Modeling for Mobile Communication Fading Channel Based on Regression Support Vector Machine

Jingwen Tian, Meijuan Gao
Department of Automatic Control
Beijing Union University
Beijing, China
ttjjww999@163.com

Shiru Zhou
Department of Automatic Control
Beijing Union University
Beijing, China
ttgg500@163.com

***Abstract*—Aimed at the complicated and nonlinear relationship between input and output property of wireless channel and the advantages of support vector machine (SVM), a method for wireless channel modeling and simulation based on regression SVM is presented in this paper. The SVM network structure for communication fading channel modeling is established. Moreover, we propose a self-adaptive parameter adjust iterative algorithm to confirm SVM parameters, thereby enhancing the convergence rate and the forecasting accuracy. We discussed the fading channel model and analyzed the impact factor of little-scale fading channel modeling. With the ability of strong nonlinear function approach and fast convergence rate and well generalization of SVM, the modeling method can implement the modeling and simulation of fading channel rapidly and effectively by learning the propagation characteristic information of wireless channel. The simulation result shows the feasibility and validity of modeling method.**

Keywords- mobile communication; fading channel; modeling; support vector machine

I. INTRODUCTION

Mobile communication is one of the communication fields what are developing fastest, while the modeling of wireless channel is a difficulty for analysis and designation of mobile communication. The main assignment of mobile communication fading channel modeling is to acquire the propagation characteristic of wireless channel like fading, frequency shift, time-delay, etc, according to measuring or theoretic analysis, and then describe the property with mathematical model, which will simulate the changes experienced by signals transmitted in the real environment as real as possible.

According to different modeling method, wireless channel model can be divided into certain model based on theory computing and statistical model based on real-measured data. The certain model generally analyzes the propagation characteristic of electric wave in wireless environment using electromagnetic field theory, and describes the wireless channel with various mathematic models. However, this method always requires some supposed condition to simplify the mathematic model of wireless channel, so this kind of description has relative big difference with real channel condition. The statistical model generally gets the data of channel character according to electric wave real-measuring experiment under different transmitting environments. Some useful results can be obtained by statistical and analysis of real-measured data. The statistical model has being an important method for research of mobile communication channel.

Artificial Neural Network (ANN) is a new development technique in recent years, its ability of nonlinear function approach and the ability of self-adaption learning had been studied both in theory and application [1]. At present, The ANN has been used in the modeling of wireless communication channel, along with its nonlinear mapping capability and data processing character. Some researcher has used BP network to build an appropriate simulating model for wireless channel [2]. But the BP has some problems such as converge to local minimum, the overfitting and the structure of ANN is always decided by experience because it doesn't have a good guiding theory.

Support Vector Machine (SVM) proposed by Vapnik is a newly developed technique which based on statistical learning theory [3]-[4], it adopts Structure Risk Minimization principle which avoids local minimum and effective solves the over learning and assures good generalization ability and better predict accuracy. The special predominance of SVM in resolve limited samples, non-linear function and multidimensional pattern recognition make it become a kind of excellent machine learning method [5]. The real wireless channel is nonlinear, and the regression SVM has good property in simulating nonlinear system. So, if we training a proper network model with enough real-measured data, the wireless signal channel can be simulated. Based on the excellent approaching capability of nonlinear function, good learning mechanism of regression SVM, a modeling and simulation method for wireless channel based on regression SVM is presented in this paper.

II. WIRELESS CHANNEL MODELING THEORETICAL ANALYSIS

A. Fading Channel Model

Wireless channel is the transmission medium of mobile communication, all information is transmitted in this channel. So the property of channel directly decides the communicating quality. If we want to transfer useful information with high quality and big capability on a limited frequency resource, we have to clearly know the characters

978-0-7695-3610-1/09 $25.00 © 2009 IEEE
DOI 10.1109/NSWCTC.2009.229

of channel. The main characteristic of mobile communication channel is multi-path propagation. The propagation model of wireless channel can be divided into large-scale propagation model and small-scale propagation model. When the mobile station moves in a big range, the high building, massif, wood, etc will reflect the electromagnetic wave, so the receiving signal will be influenced and fluctuation. The fluctuation and path loss is called large-scale fading, or shadow fading. Large-scale fading will be influenced by the distance between the receiver and transmitter, and the ambient environment.

On the other hand, when the mobile station moves in a smaller range, for the multi-path of mobile communication channel, movement of mobile station, and different scattering environment, the mobile channel will produce chromatic dispersion at time, frequency and angle. This result in quick change of amplitude, phase and angle of the signal, this change is generally called small-scale fading. While being in the propagation process, signals will be influenced by various environment factors, so reflection, diffraction and scattering will be generated, and this result in the signal arrived at the receiver is a superposition of multi-path signal. Owing to the signal from different path has different intensity, different phase, then the envelope of multi-path signal superposed obeys Rayleigh distribution under the circumstances of without nonstop path, the small-scale fading is generally called Rayleigh distribution. When there has a nonstop path, the multi-path signal obeys Rician distribution. According to the time chromatic dispersion, the channel can be divided into flat fading channel and frequency selective fading channel. According to the frequency chromatic dispersion, channel can be divided into fast fading channel and slow fading channel. The modeling and simulation of small-scale fading is researched in this paper.

B. *Theoretical Analysis*

The small-scale fading of wireless channel can be described with scattering model, because of the superposition of multi-path signal, the received baseband equivalent signal $S(t)$ is generally modeled as a pluralism Gauss wide sense random process, that is,

$$g(t) = g_1(t) + jg_2(t) \tag{1}$$

here, $g_1(t)$ and $g_2(t)$ are mutual independence real random process.

The envelop of $S(t)$ is

$$R(t) = \sqrt{(g_1(t))^2 + (g_2(t))^2} \tag{2}$$

In the mobile communication system, the relative motion between the transmitter and the receiver will result in Doppler frequency shift, and the signal will display the stochastic frequency modulation characteristic. The Doppler frequency shift is expressed as follow formula (3).

$$f_d = f_{\max}\cos\psi = \frac{Vf_c}{c}\cos\psi \tag{3}$$

here, V is the velocity of mobile station, c is velocity of light, ψ is the incidence angle, $f_{\max} = \dfrac{Vf_c}{c}$ is the maximum Doppler frequency shift, f_c is carrier wave frequency.

Each multi-path weight will experience different Doppler frequency shift, and the summarize effect is Doppler expand, and the expand amplitude is $2f_{\max}(-f_{\max} \sim f_{\max})$. Doppler expand is equalized to the received signal $g(t)$ passes a Doppler filter with a $2f_{\max}$ bandwidth. The time varying property of channel resulted by Doppler expand is described using coherence time T_c. T is the symbol space of send symbol. When $T > T_c$, channel is called time selective fading or fast fading; when $T < T_c$, channel is called time non-selective fading or slow fading. If the propagation time delay τ of all the multi-path weights of the channel is far less than T, this channel is called plat fading channel; otherwise, this channel is called frequency selective fading channel.

For the flat fading, the power spectrum of the real part and the imaginary part of $S(t)$ satisfy a specific expression, such as Jakes's power spectrum [6] expression (4).

$$P_{g_i}(f) = \begin{cases} \dfrac{\sigma_0^2}{\pi f_{\max}\sqrt{1-(f/f_{\max})^2}}, & |f| < f_{\max} \\ 0, & |f| \geq f_{\max} \end{cases} \quad i = 1,2 \tag{4}$$

here, $f_{\max}$ is the maximum Doppler frequency shift, σ_0^2 is the variance of the real part or the imaginary part. The fading channel which satisfies the expression (4) is Rayleigh's fading channel.

The expression of Clarke's channel reference model [7] is

$$\begin{aligned} g(t) &= \lim_{N\to\infty} E_0 \sum_{n=1}^{N} C_n e^{j(2\pi f_{\max} t\cos\alpha_n + \phi_n)} \\ &= \lim_{N\to\infty} E_0 \sum_{n=1}^{N} C_n (\cos(2\pi f_{\max} t\cos\alpha_n + \phi_n) \\ &\qquad + j\sin(2\pi f_{\max} t\cos\alpha_n + \phi_n)) \end{aligned} \tag{5}$$

here, E_0 is the constant, C_n, α_n and ϕ_n separately represents the gain, the propagation angle and the original phase of the number n path.

Suppose that $\sum_{n=1}^{N} E\{C_n^2\} = 1$ and $E_0 = \sqrt{2\sigma_0^2}$, the mean and correlative statistical property of Clarke's channel reference model [7] is

$$\begin{cases} E\{g(t)\} = 0 \\ R_{g_i g_i}(\Delta t) = \sigma_0^2 J_0(2\pi f_{\max}\Delta t),\ i = 1,2 \\ R_{g_1 g_2}(\Delta t) = R_{g_2 g_1}(\Delta t) = 0 \\ R_{gg}(\Delta t) = 2\sigma_0^2 J_0(2\pi f_{\max}\Delta t) \end{cases} \tag{6}$$

here, $J_0(\cdot)$ is the first kind zero order Bessel function.

Clarke's channel reference model is used for the reference which evaluates the capability of the simulation model in this paper.

III. Channel Modeling Affect Factors

The small-scale fading directly reflect the complexity and the randomness of wireless channel, it is the basic problem which decide the capability of mobile communication system. There are many factors inflecting the small scale fading, but the main factors of the small scale fading are multi-path propagation, movement velocity of mobile station and environment object, and signal bandwidth. The multi-path propagation can cause the signal spread on the time. The mobility of mobile station can cause Doppler frequency shift, the movement velocity of the mobile station environment object can cause time-varying Doppler frequency shift. If the signal band width is bigger than the correlative band width, different frequency component can get different attenuation, this causes the frequency selective fading, at the time some frequency of the receiving signal acquire more gain than other component, this makes the receiving signal to produce distortion, thereby causing the inter-symbol interference. If the signal band width is far smaller than the correlative band width, the signal can experience flat fading process, and meanwhile the frequency characteristic of the sending signal will keep itself in the receiver.

IV. Channel Modeling Method Study

A. The Principle of SVM

SVM is proposed which is based on the idea of optimal classify hyperplane of linearly separable. Suppose we have two classes samples of linearly separable, H is the class line which divide the two classes without mistake, H_1 and H_2 are the line that pass through the points which are the nearest to the class line in each classes samples and parallel to the class line. The distance between H_1 and H_2 is called the separating margin of the two classes. We want the optimal class line not only can separate the two classes correctly which ensure the experience risk minimization, but also can have the maximum separating margin of the two classes which ensure the real risk minimization. For the high dimension, the optimal class line is the optimal classify hyperplane.

The classify function can be described as follow:

$$f(x) = \operatorname{sgn}\{(w^* \cdot x) + b^*\} = \operatorname{sgn}\{\sum_{i=1}^{n} \alpha_i^* y_i (x_i \cdot x) + b^*\} \quad (7)$$

here, w is the normal of the hyperplane, b decides the place which relative the origin point, (x_i, y_i) is linearly separable sample set.

For the optimal non-linear classify problem, we can transform it to another high dimensional space such that the problem will be linear problem. If the dot product $(x \cdot x_i)$ is replaced by the kernel function $K(x, x')$, equal that transforms the original characteristic space to a new characteristic space, the optimal classify function as follow:

$$f(x) = \operatorname{sgn}(\sum_{i=1}^{n} \alpha_i^* y_i K(x_i, x) + b^*) \quad (8)$$

The rest condition of the algorithmic keep changelessness, this is Support Vector Machine.

The basic thought of the SVM could be generalized as following: at first, transform the input space to a high dimensional space by non-linear transformation, then we work out the optimal classify hyperplane in the new space, while the non-linear transformation is achieved by defining a proper kernel function.

The classify function obtained by the support vector machine is analogous to a neural network in formally, it's output is a linear combination of numbers of middle layer nodes, and the every node of the middle layer corresponds to the inner product of the input sample and a support vector, so it is also called as the support vector network, the sketch map of support vector machine is shown in Fig. 1.

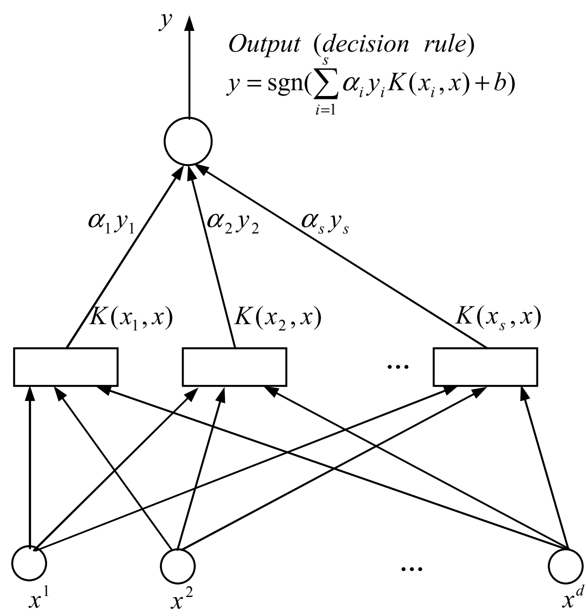

Figure 1. The sketch map of support vector machine

B. Regression Support Vector Machine

At first, the mathematics description of the function regression problem is present. Suppose have the sample data $\{x_i, y_i\}$ ($i = 1, \cdots, l$). Among them, $x_i \in R^n$ are n -dimensional sample input, $y_i \in R$ are sample output, then the function regression is to find a function f through sample training, except for the training sample, x can find out the corresponding y through f .

Definition 1 (linearity) ε -insensitive loss function $L^{\varepsilon}(x, y, f)$ is defined as follow:

$$L^{\varepsilon}(x,y,f)=|y-f(x)|_{\varepsilon}=\begin{cases}0 & |y-f(x)|\le\varepsilon\\ |y-f(x)|-\varepsilon & else\end{cases} \quad (9)$$

here, f is a real value function on the field X. The new loss function describes a sort of ε insensitivity model that if the difference between predicted value and actual value is less than ε, the loss equal to 0.

Through solve the optimization problem (10) and (11), we can get w and the estimate function (12).

$$\min \phi(w)=\frac{1}{2}\|w\|^2+C\sum_{i=1}^{l}(\xi_i+\hat{\xi}_i) \quad (10)$$

$$subject\ \ to\begin{cases}y_i-((w\cdot x_i)+b)\le\varepsilon+\xi_i\\ ((w\cdot x_i)+b)-y_i\le\varepsilon+\hat{\xi}_i\\ \xi_i,\hat{\xi}_i\ge 0\quad i=1,\cdots,l\end{cases} \quad (11)$$

here, $C(C>0)$ is a constant called penalty factor which be used to express the compromise between the smoothness of function f and the value of that allow error is greater than ε. $\xi,\hat{\xi}$ are slack variable.

$$\begin{cases}w=\sum_{i=1}^{l}(\alpha_i-\hat{\alpha}_i)\ x_i\\ f(x)=\sum_{i=1}^{l}(\alpha_i-\hat{\alpha}_i)\ (x_i,x)+b\end{cases} \quad (12)$$

here, x_i which correspond to $(\alpha_i-\hat{\alpha}_i)\ne 0$ is support vector, variable w reflect the complexity of the function.

We use kernel function $k(x,x')$ to replace dot product in the formula (12), and obtain the regression SVM function (13).

$$f(x)=\sum_{i=1}^{l}(\alpha_i-\hat{\alpha}_i)k(x_i,x)+b \quad (13)$$

here, kernel function $k(x_i,x)$ is discretional symmetry function which satisfy the Mercer condition.

V. FADING CHANNEL MODELING BASED ON REGRESSION SVM

A. Parameters Ascertain of Regression SVM

The performance of support vector machine method depends on the selection of kernel function and its width coefficient, penalty factor C and insensitive coefficient ε, so the preferences is very important, it will influence the result of regression directly.

We adopt regression SVM of radial basis function (RBF). The insensitive coefficient ε reflects the limitation of SVM allowed noise range in data. The insensitive coefficient ε adopts $\varepsilon=0.5D$ in this paper, and D is the variance of noise distributing function. We proposed a self-adaptive parameter adjust iterative algorithm to confirm penalty factor C and kernel function width parameter σ^2. The steps of iterative algorithm as follow:

(1) Confirm the initial value of penalty factor C and kernel function width parameter σ^2 randomly, execute support vector regression estimate using the initial values, and compute the average fitting relative error.

(2) Adjust penalty factor C and width parameter σ^2 according to certain step length ΔC and $\Delta\sigma^2$, execute support vector regression estimate using the adjusted parameter, and compute the average fitting relative error of the adjusted parameter.

(3) If the average fitting relative error is smaller and it can satisfy the requirement of system, them we should judge the complexity of the regression function, if it was not complex, turn(4); if the average fitting relative error is not smaller, then adjust step length ΔC and $\Delta\sigma^2$, turn (2); if the average fitting relative error is smaller, but it can not satisfy the requirement of system, turn (2); if average fitting relative error can satisfy the requirement of system, but the regression function is too complex, then adjust step length ΔC and $\Delta\sigma^2$, and turn(2).

(4) Get the optimal regression SVM parameters and the iterative algorithm end.

B. Simulation Result

According to the formula (5), we know that the Clarke's channel reference model is expressed in two road signals, and the two road signals are independent with each other. So in the simulation process, we use two same regression SVM to approach the two road signals respectively, then comparing the output signal of the two networks with the calculating data of Clarke's channel reference model, in order to judge the capability of simulation model.

In order to do the channel analysis and modeling, firstly we should collect and collate all kinds of channel model, namely, in the different environment, carrying through the electric wave propagation actual measurement experiment, in order to obtain the data which reflect the channel characteristic and form the training samples and the testing samples. The training samples have the data information of 1000 sampling point. The testing data have 100 sampling points which was used to test the channel simulation result with the regression SVM, and comparing the result with the theoretical calculation.

We can get many group training samples and testing samples and every training sample is composed of 10-inputs and 1-output. We implement the corresponding algorithm program using C++. In order to show the advantage and feasibility of regression SVM, we adopt regression SVM and radial basis function neural network (RBFNN) to modeling and simulation the wireless channel. SVM uses radial basis function, the best parameters of SVM through the self-adaptive parameter adjust iterative algorithm optimize is $\varepsilon=0.1$, C=500, σ^2=5, for the RBFNN, the system error is 0.001, the width of kernel function σ^2 is 5, equal to the width of kernel function of SVM. After all samples are normalized, we select different training sample numbers and different test samples numbers every time and input the training samples into the regression SVM model and

RBFNN to learn, then use the test samples to test the result. Repeating the recursion operation, the multi steps predicting can be achieved. The AWAGN channel with Doppler frequency shift is used for simulation in this paper. The result of train and test by regression SVM and RBFNN is shown in table 1.

TABLE I. TRAIN AND TEST RESULTS BY REGRESSION SVM AND RBFNN

train sample	test sample	Regression SVM		RBFNN	
		mean squared errors of train sample	mean squared errors of test sample	mean squared errors of train sample	mean squared errors of test sample
80	20	0.0084	0.0613	0.0071	0.1086
100	30	0.0076	0.0732	0.0059	0.1279
120	40	0.0053	0.0936	0.0042	0.2382
150	50	0.0041	0.1019	0.0035	0.3116

From the table 1, we can see the mean squared errors of training samples of SVM is bigger than the RBFNN, but to the mean squared errors of testing samples, the RBFNN is bigger. It shows that the generalized ability of the regression SVM is stronger than the RBFNN. When the numbers of the training sample were changed, the fluctuating range of the generalize error of SVM is smaller than the RBFNN, it shows that the degree of depending on the sample data of regression SVM is smaller than the RBFNN. So the regression SVM is a preferable method at the modeling, predicting, simulation etc, and it has strong capability of simulation the actual channel.

VI. CONCLUSION

Owing to the SVM is a convex quadratic optimization problem, it can assure the extremum result is the global optimum result, and it can effectively solve the overfitting problem of artificial neural network [8], it has good generalized ability and better classified accuracy. So the channel modeling method based on regression SVM is presented and it is applied to mobile communication fading channel modeling in this paper. With the ability of strong nonlinear function approach, strong self-learning, well generalization and fast convergence rate of regression SVM, the modeling method can implement the modeling and simulation of fading channel rapidly and effectively by learning the propagation characteristic information of wireless channel.

There is another advantage to adopt the regression SVM network, owing to the network construct is fixed relatively, if we need to remodeling for a wireless channel, just training the regression SVM network with different sample data. This is an important characteristic to the channel modeling for it cuts cost of the reconstruct, especially in analyzing and modeling the actual channel data.

ACKNOWLEDGMENT

This work was supported in part by the National Natural Science Foundation of Chin under Grant No.40674028 and the Beijing Education Special Project under Grant PXM2008_014209_054622 and the Ministry of Education of China Science and Technology Research Project under Grant No. 206003.

REFERENCES

[1] Jiao Licheng, "Neural network system theory," Xian: Xi an Electronic Science and Technology University Press, 1995.

[2] Zhou Yindong, Chang Qing, Jiang Jinjing, Mei Shunliang, "A Novel Neural Network Approach for Modeling Wireless Channels," RESEARCH & DEVELOPM ENT, no. 2, pp. 143-146, 2005.

[3] V.Vapnik, Statistical Learning Theory, Wiley, 1998.

[4] J.Weston and C. Watkins, Support vector machines for multi-class pattern recognition, In Proceeding of the 6th European symposium on Artificial Neural Network (ESANN), 1999.

[5] Nello Cristianini, John Shawe-Taylor, An Introduction to Support Vector Machines and Other Kernel-Based Learning Methods, Beijing: electronic industry publishing house, 2005.

[6] JAKES W C, "Microwave mobile communications," New York: Wiley-Inter science, 1974.

[7] CLARKER H, "A statistical theory of mobile-radio reception," Bell Syst Tech J, vol. 47, no. 6, pp. 957-1000, 1968.

[8] Bian Zhaoqi, Zhang Xuegong, Pattern recognition, Beijing: Tsinghua university publishing house, 2000.

[9] PO PM F, BEAUL IEU N C, "Limitations of sum of sinusoids fading channel simulators," IEEE Trans Commun, vol. 149, no. 4, pp. 699-708, 2001.

[10] XIAO C, ZHEN G Y R, BEAUL IEU N C, "Secondorder statistical properties of the WSS Jakes' fading channel simulator," IEEE Trans Commun, vol. 50, no. 6, pp. 888-891, 2002.

[11] ZHENG Y R, XIAO C, "Improved models for generation of multiple uncorrelated Rayleigh fading waveforms," IEEE Commun Letter, vol. 6, no. 6, pp. 256-258, 2002.

[12] ZHENG Y R, XIAO C, "Simulation models with correct statistical properties for Rayleigh fading channels," IEEE Trans Commun, vol. 51, no. 6, pp. 920-928, 2003.

[13] LI Zi, CAI Yueming, "Simulation Models for Rayleigh Fading Channels," Journal of PLA University of Science and Technology, vol. 5, no. 2, pp. 1-8, 2004.