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A study of propagation path-loss models

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ABSTRACT : *An Empirical model is efficient and simple to use, as it is obtained from in-depth field measurement. The input data here are qualitative, though not very correct for area like dense urban area, rural area and others. On the other hand, Site-specific models are based on numerical methods and the finite difference time- domain (FDTD) technique. The input data here are very precise and in depth whileTheoretical models are obtained from physical hypothetical assumption with inclusion of some moderate conditions. This can be seen when, for instance, considering the over-root top, the diffraction model here is obtained by the use of physical optics with the assumption of constant heights and buildings spacing.*
Keywords - *free, time, domain, path, propagation, cost, power*

I. FREE SPACE PROPAGATION MODEL

Free space propagation model assumes that there is no obstacle between the transmitter and receiver during signal propagation. The transmitter radiates signal to an infinite distance without any issue of signal absorption or reflection. If the transmitter propagates signal at 360^0 using a fixed power with an ever increasing sphere, then the transmitter will have a power flux of

$$P_d=P_t/4\pi d^2 \quad 1$$

Where P_t is the power transmitted (w/m^2)

P_d is the power obtained when the distance is d from antenna (1).

According to (2), free space propagation model shows that the signal received by the receiver decays with distance between the transmitter and receiver at a rate of 20dB/decade.

The path loss for free space model is given. Thus;

$$PL_{FSPL}=32.45+20log_{10}(d)+20log_{10}(f)\ [dB] \quad 2$$

Where;

f is the frequency in MHz

d is the distance between transmitter and receiver km

(3), (4), (5).

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II. HATA PROPAGATION MODEL

The Hata model is a set of equation obtained on measurements and extrapolations taken from curves that are derived by Okumura. It is an empirical formular for graphical path loss.(1), (2).

Hata presented the prediction area into three divisions: Open, suburban and urban areas. This model is appropriate for frequency range of 150-1500 MHz (UHF) and for distance of 1km-20km. However, Hata model does not consider terrain profile like hills that are found between transmitter and receiver. (2)

In the words of (3), Hata model for calculation of path loss are used in three situations namely:

Situation1: Urban Hata pathloss

$$PL = 69.55 + 26.16log_{10}(f) - 13.82log_{10}(hb) + (44.9 - 6.55log_{10}(hb))log_{10}(d) + s\text{-}a(hm) \quad 3$$

Situation 2: Surban Hata pathloss

$$PL=PLUrban-2((log_{10}f/28))^2-5.4 \quad 4$$

Situation 3: Rural Hata pathloss

$$PL=PLUrban - 4.78(log_{10}(f)^2) + 18.33log_{10}(f) - 40.98 \quad 5$$

Where the MS (Mobile station) antenna correction factor for the entire above situation is:

$$a(h_m)=1.11log_{10}(f) - 0.7)h_m - (1.56log_{10}(f) - 0.8)\text{ in dB} \quad 6$$

f is the frequency in MHZ
h_m is the height of the mobile antenna in meters
h_b is the height of the base station antenna in meters (1), (3), (5)

III. SUI MODEL

This stands for Stanford university Interim model. It is developed by Stanford University for frequency band of 2.5GHZ. In this model, the height of the base station antenna can be any value between 10m to 80m while that of the receiver can be between 2m to 20m based on (5).

The SUI model listed out three classes of terrain namely: terrain A, B, and C. According to (6) and (5), terrain A is suitable for dense urban locality, terrain B for hilly regions, while terrain C is appropriate for rural community with considerable vegetation. The authors also stated that the basic pathloss equation of the Stanford university interim model is thus:

$$PL = A + 10\gamma \log_{10}\left({}^{d}/_{do}\right) + X_f + X_h + S \text{ for } d>d_o \quad 7$$

Where,
d is the distance between Base Station and Receiving antenna (m)
d_o is 100 meters
λ is wavelength in meters.
X_f is the correction for frequency
X_h is the correction for receiving antenna height in meters
S is the correction for shadowing in dB
γ Is the path loss exponent

(5) further stated that random variables can be taken as the path loss exponent γ while the weak fading standard should be derived. Hence, the parameter A, which is the Attenuation is presented as,

$$A = 20\log_{10}({}^{4\pi d_o}/_{\lambda}) \quad 8$$

$$\gamma_\gamma = a - bh_b + ({}^{c}/_{h_b}) \quad 9$$

Where;
h_b is base station antenna height which is between 10m to 80m.
Constant a, b, and c depend on the terrain type.
The value of ϒ is 2 for free space, $3<\gamma<5$ for urban NLOS environment, and $\gamma>5$ for indoor propagation.
Also;
$X_f = 6.2 \log_{10}(f/2000)$ 10
$X_h = -10.9\log_{10}(h_f/2000)$ 11

IV. ECC-33 MODEL

The ECC-33 model stands for Electronic communication committee-33 model. ECC extrapolated the Okumura measurements and amended its assumption to closely depict a fixed wireless access system (7). This path loss model, otherwise known as ECC- 33 model, is suitable for suburban small urban areas and represented thus,

$$PL = PL_{fs} + PL_{bm} - G_b - G_m \quad 12$$

$$PL_{fs} = 92.4 + 20\log_{10}(d) + 20\log_{10}(f) \quad 13$$

$$PL_{bm} = 20.41 + 9.83\log_{10}(d) + 7.894\log_{10}(f) + 9.56(\log_{10}(f))^2 \quad 14$$

$$G_b = \log_{10}\left({}^{h_b}/_{200}\right)\{13.98 + 5.8[\log_{10}(d)]^2\} \quad 15$$

$$G_m = [42.57 + 13.7\log_{10}(f)][\log_{10}(hm) - 0.585] \quad 16$$

Where,
PL_{fs} is the free space path loss
PL_{bm} is the basic median path loss
(3) (7)

V. COST-231 PROPAGATION MODEL

This stands for Co-operative for Scientific and Technical research. It is an enhanced version of the Hata propagation model. That is, it employs suitable correction factors to improve the limitations of the Hata model.(1). Cost-231 model makes use of four variables in predicting propagation loss. The variables are Frequency, height of base station, height of receiver's antenna and distance between base station and receiver antenna (2).

The Cost hata Path loss equation is given by

$$PL(dB) = 46.3 + 33.9log(f_c) - 13.82log(h_b) - a(h_m) + (44.9 - 6.55log(h_b))log_{10}(d) + c_M \quad 17$$

Where;

C_M may be 0 for suburban city or 3 for metropolitan city (ogbulezie, et al., 2013)

VI. LEE PROPAGATION MODEL

According to (3), this model predicts the pathloss in urban, suburban, rural and free space regions.

CASE 1:

For Urban region= $123.77 + 30.5log_{10}(d) + 10nlog_{10}(^f/_{900}) - \alpha_o$ 18

CASE 2: for suburban region

$$PL = 99.86 + 38.4log_{10}(d) + 10nlog_{10}(^f/_{900}) - \alpha_o \quad 19$$

CASE 3: For Rural region

$$PL = 86.12 + 43.5log_{10}(d) + 10nlog_{10}(^f/_{900}) - \alpha_o \quad 20$$

CASE 4: For free space region

$$PL = 96.92 + 20log_{10}(d) + 10nlog_{10}(^f/_{900}) - \alpha_o \quad 21$$

Where n is an experimental value, say 3

α_o is the correction factor.

Hence;

$$\alpha_o = \alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 \quad 22$$

Where;

$\alpha_1 = (^{h_b}/_{30.48})^2$

$\alpha_2 = (^{h_m}/_3)^k$

$\alpha_3 = (^{P_t}/_{10})^2$

$\alpha_4 = (^{G_b}/_4)$

$\alpha_5 = G_m$

Note k could be chosen to be 2

VII. REGRESSION MODEL

Regression models are used to predict one variable from one or more other variables. (8). These models are very powerful tools that help scientists forecast about past, present or future activities through the use of information from past or present happenings. According to these authors, a regression model can be represented as shown in the equation below,

$$\gamma = b_o + b_1 \quad 23$$

$$b_1 = \frac{\sum(x_i - \bar{x})(Y_i - \bar{Y})}{\sum(x_i - \bar{x})^2} \quad 24$$

$$b_o = \frac{1}{n}\left(\sum Y_i - b_1 \sum x_i\right)$$

$$= \bar{\gamma} - b_1\bar{x} \quad 25$$

Where;

Υ is the dependent variable which is the attenuation represented as A

χ is the independent variable which is represented as D_d

b_o Is the intercept

b_1 is the slope calculated from equation (24) and (25).

In other words, equation (23) can be re-written as

$$A = b_o + b_1 D_d \quad 26$$

Where; D_d is the independent variable

Hence, equation (26) is used to calculate the empirical formular while equation (25) and (24) are used to determine the values of b_0 and b_1 in that order.

VIII. LEAST SQUARE FORMULATION

According to (9), "Finer propagation models use partition- dependent attenuation factors, which assumes n=2 free space path loss with additional path loss based on the objects that lie between the transmitter and receiver". The author highlighted that for outdoor-to- indoor propagation environment, the object may consist of house exteriors, trees, wooded patches, plaster board walls, and so on. Then the path loss, for 1m free space at any given point, can be expressed by equation (27) below:

Pathloss, $PL(d) = 20log_{10}(d) + a \times x_a + b \times x_b + \cdots$ 27

Where;

a, b,… are the quantities of each partition type between the receiver and transmitter.

x_a, x_b,… are their respective attenuation values in dB. When the data at a known site is measured, the unknown in equation (27) are the individual attenuation factors X_a, X_b etc. One of the methods suggested for the computation of the attenuation factors is to reduce or minimize the mean- square error of measured versus predicted data.

In the words of the author, if P_i stands for the path loss with respect to 1m Free Space measured at the ith location, it then means that N number of measurement will give rise to the system of equation written:

$$P_1 = 20l0g_{10(d1)} + a_1 \times x_a + b_1 \times x_b \quad 28$$

$$P_2 = 20log_{10}(d_2) + a_2 \times x_a + b_2 \times x_b \quad 29$$

$$P_N = 20log_{10}(d_N) + a_N \times x_a + b_N \times x_b \quad 30$$

Putting this equation in a succinct form, that is using matrix notation.

$$A\vec{x} = \vec{p} - 20\log 10\ (\vec{d}) \quad 31$$

Where;

$$\vec{p} = \begin{bmatrix} P_1 \\ P_2 \\ \vdots \\ P_N \end{bmatrix}$$

$$\vec{d} = \begin{bmatrix} d_1 \\ d_2 \\ \vdots \\ d_N \end{bmatrix}$$

$$\vec{x} = \begin{bmatrix} x_a \\ x_b \\ \vdots \\ x_z \end{bmatrix}$$

$$A = \begin{bmatrix} a_1 & b_1 \cdots & z_1 \\ a_2 & b_2 \quad \cdots & z_2 \\ \vdots & \vdots & \vdots \\ a_N & b_N \cdots & z_N \end{bmatrix} \quad 32$$

(9)

There are more measured points in P compared to the unknown in X in equation (31), hence, it cannot be solved immediately. Therefore, multiplying both sides of equation (31) by the transpose of A produces a tractable linear matrix equation.

$$A^T A_{\vec{x}} = A^T[\vec{p} - 20log(\vec{d})] \quad 33$$

This equation is termed the "normal equation". Solving the normal equations - taking the proper precaution against ill- conditioned matrices simultaneously minimizes the mean square error with respect to all values in X. since these data represent large – scale path loss, which tends to a log – normal distribution, the mean –square error criterion, as well as mean and standard deviation comparisons are based on the dB values of path loss. (9) give the forecasts that match measurement with a non-zero mean and small standard deviation error.

IX. PATHLOSS EXPONENT MODELS WITH AGGREGATE PENETRATION LOSS (APL)

"Adding penetration loss into the path loss exponent model increases its accuracy for outdoor –to- indoor propagation'' (10). The method used in this model is to first estimate the strength of the signal received using the outdoor in value. Following this is the addition of aggregate propagation loss (APL) to the outdoor result in order to obtain the indoor received power. The formula for this model is expressed in equation (34) below;

$$PR = P_T + G_T + G_R + 20log_{10}\left[\frac{1}{4\pi}\left(\frac{\lambda}{1m}\right)\right] - 10n_{out}\,log\left(\frac{d}{1m}\right) - APL \qquad 34$$

According to the authors, there is a difference between aggregate penetration loss and penetration loss of the partition - based model. Aggregate Penetration Loss (APL) stands for an average difference that exists between the indoor and outdoor path loss, not minding the location inside the house. It is worth to know that APL does not consider the particular number of wells or height above ground level. Also, the author defined partition based penetration loss as the difference in path loss between , two position or location that are positioned on the immediate inside and outside of the exterior wall.

X. PARTITION-BASED OUTDOOR - INDOOR MODEL

(10) emphasized that pseudo deterministic methods do use the partition – based path loss model because the standard deviation (error) encountered in path loss by the use of exponent models for outdoor to indoor propagation could be enormous wide spread neighborhood use of a wireless network. The partition-based path loss model is expressed as equation (35) below;

$$P_R = P_T + G_T + G_R + 20log_{10}\left(\frac{\lambda}{4\pi d}\right) - \sum_{i=1}^{N} xi \qquad 35$$

X_i is the value for attenuation of the ith obstruction that is intersected by the line drawn from the transmitter to the receiver point.

This outdoor obstruction could be a deciduous or coniferous tree, an area of terrain, a building and so on.

Also, the indoor obstruction is usually a wall. Partition-based- outdoor to indoor model can be extended to three dimensions by taking cognizance of the high and low blocking of trees.

These authors (10), revealed that the partition based outdoor-to-indoor model performs better when the transmitter-receiver (TR) separation is less than 50m and for more distant transmitters, once the surrounding area has just a few scatterers. When the number of the surrounding scatterers is on the high side, this result to the domination of multipath penetration which leads to the loss of physical significance of the partition-based model. This could happen, for instance, when the model try to forecast propagation through a building. One of the disadvantages of the partition-based model is that it requires a site-specific database with outdoor site characteristic and indoor floor plans. There is also the possibility that some of the application might require such a detail and extra accuracy, according to the authors.

XI. CONCLUSION

Free space propagation model calculates pathloss in the absence of an obstacle during signal propagation. Based on field measurements, and plotted curve, the Hata model is used to calculate the Pathloss. In the SUI model, the height of the base station antenna varies between 10m to 80m while that of the receiver can be between 2m to 20m.The ECC-33 model extrapolates field measurements and amended its assumption to closely depict a fixed wireless access system. The Cost-231 model is an improvement on the Hata model by employing four variables to calculate pathloss

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