

PRACTICAL LINK BUDGET DESIGN FOR WIRELESS SYSTEMS USING PATH LOSS MODELS

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Abstract

Most radio propagation models are derived using a combination of analytical and empirical methods. But with these methods however, the validity of an empirical model at transmission frequencies or environment other than those used to derive the model can only be established by additional measured data in the new environment at the required transmission frequency. This paper uses the path loss model to estimate the received signal level as a function of distance so as to be able to estimate the SNR for a system with large-scale coverage such as mobile communication systems. Practical path loss estimation considerations based on log - distance path loss model was discussed extensively. Finally, procedure to determine the percentage of coverage was highlighted using the results from an experimental measurements for a practical cellular network.

Key words: Propagation models, path loss models, loss exponent, coverage area.

1. Introduction

The mobile radio channel places fundamental limitations on the performance of wireless communication systems. The transmission path between the transmitter and the receiver can vary from simple line-of-sight to one that is severely obstructed by buildings, mountains, and foliage. Unlike wired channels that are stationary and predictable, radio channels are extremely random and do not offer easy analysis. Even the speed of motion impacts how rapidly the signal level fades as a mobile terminal moves in space. Modeling the radio channel has historically been one of the most difficult parts of mobile radio system design. Most radio propagation models are derived using a combination of analytical and empirical methods. The empirical approach is based on fitting curves or analytical expressions that recreate a set of measured data. This has the advantage of implicitly taken in account all propagation factors, both known and unknown, through actual field measurement. However, the validity of an empirical model at transmission frequencies model can only be established by additional measured data in the new environment at the required transmission frequency.

This paper uses the path loss model to estimate the received signal level as a function of distance, so as to be able to predict the SNR for a model communication system which normally requires larger scale coverage. The practical path loss estimation techniques are extensively discussed in this paper. Again, the method for the computation of the relationship between the boundary coverage and the percent of area covered within the boundary is also highlighted.

2. Practical Path Loss Estimation Considerations

Both theoretical and measurement - based propagation models indicate that average received signal power decreases logarithmically with distances, whether outdoor or indoor channels.

In Log-distance path loss model, the average large - scale path loss for an arbitrary Transmitter/Receiver (T-R) separation is expressed as a function of distance by using a path loss exponent, n :

$$\overline{PL}(dB) = \overline{PL}(d_0) + 10n \log(d/d_0) \quad (1)$$

Where n is the path loss exponent, which indicates the rate at which the path loss increase with distance, d_0 is the close - in reference distances which is determined from measurements close to the transmitter, and d is the T-R separation distance. The bars in equation (1) denote the ensemble average of all possible path loss values for a given value of d . When plotted on a log-log scale, the modeled path loss is a straight line with a slope equal to $10n$ dB/decade.

The value of n depends on the specific propagation environment. For example, in free space, n is equal to 2, and when obstructions are present, n will have a large value. Table 1.0 lists typical path loss exponents obtained in various variable radio environments [1].

Table 1.0: Path loss exponents for different Environments.

Environment	Path loss exponent, n
Free Space	2
Urban area cellular radio	2.7 to 3.5
Shadowed Urban cellular radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2.3

It is important to select a free space reference distance that is appropriate for the propagation environment. In large coverage systems, 1 km reference distances are commonly used, whereas in microcellular systems, much

smaller distances (such as 100m or 1m) are used [1]. The reference path loss is calculated using the free space path loss given by equation (1) or through field measurements at distance d_0 .

The model in equation (1) does not consider the fact that the surrounding environmental clutter may be vastly different at two different locations having the same T-R separation. This leads to measured signals which are vastly different than the average value predicted by equation (1). Measurements have shown that at any value of d , the path loss $PL(d)$ at a particular location is random and distributed log-normally (normal in dB) about the mean distance – dependent value [2]. That is:

$$PL(d) \text{ [dB]} = PL(d) + X_\sigma = \overline{PL}(d_0) + 10n \log(d/d_0) + X_\sigma \quad (2)$$

Where X_σ is a zero – mean Gaussian distributed random variable (in dB) with standard derivation σ (also in dB). And,

$$P_r(d) \text{ [dBm]} = P_t \text{ [dBm]} - PL(d) \text{ [dB]} \quad (3)$$

The log-normal distribution describes the random shadowing effects which occur over a large number of measurement locations which have the same T-R separation, but have different levels clutter on the propagation path. This phenomenon is referred is as log-normal shadowing. Simply put, log-normal shadowing implies that measured signal levels at a specific T-R separation have a Gaussian (normal) distribution about the distance dependent mean of equation (1), where the measured signal levels have values in dB units. The standard deviation of the Gaussian distribution that describes the shadowing also has units in dB.

3. Practical Path Loss Component Calculations

The close-in reference distances d_0 , the path has exponent n , and the standard derivation, σ statistically describes 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, using linear regression such that the difference between the measured and estimated path losses is minimized in a mean square error sense over a wide range of measurement locations and T-R separations.

Since $PL(d)$ is a random variable with a normal distribution in dB about the distance-dependent mean, so is $P_r(d)$, and the Q-functions or error function (erf) may be used to determine the probability that the received signal level will

exceed (or fall below) a particular level. The Q-function is defined as:

$$Q(z) = \frac{1}{\sqrt{2\pi}} \int_z^\infty \exp\left(-\frac{x^2}{2}\right) dx = \frac{1}{2} \left[1 - \operatorname{erf}\left(\frac{z}{\sqrt{2}}\right) \right]$$

where, $Q(z) = 1 - Q(-z)$

The probability that the received signal level (in dB power units) will exceed a certain value r can be calculated from the cumulative density function as:

$$P_r [P_r(d) > r] = Q\left(\frac{r - P_r(d)}{\sigma}\right) \quad (5)$$

Similarly, the probability that the received signal level will be below r is given by:

$$P_r [P_r(d) < r] = Q\left(\frac{P_r(d) - r}{\sigma}\right) \quad (6)$$

A graph of $Q(z)$ versus z is given in fig 1

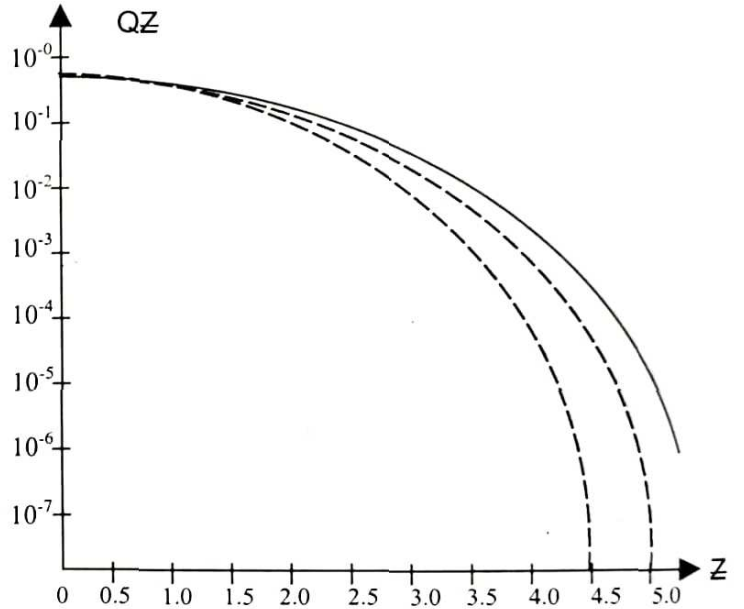


Fig 1: plot of the Q – function

Table 2.0: Displays some values for the erf function from, $Z = 0.1$ to $Z = 2.0$

Z	erf(z)	Z	erf(z)
0.1	0.11246	1.1	0.88021
0.2	0.22270	1.2	0.91031
0.3	0.32863	1.3	0.93401
0.4	0.42839	1.4	0.95228
0.5	0.52049	1.5	0.96611
0.6	0.60385	1.6	0.97635
0.7	0.67780	1.7	0.98375
0.8	0.74210	1.8	0.98909
0.9	0.79691	1.9	0.99279
1.0	0.84270	2.0	0.99532

4. Determination Of The Percentage Of Coverage Area.

It is clear that due to random effects of shadowing, some locations within a coverage area will be below a particular desired received signal threshold. It is often useful to compute how the boundary coverage relates to the percent of area covered within the boundary. For a circular coverage area, having radius R from a base station, let there be some desired received signal threshold γ . We are interested in computing $U(\gamma)$; the percentage of useful service area (i.e. the percentage of area with a received signal that is equal or greater than γ), given a known likelihood of coverage at the cell boundary.

Letting $d = r$ represent the radial distance from the transmitter, it can be shown that if $*P_r [P_r(r) > \gamma]$ is the probability that the random received signal at $d = r$ exceeds the threshold γ within an incremental area dA , then $u(r)$ can be found by (Jakes, W.C):

$$u(\gamma) = \frac{1}{\pi R^2} \int_0^R \int_0^{2\pi} P_r[P_r(r) > \gamma] r dr d\theta$$

$$= \frac{1}{2} \{ 1 + \exp(1/b^2) [1 - \text{erf}(1/b)] \} \quad (7)$$

Equation 7 can be evaluated for a large number of values of σ and n , as shown in fig 2 [5]. For example, if $n = 4$, and $\sigma = 8\text{dB}$, and if the boundary is to have 75% boundary coverage (75% of the time the signal is to exceed the threshold at the boundary), then the area of coverage is equal to 94%. If $n = 2$ and $\sigma = 8\text{dB}$, a 75% boundary coverage provides 91% area coverage.

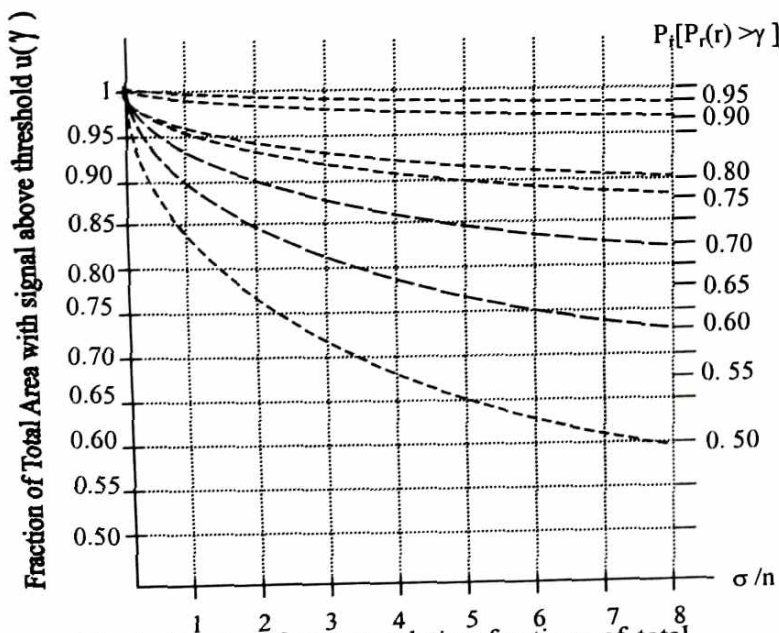


Fig 2: Family of curves relating fractions of total area with signal above threshold $u(\gamma)$ as a function

of probability of signal above threshold on the cell boundary.

If $n = 3$ and $\sigma = 9\text{dB}$, then 50% boundary coverage provides 71% area coverage.

For a practical estimation for the coverage area, four received power measurement were taken from experimental measurements carried out in a practical cellular networks [6] and given in table 3.0.

Table 3.0: Power measurements for a practical cellular network.

Distance from frameworks	Received Power
100m	0 dBm
200m	- 20dBm
1,000m	- 35dBm
3,000m	- 70dBm

We may assume here that these measurements follows the model in equation (2), where $d_0 = 100\text{m}$. Let us show how to predict the percentage area with – in a 2km radius that receives signal greater than – 60dBm.

The procedure to solve this problem is as follows:

- Find the minimum mean square error (MMSE) estimate for the path loss exponent, n . The MMSE estimate may be found using the following method. Let p_i be the received power at a distance d_i and let $\hat{p}_i$ be the estimate for p_i using the $(d/d_0)^n$ path loss model of equation (1). The sum of squared errors between the measured and estimated values is given by:

$$j(n) = \sum_{i=1}^k (p_i - \hat{p}_i)^2 \quad (8)$$

The value of n which minimizes the mean square error can be obtained by equating the derivative of $j(n)$ to zero and then solving for n .

Using equations (1), we find $\hat{p}_i = p_i(d_0) - 10n \log(d_i/100\text{m})$,

Recognizing that $P(d_0) = 0\text{dBm}$, we find the following estimates for $\hat{p}_i$ in dBm:

$$\hat{p}_1 = 0, \quad \hat{p}_2 = -3n, \quad \hat{p}_3 = -10n, \quad \hat{p}_4 = 14.77n$$

The sum of squared errors is then given by:

$$j(n) = (0 - 0)^2 + [-20 - (-3n)]^2 + [-35 - (-10n)]^2 + [-70 - (-14.77n)]^2 = 6525.2887n + 327.153n^2$$

$$dJ(n)/dn = 654.306n - 2887.8.$$

Setting this equal to zero; the value of n is obtained as $n = 4.4$

- Calculate the standard derivation about the main value.

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