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The Research of Wireless Sensor Network Channel Propagation Model in the Wild Environment

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Abstract: The survey shows that for the layout environment of wireless network, channel propagation model of wireless network still needs to be improved, especially low altitude propagation channel. In order to effectively study and design any random layout of wireless sensor node on the wild environment, several classic application scenes of wireless network are tested and improved in this paper. Since sample data are fitted by linear regression algorithm based on the method of least square, some meaningful conclusions about low-altitude path loss model are obtained. When antenna height is fully close to surface, thus the loss model of single broken line can be adopted. When antenna height is higher and LOS exists, the double broken line model can be adopted. At the same time other channel parameters related with network design are also measured. Those data provide an important scientific basis for the research of wireless sensor network. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Measurement and analysis, Propagation path loss model, Wild environment signal spread, Wireless sensor network, Channel propagation model.

1. Introduction

International research on wireless sensor network has been five or six year's history. And the scope of the study is wide-ranging [1]. The early studies focused on that under the premise of energy efficiency and limited resources, combined with ad hoc network technology, how to implement the upper routing and networking as well as the access protocol. But large number of simulation experiments was carried out under many assumptions. So it led to a large gap between research and practical application. Especially the underlying physics of the wireless sensor networks often been neglected in previous studies so that There is still lack of effective research on channel propagation model of the wireless sensor network. Recently some papers [2] pointed out that, in order to design a low-redundant, energy-efficient wireless sensor network and to accurately assess the performance of the network protocol at simulation stage, the channel propagation model of the application environment need to be more extensively studied.

In early study on cellular wireless channel propagation model [3], antenna height of transceiver node is from a few meters to tens of meters and coverage range of the signal is over 1 km. Due to the absence of the corresponding application-driven, there is the lack of effective measurement and deepen analysis on path loss model of transceiver antenna when it is close to ground and height is ten centimeters as well as dissemination range is over

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100 m. Recently, demand for estimate and measurement of path loss model on the actual surface is growing, compared with the previous studies, under the network of energy-constrained conditions, studies on path loss of low-altitude and close-ground wireless propagation is more micro and precision. In addition, because of the resources and energy consumption of the sensor nodes, in general communication distance among nodes is with 100 meters. In reference [4], a testing method of the actual channel is introduced into the wireless sensor network research. Author pointed out that, within the transmission range of the wireless nodes, the received signal is time-varying and unstable state. But author did not explain the reason of phenomenon. Reference [5] analyzes influence of irregular wireless propagation on routing layer protocol. In references [6, 8], propagation channel of wireless sensor network is measured based on different methods. But integrity of parameters and analysis is still inadequate.

In summary, study on the channel propagation model of the wireless sensor network can be concluded as following lists:

1) Determine the typical application environment and layout pattern of wireless sensor network. Based on the typical application, analyze wireless channel propagation model.

2) In wireless sensor network, check whether wireless signal propagation along the surface at low altitude complies with characteristics of the traditional channel propagation model. If there is a difference between the two, establish new mathematic model.

3) Combined with the actual determination of general model of channel propagation, restraining factors of protocol design of energy-constrained wireless sensor network need to be deeply analyzed. For example: some important performance indicators of network protocol.

4) Combined with achievement of previous analysis and network simulation software, such as NS-2, QualNet, A realistic channel propagation model based on simulation platform of wireless sensor network is built. And according to the model, a feasible, low redundancy, energy-efficient wireless sensor network system is simulated and designed.

This paper focuses on large scale randomized layout of wireless sensor network along the surface in the wild environment. The kind of the network is one of the most typical and complex network models in the application of wireless sensor network. So study for features of channel propagation model in wild environment contributes to optimization of network communication solution.

In this paper, for classic wild environment, path loss model of transceiver nodes in the range of 100 m is measured and analyzed. At the same time other channel parameters which is related with network design is also measured. Those data provide important scientific basis for research of wireless sensor network.

2. Test Scheme

In general, it is expected that a large number of high-quality information can be obtained at the layout area of wireless sensor network and the node itself has a certain degree of concealment. So some features of wild environment can be summarized .for example complex terrain environment, relatively flat in small-scale (100 m), many obstacles (mound, weeds, trees). Therefore, if propagation model of low-altitude antenna is measured directly, there are certain difficulties. The collected data can not draw useful model directly so that subsequent analysis is impacted. The obvious feature of the phenomenon is variance value of shadow fading caused by different obstacles. Therefore, three different test scenarios are selected for the testing program to examine influence of different scenarios on path loss. The three scenarios have some certain value to some applications of wireless sensor network such as the target tracking, path monitoring, and ecological monitoring. Further, assume that the transceiver nodes are in a quiescent state and relative isolation, the measurement can reveal fully feature of path loss on average. Three test scenarios are chosen as follows:

1) Wild grass without building. The ground is relatively flat with sparse small mound and weed.

2) Flat cement road.

3) Surface is undulation and communication is based on non-line-of-sight.

In the first two scenes, some factors such as different antenna height, influence of terrain on path loss model are tested an analyzed. There is line of sight propagation (LOS) between nodes. In the third scene, compared with the previous two scenarios, the propagation characteristics of the low-altitude antenna are analyzed under NLOS circumstance. Other complex factors will be tested in the subsequent experiments. In addition the first scenario is a typical scene. Principle of measuring link characteristics and designing network is irregular and asymmetric link distribution respectively. In this experiment, 25 cm, 45 cm, 100 cm three antenna height are chosen according to the typical wild environment application of wireless sensor network.

The sensor node includes the Chipcon’s CC1100 communication chip and TI's MSP430 microcontroller. In consideration of diffraction ability of electromagnetic wave propagation in the wild environment, 433 MHz band is selected. However, in order to improve the accuracy of the measured value and convenient for recording and analyzing data, a signal generator (Agilent E4433B) is applied in the path loss model and irregular testing. Based on 433 MHz, a power of 10 dBm single carrier signal is produced. Handheld spectrum analyzer (R & SFSH3) is selected as receiving device. It can test signal along straight line. At the same time, sensor nodes are laid in order to complete the asymmetric link distribution test. The transceiver antenna uses two $\lambda/4$ monopole omni directional antennas. The antennas connect with transceiver equipment through a low-loss RF coaxial cable. Since the test focus on characteristics of relative fading of wireless signal on propagating, the above settings can effectively achieve the expected experimental results.

3. Testing Results and Analysis

Regression method is applied to analyze data from different experimental in order to fit surface's wireless channel model. Some related issues about design of wireless sensor network are further discussed.

3.1. Testing and Analysis of Path Loss Model

In order to gain effective low-altitude path loss model and strengthen research foundation of wireless network, Determination and Analysis for the differences between path loss model of the low-altitude transceiver antennas and tradition path loss model, such as free-space model, two-ray propagation model, and logarithmic model, becomes necessary.

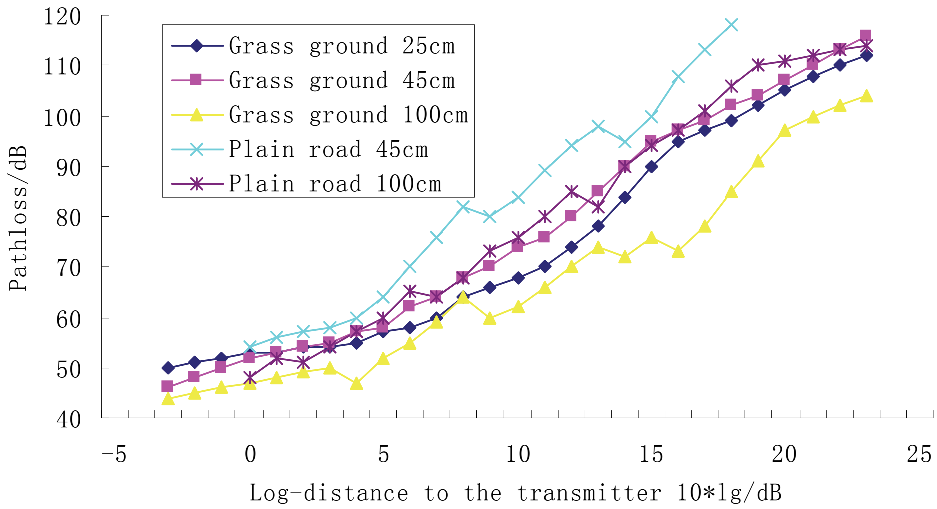


Fig.1. Log distance path loss due to different antenna heights on grass ground and plain road, respectively.

In Fig. 1, under grass and flat-road scenarios, the different curves shows dynamic correlation between determination path loss values based on different antenna heights and logarithmic distance. In the various test scenarios, the transmitting power, receiving and testing methods are all the same. In Fig. 1, the value of measured point of each distance is actually average value of space and time sample. Sample size is set to 50. As can be seen from the Fig. 1, although the antenna heights is very close to the surface, path loss values in the range of 100 m's propagation distance keep substantially linear relation with logarithmic distance scale. It makes process of conventional logarithmic distance regression available. At the same time, the Fig. 1 shows that higher antenna height is, smaller path loss is. The trend is more obvious when the distance is far away from the transmitter. Fluctuation of curve in Fig. 1 is mainly caused by distribution of shadow variance which is produced by the presence of obstacles in the test environment.

According to the above test results and analysis, the method of linear regression can be used to fit the propagation path loss model of low altitude ground antenna. In the traditional path loss model, log-distance model based on single broken line and log-distance model based on double folding line are often used. Actually typical two-ray model [3] is log-distance model based on double broken line. The two path loss model is described as the following formulas (1), (2):

$$L(d) = L_0 + 10n\lg 10d + X_\sigma \,, \tag{1}$$

$$L(d) = \begin{cases} L_{b1} + 10n1\lg d + X_{\sigma 1} & d \le d_b \\ L_{b2} + 10n2\lg d + X_{\sigma 2} & d > d_b \end{cases} \,, \tag{2}$$

$$d_f = \sqrt{(\Sigma^2 - \Delta^2)^2 - 2(\Sigma^2 + \Delta^2)^2(\lambda/2)^2 + (\lambda/2)^4} \,, \tag{3}$$

where n represents slope. L_0, L_{b1}, L_{b2} represents path loss values at a distance of 1m from emission point. $\sum = h_T + h_R$ $\Delta = h_T - h_R$ h_T, h_R is height of transceiver antennas. d_b is position of abrupt change point. In tradition two-ray model, d_b is the same with blocked distance d_f of first Fresnel zone. The slope before change occurs is 2 while the slope after change occurs is 4. X_σ represents sample standard deviation caused by shadow fading. Generally the sample space is considered to meet the Gaussian distribution with zero-mean.

In order to more accurately establish path loss model of low-altitude surface antenna, least square method is applied to manage regression process of single broken line model and double broken line model. d_b is distance of unknown discrete abrupt change points. Regression process algorithm of double broken line model is shown as follow:

Set actual measurement distance of m sample points: $d_1, d_2, \cdots, d_m$, the path loss equation of sample:

$$L(d_i) = \begin{cases} L_{b1} + 10_{n1}\lg d + X_{\sigma 1} & d \le d_b \\ L_{b2} + 10_{n2}\lg d + X_{\sigma 2} & d > d_b \end{cases} \quad (i = 1, 2, \cdots, m), \tag{4}$$

According to the method of least square, make the sum of squared deviation of $L'(d_i)$ and formula (4): $Q(L_{b1}, L_{b2}, n1, n2)$ minimum. The equation is showed as follow:

$$Q(L_{b1}, L_{b2}, n1, n2) = \sum_{i=1}^{b}(L(d_i) - |L_{b1} - 10n1\lg d_i|)^2 + \sum_{i=b+1}^{m}(L(d_i) - L_{b2} - 10n1\lg d_i)^2, \tag{5}$$

where b represents index number of unknown abrupt change points. It decides the positions of end points of two broken lines. Then enumerate b set from 1 to m.

Coefficient $L_{b1}, L_{b2}, n1, n2$ of equation is calculated respectively. Then according to the minimum Q value, the index b of the corresponding sample points is obtained. And based on those coefficients, partial derivative of Q on $L_{b1}, L_{b2}, n1, n2$ can be calculated. Set the value as 0. Finally the expression is shown as follow:

$$\begin{cases} n1 = l_{10\lg d, L(d)}(1,b) \Big/ l_{10\lg d, 10\lg d}(1,b) \\ L_{b1} = \frac{1}{b}\sum_{i=1}^{b} L(di) - \frac{1}{b} n1 \sum_{i=1}^{b} 10\lg d_i \\ n2 = l_{10\lg d, L(d)}(b+1,m) \Big/ l_{10\lg d, 10\lg d}(b+1,m) \\ L_{b2} = \sum_{i=b+1}^{m} L(di) \Big/ (m-b) - n2\sum_{i=b+1}^{m} 10\lg d_i \Big/ (m-b) \end{cases}, \tag{6}$$

Inside

$$l_{x,y}(a,b) = \sum_{i=a}^{b} x_i * y_i - \frac{\sum_{i=a}^{b} x_i * \sum_{i=a}^{b} y_i}{b-a+1}, \tag{7}$$

$$l_{x,y}(a,b) = \sum_{i=a}^{b} x_i^2 - \frac{(\sum_{i=a}^{b} x_i)^2}{b-a+1}, \tag{8}$$

Regression process of single broken line is similar with that of double broken line. But it do not need to locate abrupt change point d_b.solution procedure of L_0, n is the same with above double broken line model.

Fitting model of various scenes depends on residual standard deviation σ value of repression process. Corresponding Model of minimum σ is selected as fitting model. Residual standard deviation of repression process of single broken line is shown as follow:

$$\sigma_s = \sqrt{\frac{l_{L(d),L(d)}(1,m) - nl_{10\lg d, L(d)}(1,m)}{m-2}}, \tag{9}$$

Residual standard deviation of repression process of double broken line is shown as follow:

$$\sigma_d = (b\sqrt{\frac{l_{L(d),L(d)}(1,b) - n1l_{10\lg d, L(d)}(1,b)}{b-2}} + (m-b)\sqrt{\frac{l_{L(d),L(d)}(b+1,m) - n2l_{10\lg d, L(d)}(b+1,m)}{m-b}})/m \tag{10}$$

If $\sigma_s \le \sigma_d$, single broken line model is chosen. If $\sigma_s > \sigma_d$, double broken line model is chosen.

Sample's standard deviation X_σ caused by shadow fading is shown as follow:

$$X_\sigma = \sqrt{\frac{1}{m-1}\sum_{k=1}^{m}(L'(d_k) - L(d_k))^2} \tag{11}$$

According to regression processing algorithm, above six scenarios is handled based on fitting method. The parameters of difference scenarios are analyzed and those results are shown in Table 1.

By analyzing the regression data in Table 1, some important conclusions can be revealed. When the antenna heights is 45 cm or 100 cm and LOS (Line of Sight) is available, the accuracy of double broken line model is better than that of single broken line model and location of abrupt change point is far away transmitter. The accuracy of regression value is determined by residual standard deviation of minimum regression data. But when the antenna heights are close to surface, based on the residual standard deviation, a single broken line model is more suitable. This conclusion is further verified in the grass that is non-line-of-sight scene and the abrupt change point is very close to the transmitter.

Formula (11) can determine that whether standard deviation X_σ caused by shadow fading meets Gauss distribution with Zero-mean by calculating statistical mean μ^σ and statistic variance σ^σ (Table 1). Set three difference scenes as example. The three models are single broken line model of non-line-of-sight on grass, double broken line model of 45 cm antenna on grass and highway's double broken line model of 45 cm antenna on grass respectively. Distribution of shadow standard deviation is shown in Fig. 2. In three models, probability of occurrence of fading is larger at near μ^{σ} value. Furthermore, shadow standard deviation of low–altitude surface's antenna can adopt model of Gauss distribution with Zero-mean.

From Table 1, there are larger differences among abrupt change points of each double broken line. In the case of low-altitude surface's antenna, value of abrupt change points is greater than that value in two-ray model of the cellular system (Formula (3)). Based on condition $h_T h_R >> \lambda$ value of abrupt change point in two-ray model can be deduced to blocked distance of the first Fresnel zone. But this condition can not be satisfied in case of low altitude. In addition, value of abrupt change point is not only determined by antenna height, but also is related to terrain. When ground is uneven, especially wavy terrain, the first Fresnel zone is easy to be blocked even higher-order Fresnel zone is blocked possibly. From Fig. 2 because of flat, the first Fresnel zone is easy to be blocked in the highway. So, under the same antenna height, abrupt change points of highway is further than that of grass.

In Table 1, by analyzing loss exponent of each model, loss index of single broken line is about 3.6 in the two conditions of grass that are 25 cm antenna and LOS. This index value shows trend of fading in near-field and far-field in the case of completely close to the surface and NLOS. When heights of antenna on grass and highway are set to 45 cm and 100 cm, because of LOS and even surface, effect of superimposition of dual-path electromagnetic wave is revealed obviously. Compared with traditional two-ray model, the procedure does not comply with of original principle of loss index decay. In double-ray model of the cellular network, equation (12) is often used to create model of loss exponent.

$$\gamma = a - bh_b + c / h_b + x\sigma_r \qquad (12)$$

Inside, h_b is antenna height. Precondition of equation (12) is $10m \le h_b \le 80m, a, b, c$ c is environment constant. x is Gauss distribution with zero-mean $N[0,1]$, σ_r is standard deviation of loss exponent. When antenna is placed on surface low altitude, there is more complex relationship between abrupt change point and loss exponent. Conventional formula (3), (12) can not fit for modeling. So correlation model of abrupt change point and loss exponent need to be studied deeply.

Table 1. Measured parameters in different scenes.

Model	Parameter	Grass 25 cm	Grass 45 cm	Grass 100 cm	Highway 45 cm	Highway 100 cm	NLOS on grass
Regression model based on Single broken line	N	3.6	3.16	2.87	3.19	2.63	3.58
	L_0	46.8	45.5	35.6	42	40.3	45.2
	Residual standard deviation of regression σ_s	2.01	2.46	4.40	4.13	3.42	2.05
	X_σ average value	1.70	2.48	3.83	3.33	3.02	2.58
	X_σ standard deviation	1.40	1.58	2.67	3.05	2.05	1.17
	$d_{\max}$	31.6	50.1	165.9	66.1	173.8	33.9
Regression model based on double broken line	N_1	2.09	1.40	2.19	0.88	2.07	2.89
	N_2	3.85	3.43	5.44	3.90	5.14	3.68
	Residual standard deviation of regression σ_1	2.22	0.74	2.91	1.03	1.30	0.34
	Residual standard deviation of regression σ_2	1.34	1.67	1.66	1.56	1.65	2.10
	X_σ average value μ_σ	1.35	2.06	2.72	1.82	1.71	2.53
	X_σ standard deviation σ_σ	0.85	0.95	1.23	1.45	0.81	1.18
	Abrupt change point/m	4.0	3.0	44.0	5.0	46.0	4.0
	$d_{\max}$	30.9	53.7	107.2	58.2	109.7	33.1
Tradition two-ray model	$d_{\max}$	63	126	252	126	252	63
Free-space model	$d_{\max}$	457	531	1660	794	966	550

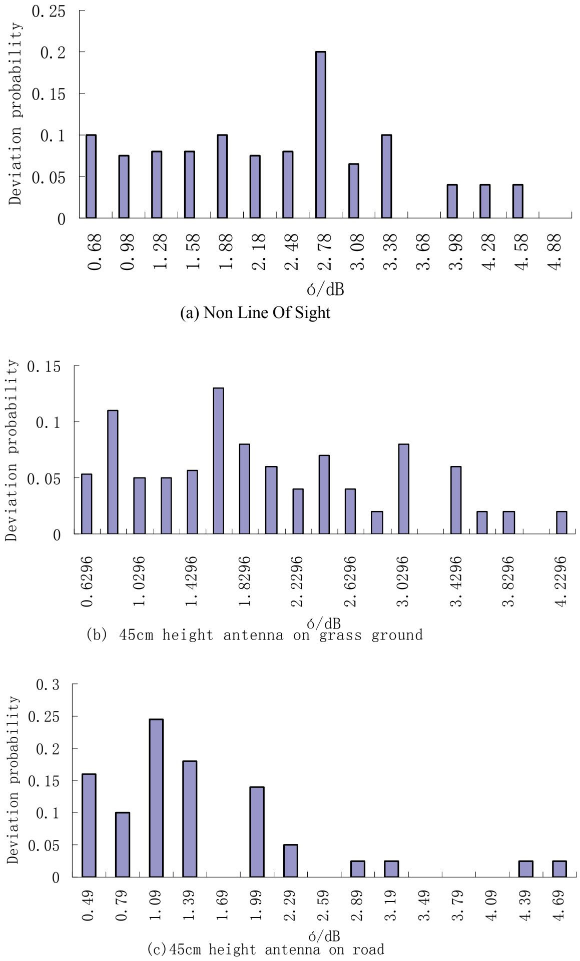


Fig. 2. Distribution of shadow deviation in different scenes.

Under the premise of certain transmitting power and sensitivity, the maximum transmission distance d_{max} of nodes is determined by path loss. In Table 1, when transmitting power is 10 dBm and sensitivity is -90 dBm, maximum propagation distances of the nodes in various path loss models are calculated (without the shadow of variance). It can be seen that for low altitude propagation, there is great difference between actual model and traditional two-ray model as well as free space model. Uncertainty of the two-ray model comes mainly from calculation of abrupt change point. It also indicates that modeling of abrupt change point is important for low-altitude propagation model. If the two traditional models are used in simulation experiment, the results will be inconsistent with the actual circumstances. Thereby design and analysis of upper-layer protocols are seriously affected.

3.2. Testing Propagation of Irregular Radio Wave

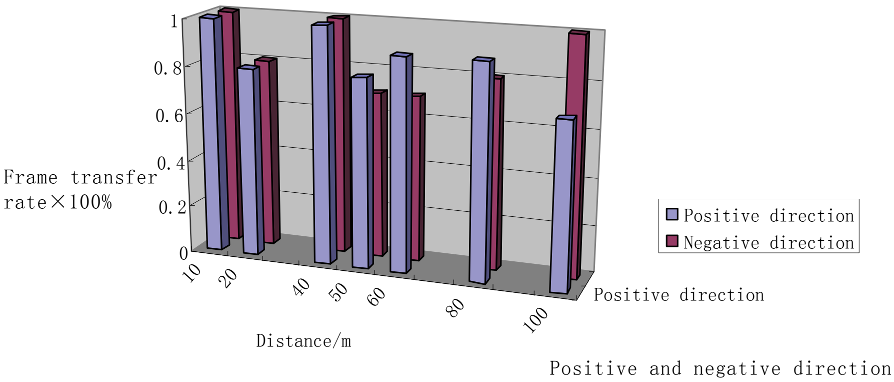
In the case of propagation of low altitude antenna, much uncertainty fading will be caused, because transmission path and direct path is close to ground. In simulation of wireless network, neighbors and interference of node are key elements for design of upper layer protocol. So a common unified communication radius is used to calculate neighbors and interference of node. In this situation, coverage of signal and range of interference are seen as a regular round shape.

In addition, influence of irregular radio wave on protocol can be revealed through distribution of asymmetric link. Asymmetric link is defined as difference of the correct reception rates of frames when transceiver node adopts the bidirectional communication. If difference of the correct reception rates of the bidirectional frames is greater than certain threshold, routing can not be used generally. Asymmetric distribution among sensor nodes is tested in difference conditions. Placement of nodes is set to 100 cm and surface respectively while transmitting power is set to 0 dBm and 10 dBm respectively. Results are shown in Fig. 3.

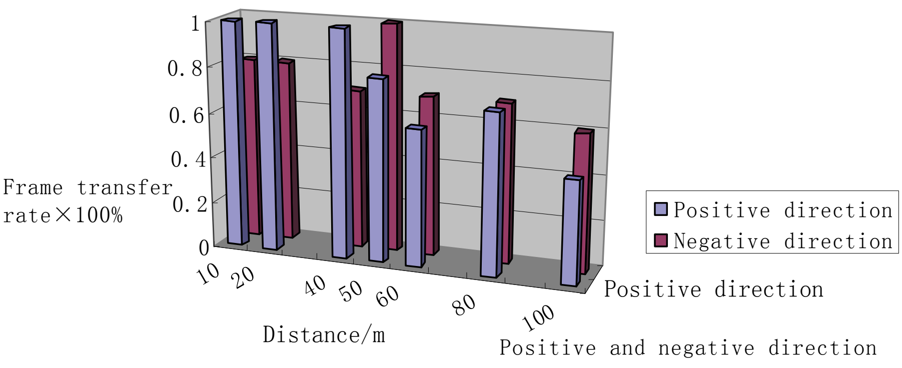
Fig. 3 shows, when antenna height on the grass is 100 cm and transmitting power is 10 dBm, asymmetric link do not exist. When antenna height on the grass is 100 cm and transmission power is 0 dBm, distribution of asymmetric link becomes obvious in the remote place of propagation path because of low transmission power. When nodes are placed on surface of grass and transmitting power is 10 dBm, deep shadow fading in some locations can cause asymmetric link. When nodes are placed on grass surface and transmitting power is 0 dBm, distribution of asymmetric link becomes obvious and quality of link becomes poor. In the worst case, difference of correct reception rates of frames reaches to 30 % in bidirectional communication. In conclusion, in order to lay sensor nodes effectively, characteristics of channel propagation must be analyzed thoroughly at the early stage of network design. In addition, design of energy-efficient the network protocol must be based on realistic channel model.

4. Conclusion

Currently most of researches about wireless sensor network are based on the traditional path loss model and some assumption. But, because the path loss model has strong impact to the result of network simulation, impractical model will reduce reliability of results even error possibly occurs. The survey shows that for layout environment of wireless network, channel propagation model of wireless network need to be still improved, especially low altitude propagation channel. In order to effectively study and design random layout of wireless sensor node on wild environment, several classic application scenes of wireless network are tested and improved in this paper. Since sample data is fitted by linear regression algorithm based on the method of least square, some meaningful conclusions about low-altitude path loss model are obtained. It is proved that log Gaussian shadow distribution is still suitable for low-attitude surface's channel. But when antenna height is very low and propagation path is along the surface, loss exponent at abrupt change point has obvious fluctuation before and after change occurs. Thus it is proved that existing model is unworthiness. When antenna height is fully close to surface, loss model of single broken line can be adopted .when antenna height is higher and LOS exist, double broken line model can be adopted. In this paper, model parameters of several different scenes are given. In addition, maximum range of node transmission indicates tradition path loss model is unrealistic in low-attitude situation. But correlation model of mutating points and loss exponent need to be studied deeply.



(a) 0dBm TX PWR of 100cm height antennaon grass ground



(b) 0dBm TX PWR of ground placement on grass ground

Fig. 3. Distribution of irregular radio propagation of 45 cm height antenna on grass.

In the wild environment, Determination of channel propagation model of wireless sensor network need to be further improved. At the same time, characteristics of small-scale fading also need to be measured in order to design energy-efficient network. In order to design a low-redundant, energy-efficient wireless sensor network and accurately assess the performance of the network protocol in simulation research stage, created model must meet features of realistic channel propagation. Thus whole simulation research platform of wireless network can be established based on this model.

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