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Prediction of Wireless Sensor Network Signal Attenuation in Plantation Environment

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Abstract

Because wireless sensor network signal attenuation phenomenon exists in the process of transmission in plantation environment, mastering the law of 2.4GHz wireless sensor network signal attenuation in plantation environment has become a key to the rational distribution of wireless sensor networks in the forest. In this paper, an intelligent forecasting method using wavelet and regression analysis is presented to predict 2.4GHz wireless sensor network signal attenuation in plantation environment. By using wavelet decomposition on the average field strength values, the characteristics in the wavelet scale sequences can be recognized. And by using simple linear regression analysis, the decomposed data can be predicted. Then data after regression analysis can be used in wavelet reconstruction. Finally, the obtained results will be compared with the other average field strength values. The comparison shows that this wavelet and regression analysis method is effective to the prediction of 2.4GHz wireless sensor network signal attenuation.

Keywords: *wireless sensor network, signal attenuation, wavelet and regression analysis, plantation, prediction*

1. Introduction

Wireless sensor network (WSN) is a hot technology in current information field, and also an important branch of Internet of things technology, which has been vigorously supported and developed in China. It has many advantages, including specific application oriented, small size, low cost, wide monitoring area, etc. So it has a unique technological advantage in the forest monitoring, disaster prevention and control, precision agriculture and other fields [1, 2]. Because wireless sensor network signal attenuation phenomenon exists in the process of transmission in plantation environment, mastering the law of 2.4GHz WSN signal attenuation in plantation environment has become a key to the rational distribution of wireless sensor networks in the forest [3]. In recent years, in view of the 2.4GHz WSN radio frequency signal attenuation phenomenon in the process of transmission in the forest, relevant researches have been carried out by domestic and foreign scholars. And loss models of signal attenuation and empirical statistical models have also been respectively established [4-8]. However, because of the influence of various environmental factors in the forest, the further study to improve the accuracies of such models are still needed.

In this paper, in order to predict 2.4GHz wireless sensor network signal attenuation in plantation environment, wavelet and regression analysis are used. Wavelets are a recently developed mathematical tool for signal analysis. Over the past years, much has been accomplished in the development of the theory of wavelets, and people are continuing to find new application domains. To date, the primary application of wavelets has been in the areas of signal processing, image compression, data compression, seismic studies, denoising data and so on [9-10]. Regression analysis is a Mathematical Method to study the relationship between variables, which is playing an important role in data processing. In statistics, linear regression is an approach to modeling the relationship between a scalar dependent y and one or more explanatory variables denoted x. The case of one explanatory variable is called simple linear regression [11].

This paper introduces the prediction of 2.4GHz wireless sensor network signal attenuation in plantation environment which is using wavelet and regression analysis. In

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SectionⅡ, relevant principles including wavelet analysis and simple linear regression are described. In Section Ⅲ, data measurement is described, basic steps of the prediction using wavelet and regression analysis are described in detail, and results comparison is presented to show high accuracy of the method. Finally, Section Ⅳ concludes the paper, then deficiencies of this method are pointed out and further research is needed.

2. Relevant Principles

2.1. Wavelet Analysis

Wavelet analysis is a new transform analysis method and a fast calculation tool, which is developed on the basis of Fourier analysis. Wavelet functions are created from a single characteristic shape, known as the mother wavelet function, by dilating and shifting the window. Like the sine wave in Fourier transforms (FT), the mother wavelet is the basic block to represent a signal in wave transforms (WT). However, unlike the FT whose applications are fixed as sine or cosine functions, the mother wavelet has many possible functions. There are some of the popular wavelets including Daubechies, Harr, Coiflet, and Symlet.

The main characteristic of the wavelet analysis is that wave transforms can fully highlight the characteristics of some aspects of the problem. For example, the wavelet can be expanded to a coarse scale to analyze low frequency, long duration features in the signal. On the other hand, it can be shrunk to a fine scale to analyze high frequency, short duration features of a signal. Therefore any details of the signal can be extracted, analysis, and the common function space, as well as the function of the local smoothness properties also can be described by wavelet expansion coefficients [9, 12].

Because the original signal or function can be represented in terms of a wavelet expansion using coefficients in a linear combination of the wavelet functions, data operations can be performed using just the corresponding wavelet coefficients. The transformation process from time domain to time scale domain is a wavelet transform, technically known as signal decomposition because a given signal is decomposed into several other signals with different levels of resolution. From these decomposed signals, it is possible to recover the original time domain signal without losing any information. This reverse process is called the inverse wavelet transform or signal reconstruction [13].

2.2. Simple Linear Regression

Regression analysis is a widely used method for quantitative prediction, whose task is to determine the predictive value and the relationship between influencing factors. Simple linear regression is the most commonly used technique for determining how one variable of interest (the response variable) is affected by changes in another variable (the explanatory variable).

Generally, the equation of linear regression can be obtained by the method of least squares. The experience fitting equation is as follows:

$$b = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sum_{i=1}^{n}(x_i - \overline{x})^2}$$
$$a = \overline{y} - b\overline{x} \quad (1)$$

Simple linear regression is the least squares estimator of a linear regression model with a single explanatory variable. In other words, simple linear regression fits a straight line through the set of n points in such a way that makes the sum of the model's squared residuals (that is, vertical distances between the points of the data set and the fitted line) as small as possible.

Suppose there are n data points {yi, xi}, where i = 1, 2, …, n. The goal is to find the equation of the straight line: $y = a + bx$, which would provide a "best" fit for the data points. Here the "best" will be understood as in the least squares approach: such a line that minimizes the sum of the linear regression model's squared residuals [11, 14].

3. Prediction and Comparison
3.1. Data Measurement

There are several equipments in data measurement, including field strength meter, transmitter module and receiving antenna. The field strength meter is the portable, multi-functional Protek 3290N produced by company GSI in Korea, the transmitter module is IRIS wireless sensor network node produced by company Crossbow in America, and the receiving antenna is HG2458-09P antenna produced by company TP-LINK in America.

The time of data measurement is April, and the site is the plantation in Changping District, Beijing, where the terrain is flat, trunk level is clear, tree specie is willow, tree diameter is from 10cm to 20cm, plant spacing is from 1m to 2.5m, average height is from 5m to 8m and canopy density is 0.5. The data measurement scene is shown in Figure 1.

Figure 1. The Data Measurement Scene

In the process of measurement, the transmitting module is fixed at point A, the receiving antenna moves along a fixed direction (P1, P2…Pi), the start and end positions are 10m and 45m from the transmitter module respectively, and the interval is 5 meters each time, shown in Figure 2. The frequency of wireless sensor network signal is 2.4GHz, the height of the antenna is 1.32m, and antenna polarization mode is horizontal polarization [3].

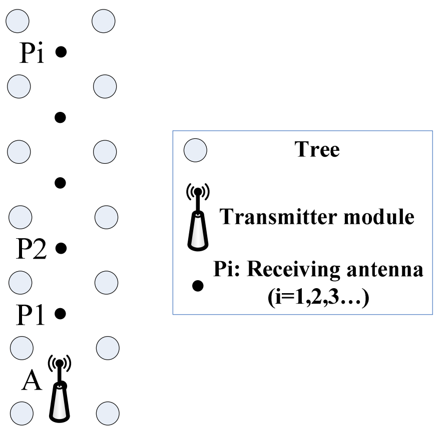

Figure 2. Schematic Diagram of the Measuring Process

At the time of measurement, we get 20 groups of field strength values (expressed by EV) at each position, and divide them into two parts. Then the average values of both two parts, which are respectively used for prediction and comparison, can be got. The measured distance d and corresponding EV's averages are shown in Table 1.

Table 1. Measured Data of Plantation

d(m)	EV1(dBm)	EV2(dBm)
5	-80.578	-79.369
10	-82.527	-81.256
15	-84.917	-85.369
20	-86.696	-85.169
25	-85.045	-84.174
30	-87.610	-88.453
35	-87.702	-87.151
40	-88.070	-89.781
45	-88.567	-88.999

In the table, EV1 represents the average field strength values (dBm), which is used for prediction. EV2 represents the other average field strength values (dBm), which is used for comparison.

3.2. Basic Steps

There are four basic steps [9, 12, 13], [15-17]. The specific steps are as follows:

Step 1: Choose the mother wavelet. When we use wavelet transforms to reflect the approximate performance of the overall signal, it usually uses a larger scale wavelet; when we use wavelet transforms to reflect the details of the signal, it usually uses a smaller scale wavelet. The series of Daubechies wavelets are often abbreviated to DbN, where N is the order number. They have good properties, such as compact support, orthogonality, regularity, etc. And this type of wavelets is easy to construct, to signal multi-scale decomposition and reconstruction. The length of DbN branch set and filter are 2N, and vanishing moment is N. Because of good expansibility, it can be flexible in dealing with the edge problems caused by increasing the length of branch set. In this paper, Db4 wavelet is chosen for data preprocessing.

Step 2: Determine the decomposition level (L) of wavelet transforms. The more the wavelet decomposition is, the better the smoothness and stability of signal are. However, due to the increase of decomposition level, the error will be bigger. Therefore, it should not be too much or too little in the selection of decomposition level. In this paper, the decomposition level is 3 (L=3).

Wavelet analysis will be carried out on the field strength and distance respectively. For example, by using the Db4 wavelet on the three-level decomposition of field strength, 4 sub-sequences: d1, d2, d3, c3 are obtained, where c3 is the low frequency sequence, this sequence has filtered the partial singular values of original sequence and high frequency components, so it can better embody the essence of change trend. The remaining d1, d2 and d3 are high frequency detail sequences. Figure 3 and Figure 4 are respectively field strength attenuation data curve and its three-level decomposition component data curves.

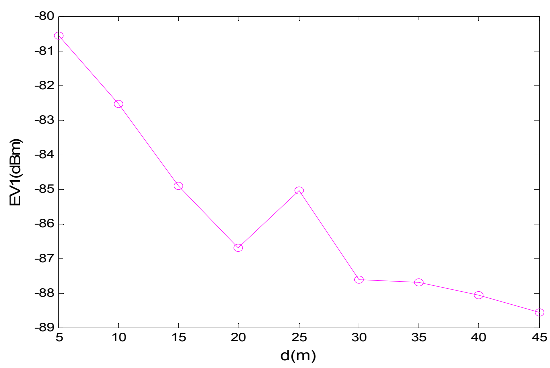

Figure 3. Field Strength Attenuation Data Curve

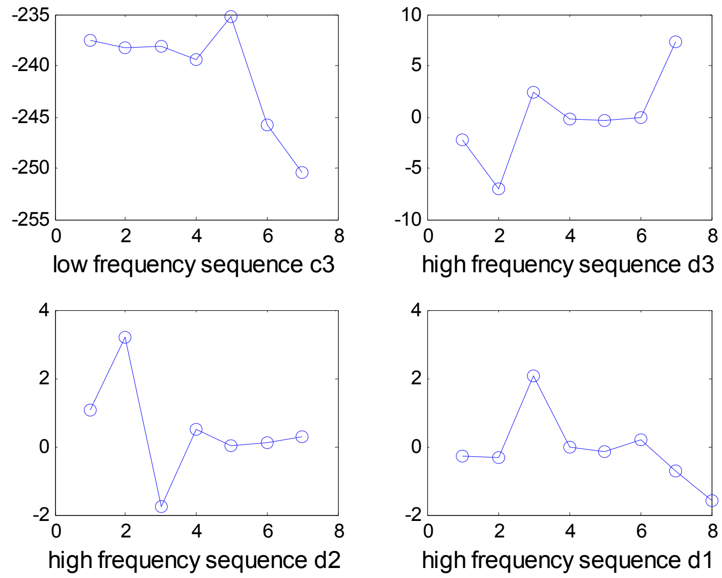

Figure 4. Three-level Decomposition Component Data Curves

Step 3: Regression analysis. After decomposition, regression analysis will be carried out on sub-sequences of field strength and sub-sequences of their corresponding distance respectively. By using simple linear regression on each scale component sequence fitting, whose fitting curve equation is: $y = a + bx$, the coefficient will be found, and the predictive values will be calculated. In Figure 5, the fitting effects of each sequence are shown.

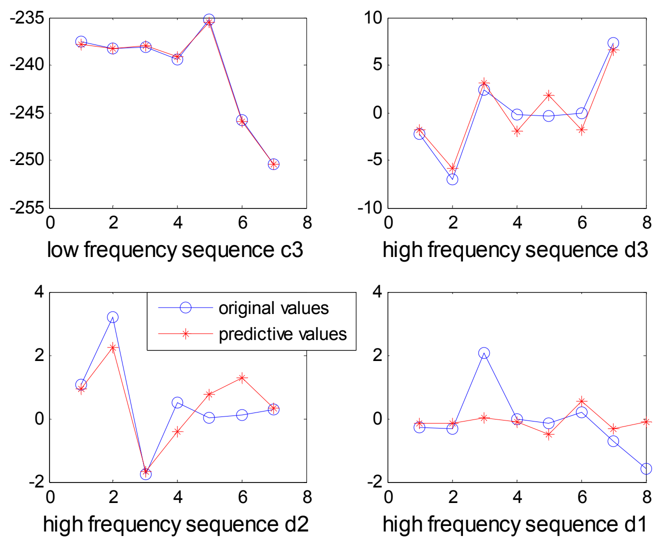

Figure 5. Fitting Effects of Each Sequence

Step 4: Wavelet reconstruction. The predictive values of each scale component sequence should be put on wavelet reconstruction. Then the values of field strength prediction will be obtained, as shown in Figure 6.

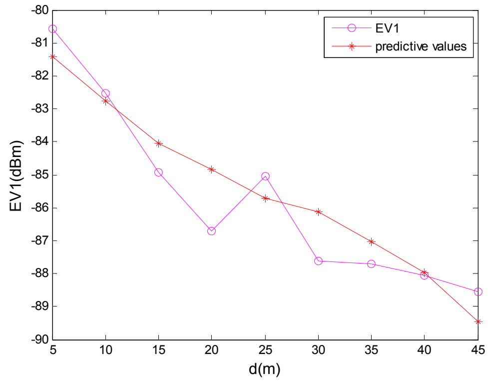

Figure 6. Values of Field Strength and Its Prediction

3.3 Results Comparison

In order to verify the accuracy of prediction in the above method, we will compare the average field strength values for comparison with predictive values using wavelet and regression analysis. The results comparison is shown in Table 2. Where, EVpre represents field strength predictive values (dBm), Δ represents the error values between EV2 and EVpre (dBm), θ represents measurement accuracy [3]. The formulas are shown as follows:

$$\triangle = |EV_{pre} - EV2| \quad (2)$$

$$\theta = 1 - \left|\frac{\triangle}{EV_{pre}}\right| \quad (3)$$

Table 2. Results Comparison

d(m)	EV2(dBm)	EVpre (dBm)	Δ(dBm)	θ
5	-79.369	-81.408	2.039	0.975
10	-81.256	-82.749	1.493	0.982
15	-85.369	-84.041	1.328	0.984
20	-85.169	-84.850	0.319	0.996
25	-84.174	-85.726	1.552	0.982
30	-88.453	-86.112	2.341	0.973
35	-87.151	-87.028	0.123	0.999
40	-89.781	-87.974	1.807	0.979
45	-88.999	-89.463	0.464	0.995

According to the table, we can easily calculate the average accuracy of prediction method using wavelet and regression analysis. The formula is shown as follows:

$$\bar{\theta} = \frac{\sum_{i}^{n} \theta_i}{n} = 0.985 \quad (4)$$

The average accuracy of the method using wavelet and regression analysis is 0.985. Obviously using wavelet and regression analysis to predict 2.4GHz wireless sensor network signal attenuation in plantation environment has a high accuracy.

4. Conclusion

In this paper, wavelet and regression analysis are used to predict 2.4GHz wireless sensor network signal attenuation in plantation environment. By wavelet decomposition, each component of field strength represents it's characteristics in different frequency. Then, simple linear regression analysis is used to fit each sub-sequence. Finally, the predictive values after wavelet reconstruction are compared with the other average field strength values, it has a high accuracy and shows that this wavelet and regression analysis method is effective to 2.4GHz WSN signal attenuation. And it is helpful for us to understand the law of 2.4GHz wireless sensor network signal attenuation in plantation environment, as well as to promote the application of wireless sensor network technology in plantation ecological monitoring domain. However, there are also some deficiencies in this method. It only takes into account the distance change effects on signal attenuation in plantation environment, without considering other external conditions' change, such as antenna height, tree species, etc. So the further research needs to be done.

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