Measurement Validation of Fuzzy-like Propagation Models for Wireless Cellular Networks in Metropolitan Environment

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ABSTRACT

Increasing demand for radio channels has brought about generational developments which emanated from the explosive requirement for wireless services in a metropolitan environment is one of the major challenges facing the path loss propagation prediction. However, this prediction is necessary for link budget and in the determination of the coverage area of a particular base station. Therefore, in this paper, a fuzzy-logic based path loss prediction model is proposed for accurate link budget and optimal coverage determination. Also, a drive test is conducted and data were collected for non urban, urban, suburban, ex-urban, dense-urban, micro-urban and peri urban areas in Lagos metropolitan environment for training the proposed model. Network parameters were varied during the performance evaluation process for the 900MHz and 1800MHz bands. Results show that the mean path loss for different environments is higher for the 900MHz band compared with 1800MHz band and this shows that propagation in the 900MHz environment is characterized with more challenges and dynamic propagation conditions than in 1800MHz. Additionally, the urban environment gives the highest value for the constant offset being 60dB for 900MHz but the ex-urban environment has a constant offset of 64dB in 1800MHz.

Keywords: Drive-Test, Fuzzy-Logic, Metropolitan, Path loss,

1. INTRODUCTION

The rapid growth in wireless telecommunication services results in increased desire for next generation services by mobile subscribers. However, this event has resulted in the need for proper network coverage predictions ^[1]. It has been shown in the literature that propagation prediction models such as Okumura-Hata and the Walfisch-Ikegami (WI) are based on substantial experimental data collection and statistical analysis, which help in computing the receive signal level in a particular propagation medium ^[2]. Also, mobile communication requires high-quality received signal at the receivers, however, some receiving points provide weak signal due to obstructions such as buildings and trees between a transmitter and a receiver ^[3]. In the design of wireless communication systems, the knowledge of the propagation characteristics of a wireless radio channel is very vital in a given environment ^[4]. Moreover, path loss information is very important for link budget and in order to determine the coverage of a particular base station. Path loss is the attenuation that a signal suffers as it journeys from the transmitter to the receiver. Generally, some parameter estimations can only be obtained by field measurements if all the necessary pieces of information such as propagation predictions are not available, which in most cases involve drive test and is time consuming apart from being expensive.

Basically, path loss prediction models (PLPMs) are divided into empirical, site-specific propagation and theoretical models ^[4]. Empirical models such as Hata, Okumura and Egli models are set of algebraic equations derived from extensive field measurements. These models are accurate for environments with similar characteristics as those where the measurements were made. The input parameters for the empirical models are usually qualitative and not very specific such as a dense urban terrain, a rural terrain and some ideal environments. This model has a challenge in that it can never be used for different environments without an

adequate modification. Site-specific propagation models are derived from numerical methods such as ray-tracing method (RTM) and the finite difference time-domain (FDTD) method. The input parameters are very detailed and accurate. However, this method has a very high disadvantage because it has large computational overheads. Theoretical models such as free space and plane earth propagation models are derived based on the physical laws of wave propagation. They are more efficient than the site-specific models and the empirical models.

1.1 Literature Review

The authors in [4], present a comparative analysis of path loss prediction models for urban macro-cellular environments. Three path loss prediction models were used in the prediction of path loss, which are: free space, Hata and Egli. The calculated path loss values were compared with practical measured data obtained from a Visafone base station located in Uyo, Nigeria. The comparative analysis shows that the mean square errors (MSEs) for free space, Hata and Egli were 16.24dB, 2.37dB and 8.40dB respectively. The presented results show that the Hata's model is the most accurate and reliable path loss prediction model for macro-cellular urban propagation environments. In [5], the authors give the comparison between measured and predicted path loss for mobile communication in Malaysia. The path loss is measured in four different locations and results are obtained from different six models: Lee model, Log-normal shadowing, Stanford University interim (SUI) model, COST231 Hata model, the electronic communication committee (ECC)-33 and Egli model. Their measured results show that the SUI and the log-normal models give a better prediction and can be used to estimate path loss for prediction of mobile coverage in a microcell in Malaysia. The aspect of path loss prediction in wireless communication system using fuzzy logic is presented in [6]. Binary phase shift keying (BPSK) modulated signal is used to find the path loss using HATA empirical formula derived with the help of the Okumura curve for urban, suburban and rural areas. The identified values are given and Defuzzification is performed using faster and flexible centre of sum method. The inferred results show maximum loss in case of urban and increases at an average rate of 10dB per decade with distance. In [7], the authors propose a method to predict path loss for cellular mobile communication systems using fuzzy logic. The propagation medium is classified in to several well-established propagation environments defined as a fuzzy set such as free space, flat area terrain, light vegetation terrain, heavy vegetation terrain, and village terrain. A unique mean path loss exponent is assigned to each propagation environment, which is established by means of the experimental. Fuzzy logic is used to determine the unknown environment, which is obtained using linguistic rules that provide a fine tuning of the known propagation environments. The authors in [8] propose some modifications to the COST 231 WI model to reflect the information related to building and terrain heights of practical environments. A dual slope propagation model is developed based on the modified WI model for small cells with electrical and mechanical tilt. To validate the proposed model, propagation measurements are performed in a metropolitan area using commercially deployed small cells. The authors also suggest a procedure to compute the path loss from measurement data considering transmit antenna beam patterns, and determine the break point for the proposed dual slope model using measurement results. In [9], the authors perform comparative analysis of the basic models and artificial neural network based model for path loss prediction. Data were acquired in a drive test through selected rural and suburban routes in Minna, Nigeria and environs as dataset required for training artificial neural network (ANN) model. Multilayer perception (MLP) network parameters were varied during the performance evaluation process, and the weight and bias values of the best performed MLP network were extracted for the development of the ANN based path loss models for two different routes, namely rural and suburban routes. The performance of the developed ANN based path loss model was compared with some of the existing techniques and modified techniques. The basic empirical path loss models considered are Hata, Egli, COST-231, Ericsson models and modified path loss approach.

1.2 Contributions and Organization

Different from the existing works and conventional models, in this paper, we focus on path loss prediction model based on fuzzy logic in Lagos, Nigeria. The contribution of this paper is threefold with respect to existing works, as summarized below:

- I. The development of a fuzzy-logic based path loss prediction model for metropolitan environments.
- II. A drive test was conducted to acquire data required for training the proposed model for seven environments - non urban, urban, suburban, ex-urban, dense-urban, micro-urban and peri urban areas in Lagos metropolitan environment in Lagos, Nigeria.

- III. The performance of the proposed model is evaluated by varying the network parameters for 900MHz and 1800MHz bands.

The rest of this paper is organized as follows: Section II discusses the existing path loss prediction models. Section III describes the proposed model. Section IV presents the results and the discussions. Section V concludes this paper.

2. SOME EXISTING PATH LOSS PREDICTION MODELS

The average path loss in decibel (dB) for an arbitrary transmitter and receiver considering the distance d in an m metropolitan terrain is given as:

$$L_m(d) = L_m(d_o) + 10n \log\left(\frac{d}{d_o}\right) \quad (1)$$

where d_o is the reference distance $L_m(d_o)$ is the average reference path loss in a metropolitan environment and n is the path loss exponent, which indicates the rate at which the path loss increases with distance. The reference distance d_o in a metropolitan environment must be selected such that it is in the far field of the transmitting antenna. The typical values mostly used are 1km in microcell systems and 1m in Pico cell systems ^{[10]-[12]}.

Equation (1) indicates the parameter of the path loss model. It is important to note that since the accuracy of the path loss model depends on these parameters to determine the value of $L_m(d_o)$, this may be predicted from the free space path loss model and the value of n may be determined empirically.

2.1 Hata Model

The Hata Model was developed from the extensive empirical measurements taken by Okumura in Tokyo city, Japan. For suburban environments, the median path loss in dB is given by:

$$L_m(d) = \alpha + \beta \log(d) \quad (2)$$

Where

$$\alpha = 69.55 + 26.16 \log(f_c) - 13.82 \log(h_b) - a(h_m) \quad (3)$$

$$\beta = 44.9 - 6.55 \log(h_b) \quad (4)$$

$$\gamma = 5.4 + 2 \left[\log\left(\frac{f_c}{28}\right) \right]^2 \quad (5)$$

Also,

$$a(h_m) = (1.1 \log(f_c) - 0.7) h_m - (1.56 \log(f_c) - 0.8) \quad (6)$$

where α , β , h_m , $a(h_b)$, f_c and γ denote the correction factor that depends on frequency, correction factor for mobile antenna height, mobile antenna height, base station antenna height, frequency, and effective antenna gain respectively.

For suburban and non-urban models they are based on the urban model with the following corrections:

$$\text{Path loss(sub-urban)} = \text{path loss(urban)} - 2 \left[\log\left(\frac{f_c}{28}\right) \right]^2 - 5.4 \quad (7)$$

And

$$\text{Path loss(non-urban)} = \text{path loss(urban)} - 4.7 [\log(f)]^2 + 18.33 \log(f) - 40.94 \quad (8)$$

2.2 Free Space Propagation model

Path loss PL at a point r is defined as the ratio of transmitted power at r_0 over the received power at r , Pr . For free space propagation, the path loss is given as:

$$L(\text{Db}) = 10 \log \frac{P_t(r_0)}{dr(r)} = 10 \log \left[\frac{G_t G_r 2}{d\alpha} \right] \quad (9)$$

where G_t and G_r are the gains of the transmitting antenna (Tx) and the receiving antenna (Rx) respectively. (Tx) and (Rx) are separated by a distance d and α is the wavelength in free space.

3. PROPOSED MODEL

In this paper, we propose a fuzzy-logic based path loss prediction model for metropolitan environments as illustrated in Fig. 1.

Figure 1. Block Diagram of a Generic Fuzzy Logic Type 2 Model

3.1 Fuzzy logic

Fuzzy logic applies fuzzy set theory in which a variable is a member of one or more sets with a specified degree of membership. In the literature, some researchers have also applied the fuzzy logic methods to compute non-linear and ill-defined systems [13]-[14]. Though most of these methods focus on the type-1 fuzzy logic. Over the years, there has been an approach to model uncertainty which has called into play the type-2 fuzzy logic system. We have also observed that from a concept of the type-2 fuzzy logic, it is possible to predict the path loss using "IF-THEN" rules. The propagation environment inputs are converted by the fuzzifier to type-2 fuzzy set and later inference using the IF-THEN rule based on the path loss prediction outputs via the output processing. Moreover, it is worthy to note that the areas vary from terrain to terrain, requiring wide range databases, which is difficult to clutter terrain factors by the generic conventional method. This is the premise that led to the development of the type-2 fuzzy logic system for a metropolitan environment which yielded more accuracy in computation.

3.2 Fuzzy Logic Type-2 system

The arrangement of the type-2 fuzzy logic system is close to the structure of fuzzy logic system. The basic difference between them is the membership function and the output as shown in Fig. 1. For a type-1 Fuzzy logic system, the output processing block contains only the defuzzifier. The fuzzifier maps the crisp input into a fuzzy set, to become a type-2 set. In the type-1 case, in the "IF THEN" rules, the i th rule has the form "R": if $x_1 = F_1$ and $x_2 = F_2$ and $\dots x_n = F_n$. Then, y is G , where x 's are inputs; F_1 's are antecedent sets ($i = 1 \dots p$); y is the output; and G 's are consequent sets. The common distinction between type 1 and type 2 is associated with the nature of the membership functions, which is not important while forming the rules, hence, the structure of the rules remain exactly the same as in the type 2 case. The proposed fuzzy-logic model for path loss prediction is shown in Fig. 2.

Figure 2. The Proposed Fuzzy-Logic Model for Path Loss Prediction.

However, it is noted that the only difference is that all of the sets involved are of type-2 so the i th rule in a type-2 fuzzy logic system yield the form “R”if $x_1, \hat{F}^l$ and x_2 is $\hat{F}^l$ and... x_p is $\hat{F}^l$, THEN, y is $\hat{G}^l$.

3.3 Fuzzy Inference

The behavior of the system which relates the input and the output variables of the system is governed by a set of rules Atypical rule would be

If x is A , Then y is B

$$150 \leq f_c \leq 220M \text{ Hz}$$

$$1 \leq h_m \leq 10m$$

$$1 \leq d \leq 20km$$

If x is A , Then y is B , when a set if input variables are read, each of the rule that has any degree of truth in its premise is fixed and contributes to the form of the fuzzy-logic system (FLS) by approximately modifying it when all rules are fixed. The resulting system is expressed as a fuzzy set to represent the constraints output. The process is referred to as “Inference”.

3.4 Path loss Fuzzy Membership Function

Fuzzy logic over the years has been used to model a lot of systems, which cannot be defined in an absolute manner. In this work, the RS-power and distance inputs have a Gaussian membership function type, while the path loss which is the output is of triangular membership function type.

3.5 Defuzzification

Defuzzification is the method used for conversion of fuzzy quantity into crisp quantity. There are many methods available for defuzzification. The most common one is the Centroid method, which utilizes the formula in equation ⁽¹⁰⁾. In this paper, the Mamdani is chosen rather than the Sugeno ^[14]. The Mamdani FIS in this case is fed with two inputs namely the Received power (RSPower) and the distance of the user equipment (UE) while the output is the path loss of the channel. A 25-rules inference scheme is used for simplicity in order to avoid the complexity that comes with many rules if applied. Fig.3 shows the defuzzification of the testing rule.

4. RESULTS AND DISCUSSIONS

Path loss exponents for seven environments were computed for fuzzy type 1 and 2 in 900 MHz and 1800 MHz and presented in Tables I-IV. The Ex-urban has the lowest path loss exponent of 5.11 in the 900MHz and 5.60 in the 1800MHz as can be seen from Tables I, III and II, IV respectively. This is due to the fact that signals are most likely not obstructed. The sub-urban area has the lowest prediction error. Line of sight can still be expected on some test locations. Although sites visited were located in cities where building heights, billboards and vegetation contribute to the increase in the path loss exponent from free space value of 2. As seen from the Table V, the Mean Prediction error is less than 3.66 dB. Furthermore, path loss exponents are observed to become smaller as the received signal strength (RSS) increases and at shorter distances.

Figure 3. Defuzzification of the Testing Rule.

Table I. 900MHZ -FUZZY TYPE 1

Environment	Path loss Exponent	Relative Error
Non Urban	6.768421053	7.88741E-08
Urban	5.269172932	-7.68201E-07
Sub urban	6.180451128	1.42554E-15
Ex Urban	5.105263158	4.09192E-06
Dense Urban	7.051128	5.51365E-07
Micro Urban	6.196992481	-8.01716E-07
Peri Urban	7.13283208	0.03783157

Table II. 1800MHZ -FUZZY TYPE 1

Environment	Path loss Exponent	Relative Error
Non Urban	5.780451128	0.035545629
Urban	5.936842105	0.068674113
Sub urban	5.869172932	0.113569189
Ex Urban	5.598496241	0.129029705
Dense Urban	5.866165414	0.157775717
Micro Urban	7.132330827	-0.112865623
Peri Urban	7.260150376	-0.068496956

Table III. 900MHZ -FUZZY TYPE 2

Environment	Path loss Exponent	Relative Error
Non Urban	6.768421053	2.38184E-07
Urban	5.269172932	-1.10724E-05
Sub urban	6.180451128	-2.25122E-14
Ex Urban	5.105263158	9.70393E-06
Dense Urban	7.051128	1.32682E-06
Micro Urban	6.196992481	-2.50423E-06
Peri Urban	7.13283208	0.1910968

Measured path loss values were compared to fuzzy path loss models and they are in good agreement with Okumura Hata models. Its regression is evident in accordance to distance and antenna heights. The value of

constant offset is at the highest in Urban environments being 60 dB for 900MHz but the Ex-urban environment of the 1800MHz has a constant offset of

Case I: Path loss from Linear Regression Model for 900 MHz

Case II: Path loss from Linear Regression Model for 1800 MHz

Figure 4. Comparison of 900 MHz and 1800 MHz of Linear Regression model.

Figure 5. Comparison of Mean Prediction Error from Least Square Regression (LSSQR), Fuzzy type 1 (FUZZTS 1) and Fuzzy type 2 (FUZZTS 2)

64dB. This occurs due to the obstruction and the line-of sight connection is lost earlier than assumed comparing with the assumed reference point. Moreover, propagation behind the corners of buildings was observed to cause 20-25 Db attenuation to the path loss values in urban environment. Fig4 demonstrates the comparison for linear regression model for 900 MHz and 1800 MHz. It is observed that higher path loss values are obtained at 1800 MHz than at 900 MHz. This is due to early connection loss. The mean prediction error gives a summary of the analyzed data in the units of the dependent variable as shown in Fig. 5. The proposed model gives mean

prediction error of 1.6dB as compared to LSSQR and FUZZTS1. Fig. 6 shows the comparison of the proposed model for 900 MHz and 1800 MHz. Almost the same path loss values were obtained, this shows that the proposed model is a reliable tool in estimating outdoor power levels. Hence, the fuzzy-logic based model can be applied to both range of signal strength at 900MHz and 1800MHz for better path loss prediction.

Case I: Path loss from fuzzy type-2 model for 900 MHz

Case II: Path loss from fuzzy type-2 model for 1800 MHz

Figure 6. Comparison of 900 MHz and 1800 MHz of fuzzy type-2 model.

Table IV. 1800MHz -FUZZY TYPE 2

Environment	Path loss Exponent	Relative Error
Non Urban	6.768421053	0.10836075
Urban	5.269172932	0.991204417
Sub urban	6.180451128	-1.833281284
Ex Urban	5.105263158	0.306100803
Dense Urban	7.051128	0.380499613
Micro Urban	6.196992481	-0.352129976
Peri Urban	7.13283208	-0.352488794

Table V. 1800MHz -FUZZY TYPE 2

S/N	Environment	900 MHz Station		1800 MHz Station	
		R^2	RMSE	R^2	RMSE
1	Non Urban	0.98	2.44	0.91	5.52
2	Urban	0.45	16.71	0.93	4.55
3	Sub urban	0.87	6.84	0.97	3.05
4	Ex Urban	0.99	0.52	0.93	4.41
5	Dense Urban	0.99	1.36	0.94	4.38
6	Micro Urban	0.99	0.77	0.90	6.91
7	Peri Urban	0.99	6.29	1.07	3.99

4. CONCLUSION

In this paper, we have proposed a fuzzy logic based path loss prediction model for metropolitan environment. The performance of the proposed model has been evaluated at 900MHz and 1800MHz bands. The proposed model is more efficient, faster and accurate than the physical and empirical methods. In addition, it can be used

to cover large distances and it has a potential in telecommunication industry for link budget and in the determination of the coverage area of a base station.

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