Path Loss Models in Land Comm Links with Irregular Built up Terrain

We will anaylse radio wave propagation in built up areas, when both terminal are located in LOS and/or NLOS conditions at street level, with the assumption that buildings are randomly distributed over irregular terrain. We will discuss two models used in industry for the prediction of path loss.

The Okumura's Empirical Model

A landmark study by Yoshihisa Okumura, Ohmori, Kawano and Fukuda (in the review of the Electrical Communication Laboratory, Vol 16, No 9 – 11, sept 1968). Is one of the first attempts to quantify, in a statistical way, propagation in the mobile environment for frequencies from 150 MHz to 2GHz. The study was performed in Kyoto, Japan, from a moving van travelling at a speed of 30 km/h. The test equipment used had a high sensitivity of -125 dBm, and a dynamic range of 50 dB.

The method is basically an empirical method of predicting the average power within the communication channel – mobile base station. Okumura curves refer to the signal level in 50 % of locations, and is therefore referring to the median signal level. The field strength at any range is near to being log normally distributed, and so is virtually symmetrically distributed about the median. It is more usual today to design for 90% coverage in 90% of locations, and this upper decile value will give a figure that more realistically reflects a consistent standard of coverage. The relationship between the mean and the upper decile value is given by:

$$\text{Mean} = \text{Level}(90\% / 90\%) + 1.28\rho \qquad [1]$$

where ρ is the standard deviation. Typical field strength deviations for various terrains are shown in Table 1.

Terrain	Standard Deviation (dB)
Urban	8 - 12
Suburban	6
Flat Suburban	3 - 5
Rural	3
Water Paths	1.5

Okumura curves describe the average attenuation $A_{Ru}(f,d)$ relative to free space for quasi-smooth terrain in an urban environment. The average path loss according to Okuruma et al is given as:

$$L_{50} = L_{FS} + A_{Ru}(f,d) + H_{Tu}(h_T,d) + H_{Ru}(h_R,d) \qquad [2]$$

Note that [2] contains a few correction factors. The second correction factor, $H_{Tu}\left(h_T,d\right)$ is the base station antenna gain factor and the third correction factor, $H_{Ru}\left(h_R,d\right)$ is the moving vehicle antenna height gain.

Hata Model

The results obtained by Okumura were summarized in a formula that gives the path loss suitable for computer implementation by Hata. Hata's analytical expressions for average path loss, L_{50} for urban, suburban and rural areas are applicable only over

quasi-smooth terrain. The average path loss is given in dB as:

$$L_{50} = 69.55 + 26.16\log f_0 - 13.82\log h_T - a\left(h_R\right) + \log d\left(44.9 - 6.55\log h_T\right) \qquad [3]$$

where $150 \le f_0 \le 1.5GHz$, $30 \le h_T \le 200m$, $1 \le h_R \le 10m$ and $1 \le d \le 20km$. $a\left(h_R\right)$ is the correction factor for the terrain that is height dependent – correction factor for mobile antenna height that is computed as follows:

For medium size cities:

$$a\left(h_R\right) = \left(1.1\log f_0 - 0.7\right)h_R - \left(1.5f_0 - 0.8\right)$$

For a large city:

$$a\left(h_R\right) = \begin{cases} 8.29\left(\log 1.54h_R\right)^2 - 1.1 & f_0 \le 200MHz \\ 3.2\left(\log 11.75h_R\right)^2 - 4.97 & f_0 \ge 400MHz \end{cases}$$

For Suburban areas:

$$L_{50} = L_{50}(urban) - 2\left(\log\frac{f_0}{28}\right)^2 - 5.4dB$$

For open and rural areas:

$$L_{50} = L_{50}(urban) - 4.78\left(\log f_0\right)^2 + 18.33\log f_0 - 40.94\ \text{dB}$$

For a nominal antenna height of 1.5m, the values of $a\left(h_T\right)$ are:

Urban = 0dB

Suburban = -9.88 dB

Rural = -28.41 dB

The Cost 231 Walfisch-Ikegami Model

The Cost 231 model is a combination of deterministics and empirical modeling and considers the loss to be made up of three components: free space, roof to street diffraction and scatter loss, and multiscreen loss. It is based on important urban parameters such as building density, average building height and street width. In this model, antenna height is generally lower than the average buildings' height, so that the waves are guided along the street. This model is widely used in Europe and is designated for short-range services such as GSM and PCN.

The total path loss according to this model is given as:

$$L = L_f + L_r + L_m$$

For LOS conditions: Path loss formula has same form as the free space formula changing only constants before log d.

$$L_{50}(LOS) = L_f = 42.6 + 20\log f_0 + 26\log d$$

For NLOS conditions: The semi-empirical path loss formula is given as:

$$L_{50}(NLOS) = 32.4 + 20\log f_0 + 20\log d + L_{RD} + L_{MD}$$

L_{RD} represents rooftop diffraction loss and is characterized by:

$$L_{RD} = -16.9 - 10\log \Delta a + 10\log f_0 + 20\log \Delta h_R + L(0)$$

$L(0)$ is the loss due to elevation angle, h_R is the mobile vehicle antenna height and Δa is the distance between the vehicle and the building.

L_{MD} is the component that represents multi diffraction loss due to surrounding buildings.

$$L_{MD} = K_0 + K_a + K_d \log d + K_f \log f_0 - 9\log a$$

where

$$K_0 = -18\log(1 + \Delta h_T) \qquad h_R > h_{rooftop}$$

$$K_a = \begin{cases} 54 - 0.8\Delta h_T & d \geq 0.5km,\ h_R > h_{rooftop} \\ 54 - 1.6\Delta h_T & d < 0.5km,\ h_R < h_{rooftop} \end{cases}$$

$$K_d = 18 - 15\left(\frac{\Delta h_T}{h_{rooftop}}\right)$$

$$K_f = \begin{cases} 4 + 0.7\left(\frac{f_0}{925} - 1\right) & \text{for suburban} \\ 4 + 1.5\left(\frac{f_0}{925} - 1\right) & \text{for urban} \end{cases}$$

Radio wave Propagation

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