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Propagation Analysis of 2.4 GHz Wireless Sensor Network Signal in a Plantation

[1] Xin LUO, [1] Junguo ZHANG, [2] Feng ZHOU, [1] Hua LIU, [3] Fantao LIN

[1] School of Technology, Beijing Forestry University,
Beijing, 100083, China

[2] Institute of Electrical Engineering, Chinese Academy of Sciences,
Beijing, 100190, China

[3] China Electric Power Research Institute,
Beijing, 100192, China

Tel.: 18810381696, fax: 010-62338139

E-mail: zhangjunguo@bjfu.edu.cn

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Abstract: Wireless sensor network is a popular technology on information acquisition and processing, which has been widely used in plantation ecological monitoring domain. The plantation environments, including antenna height-gain, depolarization, terrain, humidity and many factors have great influences on the propagation of 2.4GHz wireless sensor network radio frequency signal. In this paper, a complete research for propagation law of 2.4GHz wireless sensor network signal in plantation environment is presented, with using regression of support vector machines based on experimental data. A single variable prediction model is established on field strength of wireless sensor network signal in plantation environment, thus compares it with the original experience prediction model and measured data. The establishment of aforesaid model provides an important theoretical support for determining the max effective communication range of wireless sensor node and the nodes' rational distribution. It will certainly promote the application of wireless sensor network in plantation ecological monitoring field. *Copyright © 2013 IFSA.*

Keywords: Signal of wireless sensor network, Plantation, SVM, Field strength, Prediction model.

1. Introduction

Wireless sensor network (WSN) is a newly arisen technology on information acquisition and processing. Nowadays, the technology of WSN is playing an important role in forest fire detection, pest monitoring, etc. Some scholars have established the forest fire detection system based on Zigbee wireless sensor network [1]. Zigbee is a common standard of wireless sensor network, 2.4 GHz wireless radio frequency signal is the communication media. In plantation, wireless sensor network applications are growing in an exponential. However, plantation environment has a great influence on propagation of wireless sensor network radio frequency signal [2, 3]. It is an important basis of determining the nodes' max effective communication range, the nodes' rational distribution to master the propagation law of 2.4 GHz wireless sensor network signal in plantation environment, and establish the prediction model on field strength of wireless sensor network radio frequency signal in plantation environment. Since 1960s, some scholars have begun to study the propagation characteristics of wireless communication transmission signal in plantation environment, and developed some classical models [4-9]. Recent years, research in this field can be divided into two categories: improving the classical models and getting empirical models based on the measurement data [10-13]. However, there are some geographical and environmental limitations in classical models, and the predictive results of some experience prediction models are not universally applicable.

On the basis of experimental results, this paper applied support vector machines [14-16], which was a method based on small sample theory, to establish the prediction model on field strength of 2.4 GHz wireless sensor network radio frequency signal in plantation environment, and compared its predictive results with the original experience prediction model and experimental data.

2. The Experiment on the Propagation of 2.4 GHz Wireless Sensor Network Radio Frequency Signal in Plantation Environment

2.1. Experimental Site

Experimental site is the plantation at the bank of Wenyu River in Changping District, Beijing. Its terrain is flat, with dense grasses near surface. The plantation mainly includes poplars and willows, tree diameter is from 15 cm to 25 cm, plant spacing is from 3 m to 3.5 m, average height is from 7 m to 10 m, canopy density is 0.75, experimental time is August, trunk level is clear. The experimental scene is shown in Fig. 1.

Fig. 1. Experiment scene of plantation environment.

2.2. Experimental Equipment

2.2.1. Field Strength Meter

The field strength meter in experiment is the portable, multi-functional Protek 3290N produced by company GSI in Korea, as shown in Fig. 2.

Fig. 2. Protek 3290N field strength meter.

The major technical parameters of Protek 3290N is shown in Table 1.

Table 1. Main technical parameters of Protek 3290N.

Frequency Range	35 MHz~2900 MHz
Measuring Range	-45 dBm~-110 dBm
Resolution	3.125 kHz
Accuracy	±1.5 PPM
Working Power	9 V
Input Impedance	50 Ω

2.2.2. Transmitter Module

The transmitter module in experiment is IRIS wireless sensor network node produced by company Crossbow in America, as shown in Fig. 3. IRIS node supports IEEE 802.15.4 protocol, working at 2.4 GHz. Transmitting power is 3 dB.

Fig. 3. IRIS node.

2.2.3. Transmitter Module

The measuring antenna in experiment is HG2458-09P antenna produced by company TP-LINK in America, as shown in Fig. 4.

Fig. 4. HG2458-09P antenna.

The major technical parameters of HG2458-09P antenna is shown in Table 2.

Table 2. Main technical parameters of HG2458-09P antenna.

Frequency	2400□2500 MHz
Gain	9 dBi
Standard	WiFi
Horizontal beam width	65°
Vertical beam width	25°
Impedance	50 Ohm
Maximum input power	1 Watts
VSWR	<1.5:1avg
Working temperature	-40°C/+85°C
Joint	N-Female
Polarization	Horizontal/Vertical

2.3. Experimental Method

The schematic diagram of field strength measurement principle is shown in Fig. 5.

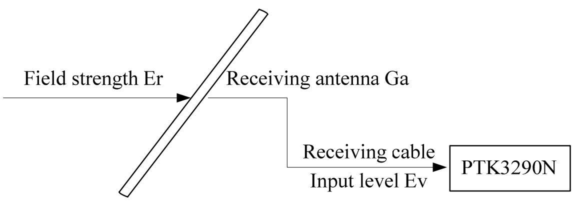


Fig. 5. Schematic diagram of electric field strength measurements.

E_r is field strength value of receiving location, dBμV /m. E_v is the reading data of field strength meter, dBm. According to Fig. 5, the relationship between E_r and E_v is shown in (1).

$$E_r = E_V - G_a - 20\lg l_e + L_f + 6 + K, \quad (1)$$

where K is the antenna correction factor (dB). G_a is the receiving antenna gain (dB). l_e is the receiving antenna effective length(m), $l_e = \lambda / \pi$. L_f is the receiving feed line loss (dB). 6 is the correction value from terminating-value to open-value. Because the feed line in experiment is coaxial cable and is also very short, L_f is neglected. HG2458-09P antenna G_a is 9. So the final formula is shown in (2).

$$E_r = E_V - 9 + 108.75 = E_v + 99.75, \quad (2)$$

where 108.75 is the correction value from dBm to dBμV/m.

2.4. Experimental Process

The propagation experiments were performed by means of separate transmitter and receiver. The receiver was moved along different radials by 5 meters each time. These radials began at the transmitter location, and they went along a straight line moving away from it. Each point should be measured no less than 10 times. The location of transmitter and receiving antenna is shown in Fig. 6.

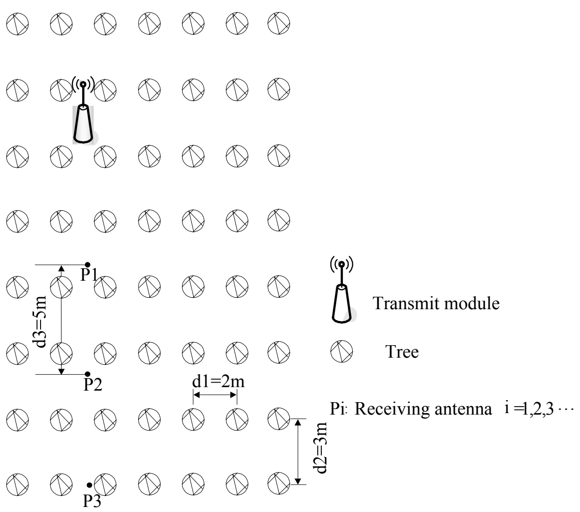


Fig. 6. Schematic diagram of transmitter module and receiving antenna.

2.5. Experimental Results

The propagation of wireless sensor network radio frequency signal in grassland environment is associated with signal frequency, distance, antenna height, polarization mode, etc [17]. In this paper, the data is all measured under the condition of 2.4 GHz signal frequency, 1.5m antenna height and horizontal polarization, so the establishment of prediction model on field strength is focused on distance. In experiment, we got the value of E_v no less than 10 groups at each position. The measured distance d and corresponding E_v's averages are shown in Table 3.

Table 3. Experimental data of plantation.

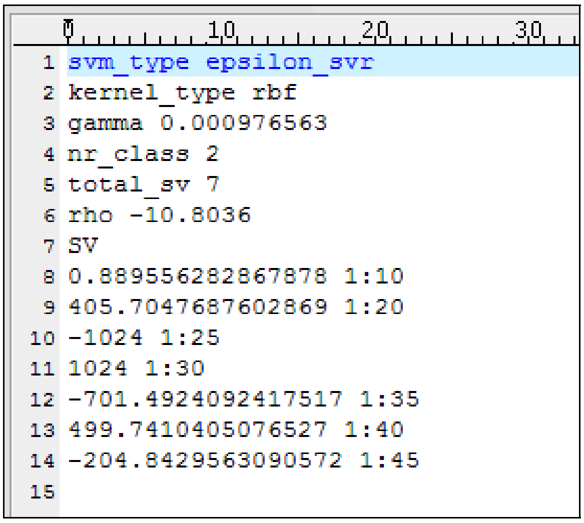
d (m)	E_V (dBm)	E_r (dBµV/m)
10	-84.544	15.207
15	-87.263	12.487
20	-89.120	10.630
25	-90.882	8.868
30	-91.163	8.587
35	-91.928	7.822
40	-91.949	7.801
45	-92.690	7.060

3. Establish Prediction Model on Field Strength of 2.4 GHz Wireless Sensor Network Signal in Plantation Environment Based on SVM Regression

3.1. Model Establishment

This paper applied support vector machines, which was a method based on small sample theory, to do a regression analysis of the measured data shown in Table 3, and established the prediction model on field strength of 2.4 GHz wireless sensor network signal in plantation environment. SVM, which has been put forward by Vapnik in recent years, can transform linear inseparable problems to linear separable ones by mapping linear sample to high dimension space and then seeking optimal linear classification face in high dimension space. It is a good theory of small sample classification and regression at present [18, 19]. The principle of SVM regression is not described in detail here, which is shown in [20, 21].

This paper selects the data in Table 3 to compose a training set, and establishes regression model using LIBSVM software package developed by Professor Lin Chih-Jen in National Taiwan University (kernel function: RBF). The result is shown in Fig. 7.



```
svm_type epsilon_svr
kernel_type rbf
gamma 0.000976563
nr_class 2
total_sv 7
rho -10.8036
SV
0.889556282867878 1:10
405.7047687602869 1:20
-1024 1:25
1024 1:30
-701.4924092417517 1:35
499.7410405076527 1:40
-204.8429563090572 1:45
```

Fig. 7. Regressive result of LIBSVM on plantation.

Furthermore, the prediction model is got on field strength of 2.4 GHz wireless sensor network signal in plantation environment, as shown in (3).

$$\begin{aligned} E_{ryuf} &= 0.889666282867878\times e^{-0.000976563\times|d-10|^2} \\ &+405.7047687602869\times e^{-0.000976563\times|d-20|^2} \\ &-1024\times e^{-0.000976563\times|d-25|^2} +1024\times e^{-0.000976563\times|d-30|^2} \\ &-701.4924092417517\times e^{-0.000976563\times|d-35|^2} \\ &+499.7410405076527\times e^{-0.000976563\times|d-40|^2} \\ &-204.8429563090572\times e^{-0.000976563\times|d-45|^2} \\ &+10.8036 \end{aligned}, \quad (3)$$

where E_{ryuf} represents field-strength prediction value (dBµV/m); d represents the distance between test points and signal transmitter module (m).

3.2. Calibration of Model

In order to check the accuracy of empirical propagation path loss prediction model of 2.4 GHz wireless sensor network signal presented in this paper, we calibrate this model by experimental data in plantation, and also compare it with another prediction model described in [2].

$$\begin{aligned} E_{ryuf} &= 40.043 - 20\lg(d) + \\ & 20\lg(0.949e^{-0.010d}) - 0.26d^{0.6} \end{aligned}, \quad (4)$$

where E_{ryuf} represents field-strength prediction value (dBµV/m); d represents the distance between test points and signal transmitter module (m).

The Measured data and the corresponding prediction value of field-strength by those two models are shown in Table 4 and 5 respectively. Where, E_{Vf} represents field-strength experimental value (dBm), E_{vyuf} represents field-strength prediction value (dBm), d represents the distance between test points and signal transmitter module(m), Δ represents measurement error between E_{vf} and Evyuf (dBm), θ represents precision, and $E_{Vyuf} = E_{ryuf} + 9 - 108.75 = E_{ryuf}$ - 99.75.

Table 4. Comparison between field strength measured values and predictive values of SVM model.

d (m)	E_{Vf} (dBm)	E_{Vyuf} (dBm)	Δ (dBm)	θ
10	-84.678	-84.668	0.009	0.999
15	-86.790	-87.155	-0.365	0.996
20	-87.633	-89.246	-1.613	0.982
25	-88.681	-90.678	-1.997	0.978
30	-90.917	-91.452	-0.535	0.994
35	-91.468	-91.802	-0.334	0.996
40	-92.015	-92.075	-0.060	0.999
45	-92.802	-92.565	0.237	0.997

Table 5. Comparison between field strength measured values and predictive values of experimental model.

d(m)	EVf(dBm)	EVyuf(dBm)	Δ(dBm)	θ
10	-84.678	-82.065	2.612	0.968
15	-86.790	-86.307	0.484	0.994
20	-87.633	-89.488	-1.856	0.979
25	-88.681	-92.086	-3.405	0.963
30	-90.917	-94.311	-3.394	0.964
35	-91.468	-96.278	-4.810	0.950
40	-92.015	-98.055	-6.041	0.938
45	-92.802	-99.687	-6.885	0.931

The precision θ is shown in (5).

$$\theta = 1 - \frac{|\Delta|}{theoretical \cdot value} = 1 - \frac{|\Delta|}{E_{Vyuf}}, \quad (5)$$

where Δ is the measurement error.

The field strength measured value and predictive value at each position are shown in Fig. 8.

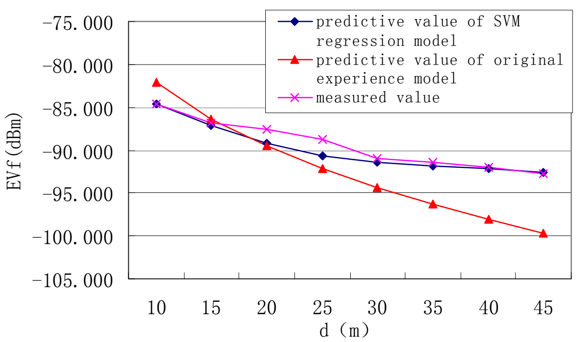


Fig. 8. Comparison of field strength measured values and predictive values of each test point.

According to Table 4 and 5, the average precision of SVM regression prediction model is 0.993; the average precision of original experience prediction model is 0.961. Obviously, the results obtained by the present models are in good agreement with experimental data and published results.

4. Conclusions

As an advanced technology on information acquisition and processing, wireless sensor network has a wide application prospect in forest ecological monitoring domain. To promote its application in forest ecological domain, a complete research for propagation law of 2.4 GHz wireless sensor network signal in plantation environment is presented in this paper, with using regression of SVM based on experimental data, a single variable prediction model is established on field strength of wireless sensor network radio frequency signal in plantation environment, thus compare it with the original experience model and measured data. The establishment of aforesaid model provides an important theoretical support for determining the max effective communication range of wireless sensor node, and determining the nodes' rational distribution. In the process of establishing the model, some extrinsic conditions are fixed, such as antenna height, polarization mode, etc. The model has deficiencies, so the further perfection needs to be done.

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