

[Van87], [Zog87], [Sei91]) and is useful for predicting receiver power which scatters off large objects, such as buildings, which are for both the transmitter and receiver.

Several European cities were measured from the perimeter [Sei91], and *RCS* values for several buildings were determined from measured power delay profiles. For medium and large size buildings located 5 - 10 km away, *RCS* values were found to be in the range of $14.1 \text{ dB} \cdot \text{m}^2$ to $55.7 \text{ dB} \cdot \text{m}^2$.

3.9 Practical Link Budget Design using Path Loss Models

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 taking into account all propagation factors, both known and unknown, through actual field measurements. However, the validity of an empirical model at transmission frequencies or environments 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. Over time, some classical propagation models have emerged, which are now used to predict large-scale coverage for mobile communication systems design. By using path loss models to estimate the received signal level as a function of distance, it becomes possible to predict the SNR for a mobile communication system. Using noise analysis techniques given in Appendix B, the noise floor can be determined. For example, the 2-ray model described in section 3.6 was used to estimate capacity in a spread spectrum cellular system, before such systems were deployed [Rap92b]. Practical path loss estimation techniques are now presented.

3.9.1 Log-distance Path Loss Model

Both theoretical and measurement-based propagation models indicate that average received signal power decreases logarithmically with distance, whether in outdoor or indoor radio channels. Such models have been used extensively in the literature. The average large-scale path loss for an arbitrary T-R separation is expressed as a function of distance by using a path loss exponent, n .

$$PL(d) \propto \left(\frac{d}{d_0}\right)^n \quad (3.67)$$

or

$$PL(\text{dB}) = PL(d_0) + 10n \log\left(\frac{d}{d_0}\right) \quad (3.68)$$

where n is the path loss exponent which indicates the rate at which the path loss increases with distance, d_0 is the close-in reference distance which is determined from measurements close to the transmitter, and d is the T-R separation

distance. The bars in equations (3.67) and (3.68) 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 per 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 larger value.

It is important to select a free space reference distance that is appropriate for the propagation environment. In large coverage cellular systems, 1 km reference distances are commonly used [Lee85], whereas in microcellular systems, much smaller distances (such as 100 m or 1 m) are used. The reference distance should always be in the far field of the antenna so that near-field effects do not alter the reference path loss. The reference path loss is calculated using the free space path loss formula given by equation (3.5) or through field measurements at distance d_0 . Table 3.2 lists typical path loss exponents obtained in various mobile radio environments.

Table 3.2 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 to 3

3.9.2 Log-normal Shadowing

The model in equation (3.68) 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 (3.68). 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 [Cox84], [Ber87]. That is

$$PL(d) = \overline{PL}(d) + X_\sigma = \overline{PL}(d_0) + 10n \log\left(\frac{d}{d_0}\right) + X_\sigma \quad (3.69.a)$$

and

$$P_r(d) = P_t(d) - PL(d) \quad (\text{antenna gains included in } PL(d)) \quad (3.69.b)$$

where X_σ is a zero-mean Gaussian distributed random variable (in dB) with standard deviation σ (also in dB).