Outdoor propagation of signals between wireless sensor nodes

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In this paper we present outdoor propagation of wireless sensor nodes in different scenarios. We observe some cases in which we measure Received Signal Strength (RSS) and then by calculations we find the Path Loss (PL) of the signal, the Path Loss constant (n), and the Standard Deviation (σ). Additional losses are caused by refractions from the ground and the trees. In practice, the values of (n) and (σ) are computed from measured data, using linear regression, such that the difference between the measured and estimated path losses is minimized in a mean square error sense (MMSE method) over a wide range of measurement locations and T-R separations. Log-normal shadowing model is used in for predicting large-scale coverage for wireless sensor networks and is derived out of a combination of analytical and empirical methods. This model implies that measured signal levels at a specific T-R separation have a Gaussian (normal) distribution about the distance-dependent mean, where the measured signal levels (received power) have values in dBm units. The standard deviation of the Gaussian distribution that describes the shadowing has also units in dBm. Thus, the random effects of shadowing are easily accounted for the case of Gaussian.

Разпространението на сигнали между безжични сензорни възли в отворени пространства (Златан Ганев). *В тази статия са разгледани различни случаи за предаване на данни между безжични сензорни възли, разположени в отворени пространства. В направените експерименти се измерва Силата на Приетия Сигнал (RSS) и след това чрез изчисления са намерени Загубите при предаване на сигналите (PL), Константата на Загубите (n), Стандартното отклонение (σ). Допълнителните загуби са причинени от отразяването на сигнала от земята и от дърветата. В практиката, стойностите на (n) и (σ) се изчисляват чрез линейна регресия, по метода на „най-малките квадрати“, като се използват резултатите от направените измервания на определена дистанция между предавателя и приемника. Използван е моделът „Log-normal shadowing model“ за прогнозиране на обсега на покритие на безжични сензорни мрежи, който се базира на аналитични и емпирични методи. При този модел е характерно, че нивата на измерените сигнали имат Гаусово (нормално) разпределение с нулева средна стойност, където измерените нива на сигнала (приетата мощност) се отчита в dBm. Стандартното отклонение на Гаусовото разпределение, която отчита засенчването също се измерва в dBm. По този начин случайните процеси при засенчването се отчитат по метода на Гаус.*

Introduction

In this paper we present outdoor propagation of wireless sensor nodes in different scenarios. "*Log-normal shadowing model*" is used here for predicting large-scale coverage for wireless sensor networks. Applying this model we can estimate the energy capacity of WSN (wireless sensor network), before such systems to be deployed.

First, we measure Received Signal Strength Indicator (RSSI). Then we calculate Received Signal Strength (RSS), Path Loss (PL), Path Loss exponent (n) and Standard Deviation (σ), assuming Gaussian noise in the channel. After that we estimate Path Loss (PL), at given distance (d).

In practice, the values of n and σ are computed from measured data, using linear regression, such that the difference between the measured and estimated path losses is minimized in a mean square error sense (MMSE method) over a wide range of measurement locations and T-R separations [1]-[11].

Propagation model and formulas for statistical processing of data results

Path-loss shadowing model

Path-loss shadowing model is used, presented by the following formula [1-5]:

(1) $$PL[dBm] = PL(d_0) + 10n\log_{10}(d/d_0) + X_\sigma$$

This is an empirical model, which analytically approximates the measurements results. The received signal strength RSS in function of distance may be presented by the same one in the following way [4]:

(2) $$RSS[dBm] = P_t - PL(d)$$

(3) $$RSS[dBm] = P_t - PL(d_0) - 10n\log_{10}(d/d_0) - X_\sigma$$

where d is the distance of receiving and transmitting (T-R), d_0 is the reference distance, Pt is the transmitting power in (dBm), PL are the losses in (dBm), n is the the path loss constant. X_σ is a random variable with Gaussian distribution and zero mean with standard deviation σ. It has approximate value from 8 to 10 dBm and it can be found by the following formula also:

(4) $$X\sigma(x) = \frac{1}{\sigma\sqrt{2\pi}}\exp\left(\frac{-(x-\mu)^2}{2\sigma^2}\right)$$

where μ is the RSS mean value, σ is the standard deviation and x is the RSS variable measured or simulated. Usually X_σ is between 8 and 10 dB [13].

Finding n and σ

The least squares method is used (MMSE - minimum mean square error) for finding out the path loss constant n and the standard deviation σ [5].

We consider the fact that the reference distance for indoor signal distribution is do = 1 m and that the losses for that distance in this particular case PL (do) are known.

The sum of squared errors that should be minimized is

(5) $$S(n) = \sum_{k=0}^{N}\left(p_k - p'_k\right)^2$$

where with p' we have denoted the received power RSS, calculated by the equation:

(6) $$p_k' = RSS_k = RSS_k(d_0) - 10n\log_{10}(d_k/d_0)$$

and with p – the received power , obtained from the measurements.

K = 1,2…,N ,and N is the total number of measurements made.

The necessary condition for a minimum is expressed in the following way [1], [2], [5]:

(7) $$\frac{dS}{dn} = 0$$

and hence we mathematically define the path loss constant n.

The standard deviation σ (dBm) is found using the formula [1], [2], [5] :

(8) $$\sigma = \sqrt{S(n)/N}$$

It has been found that by increasing the number of measurements σ decreases.

Experiments and results from simulations

The experiments are made in the area of the University of Patra – Greece.

Experimental Setup

The propagation of the RF signal is tightly coupled to the environment due to well known phenomena such as reflection, diffraction, and scattering. In the following the focus is on outdoor unobstructed and tree-obstructed environments and their influence on the RF signal propagation.

We first started with empirical study of the RF signal propagation in tree obstructed grove environment Figure 1.

Fig.1. Olive garden.

The experiments took place in an olive grove of 50m X 80m with the trees located approximately every 4-5m as shown in Figure 2 [4].

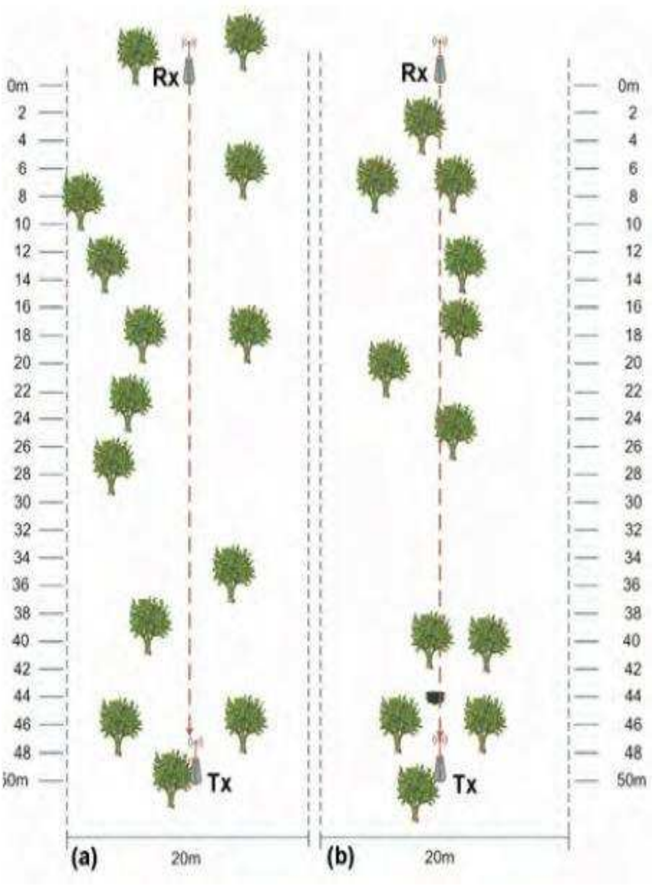

Fig.2. Garden environment (a) with free LoS, (b) with NLoS.

A diagram of the experimental setup is shown in Fig.3 The sensor nodes are placed on two –meter tripods. On the first tripod (from right to left in the figure) one transmit node T is placed, located at a height of 1,1m.

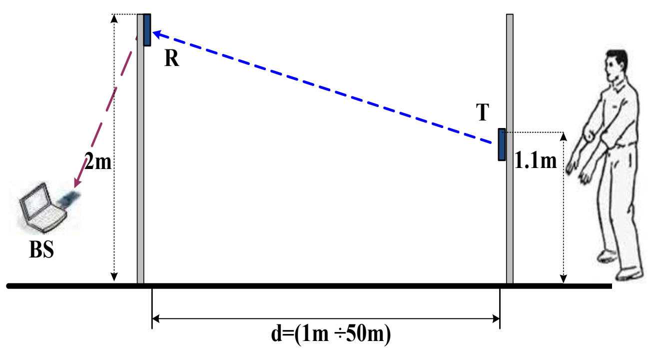

Fig.3. Experimental setup.

At every 150ms, T transmit a package of information to the receiving node R, located on the second tripod at a height of 2m. 100 packages are sent for each measurement respectively from T to R. The received information from R is transmitted to the Base Station (BS), which is connected to a laptop via USB, where it is processed and RSSI (Received Signal Strength Indicator) is extracted from it. This is done at each meter for a distance of d=1-50m. The transmitting frequency is f=2.48GHz, and the transmitting power is Pt=0dBm [3].

Two different measurements were performed: (1) T-R distance with free line of sight (LoS) with trees around as shown in Figure 2 (a), and (2) T-R distance with trees located between T-R pair, i.e. there is NLoS as shown in Figure 2 (b).

The measurements results and calculations are made in the following sequence:

Finding RSSI

It is found by special software program that converts the received information from the transmitter T in the numbers that are displayed on the laptop (Fig.4).

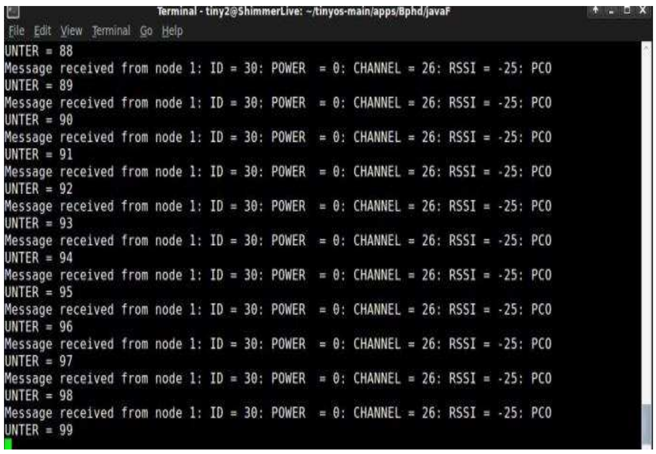

Fig.4. Finding RRSI.

Finding RSS and PL

According to the specification for CC2420 [12] the given formula is used:

(9) RSS[dBm]=RSSI_VAL+RSSI_OFFSET

by which the received signal strength RSS from the transmitter is calculated in [dBm].

In (9) RSS_OFFSET is the empirically found value of RSSI as a result of the experiment. For this purpose a special software program is used, that works in operational system TinyOS. According to [12], RSS_VAL is -45 dBm. Therefore, for example, if we have extracted from the program register for RSSI the number 30 (which is, as we have already said, RSSI_OFFSET) so the received signal strength according to (11) will be:

$$RSS = -35\ dBm + (-45)\ dBm = -80\ dBm$$

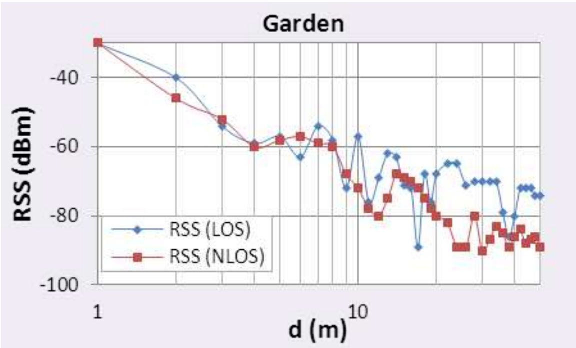

Fig.5. RSS with (a)LoS and (b)NLoS.

Figure 5 presents the results for RSS over the distance in two different environments: (a) grove with trees with LoS, (b) grove with trees with NLoS.

By using Formula (2) PL for signal distribution from the transmitter is calculated.

The results are presented in Fig .6

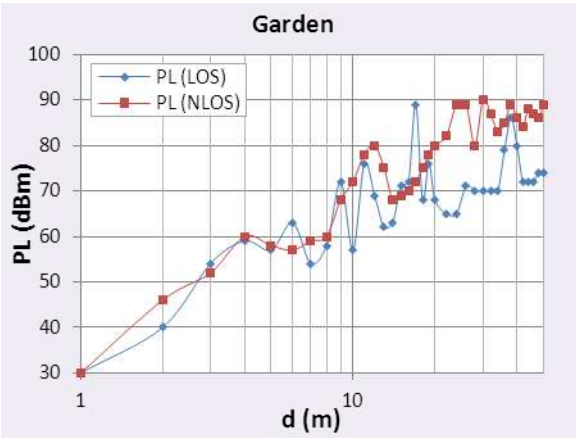

Fig.6. PL with (a)LoS and (b)NLoS.

The results of measurements and calculations are shown in Table 1.

Table 1

d (m)	RSSI(LoS) (dBm)	RSSI(NLoS) (dBm)	RSS(LoS) (dBm)	RSS(NloS) (dBm)	PL(LoS) (dB)	PL(NloS) (dB)
1	15	15	-30	-30	30	30
2	5	-1	-40	-46	40	46
3	-9	-7	-54	-52	54	52
4	-14	-15	-59	-60	59	60
5	-12	-13	-57	-58	57	58
6	-18	-12	-63	-57	63	57
7	-9	-14	-54	-59	54	59
8	-13	-15	-58	-60	58	60
9	-27	-23	-72	-68	72	68
10	-12	-27	-57	-72	57	72
11	-31	-33	-76	-78	76	78
12	-24	-35	-69	-80	69	80
13	-17	-30	-62	-75	62	75
14	-18	-23	-63	-68	63	68
15	-26	-24	-71	-69	71	69
16	-27	-25	-72	-70	72	70
17	-44	-27	-89	-72	89	72
18	-23	-30	-68	-75	68	75
19	-31	-33	-76	-78	76	78
20	-23	-35	-68	-80	68	80
22	-20	-37	-65	-82	65	82
24	-20	-44	-65	-89	65	89
26	-26	-44	-71	-89	71	89
28	-25	-35	-70	-80	70	80
30	-25	-45	-70	-90	70	90
32	-25	-42	-70	-87	70	87
34	-25	-38	-70	-83	70	83
36	-34	-40	-79	-85	79	85
38	-41	-44	-86	-89	86	89
40	-35	-41	-80	-86	80	86
42	-27	-39	-72	-84	72	84
44	-27	-43	-72	-88	72	88
46	-27	-42	-72	-87	72	87
48	-29	-41	-74	-86	74	86
50	-29	-44	-74	-89	74	89

Finding n and σ

Formulas (5)-(8) are used ,as well as, linear regression along with the minimum mean square error method (MMSE) for finding out the PL, constant n and the standard deviation σ in an Matlab environment (Fig.7). In our case for (a) LoS and (b) NLoS are found respectively the following values:

(a) n_{LoS}= 2,9868 ; σ_{LoS}= 6,3849
(b) n_{NLoS}= 3,6861 ; σ_{NLoS}= 4,6209

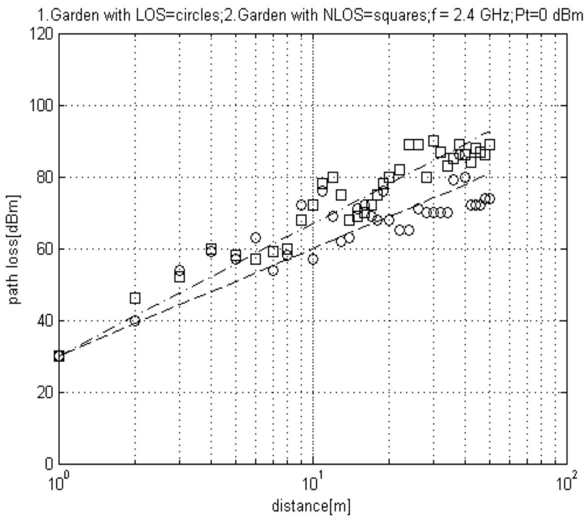

Fig.7. Linear regression (MMSE).

Finding received power P_r ($P_r \equiv RSS$) at given distance (d)

By using Formula (3) and assuming that X_σ is equal to 9, P_r at given distance (d=20.5m) is calculated. From Table1 we have $PL(d_0)$= -30 dB.

(a) With LoS

$$\Pr(\mathrm{d}) = RSS[dBm] = P_t - PL(d_0) - 10n\log_{10}(d/d_0) - X_\sigma$$
$$\Pr(20{,}5) = 0 - (-30) - 10.2{,}9868.\log_{10}(20{,}5/1) - 9 = -18{,}18[dBm]$$

(b) With NLoS

$$\Pr(\mathrm{d}) = RSS[dBm] = P_t - PL(d_0) - 10n\log_{10}(d/d_0) - X_\sigma$$
$$\Pr(20{,}5) = 0 - (-30) - 10.3{,}6861.\log_{10}(20{,}5/1) - 9 = -27{,}35[dBm]$$

Conclusion

The log-normal distribution describes the random *shadowing* effects which occur over a large number of measurement locations which have different levels of clutter on the propagation path. This phenomenon is referred to as "*Path-loss Shadowing model".*

In our case this model implies that measured signal levels at a specific T-R separation (d=50m) in an olive garden, where the measured signal levels (RSS) have values in dBm units. The standard deviation of the Gaussian distribution that describes the shadowing has also units in dBm. Thus, the random effects of shadowing are easily accounted for the case of Gaussian distribution.

The roughness of the ground in the tree grove (grass, holes, stones, etc) and the nearby trees are sources of reflection and scattering of the radio waves, which may explain the difference between the curves for cases in Fig.4,5 (a) and (b).

Fading in the channel represents the short-term effects due to multi-path propagation [5]. The path loss exponent n is changing for different scenarios in the interval ($1<n<6$) [1], [5]. Particularly, for the free-space path loss exponent is n = 2. But in our case n>2 because we have a multiple reflections from the obstacles which leads to attenuation of the signal.

From our calculations is visible that the path loss constant (parameter n) is bigger for the case with NLoS (nNLoS= 3,6861) then transmission with LoS (nLoS= 2.9868). Respectively, this leads to higher losses in the propagation of signals in this case (Fig.6, 7) This can be explained by different paths from reflections and shadowing effects from the trees.

In conclusion we can say that the models we use could be applied to variety of scenarios in the area of WSN. We can use this models in different kind of environments, with different carrier frequencies and distances to find Received Power P_r at given distance (d).

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