Path Loss Correction for Signal Propagation amongst Low Roof Top Buildings using Fuzzy Logic

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ABSTRACT
Performance of current path attenuation prediction models encounters huge deviation from their true behavior when deployed for the locality apart from the one for which it had been proven for. This work deals with introducing the path loss on the basis of measured data and representation of the same in a different approach for the mentioned Fuzzy Inference system based analysis. The empirical data collection followed by curve-fitting for path loss evaluation on decibel scale with Normal random variable distribution for representing the shadow fading. Our paper introduces a new methodology for prediction of path loss for betterment in QoS via. Network planning specifically for mobility prone communication systems deploying fuzzy approach. The Transmission discontinuities encountered during propagation has been differentiated in to a variety of factors defined as fuzzy sets such as free space, flat terrain, low foliage terrain, high foliage terrain, and country side terrain. path loss exponent (n) has been applied for varied propagation profiles, Mamdani Fuzzy Inference has been deployed for prediction of "n" path loss exponent for any kind of scenario, which was obtained on the basis of set of symbolic rules that avails an approximation to the known propagation scenarios. Bertoni's model proposed by H.L. Bertoni's has been used for the present analysis.

Keywords
Path loss measurement, Path loss predication, Fuzzy Inference, Fuzzy Modeling.

1. INTRODUCTION
Fundamental phenomenon justifying radio propagation are different and hence they are specified by the popular physical properties like: reflection, refraction, path loss, fading, scattering and shadowing for radio signals. Path loss is defined as attenuation in the information signal's strength during propagation from source to the destination. Generally, the path loss varies proportionally with frequency and distance [5].

$$PL \propto D^{-n} \quad (1)$$

Gradual and slow variation of signal strength around its average value is called as shadowing where as the rapid variation in the received message signal strength due to multipath propagation is referred to as fading. Accuracy in path loss prediction becomes prominently important better network planning and thus imparting better QoS. Performance and accuracy of any path loss prediction scheme is justified upon data sets such as: Foliage Cover, Residential Cover, and Atmospheric viabilities along with other factors like height of base station, height of mobile and orientation of street angle and many more factors of concern preferably important for network planning now a days.

Different types of outdoor propagation models are used and deployed for determining path loss over variable profile features. Generally, all these different models are used with specific idea of predicting signal strength at some definite receiving point or in a desired location of interest (called zone/sector), the methods may vary in their approach of utility in terms of factors like compatibility and reliability. Most of these models are fundamentally laid down on a well defined algorithmic perception of measured data obtained from empirical test drives [5]. However reliability of these models remains a concern specific to the environment other than for which they have been designed. Measurement drives considering path loss in the practical scenarios and thus their result may be applied to existing models for betterment in reliability of the same [1]. Both theoretical measurement based propagation models indicate that average received signal power decreases logarithmically with distance, whether in outdoor or indoor radio propagations. The average large-scale path loss for an arbitrary Tx-Rx distance separation is made directly proportional to the distance by using a path loss exponent "n" as mentioned below:

$$PL\,(d)\ \alpha\ (\frac{d}{d0})^n$$

$$PL\,(dB) = PL\,(d0) + 10nlog\,(d/d0) \quad (2)$$

Where 'n' denotes the path loss exponent, depicting the variability in the link loss with respect to the distance, d0 termed as reference distance and d referred as Tx-Rx separation [5]. Value of this exponent 'n' depends on fixed propagation scenario, as for free space n=2 and for discontinuities in the propagation path 'n' attains a larger value. The reference distance must always lie in the far field of the radiation pattern radiating from the element such that that near field may not impact the reference path loss. A fundamentally accepted value of 1 Km for macro cell system is used, 100 m in micro cell systems and 1 m in Pico cell systems.

The Bertoni's model [18] mentioned in the literature presented an empirical formula for prediction of path loss [9].

In this paper an empirical path loss model for a typical suburban city of India has been proposed. (Patel Nagar, Dehradun).

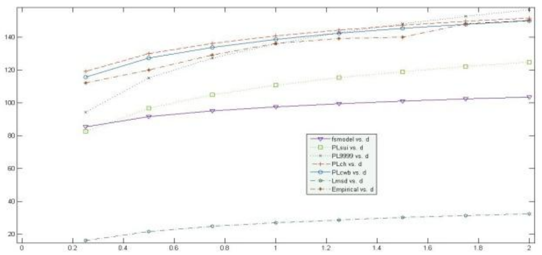

Fig.1.Cumulative comparison of path loss attributed to different models with respect to measured data path loss.

Empirical drive test were performed out in the suburban region of Patel Nagar, Dehradun of its GSM based System. The developed model is also compared with Bertoni's model, which is widely used for path loss prediction in scenarios with low roof top residential outlook.

2. BERTONI MODEL

This model is most suitable for flat sub-urban & urban areas with uniform building height. Among other models this model gives a more precise path loss. This is a result of additional parameters introduced which characterize different environments. It also covers distinguishing on basis of terrain features. The path loss equation for the same is given as:

For LOS condition

$$PL(LOS) = 42.6 + 26\,log(d) + 20log(f) \quad (3)$$

For N-LOS condition, it follows as:

$$PL_{LOS}=\{ L_{FSL} + L_{rts} + L_{msd} \quad ,\text{for urban \& sub-urban}$$

$$L_{FS} \quad ,\text{if } L_{rts} + L_{msd} > 0 \quad \} \quad (4)$$

Where,

L_{FSL} = Free space loss

L_{rts} = Roof top to street diffraction

L_{msd}= Multi screen diffraction loss

ll material on each page should fit within a rectangle of 18 x 23.5 cm (7" x 9.25"), centered on the page, beginning 2.54 cm (1") from the top of the page and ending with 2.54 cm (1") from the bottom. The right and left margins should be 1.9 cm (.75"). The text should be in two 8.45 cm (3.33") columns with a .83 cm (.33") gutter.

This model relies on ray tracing technique considering each building block as a diffraction screen.

The major feature of Bertoni's model is that it deals with path gain instead of path loss parameter which is a common trait in other models, although related to the later as:

$$\textbf{PG} \equiv \textbf{Path Gain} = \frac{\textit{recieved power}}{\textit{transmitted power}} \quad (5)$$

(PG is always less than 1)

$$\textbf{PL} \equiv \textbf{Path Loss} = \frac{\textit{transmitted power}}{\textit{received power}} \quad (6)$$

(PL is always greater than 1)

When expressed in dB, $PGdB = 10logPG = -L$

Where $L \equiv 10logPL$

If $P = PT\,A\,/R^{\,n}$, then $PGdB = 10log\,A - 10nlog$ R and $L = -10log\,A + 10nlog\,R.$ (7)

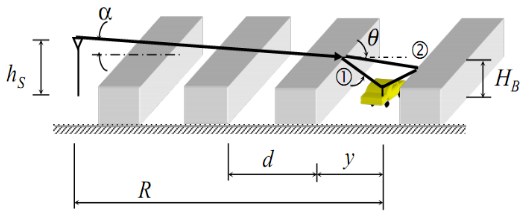

Fig.2.Bertoni model implementation layout for propagation path gain over buildings

Major factors facilitating Bertoni model to be considered are:

1. Low building environment facilitation by deploying uniform radio absorbers array in place of rows of buildings.
2. Street grid organization made aptly suitable by accounting for intra-building spacing and back-to-back spacing.
3. Use of simple geometric techniques for lower building scenario and ray-tracing techniques for high-rise building scenario both.
4. Considering propagation as a roof-top phenomenon.
5. Classification of path loss i.e. path gain in to three subtle factors each accounting for free-space loss, diffraction loss due to edges etc. is depicted as physical approximation asFig.3 [2],:

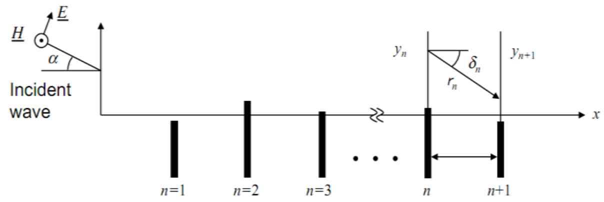

Fig.3. Physical optics approximation for roof-top field reduction

Path Gain

$$PG = (PG0)\,(PG1)\,(PG2) \quad (10)$$

Where,

$PG0 = \frac{\lambda}{4\pi r^2}$[free-space path gain]

$PG1 = Q2$ [Reduction in the field at the roof top just before the mobile due to propagation past previous rows of buildings given by a factor Q].

$PG_2=\frac{1}{2\pi k\rho_1}\left(\frac{1}{|\theta_1|}-\frac{1}{2\pi-|\theta_1|}\right)^2+\frac{|\Gamma|^2}{2\pi k\rho_2}\left(\frac{1}{|\theta_2|}-\frac{1}{2\pi-|\theta_2|}\right)^2$ which accounts for the roof top field down to mobile i.e. summing the ray powers to get the small average.

Where, ρ_1 and ρ_2 have their usual meanings as in electromagnetic studies.

Reduction of rooftop fields for a spherical wave incident on the rows of buildings is the same as the reduction for an incident plane wave after many rows. Reduction in the field strength occurs due to multiple forward diffractions past an array of absorbing screens for a plane wave with unit amplitude that is incident at glancing angle α as depicted in Fig.3.earlier.

The physical analogy deployed in Bertoni's model is based on ray tracing techniques and involves replacing buildings by parallel absorbing screens. For parallel screens, the reduction factor is found by repeated application of the Kirchhoff integral. Going from screen n to screen n+1, the integration is as:

$$H(x_{n+1}, y_{n+1}) = \int_{-\infty}^{\infty}\int_{h_n}^{\infty}(\cos\alpha_n + \cos\delta_n)H(x_n, y_n)\frac{jke^{-jkr}}{4\pi r}dy_n dz_n \quad (11)$$

3. PATH LOSS MODEL BASED ON THE FIELD MEASUREMENTS

Field measurements in the concerned scenario was performed for which a path loss model is to be developed, this encompasses the merit of deployment of different environmental entities regardless of the fact whether they can be separately resolute. From the measured data, a path loss model is developed by statistical analysis of the data. After performing the field measurement task efficiency of such models becomes highly validated. Field measurements were performed in the suburban region of Patel Nagra; Dehradun for its GSM based system. All the measurements were made for mobile terminal using TEMS-10.1 ASCOM utility rifs.

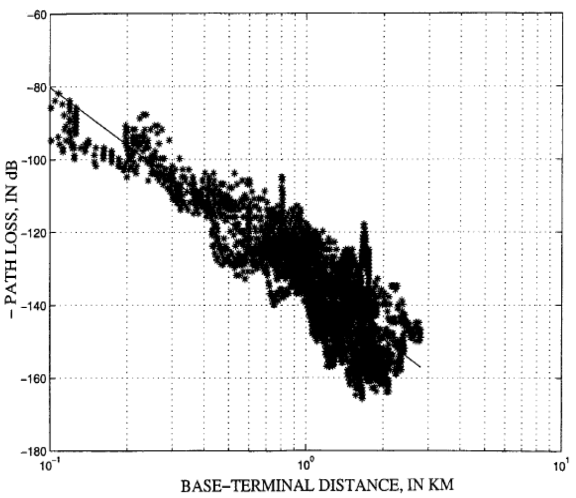

Fig.4. Scatter plot of path loss and distance with respect to base terminal (base antenna height was above 30 m)

Measurements were taken in only two zones/sectors due to terrain limitations and permissions as further cover comes under military area. For macro cellular system, the reference distance is taken as d0 = 0.5 km. Starting from 0.5 km, measurements were taken in intervals of 0.5 km in two of the concerned zones. In all, 3 cellular base stations were involved in the field measurements. For each of these, the test signal was transmitted close to 1800 MHz, and the mobile drive test car drove around the cellular coverage area at an angular span of 180 degrees measuring and recording local mean power in two sectors. In The global positioning system (GPS) data were also collected, which made it possible to determine the radial distance from the base station related with each power measurement. The experimental data were taken at distances ranging from 500 meters to 5 km as the range of clear signal is 2 km to 5 km power measured by Spectrum Analyzer at different locations in intervals of 0.5km as summarized in Table.1.

The Table.2 above depicts the measured valued obtained for power received levels obtained during the drive test. The measured values for received power varies with the distance in different sectors, median values for ungrouped frequency distribution of the received power for model formulation can be deployed. The reference path loss Lp (d0) is 112.6 dB. The path loss exponent n is obtained from the measured data, by linear regression such that the difference between the measured and estimated path loss is minimized in a mean square sense. The sum of squared error is given by:

$$E(n) = \sum_{i=1}^{k}\{Lp(di) - \acute{L}p(di)\}2 \quad (12)$$

Where Lp (di) is the measured path loss at distance di and Ĺp (di) is its estimate using equation (1). The value of n, which minimizes the mean square error, is obtained by equating the derivative of equation (12) to zero, and when solving for n.

$$dE(n)/\,dn = 0$$

The obtained value for n = 4.34.

Table.1. Empirical Measurements Based Results for 1800 MHz

Distance from the transmitter(in Km)	**Path Loss (in dB)**
0.5	112.6
1	118.7
1.5	130.7
2	139.1
2.5	142.2

Table.2. Received Power values using Tems10.1

Distance from transmitter d (km)	**Received power in different zones, (dBm)**		**Median value, (dBm)**
	α	β	Mean Value
1.0	-74	-72	-73
1.5	-77	-75	-76
2.0	-79	-77	-78
2.5	-81	-79	-80

4. MAMDANI FUZZY INFERENCE PATH LOSS MODELS

Mamdani Fuzzy inference system is based on fuzzy logic science, which rationalizes uncertainty in events to make it predictable. It considers vague concepts and provides a logical output for same. Fuzzy Logic has been extensively used in many applications where precise mathematical modeling is not feasible [7,8]. It enables us to utilize the concept of Fuzzy logic to characterize an undefined propagation scenario from a set of available scenario sets. This concept has been illustrated as Fig.5 where the propagation has been featured into several propagation scenarios defined as an input fuzzy set such as X1 = Residential cover and X2 = Foliage cover. These crisp input sets are firstly by fuzzified using some fuzzifier entity to fuzzy sets and then developed to be used along with fuzzy rule base leading to a fuzzy output. To obtain crisp output sets, a method call "de-fuzzification" is used to extract a crisp value that best represents the link loss values.

Fuzzy logic reasoning is then put to action for determining the link slope for a propagation scenario which is unknown by its nature but do closely approximate one of the available environments scenarios.

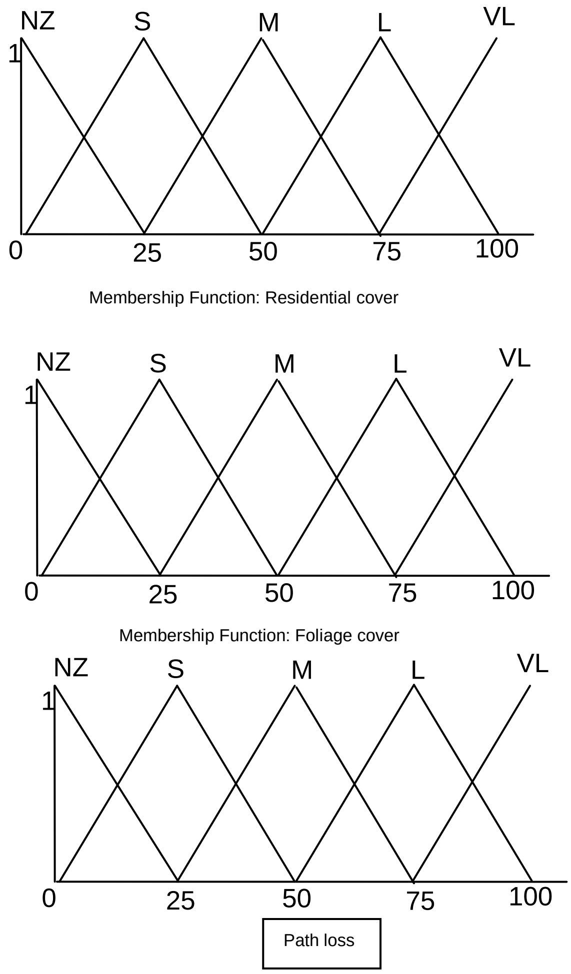

Fig.5. Fuzzy Linguistic Membership Functions

We have used triangular membership functions and classified the fuzzy variable into 5 levels as NZ: Nearly zero, S: Small, M: Medium, L: Large, and VL: Very large.

The different input scenario based variables may be classified as:

For input X1, Residential cover,

Very large = Dense Urban: Down-town having high rise buildings and very high mass.

Large = Urban: Down-town having high rise buildings on both sides of the vegetations.

Medium = Suburban: Just outside of down-town area, residential areas.

Small = Rural: Open area, roads and highways, having no residential areas.

Nearly zero = Free Space: A propagation environment having no obstructions.

For input X2, Foliage covers,

Very large vegetation mass: Virgin forest

Large vegetation mass: Thick forest, timber forest.

Medium vegetation mass: Public Park, zoo garden.

Small vegetation mass: Herb-garden, flower garden, dwarf canopy.

Nearly zero = Free Space: A propagation environment having no vegetation.

The scenarios to be predicted may be obtained by means of the following fuzzy Rule sets:

Rule1: if X1 = VL, then Y → 3

Rule2: if X1 = L, then Y = L

Rule3: if X1 = M, then Y = M

Rule4: if X1 = S, then Y = S

Rule5: if X1 = NZ, then Y → 2

Rule6: if X2 = VL, then Y → 4

Rule7: if X2 = L, then Y = L

Rule8: if X2 = M, then Y = M

Rule9: if X2 = S, then Y = S

Rule10: if X2 = NZ, then Y → 1

Rule11: if X1 = M, and X2 = L, then Y = L

Rule12: if X1 = M, and X2 = M, then Y = M

Rule13: if X1 = M, and X2 = S, then Y = M

Apparently, the above linguistic rule provides a fine tuning of propagation environments which have already been established experimentally. Now, we implement the above rules to find the output results. Fuzzy output value has very little practical use as most application requires non fuzzy (crisp) control actions therefore it is necessary to produce a crisp value to represent the possibility distribution of the output using defuzzification. Sum of means method for defuzzification is used for the present analysis can be expressed as:

$$f(y) = \sum\mu(y).y$$

$$\sum\mu(y)$$

and applying Sum of means method we obtain:

$$f(y) = \sum_{m=1}^{n} E^m D^m$$

Where*:*

f(y) is the crisp output value

E^m is the crisp weighting for the linguistic value LV^m

D^m is the membership value of y with relation to the linguistic value LV^m

5. RESULTS

The experimental data were analyzed to find path loss slope for each terrain by linear regression. The results obtained by using fuzzy logic approximation are shown in Table-3.

Table.3. Values for Link Loss Slope using Fuzzy inference

Terrain Type	Fuzzy Path Loss Slope (n)
Clear Area	2.2
Light Vegetation	3.3
Small Town	4.1
Heavy Vegetation	4.7

6. CONCLUSION

Path loss models based on measured data have been presented using linear regression and Fuzzy logic. The models are based on a simple dn exponential path loss Vs. distance relationship.

It has been shown from the above considerations and relations; the fuzzy logic set approach to path loss prediction puts a new method for communication analysis in complex system, which RF propagation is chaotic in multipath environment owing to numerous RF barriers and scattering phenomena from several objects in the environment.

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