LOG-NORMAL SHADOWINGMODEL FOR WIRELESS SENSOR NETWORKS

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Abstract

In this paper two cases of propagation are considered: a) two- floor propagation and b) three-floor propagation in one office building. Additional losses are caused by radio waves going through ceilings and reflections and diffractions from walls and edges.

"Log-normal shadowing model" is used here for predicting large-scale coverage for wireless sensor networks. Applying this model helps one to estimate the energy capacity of WSN (wireless sensor network), before such systems to be deployed.

First, we calculate path loss exponent (n) and then standard deviation (σ), assuming Gaussian noise in the channel. Second, we estimate the received power (Pr) at given distance (d) and predict the likelihood that the received signal level at this distance will be greater than given threshold γ:Pr[Pr(d) > γ]. Finally, we find out the percentage U(γ) of the area with a radius d, where received signal will be greater than a certain threshold γ.

1. INTRODUCTION

Our radio propagation model is derived on a combination of analytical and empirical methods. The empirical approach is based on "*curve-fitting*" method applied to measured data. All propagation factors are taken into consideration, both known and unknown, through *actual power measurements*. However, the validity of an empirical model at certain frequency or environment, can only be established by proper measurements.

2. PROPAGATION MODEL

This is an empirical model that try to approximate analytically the results of measurement. The path-loss function of the distance can be represented in the following form [1 - 3]

$$PL(d) = PL(d_0)(d/d_0)^n \tag{1}$$

or in logarithmic form [4 - 5]

$$PL_{dB}(d) = PL_{dB}(d_0) + 10n\lg(d/d_0) + X_\sigma \tag{2}$$

where (d) is the distance, (d_0) is the reference distance, and (X_σ) is a Gaussian noise power (in dB). Here MMSE (*minimum mean square error*) estimation about the path-loss exponent (n) is applied and the standard deviation (σ) is found.

The reference distance for *indoor propagation model* usually is assumed to be d_0 = 1 m, and the path loss there in our case is assumed to be $PL(d_0) = -32\ dB$.

The sum of squared errors that should be minimized is [6]

$$S(n) = \sum_{k=0}^{N} \left(p_k - q_k n\right)^2 \tag{3}$$

where new coefficients

$$q_k = -10\lg(d_k/d_0) \tag{4}$$

and

$$p_0 = 0,\ p_k = -p(d_k) + p_0 \tag{5}$$

are introduced. For the MMSE algorithm S(n) is found by the following simple quadratic expression

$$S(n) = A - 2Bn + Cn^2 \tag{6}$$

with new defined coefficients

$$A = \sum_{k=0}^{N} p_k^2;\quad B = \sum_{k=0}^{N} p_k q_k;\quad C = \sum_{k=0}^{N} q_k^2 \tag{7}$$

(k = 1,2,…,N). Here N is the *total number of the measurements*, while (k=0) is related to the reference point. The *necessary condition for minimum*

$$\frac{dS}{dn} = 0 \tag{8}$$

leads to the following equation for the path-loss exponent n

$$n = B / C \tag{9}$$

It can be shown that an appropriate expression for the *standard deviation* is

$$\sigma[dB] = \sqrt{S(n)/N} \tag{10}$$

In general, a greater number of measurements are needed to reduce σ.

3. RESULTS FROM SIMULATIONS

3.1. Calculation of the path loss exponent (n) and the standard deviation (**σ**) using measured results

Here we presented two different *best fit lines*:

a) "the two-floor results" of measurements (with circles);

b) "the three-floor results" of measurements (with squares).

The range of measurements is: d = [10–34m]. In these experiments the carrier frequency is f = 914 MHz.

Both best fit lines (with *linear regressions*) are shown by dashed lines in Fig.1.

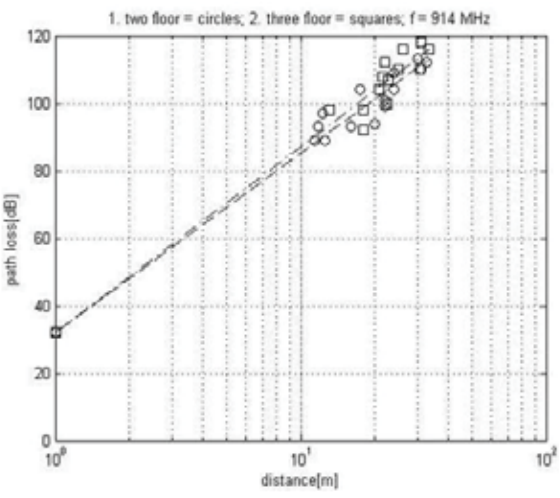

Fig. 1. Best fit linear regressions

More accurate results for the parameters of both linear regression lines are:

a) (two-floor) n_1 = 5.32; σ_1 = 3.76 dB;

b) (three-floor) n_2 = 5.52; σ_2 = 4.36 dB.

We observe one interesting and expected result from these simulations: the power parameter (n) for the case of "three-floor" is higher than the same parameter for the case of "two-floor". This event can be explained by additional "through-ceiling propagation".

3.2. Statistical data processing of the obtained results

a) two-floor case at distance d = 30m

a1) estimation of the received power (at d=30m)

It is given by the following equation [5]

$$P_r(d) = -32dB - 10n\,lg(d/d_0) \tag{11}$$

It can be found for this distance the following power

$P_r(d = 30m) = -32dB - 10(5.32)lg(30/1)$
$= -110.58dB$

A Gaussian random variable having zero mean and standard deviation σ_1 = 3.76 dB could be added to this value to simulate random shadowing effects at d=30m.

a2) likelihood prediction of the received signal - to be greater than the level "γ" (here γ = –113 dB).

The probability that the received signal level will be greater than γ = –113dB is given by the following equation [5]

$$Pr[P_r(d) > \gamma] = Q\left(\frac{\gamma - \mathrm{Pr}\,(d)}{\sigma 1}\right) = Q\left(\frac{-113+110.58}{3.76}\right) = Q(-0.644) = 0.740 = 74\% \tag{12}$$

where new auxiliary function (for argument z < 0) is involved [5]

$$Q(z) = 0.5[1 + \mathrm{erf}\,(z/\sqrt{2}\,)] \tag{13}$$

and erf(x) is the "error function" (this special function is available in Matlab).

a3) percentage prediction of the area within a d=30 m radius (that receives signals with a level greater than "γ").

The probability that the received signal level will be greater than γ= -113dB is presented by the follow n g equation [5]

$$U(\gamma)=0.5\{1+\exp(1/b^2)[1-\mathrm{erf}(1/b)]\} \quad (14)$$

where erf(x) is already defined function above and the new parameter here is

$$b = (10n\lg e)/(\sigma\sqrt{2}) = 4.345 \quad (15)$$

The value obtained by (14) is U = 89.3% (of the area that receives coverage above – 113 dB) .

b) three-floor case at distance d = 26m

Similar analysis is performed here.

b1) estimation of the received power (at d = 26m). It is given by (11)

$$P_r(d = 26m) = -32dB - 10(5.52)\lg(26/1) = -110.1dB$$

A Gaussian random variable having zero mean and standard deviation σ_2 = 4.36 dB could be added to this value to simulate random shadowing effects at *d*=26m.

b2) likelihood prediction of the received signal - to be greater than the level "γ" (here γ = –116 dB).

The probability that the received signal level will be greater than γ = –116 dB is given by (12)

$$Pr[P_r(d) > \gamma] = Q\left(\frac{\gamma-\mathrm{Pr}\ (\mathrm{d})}{\sigma 2}\right)= Q\left(\frac{-116+110.1}{4.36}\right) = Q(-1.352) = 0.912 = 91.2\%$$

where the function Q(z) is defined by (13).

b3) percentagepredictionof the area within a d = 26 m radius (that receives signals with a level greater than "γ").

The probability that the received signal level will be greater than γ = –116 dB is found by equations (14) and (15).

Here

$$b = (10n\lg e)/(\sigma\sqrt{2}) = 2.423,$$

and for the percentage is obtained the following value U = 88.2 % .

4. CONCLUSION

The log-normal distribution describes the random *shadowing* effects which occur over a large number of measurement locations which have the same T-R (transmitter – receiver) separation, but have different levels of clutter on the propagation path. This phenomenon is referred to as "*log-normal shadowing model*". 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 dB units. The standard deviation of the Gaussian distribution that describes the shadowing has also units in dB. Thus, the random effects of shadowing are easily accounted for the case of Gaussian distribution.

The closed reference distance d0, the path-loss at this distance PL(d0), the path- loss exponent n, and the standard deviation σ, statistically describe the path-loss model for an arbitrary location having a specific T-R separation, and this model may be used in computer simulation to provide received power levels for random locations in communication system design and analysis.

In practice, the values of n and σ are computed from measured data (as described above), 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.

In our case is visible that the path loss constant (parameter n) is bigger for the case in "three-floor" than the case in "two- floor" example. This can be explained by the additional shadowing effects for the "three-floor" example.

Our "*best-fit model*" (with linear regression) could be applied to variety of scenarios in the area of WSN. We can apply this model in different kind of environments, with different carrier frequencies and distances.

5. APPENDIX AND ACKNOWLEDGMENTS

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