision function can be constructed as:

$$f(x) = \sum_{i=1}^{N}(\alpha_i^* - \alpha_i)K(\mathbf{x}_i,\mathbf{x}) + b \quad (8)$$

parameter b can be calculated as:

choose α_j or $\alpha_k^* \in \left(0, \frac{C}{N}\right)$; if α_j

then $b = y_j - \sum_{i=1}^{N} (\alpha_i^* - \alpha_i) \langle \mathbf{x}_i \cdot \mathbf{x}_j \rangle + \varepsilon$

else if α_k^*

then $b = y_k - \sum_{i=1}^{N} (\alpha_i^* - \alpha_i) \langle \mathbf{x}_i \cdot \mathbf{x}_k \rangle - \varepsilon$

The result of this regression programming is a real number, decided by equation (8). CR can make a decision which combination is better in different conditions. Soft decision always performs better than hard decision, for the difference between results is more exact.

3. Expert System for CR Channel and Modulation Selection with Fuzzy Decision

Intelligence of CR finally results in expert system. The selection of channel and modulation model is decided by the controller as an expert. Expert system for CR based on SVM is proposed in this paper.

CR has many kinds of different modulation models, and can work in different frequency band [6]. The expert system is not changeless. First of all, the basic rules should be guide lines for CR. The CR itself can grade the performance of selected channel and modulation model, the criterion can be bit error rate (BER) or some others in a successful communication process. Then the expert system, use the SVM algorithm, to change the decision function (8), and update the rules itself. Flexibleness of CR determined that stabilized model wouldn't perform very well. And the expert system is also an adaptive system.

Figure 1 illustrated the adaptive update step for the CR expert system. First operation is the basic rules which have been trained by some theory methods, as a guide line for decision. In practical application, this expert system can grade the performance of chooses. Then CR can update the decision function by SVM algorithm. At this time y_i is the grade result.

Grade criterion is an important factor, which determined the performance of this expert system. We propose the BER as a criterion. In practice, BER is not calculated exactly. So the fuzzy distribution is needed to solve this problem, which is another computational intelligence.

In fuzzy mathematics, the fuzzy distribution contains following forms [7]:

A. Gauss distribution:

$$\mu(y) = \exp\left\{-\left(\frac{y-a}{b}\right)^2\right\} \qquad b > 0$$

B. Γ distribution:

$$\mu(y) = \begin{cases} 0 & y < 0 \\ \left(\dfrac{y}{\lambda v}\right)^v \cdot \exp\left(v - \dfrac{y}{\lambda}\right) & y \ge 0 \end{cases}$$

where λ>0, v>0.

C z-shaped distribution

$$\mu(y) = \begin{cases} \dfrac{1}{1+[a(y-c)]^b} & y > c \\ 1 & y \le c \end{cases}$$

where a>0, b>0.

D s-shaped distribution

$$\mu(y) = \begin{cases} 0 & y < c \\ \dfrac{1}{1+[a(y-c)]^b} & y \ge c \end{cases}$$

where a>0, b<0.

Grade criterion factor finally transformed into usable data values, and then the SVM algorithm can be workable.

Fuzzy decision plays an important role not only in the update progress, but also in the SVM input vector $\mathbf{x}_i$. Input information mentioned in section 2.1 also needs a grade criterion.

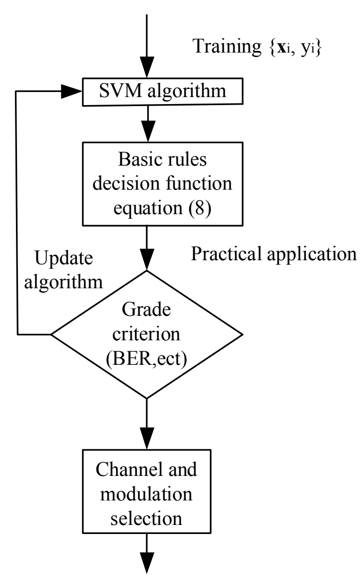

Fig 1. update the expert system

4. Simulation Result

In this section, the fuzzy function used for grade criterion is simulated. The result of this grade is used in the training serials. Training operation for SVM algorithm is common method in adaptive signal processing. Considering those factors, the simulation work illustrated fuzzy decision only.

Three different channel and modulation models have been simulated. They are the 4PSK and 64QAM modulation in adds white Gaussian noise (AWGN) channel, and 4PSK modulation in Rayleigh channel.

BER in different condition have analyzed by MATLAB in different SNR (0-20 dB), illustrated in figure 2.

Choose s-shaped distribution as the fuzzy decision function:

$$\mu(y) = 1 \Big/ \left\{1 + [300 \cdot (y - 0.0001)]^2\right\}$$

Then the grade criterion by BER is changed into a fuzzy decision, which have illustrated in figure 3.

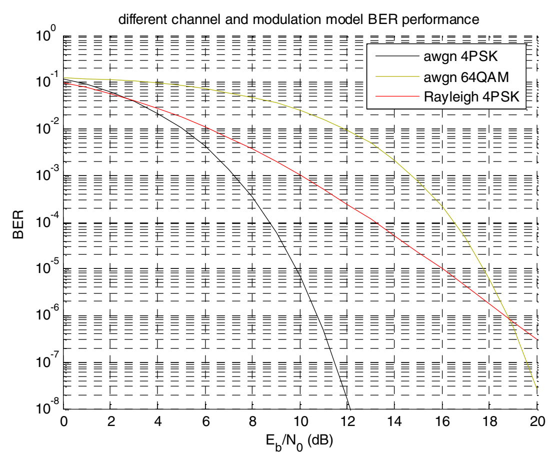

Fig 2 different channel and modulation model BER analyze

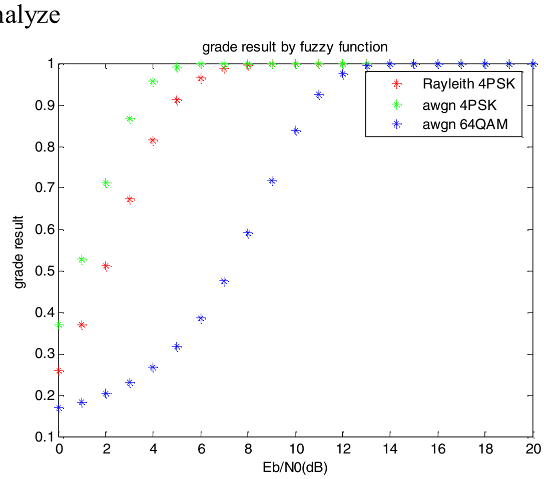

Fig 3 grade result by fuzzy function operated on BER

Form fuzzy function, the grade result is easily used for update operation. Directly use of BER (which is a small value) may amplify the added noise, but the fuzzy function will make the result convergence.

5. Conclusion

In this paper, channel and modulation selection for cognitive radio based on support vector machines is proposed. The purpose of this paper is to application computational intelligence in CR. Fuzzy mathematics is another important application, which is a proper grade criterion for SVM training operation, as illustrated in Fig 2 and Fig 3. With the improving of computational intelligence, CR will be more flexible and intelligent.

6. References

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