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PERFORMANCE EVALUATION OF EMPIRICAL PATH LOSS MODELS OF GSM SIGNAL IN KADUNA METROPOLIS

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***Abstract*—** In this work, comparison was made for some of the most popular empirical propagation models for path loss prediction in order to find a good radio frequency propagation prediction model for GSM 900 and 1800 MHz frequencies bands of Kaduna metropolis. Empirical prediction models used for this work are Free Space Path Loss (FSPL), Electronic Communication Committee-33 (ECC-33), Ericsson 9999 and Stanford University Interim (SUI). Hence, the FSPL showed better prediction for Kaduna metropolis than all the other models under review, a good path loss prediction will improve network optimization which leads to improved received signal for the GSM subscriber.

Keywords*—*Path Loss, Propagation, Frequency and Data.

I. INTRODUCTION

Propagation path loss is the loss in signal power as the signal travels from the transmitter to the receiver. Path loss is measured in different areas (rural, urban, and suburban) and propagation path loss models are used for prediction of the path loss. There are mainly three categories of these models; empirical, deterministic and stochastic. The empirical models are models obtained by observations and measurements only, and are generally used to predict the path loss. The deterministic models are models that require a complete 3-D map of the propagation environment. Whereas, Stochastic models are the models that usually model the environment as series of random variables, these models are the least accurate but require the least information about the environment and use much less processing power to generate predictions. Empirical models can be split into two subcategories namely, time dispersive and non-time dispersive [4].

Path loss models are necessary in mobile radio systems for the purposes of proper planning, estimation of interference, assigning of frequency and cell parameters which are vital for the processes of network planning [1].

Propagation of radio wave cannot be mentioned without considering the simple fact that is a function of frequency; this brings us to the electromagnetic wave described by Maxwell's equation as they carry energy in the direction of propagation. While the basics of free space propagation are consistent for all frequencies, real world channel often shows considerable sensitivity to frequency, hence, practical propagation models are frequency dependent since the designer may be required to address different phenomena at different frequency bands. The electromagnetic spectrum is loosely divided into frequency ranges; mobile Communications are mostly within the VHF (30- 300 MHz) and UHF (300 MHz - 3 GHz) bands due to the reasonable antenna sizes, minimal sensitivity to weather and moderate building penetration [7].

II. EMPIRICAL PATH LOSS MODELS

a). Free Space Path Loss Model

In this model, the received power is a function of transmitted power, antenna gain and distance between the transmitter and the receiver. The basic idea is that the received power decreases as the square of the distance between the transmitter and the receiver subjected to the assumption that there is one single path between the transmitter and the receiver. The received signal power in a free space at a distance *'d'* in meters from the transmitter is given in equation (1), the ratio of transmit to received signal powers in equation (2) and the path loss (L in dB) in equation (3).

$$P_R=P_TG_TG_R(\lambda/4\pi d)^2 \quad (1)$$

Where P_T – Transmitted signal power,
P_R – Received signal power,
G_T – Transmitter antenna Gain,
G_R – Receiver Antenna Gain and
λ – is the wavelength.
$G_T = G_R = 1$ (for Isotropic antenna)

$$P_T/P_R = (4\pi d/\lambda)^2 = (4\pi df/c)^2 \quad (2)$$

$$L=10\log(P_T/P_R)=10\log(4\pi df/c)^2$$
$$= -147.56 + 20\log d + 20\log f \quad (3)$$

Where the frequency, f is in hertz [3, 8, 9].

b). Stanford University Interim (SUI) Model

This model is categorized into three types of terrains, namely A, B and C. Type A is associated with maximum path loss and is appropriate for hilly terrain with moderate to heavy foliage densities. Type B is characterised with either mostly flat terrains with moderate to heavy tree densities or hilly terrains with light tree densities. Type C is associated with minimum path loss and applies to flat terrain with light tree densities. The basic path loss equation with correction factors is given in equation (4) [6, 8].

$$L=A+10\gamma\log_{10}(d/d_0)+X_f+X_h+s \text{ for, } d>d_0 \quad (4)$$

Where, d is the distance between the access point (AP) and the customer premises equipment (CPE) antennas in metres, d_0 = 100 m and s is a *log* normally distributed factor that is used to account for the shadow fading owing to trees and other clutter and ranges between 8.2 – 10.6 dB.

The other parameters are defined as in equations (5) and (6).

$$A = 20\log_{10}(4\pi d_0/\lambda) \quad (5)$$

$$\gamma = a - bh_b + c/h_b \quad (6)$$

Where, the parameter h_b is the base station height above ground in metres and should be between 10 m and 80 m.

For terrain A, the constants a, b(m^{-1}) and c (m) are 4.6, 0.0075, 12.6 respectively; for terrain B, are 4.0, 0.0067, 17.1 respectively and for terrain C, are 3.6, 0.005, 20 respectively. The parameter γ in equation (6) is equal to the path loss exponent. For a given terrain type the path loss exponent is determined by h_b.

Correction factors for the operating frequency and CPE antenna height for the model are expressed in equations (7) and (8).

$$X_f = 6.0\log_{10}(f/2000) \quad (7)$$

$$X_h = -10.8\log_{10}(h_r/2000) \text{ for terrain A and B}$$
$$= -20.0\log_{10}(h_r/2000) \text{ for terrain C} \quad (8)$$

Where, f is the frequency in MHz and h_r is the CPE antenna height above ground in metres.

The SUI model is used to predict the path loss in all three environments, namely rural suburban and urban.

c). ECC-33 Path Loss Model

The original Okumura experimental data were gathered in the suburbs of Tokyo which has the characteristics of a highly built-up area that are quite different to those found in typical European suburban areas. A different approach was taken which extrapolated the original measurements by Okumura and modified its assumptions so that it more closely represents a Fixed Wireless Access (FWA) system by the Electronic Communication Committee (ECC) within the European Conference of Postal and Telecommunications Administration (CEPT) in their Technical Report (ECC Report 33) of May 2003. The path loss model presented is referred to as the ECC-33 model and defined as in equation (9) [5, 8].

$$L = A_{fs} + A_{bm} - G_b - G_r \quad (9)$$

Where A_{fs}, A_{bm}, G_b, G_r are the free space attenuation, the basic median path loss, the BS height gain factor and the terminal CPE height gain factor are individually defined in equations (10), (11), (12) and (13) respectively;

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

$$A_{bm}=20.4+9.83\log_{10}(d)+7.894\log_{10}(f) +9.5[\log_{10}(f)]^2 \quad (11)$$

$$G_b=\log_{10}(h_b/200)\{13.958+5.8[\log_{10}(d)]^2\} \quad (12)$$

and for medium city environments;

$$G_r=[42.57+13.7\log_{10}(f)][\log_{10}(h_r)-0.585] \quad (13)$$

Where, f is the frequency in GHz, d is the distance between AP and CPE in km, h_b is the base station (BS) antenna height in meters and h_r is the CPE antenna height in meters.

d). Ericsson 9999 Model

This model is implemented by Ericsson as an extension of the Hata model. Hata model is used for frequencies up to 1900 MHz. In this model, the parameters can be adjusted according to the given scenario. The path loss as evaluated by this model is described as in equation (14).

$$L= a_0+a_1\log(d)+a_2\log(h_b)+a_3\log(h_b)\log(d) - 3.2(\log(11.75))^2+g(f) \quad (14)$$

Where, $g(f)=44.49\log(f)-4.78((\log(f))^2 \quad (15)$

The parameter $g(f)$ is calculated as in equation (15). The values of a_0, a_1, a_2 *and* a_3 are constant but can be changed according to environment. The defaults values given by the Ericsson model are a_0 = 36.2, a_1 = 30.2, a_2 = –12.0 *and* a_3 = 0.1. The parameter f, represents the frequency [8, 10].

III. METHODOLOGY

This work is actually for Kaduna metropolis base on the data collected from live networks. The following steps was taken for realization of this research work.

a. The base stations (BSs) were identified and their location determined.
b. The BSs parameters obtained from the network service provider.
c. The test routes and points were mapped out using GPS.
d. Received signal strength were measured at every test point using net-monitor.
e. Some of the popular empirical path loss prediction models that have their frequency ranges between the area of interest (above 800 MHz to about 1900 MHz) and their ranges of distance is from 200 m and above were validated for these locations.

IV. RESULTS AND DISCUSSION

Figures 1 to 12, shows the comparions between the measured data and the values of the empirical predicted propagation path loss models which are FSPL, ECC-33, Ericsson 9999 and SUI for all the routes, for 900 MHz and 1800 MHz frequencies.

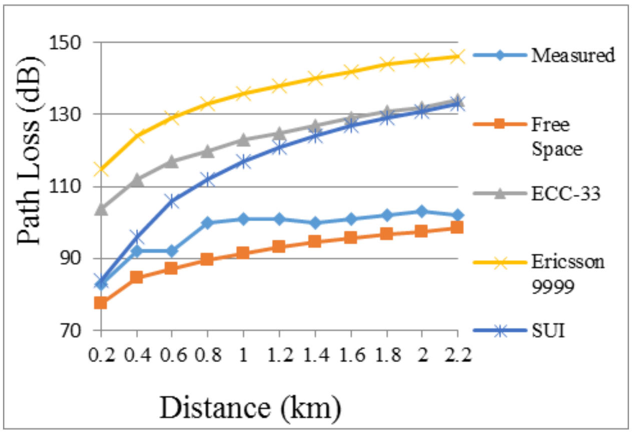

Figure 1: Path loss models for BS 1 900MHz.

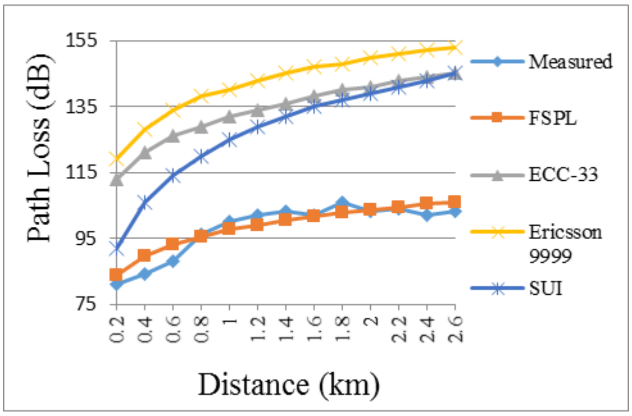

Figure 2: Path loss models for BS 1 1800MHz.

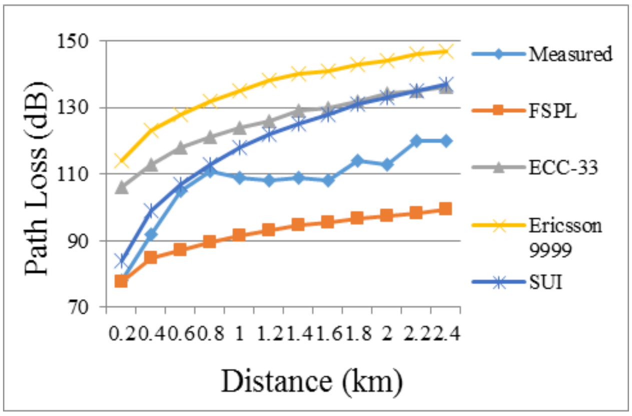

Figure 3: Path loss models for BS2 900MHz.

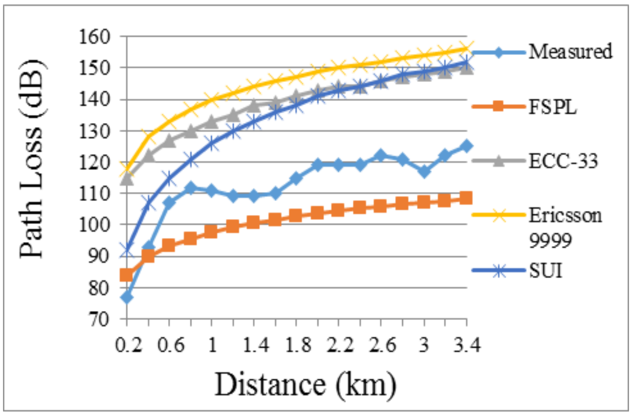

Figure 4 : Path loss models for BS2 1800MHz.

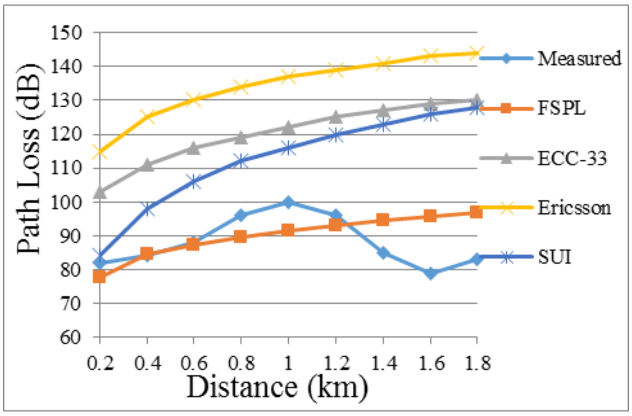

Figure 7: Path loss comparison, BS 4 900 MHz.

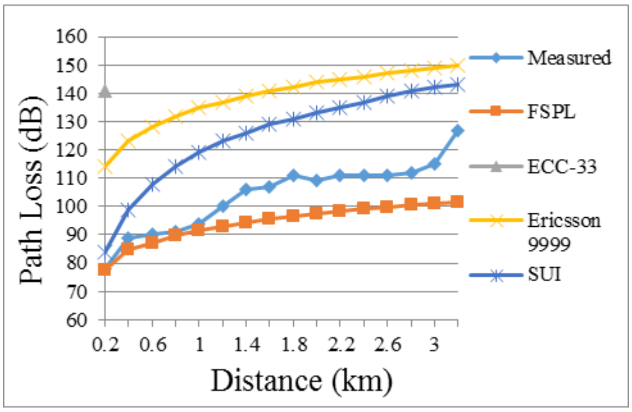

Figure 5: Path loss models for BS3 900 MHz.

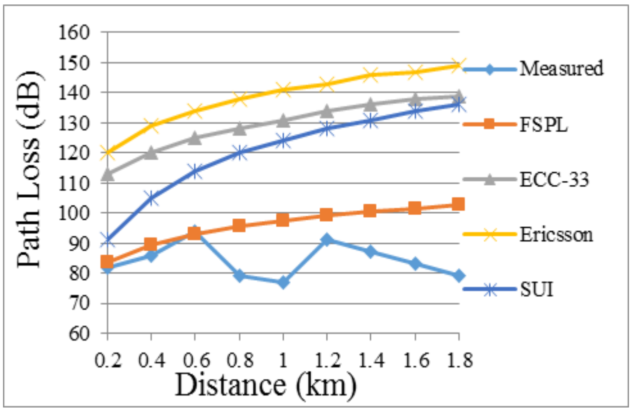

Figure 8: Path loss models for BS 4 1800MHz.

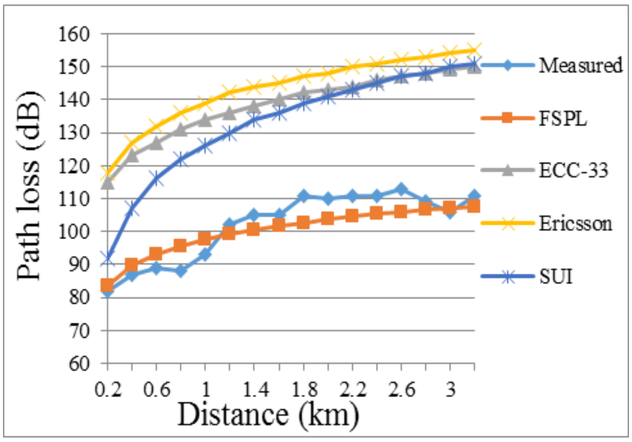

Figure 6: Path loss models for BS 3 1800MHz.

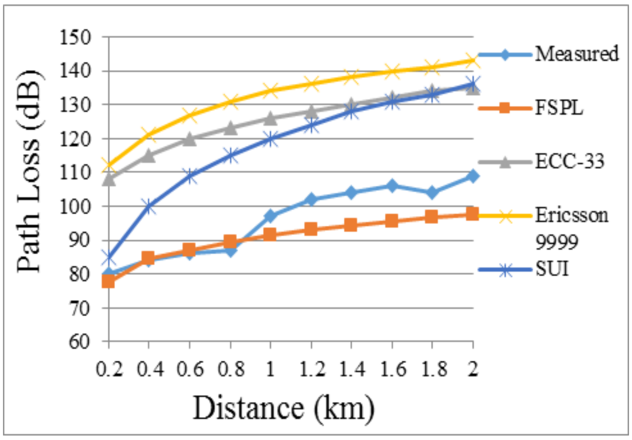

Figure 9: Path loss models for BS 5 900 MHz.

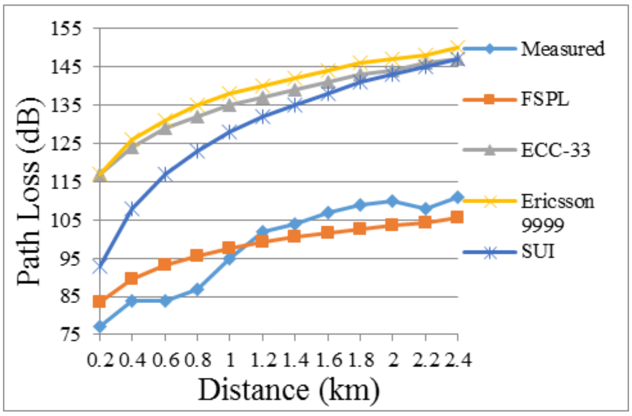

Figure 10: Path loss models for BS 5 1800MHz

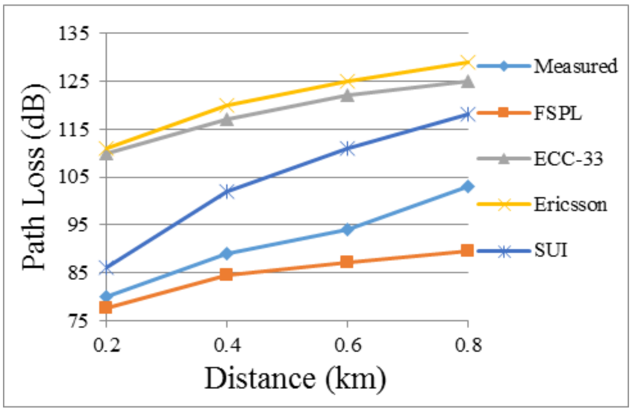

Figure 11: Path loss models for BS 6 900MHz.

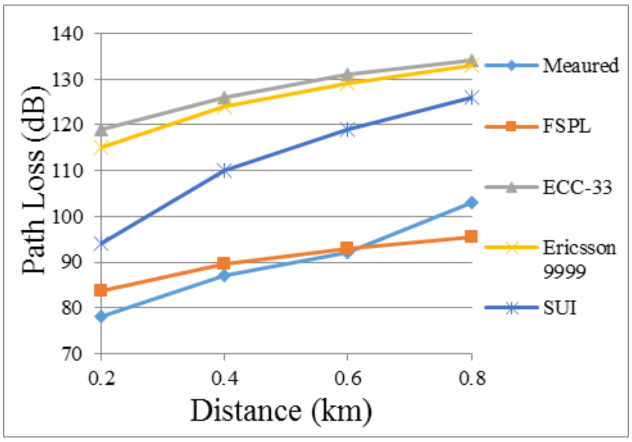

Figure 12: Path loss models for BS 6 1800MHz

The empirical predicted models performances were evaluated by the following statistical performance evaluations; (i) Mean Absolute Error (μ), (ii) Standard Deviation (σ), (iii) Root Mean Square Error (*RMSE*) and (iv) R^2.

μ is an average of the absolute errors, σ is the measure of the dispersion of a set of data from its mean, *RMSE* determine the average deviation of the predicted path loss values from the measured values and R^2 is a measure of how well the predicted values fit the measured data set or simply the measure of the correlation between the actual response and the predicted response.

A model with lowest values of μ, σ and *RMSE* and higher value of R^2 is adjudged a better prediction model for the environment.

Tables 1, shows the results of μ, σ, *RMSE*, and R^2 for the empirical predicted path loss propagation models at 900 MHz.

For BS 1, FSPL model showed low values of μ, σ and *RMSE at* 6.436, 6.354 and 6.742 respectively as compared to ECC-33 with 25.182, 9.214 and 25.486 respectively, Ericsson 9999 with 37.727, 9.709 and 37.953 respectively and SUI with 18.455, 15.597 and 20.756 respectively. For BS 3, BS 4 and BS 5 the trend is the same with BS 1. But in the case of BS 2, FSPL model showed low values only in σ while SUI model showed low values in μ and *RMSE* as compared to the other models, the values of μ, σ and *RMSE* for FSPL model are 15.1256, 6.466 and 16.228 respectively, ECC-33 are 18.083, 9.355 and 18.648 respectively, Ericsson 9999 are 28.667, 10.059 and 28.954 respectively and SUI are 12.083, 16.763 and 13.629 respectively.

As for R^2, values for BS 1 for the FSPL, ECC-33, Ericsson and SUI are 0.892, 0.864, 0.891 and 0.884 respectively, these values are high as they tend towards 1 they showed very good correlation and all the four values show minimal variations from each other. BS 2, BS 3, BS 5 and BS 6 show same pattern with BS 1. For BS 4 the values are 0.110, 0.006, 0.017 and 0.013 respectively showing fair correlation and minimum variations.

Hence, Free Space Path Loss showed better prediction for Kaduna metropolis than all the other models under review for the 900 MHz frequency.

Table 1: μ, σ, *RMSE* and R^2 for Empirical Models at 900 MHz.

Model	μ	σ	*RMSE*	R^2
FSPL BS1	6.436	6.354	6.742	0.892
ECC-33 BS1	25.182	9.214	25.486	0.864
Ericsson BS1	37.727	9.709	37.953	0.891
SUI BS1	18.455	15.597	20.756	0.884
FSPL BS2	15.125	6.466	16.228	0.875
ECC-33 BS2	18.083	9.355	18.648	0.852
Ericsson BS2	28.667	10.059	28.954	0.876
SUI BS2	12.083	16.763	13.629	0.875
FSPL BS3	9.588	6.764	11.37	0.914
ECC-33 BS3	25.438	10.111	25.726	0.921
Ericsson BS3	34.875	10.195	35.103	0.909
SUI BS3	21.313	16.798	22.171	0.902
FSPL BS4	7.067	6.116	8.796	0.011
ECC-33 BS4	32.111	8.983	33.798	0.006
Ericsson BS4	46.111	9.497	47.316	0.017
SUI BS4	24.444	14.432	28.461	0.013
FSPL BS5	5.98	6.244	7.12	0.882
ECC-33 BS5	28.2	8.711	29.397	0.903
Ericsson BS5	36.4	9.821	36.568	0.88
SUI BS5	22.2	16.196	23.191	0.893
FSPL BS6	6.775	5.17	7.942	0.937
ECC-33 BS6	27	6.557	27.166	0.958
Ericsson BS6	29.75	7.762	29.829	0.962
SUI BS6	12.75	13.817	13.407	0.961

Tables 2, shows the results of μ, σ, *RMSE*, and R^2 for the empirical predicted path loss propagation models at 1800 MHz.

For BS 1, FSPL model showed low values of μ, σ and *RMSE at* 2.877, 6.516 and 3.348 respectively as compared to ECC-33 with 36.000, 9.618 and 36.171 respectively, Ericsson 9999 with 44.154, 10.189 and 44.300 respectively and SUI with 29.539, 15.804 and

30.649 respectively. For BS 2, BS 3, BS 4 BS 5 and BS 6 the trend is the same, FSPL model showed low values as compared to the ECC-33, Ericsson 9999 and SUI models.

Table 2: *μ*, *σ*, *RMSE* and R^2 for Empirical Models at 1800 MHz.

Model	*μ*	*σ*	*RMSE*	R^2
FSPL BS1	2.877	6.516	3.348	0.838
ECC-33 BS1	36	9.618	36.171	0.861
Ericsson BS1	44.154	10.189	44.3	0.882
SUI BS1	29.539	15.804	30.649	0.886
FSPL BS2	12.582	6.927	13.277	0.832
ECC-33 BS2	26.118	10.061	26.48	0.864
Ericsson BS2	32.235	10.465	32.458	0.896
SUI BS2	21.412	16.763	22.413	0.888
FSPL BS3	4.881	6.844	5.649	0.798
ECC-33 BS3	36.25	10.111	36.435	0.871
Ericsson BS3	41.25	10.556	41.416	0.873
SUI BS3	30.875	16.759	31.818	0.867
FSPL BS4	11.911	6.244	14.421	0.011
ECC-33 BS4	41.111	8.746	46.272	0.009
Ericsson BS4	54.333	9.475	55.429	0.013
SUI BS4	36.111	14.807	39.281	0.009
FSPL BS5	6.008	6.364	6.614	0.832
ECC-33 BS5	38	9.243	38.197	0.932
Ericsson BS5	40.5	9.921	40.663	0.924
SUI BS5	31	16.414	31.499	0.922
FSPL BS6	4.175	5.202	4.85	0.931
ECC-33 BS6	37.5	6.557	37.7	0.932
Ericsson BS6	35.25	7.762	35.38	0.937
SUI BS6	22.25	13.817	22.6	0.936

As for R^2, values for BS 1 for the FSPL, ECC-33, Ericsson and SUI are 0.838, 0.861, 0.882 and 0.886 respectively, these values are high as they tend towards 1 they showed very good correlation and all the four values show minimal variations from each other. BS 2, BS 3, BS 5 and BS 6 show same pattern with BS 1. For BS 4, the values are 0.110, 0.009, 0.013 and 0.009 respectively showing fair correlation and minimum variations.
Hence, FSPL showed better prediction for Kaduna metropolis than all the other models under review for the 1800 MHz frequency.

V. CONCLUSION

The importance of path loss prediction using the empirical models and comparing them cannot be overemphasized, as regular path loss prediction and performance analysis gives the best model to be used. This improves network optimization which leads to improved received signal for the GSM subscriber, this analysis will surely give the operators the aspect of their KPI to work on and improve upon. The FSPL model showed a good performance on one BS and outstanding performance on the other five BSs. Hence, the best choice to be used for path loss prediction for Kaduna Metropolis

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