<u>Propagation in Built - Up Areas</u>

The most common environment of mobile communication is that between base station and mobiles located in a *built – up area* at street level. Built – up areas introduce two effects in the mobile radio propagation channel: (a) the shadowing effect due to buildings in the vicinity of the mobile and (b) tunnelling or channelling of radiowaves along streets. Hence, the strongest paths are often not the most obvious or direct ones and the signal strength along a radial street can exceed that of a circumferential street. Estimation of the received mobile radio signal is generally a two-stage process which involves predicting the median signal level in a small region of the service area and describing the variability about the median value.

- **CLASSIFICATION OF BUILT-UP AREAS**

Propagation of radio waves in a built–up area has been found to strongly depend on the nature of the environment, in particular the size and density of buildings. Hence, a classification of environment is required. In broad terms the environment can be classified as:

<u>*Rural*</u>: farm land with sparse building, woodland and forests.
<u>*Urban*</u>: areas dominated by tall buildings, office blocks, commercial premises
<u>*Suburban*</u>: residential houses, parks, gardens

The above classification is mainly a qualitative measure and hence can be interpreted differently in different countries. To avoid this problem it is necessary to introduce a quantitative approach to include the effect of buildings.

- **Classification approach**

The environment can be viewed as a conglomerate of numerous clustered objects. For example, a town appears as a random collection of buildings. Likewise a forest appears as a random collection of trees. If the statistical properties of groups or clusters of individual buildings/trees are known, as well as the size of each group, then it is possible to derive quantitative descriptions of the environment

Any given mobile radio service area can be viewed as a mixture of environments (for example a mixture of rural and suburban). Service area can be divided into squares of dimensions based on the Ordnance Survey maps of 500 m by 500 m which is regarded as a sample of an ensemble of composite environments with the ensembles described by a different terrain type and land cover. Characteristics that can be used in classifying land types include:

(1) Building density (percentage of area covered by buildings)
(2) Building size (area covered by a building)
(3) Building height
(4) Building location

(5) Vegetation density
(6) Terrain undulations

- **Classification methods**

A number of classification methods are available which include that introduced by Kozono and Watanabe to describe the urban environment in Tokyo, and that introduced by Ibrahim and Parsons following their measurements in inner London. Ibrahim and Parsons introduced two factors:

L: ***Land Usage Factor*** which is defined as the percentage of the 500 m by 500 m test square that is covered by buildings, regardless of their height. A good correlation was observed between path loss value and L.

U: *Degree of Urbanisation Factor* which is defined as the percentage of building site area, within the test square, occupied by buildings having four or more floors. U may vary between zero and 100 %. A value approaching zero indicates a suburb while a value close to 100% indicates a highly developed urban area.

Note that different countries have different Land Usage Factors which implies that the measurements carried out in one country can not be directly applied in another. However, with computer data of the terrain and buildings, it is possible to obtain from digitised maps the land usage parameters such as the building location, building size or base area, total area occupied by buildings, number of buildings in the area concerned, terrain height, parks and/or gardens with trees and vegetation. These can in turn be used to obtain various distributions such as building size, building area, building height, vegetation, and terrain undulation.

- **Propagation Prediction models and Techniques**

The prediction of path loss is very important for cell planning. In this section path loss prediction methods which take the effect of terrain, buildings, man-made obstacles, and vegetation are discussed. No one method applies to all situations and that the use of one model does not preclude the application of other models.

1. Effect of vegetation

The effect of vegetation was studied by Weissberger who proposed a modified exponential decay model which applies in areas where a ray path is blocked by dense, dry, in-leaf trees. The model is given by eqn. 20.

$$L = \begin{cases} 1.33F^{0.284}d^{0.588} & 14 < d \le 400 \\ 0.45F^{0.284}d & 0 \le d \le 14 \end{cases} \qquad (20)$$

where L is the loss in dB, F is the frequency in GHz, and d is the depth of the trees in meters. The difference in path loss for trees with and without leaves is 3 to 5 dB. Generally no one model is valid for all environments and the user must select a suitable model for the particular application. Most models give an estimate of the median value of the path loss i.e. the loss that is not likely to be exceeded at 50% of the locations or time.

Prediction models include the Egli model, the JRC (Joint radio Committee) model, the Blomquist-Ladell model, the Longley-Rice models, the CCIR method and the BBC method. Some of these models permit the calculation of the path loss via an empirical equation; others require the use of terrain data, atmospheric conditions and a computer to predict the received signal strength. Variations between the predictions and the actual received signal strength can be on the order of 10 dB. In the following various path loss models are presented.

2. The Egli model

Egli carried out field strength measurements between 90 MHz and 1000 MHz. He observed that the path loss had a tendency to follow a fourth power law with range from the transmitter i.e. similar to the plane earth model. However, he also observed that the loss was a function of frequency and terrain. Hence, he introduced a correction factor, β, to take these effects into account.

$$L_{50} = G_n G_m \left(\frac{h_b h_m}{d^2} \right)^2 \beta \qquad (21)$$

where for frequency effects alone

$$\beta = \left(\frac{40}{f_c(MHz)} \right)^2$$

To take into account the terrain irregularity, Egli assumes that the value of β is the median and it has a standard deviation which is terrain dependent. Assuming a log-normal distribution about the median value he produced a family of curves to show how the correction factor deviates from its value at 40 MHz as a function of terrain and frequency.

For communication at short range, the Egli formula loses its accuracy because the reflection coefficient is not necessarily close to -1. For $d << h_T h_R / 4\lambda$ free space propagation is more appropriate, but a number of significant reflections must be taken into account. In streets with high buildings, guided propagation may occur.

3. The Blomquist-Ladell model

This model assumes that the path loss is given by:

$$L = L_f + \sqrt{(L_p - L_f)^2 + L_d^2} \qquad dB \qquad (22)$$

where L_f is the free space loss, L_p is the plane earth loss, and L_d is the diffraction loss as predicted by the Epstein-Peterson method.

Over highly obstructed paths, the diffraction loss is greater than the first term under the square root and hence, the loss reduces to

$$L = L_f + L_d$$

For unobstructed paths the total loss is that of the plane earth loss i.e. $L = L_p$.

4. Young's measurements

Young conducted measurements in New York at frequencies between 150 MHz and 3700 MHz. His measurements confirmed that the path loss was much greater than was predicted by the plane earth model. It was clear from his field trials that the path loss increased with frequency and that there was evidence of strong correlation between path loss at 150 MHz, 450 MHz and 900 MHz. Investigation of Young's results by other researchers showed that an inverse fourth – power law relates the path loss to distance from the transmitter and in terms of Egli's model the relationship can be expressed as:

$$L_{50} = G_T G_R \left(\frac{h_T h_R}{d^2} \right)^2 \beta \qquad (23)$$

L_{50} is the median (50%) path loss, and β are the losses due to buildings. At 150 MHz β was found to be approximately equal to 25 dB.

5. Allsebrook's method

A series of measurements were carried out at frequencies between 75 MHz and 450 MHz in British cities (Birmingham, Bath and Bradford) by Allsebrrok and Parsons to produce a propagation prediction model. The measurements showed that a fourth – power range law provides a good fit to experimental data and Eq. 23 provides a basis for prediction with an appropriate value of β.

(1) <u>'Flat City' model:</u> when the terrain effects are negligible:

$$\beta = L_B + \gamma \qquad (24)$$

$$L_{50} = L_P + L_B + \gamma \qquad (25)$$

where L_P is the plane – earth path loss, L_B is the diffraction loss due to buildings, and γ is an additional UHF correction factor for $f_c > 200MHz$.

(2) Hilly city:

$$L_{50} = L_f + \sqrt{\left(L_P - L_f\right)^2 + L_D^2} + L_B + \gamma \qquad \text{(dB)} \tag{26}$$

An approximation of L_B is given by:

$$L_B = 20\log_{10}\left[\frac{h_0 - h_m}{548\sqrt{w' f_c * 10^{-3}}}\right] + 16 \qquad \text{(dB)} \tag{27}$$

h_0 is the average height of buildings in the neighbourhood of the mobile, h_m is the mobile's height, w' is the effective width of the street in the direction of the transmitter (the mobile is assumed to be in the middle of a street with buildings either side), and f_c is the carrier frequency (200-500 MHz).

6. The Okumura method

Following an extensive series of measurements in and around Tokyo at frequencies up to 1920 MHz, Okumura published an empirical prediction method. The basis of this method is that the path loss consists of free space loss plus an attenuation factor relative to free space which is a function of frequency and distance assuming an effective transmit antenna height of 200 m and an effective receive antenna height of 3 m. It applies for frequencies in the range 100-3000 MHz and distances from 1-100 km from the base station. Graphs for antenna factors are also supplied by the model. The Okumura model is the most referenced model and it has become a standard for other models. The various graphs can be entered into a computer and interpolation between values can be applied to evaluate the path loss.

In an attempt to make the Okumura method easy to apply, Hata established empirical mathematical relationships to describe the graphical information given by Okumura. Hata's formulation is limited to certain input parameters and is applicable only over quasi-smooth terrain. The mathematical expressions and their range of applicability are:

(1) Urban areas:

$$L_{50} = 69.55 + 26.16\log f_c - 13.82\log h_T - a(h_R) + (44.9 - 6.55\log h_T)\log d \qquad \text{(dB)} \tag{28}$$

where, $150 \leq f_c \leq 1500$ *MHz*,
$30 \leq h_T \leq 200$ *m*,
$1 \leq d \leq 20$ *km*

For small cities $$a(h_R) = (1.1\log f_c - 0.7)h_R - (1.56\log f_c - 0.8) \tag{29}$$

where $1 \leq h_r \leq 10$ m.

For large cities $$a(h_R) = \begin{cases} 8.29(\log 1.54 h_R)^2 - 11 & f_c \leq 200\,MHz \\ 3.2(\log 11.75 h_R)^2 - 4.97 & f_c \geq 400\,MHz \end{cases} \tag{30}$$

(2) Suburban areas:

$$L_{50} = L_{50}(\text{urban}) - 2[\log(f_c/28)]^2 - 5.4 \qquad \text{(dB)} \tag{31}$$

(3) Open areas:

$$L_{50} = L_{50}(\text{urban}) - 4.8(\log f_c)^2 - 18.33 \log f_c - 40.94 \qquad \text{(dB)} \tag{32}$$

When compared with the original graphs, the difference with Hata's equations is very negligible and is generally less than 1 dB. Generally, Okumura's model is complex and gives good agreement with measurements in urban and suburban environments but not as good in rural areas over irregular terrain. There is a tendency for the predictions to be optimistic. In addition, the urban environment defined by Okumura refers to that of Japan and does not necessarily apply to other countries.

7. The Ibrahim and Parsons method

Ibrahim and Parsons carried out several measurements in inner London at 168 MHz, 445 MHz and 900 MHz using a transmit antenna height of 46 m. The median value, for the path loss, for squares of 500 m by 500 m were computed and these were then used to derive empirical and semi-empirical models. The semi-empirical model is based on the flat-earth path loss of eqn. 23 which gives the median path loss where

$$\beta = 20 + \frac{f}{40} + 0.18L - 0.34H + K$$

and (33)

$$K = 0.094U - 5.9$$

U is the Degree of urbanisation factor, L is the Land Usage factor, H is the difference between the transmit antenna height and the receive antenna height above the terrain.

8. Lee's model

A propagation model described by Lee is intended for use at 900 MHz and operates in two modes, an area-to-area mode and a point-to-point mode. In the area-to-area case, the median path loss is given by:

$$L_{50} = L_0 + \gamma \log d + F_0 \tag{34}$$

Where, L_0: Median transmission loss at a range of 1 km,

γ: Slope of the path loss curve (dB/decade)

F_0: Adjustment factors used when the following reference parameters are not satisfied.

Carrier frequency: 900 MHz

Base station antenna height: 30.48 m (100 ft)
Transmitter power: 10 W
Base station antenna gain with respect to λ/2 dipole = 6 dB
Mobile antenna height = 3 m (10 ft)

$F_0 = F_1 F_2 F_3 F_4$ where: (35)

$$F_1 = \left(\frac{\text{Actual Base Station Antenna Height}}{\text{Reference Base Station Height}} \right)^2 \quad (36)$$

$$F_2 = \left(\frac{\text{Actual Transmitter Power (W)}}{10} \right) \quad (37)$$

$$F_3 = \left(\frac{\text{Actual Gain of Base Station Antenna}}{4} \right) \quad (38)$$

For F_3 , the gain is measured with respect to a $\lambda/2$ dipole and the reference antenna gain is 6 dB (= 4).

F_4: compensates for changes in the mobile antenna height. If height >10 m it can be compensated for as F_1.

Note that L_o and γ are obtained from the measurements and are tabulated below for different environments.

Propagation parameters for Lee's model

Environment	L_o	γ
Free space	91.3	20
Open (rural) space	91.3	43.5
Suburban	104	38.5
Urban area		
- Philadelphia	112.8	36.8
- Newark	106.3	43.1
- Tokyo	128	30

The point-to-point case of Lee's model takes into account the terrain. This case will not be discusses here.