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Enhanced Radio Signal Loss Prediction with Correction Factors for Urban Streets in the IMT-2000 Band

Joseph Isabona[1,*] and Samuel Azi[2]

[1]Department of Basic Sciences, Benson Idahosa University PMB. 1100, Benin City, Benin, Nigeria.
[2]Department of Physics, University of Benin PMB. 1100, Benin City, Benin, Nigeria.

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ABSTRACT

In mobile communications, the need to improve the quality of service and to predict the minimum signal power required for transmission has attracted a great deal of research attention. In this paper, the ITU-R adopted Walfisch-Bertoni (W/B) pathloss model for IMT-2000 third generation (3G) mobile networks standard, is enhanced based on experimental campaigns conducted in two CDMA2000 networks transmitting at 800MHz frequency band in South-South, Nigeria. In this enhancement method, W/B is modified to incorporate secondary knife edge diffraction and multipath reflection loss due to the buildings and objects nearest the mobile down the street. The proposed pathloss models indicate improved prediction accuracy compared to the original W/B model in terms of root mean square and relative error analysis.

Introduction

The concept of Third Generation (3G) systems is based on the global International Mobile Telecommunications (IMT-2000) initiative sponsored by the International Telecommunications Union (ITU) to create a unified global set of standards that will lead to commercial deployment of advanced wireless services. Accordingly, within ITU, the 3G systems are called IMT-2000. In the standardization forums, CDMA2000 has emerged as one of the most widely adopted third generation air interface.

Ensuring optimal performance to meet the expectations of the customers is a paramount concern in cellular wireless networks. In terrestrial mobile communication systems, electro-magnetic wave propagation is affected mainly by reflection, diffraction and scattering from buildings, cars, and other objects consisting of diverse materials and having complex surfaces. These lead to degradation of signal strength due to pathloss and areas with poor service quality, as a function of frequency, distance of separation, antenna height, antenna configuration, and local scattering environment

Signal path loss is an attenuation that signal suffers when propagate from transmitter to the receiver. To increase the robustness of the transmitted information, there is need to estimate the path loss introduced by a terrain to sufficiently compensate for the power lost during signal propagation. Received signal pathloss prediction models play an important role in the RF coverage optimization and efficient use of the available resources in wireless communication [1]. Accurate pathloss predictions models are used to find network coverage gaps and areas with poor serviceability [2]. According to [3], an accurate knowledge of channel characteristics is required for cellular operators to optimize the coverage and maintain the interference at the lowest possible level. number of pathloss models are available to estimate path loss. Most signal path loss predictions are made using techniques outlined below:

- ***Empirical Approach:*** The empirical methods of predicting signal path loss rely on measurement data, statistical properties and a few other parameters. In the empirical approach, all environmental influences are implicitly taken into account regardless of whether they can be separately recognized. Thus, the accuracy of this approach depends not only on the accuracy of the measurements, but also on the similarities between the environment to be analyzed and the environment where the measurements are carried out. Their computational efficiency is found to be effective [4]. However, the inability to explicitly account for particular features of the propagation environment is perhaps the greatest limitation of empirical approach. Examples of this model category will be the Okumura model and the Hata model.
- ***Deterministic approach:*** This approach to radio signal path loss and coverage prediction utilises the basic physical laws as the basis for the calculations. These methods need to take into consideration all the elements within a given area and although they tend to give more accurate results, they require much additional data and computational power. In view of their complexity, they tend to be used for short range links where the amount of required data falls within acceptable limits. . A typical example is representing an obstructing mountain ridge as a single isolated "knife-edge." The effect of a single knife-edge on the signal is readily found from classic diffraction theory to provide a field strength prediction at the receiver. The problem is whether a real mountain ridge can be accurately modeled as a knife-edge.
- ***Semi-deterministic approach:*** Semi-deterministic models are based on empirical models and deterministic aspects. It requires more information than the statistical approach but less than the deterministic approach [5]. It is actually a compromise between the two approaches discussed above. It tends to have both the advantages of the statistical and deterministic approaches. The inclusion of deterministic correction factors improves the

Tele:
E-mail addresses: josabone@yahoo.com

accuracy of the statistical models. It looks at environmental factors that influence propagation in a more detailed form and facilitates the statistical propagation model to simulate the real environment as close as possible. Thus it may seem to be the best option for prediction purposes. Walficsh-Ikegami (W/I) and Walficsh-Bertoni (W/B) models are typical examples of Semi-deterministic pathloss model.

However, in spite of the development of numerous pathloss prediction models so far, the generalization of these models to any environment is still questionable. They are suitable for either a particular area (urban, suburban, rural, etc.) or specific cell radius (Macrocell, Microcell, Picocell). To overcome this drawback, the model's parameters can be modified with terrain propagation mechanism correction factors or tuned according to the targeted environment. In this paper, new correction factors for (W/M) are suggested, which results in the considerable improvement on prediction accuracy.

Field-test Signal Pathloss Data Measurement Campaign and Locations

The continuous wave propagation pathloss measurement campaign and its prediction based on the pathloss model were carried out at different period of the year at Benin, Uyo and Port Harcourt (built-up cities with an average building height, street width and building spacing of 10m, 6m and 3m respectively), all in South-South Nigeria. Nine (9) BS cell sites selected for the field test in the three study locations.

Using the NOKIA 1265 CDMA test phone systems (TEMS) operated in the active mode which was provided by the studied CDMA network service provider, accompanied with an Acer portable laptop and a MAP76CSX GPS receiver for accurate location, measurement survey was conducted on received signal strength propagation level over the CDMA air interface, transmitting in 800MHz. The power from the transmitter taken is 43db.

With the aid of testing tool (i.e. NOKIA mobile handset) running on the software mode, calls were initiated at each test point until it is established and the signal strength information sent over the air interface between the base and the mobile station were read. For every site, received signal strength was measured at a reference distance of 100m from the base station and at subsequent interval of 100m up to 2000m. All measurements were taken in the mobile active mode and in three sectors of each base station. This was to ensure that the mobile phone was in constant touch with the base station. Also, measurements were taken on a uniform grid of outdoor static positions. This methodology is slightly different from the usual convectional drive-test procedure which may not cover certain inaccessible areas. At the same time, it presents some advantages because continuous measurement at the same point is captured, and this reduces systematic errors by properly windowing and averaging data. Averaging is done to compensate for variation in signal strength at a given location over time. The values of the signal strength level measured were converted into pathloss using the expression in equation (1) [10]:

$$PL\,(dB) = EIRP - RSS_{(measured)} \tag{1}$$

$RSS_{(measured)}$ = measured received signal strength (dBm)

$$EIRP = P_T + G_T + G_R - L_T - L_R \tag{2}$$

where EIRP is the effective isotropic radiated power of the base station, P_T is BS transmitted power, G_T and G_R are the gain of transmitting and receiving antenna, and L_T and L_R are feeder losses of the transmitter and the receiver, all in dB scale.

The Application of Bertoni-Walfisch model

Bertoni-Walfisch model is used as International Telecommunication Union Recommendation (ITU-R) in the standard of IMT-2000 to estimate the signal path loss in an urban environment for cellular communication. It is a semi-deterministic model which has formulation to calculate the path-loss and includes more parameters like building height and building separation distances these parameters are not considered in the case of Hata and some other models.

The Walficsh-Bertoni reduces path loss model to the sum of three factors [6]: Free space loss, PL_{fs}, diffraction from the rooftops, $PL_{rooftops}$ and diffraction and scatter loss from rooftop down the street, Pl_{down}

$$PL_{total}(dB) = PL_{mfs} + PL_{down} + PL_{roof} \tag{3}$$

Here, PL_{msf} is the free space path loss, which is the ratio of received to radiated power for isotropic antennas, and is given by

$$PL_{fs} = -10\log_{10}\left(\frac{\lambda}{4\pi R}\right)^2 \tag{4}$$

where λ is the wavelength and R is used as the horizontal separation to approximate the distance from the base station to the mobile

Diffraction and scatter loss from rooftop down the street, Pl_{down} is given by

$$PL_{down} = \frac{\lambda\rho_1}{2\pi^2\left(H_b - h_m\right)} \tag{5}$$

The diffraction from the rooftops, $PL_{rooftops}$ is given by

$$PL_{rooftops} = P(g)^2 = \left[0.1\left(\frac{\sin\delta\sqrt{\frac{d}{\lambda}}}{0.03}\right)^{0.9}\right]^2 \tag{6}$$

Here, $\sin\delta$ can be written in terms of BS height h_T, the building height H_B, and the distance R as,

$$\sin\delta = \frac{h_T - H_g}{R} \tag{7}$$

Considering Equation (7) in (6), we have,

$$(\quad PL_{rooftops} = P(g)^2 = 0.01\left(\frac{h_T - H_B}{0.03R}\right)^{1.8}\left(\frac{d}{\lambda}\right)^{0.9} \tag{8}$$

The total loss after some simplification is thus given by:

$$PL_{total} = 89.5 - 10\log\left[\frac{\rho_1 d^{0.9}}{\left(H_B - h_m\right)^2}\right] + 21\log f_m - 18\log\left(h_T - H_B\right) + 38\log R_k \tag{9}$$

Where

$$\rho_1 = \sqrt{\left(\frac{d}{2}\right)^2 + \left(H_B - h_m\right)^2} \tag{10}$$

and

f_m: Frequency in MHz.
h_T: Antenna Height in meters.
H_b : Building height in meters.
h_m : Mobile height in meters.
d: Space between buildings in meters.
R: Distance between base station transmitter and mobile station in meters.

Result with Measured Pathloss Data

Here, it is interesting to compare the measured received signal strength pathloss data with that predicted by W/B path loss model. The plots in figure 1 (a-c) shows the attenuation of the signal levels as the result of pathloss in all measurements locations.

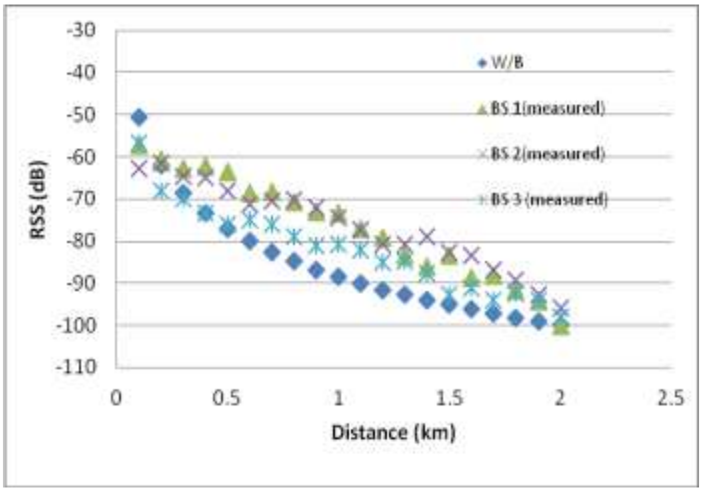

Figure 1(a): Comparison of original W/B model with measured data in location 1

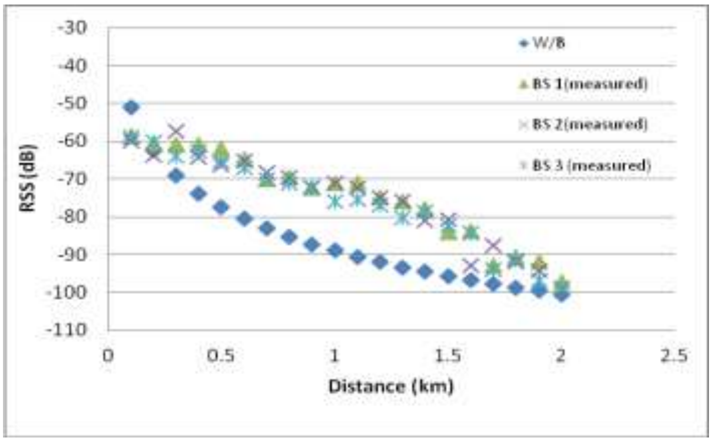

Figure 1(b): Comparison of original W/B model with measured data in location 2

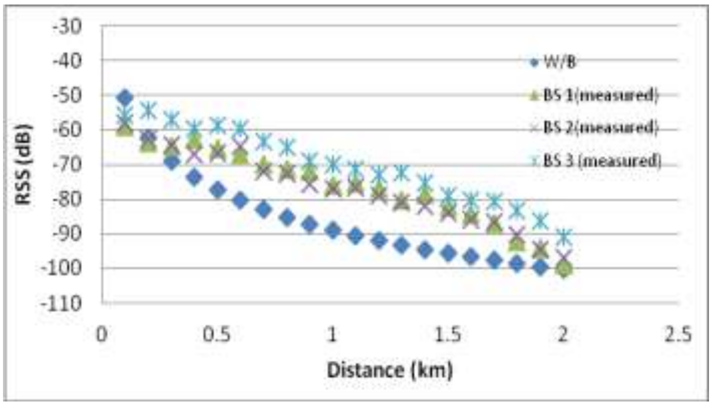

Figure 1(c): Comparison of original W/B model with measured data in location 3

As can be observed in figure 1 (a)-(c), the difference between the measured signal pathloss and that predicted with the ITU-R W/B model is excessively large. Two major reasons for over estimation of the signal pathloss are identified to develop corresponding correction factors in this paper.

Correction Factors

Here, the two major reasons for overestimation of W/B model over measured data are identified in the following.

For the first reason, predicting the diffraction loss from roof-top of the last building to the street, Lrts, only two rays were considered. These are direct diffracted ray and single reflected ray by the building before the mobile. But when RX is located in an open space, multipath reflected rays having considerable power can reach to Rx from various directions. In example, the multipath building diffracted-ground reflected ray as indicated by r_3 in figure 2 reaches the RX (MS). In the extended W/B model, we introduced a multipath reflection term defined by [7]:

$$M_{pr} = \left(1 - \exp - \left(\frac{d_t}{R}\right)^{n-2}\right) \tag{11}$$

The expression in equation (11) explain the transition of free space propagation to inverse n-power law beyond a break-point distance $d_{bp} = 4h_T\, h_m /\lambda$ *where* h_T and h_m are the transmitter and receiver antenna heights, respectively and R, the separation distance. The break point is defined here as the distance between antennas for which the ground just begins to obstruct the first Fresnel zone. If the effect of the reflected signal is considered as revealed in the expression in equation (11), then the free space model component of original W/M model(see equation 4) is modified by

$$PLmfs = 10\log\left[\left(\frac{\lambda}{4\,\pi\, r}\right)^2 \left(1 - \exp - \left(\frac{d_t}{R}\right)^{n-2}\right)\right] \tag{12}$$

with n = 2.5 for outdoor propagation environment.

Secondly, in W/B model, the authors assumed that the distance between receiver and obstruction and between the transmitter and obstruction is much larger than the obstruction height, h. In the case of our study environment, though d_1 is much larger than the h; however, d_2 is of smaller magnitude or similar magnitude than h. Hence, we cannot model the last building by means of a single knife-edge obstruction. Therefore to this, we add the attenuation loss factor due to the secondary knife-edge, PL,roof which also affect the line of sight between the top of the knife-edge and the transmitter which is considered in the following.

Thus, using the theory of optical diffraction, [8], it can be shown that the electric field strength, E_d of the knife-edge diffracted wave relative transmitted free-space field strength, E_t is given by,

$$\frac{E_d}{E_r} = \frac{\dfrac{\exp\left(-j\dfrac{2\pi}{\lambda}z\right)}{-j\lambda z}\exp\left(-j\dfrac{2\pi}{\lambda z}\right)}{\dfrac{\exp\left(-j\dfrac{2\pi}{\lambda}r\right)}{-j\lambda r}\dfrac{1+j}{2}\displaystyle\int_v^{\infty}\exp\left(-j\frac{\pi}{2}t^2\right)dt} \tag{13}$$

Electromagnetic theory tells us that each point on the wave front at $z = r$ can be considered as the source of a new spherical wave with the amplitude given by the field at that point. (This concept is called Huygens's principle.) Thus, equation (13) can be simplify to obtain,

$$\frac{E_d}{E_r} = \frac{1+j}{2}\int_v^{\infty}\exp\left(-j\frac{\pi}{2}t^2\right)dt \tag{14}$$

The integral in equation (14) is known as the complex Fresnel integral which is a function of Fresnel-Kirchoff diffraction parameter, v.

The diffraction loss parameter is defined from equation (12) as,

$$F(v) = \left|\frac{E_d}{E_t}\right|^2 = \frac{1}{2}\left|\int_v^\infty \exp\left(-j\frac{\pi}{2}t^2\right)dt\right|^2 \quad (4.9)$$

It is more convinient to write

$$F(v) = \int_v^\infty \exp\left(-j\frac{\pi}{2}t^2\right)dt = \int_0^\infty \exp\left(-j\frac{\pi t^2}{2}\right)dt - \int_0^v \exp\left(-j\frac{\pi t^2}{2}\right)dt \quad (15)$$

$$= \frac{1}{2}(1-j) - [C(v) - jS(v)] \quad (16)$$

where j is the complex operator equal to $\sqrt{-1}$, and $C(v)$ and $S(v)$ are the Fresnel cosine and sine integrals defined by:

$$C(v) = \int_0^v \cos\left(\frac{\pi t^2}{2}\right)dt \quad (4.12)$$

$$S(v) = \int_0^v \sin\left(\frac{\pi t^2}{2}\right)dt \quad (17)$$

We then have

$$F(v) = \frac{1}{2}\left[\left(\frac{1}{2} - C(v)\right)^2 + \left(\frac{1}{2} - C(v)\right)^2\right] \quad (18)$$

The expression in (18) can be approximated further as,

$$F(v) = 1 - \exp(k) \quad (19)$$

Thus, the loss due to secondary rooftop knife-edge diffraction can be determined from expression in equation (19) in dB as

$$PL_{rooftop2} = 20\log F(v) = 20\log(1 - \exp(k)) \quad (20)$$

where $k = -0.6038x0.1094^{v}$

In general, the parameter V is defined as [9]:

$$v = h\sqrt{\frac{2}{\lambda}\left(\frac{1}{r_1} + \frac{1}{r_1}\right)} \approx h\sqrt{\frac{2}{\lambda r_2}} \quad (21)$$

With

$$h = -W_b\left((\tan)^{-1}\left(\frac{h_{bs} - h_{roof}}{d - d_w}\right)\right) \quad (22)$$

Thus, the modified W/B pathloss model is given by

$$PL_{total}(dB) = PL_{mfs} + PL_{down} + PL_{roof} + PL_{roof,2} \quad (23)$$

Where $PL_{roof,2}$ and PL_{mfsf} are the additional diffraction and multipath reflection correction factors as defined in equation (20) and equation (9) respectively.

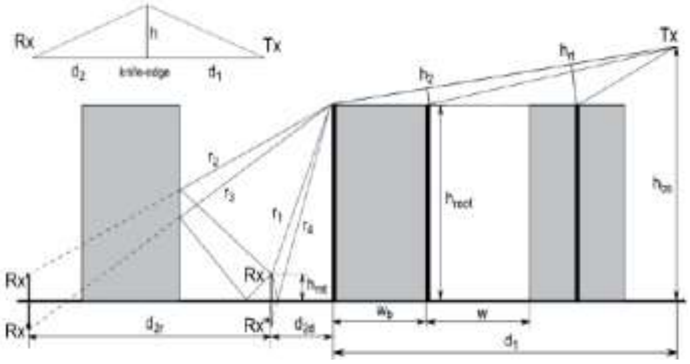

Figure 2: Overall propagation scenario and possible diffracted and reflected paths.

Again, it is interesting to compare the measured received signal strength pathloss data with that predicted by modified W/B path loss model as shown in figure 3.

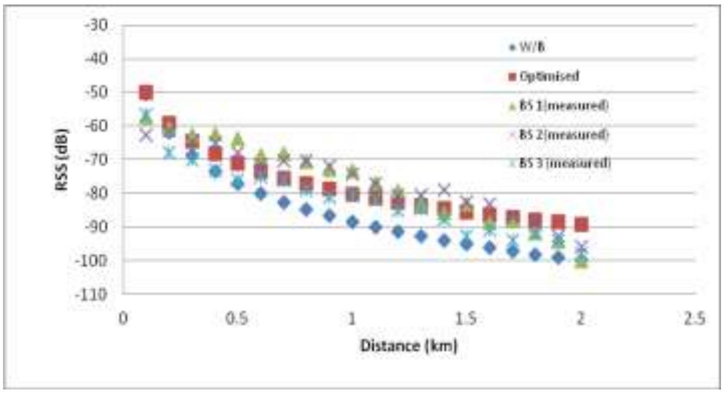

Figure 3 (a): Comparison of original W/B model and the modified signal pathloss prediction with measured data in location 1

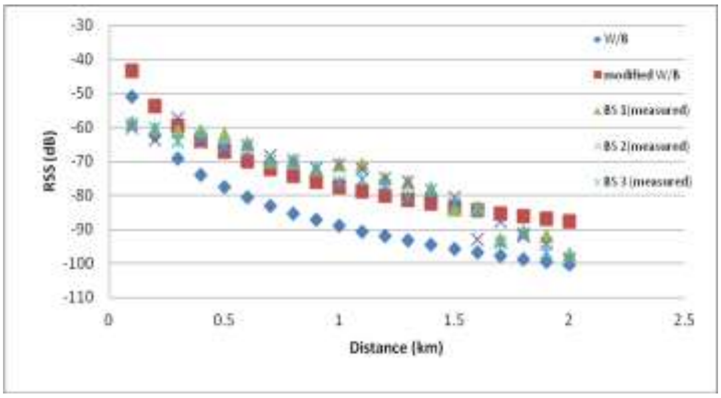

Figure 3(b): Comparison of original W/B model and the modified signal pathloss prediction with measured data in location 2

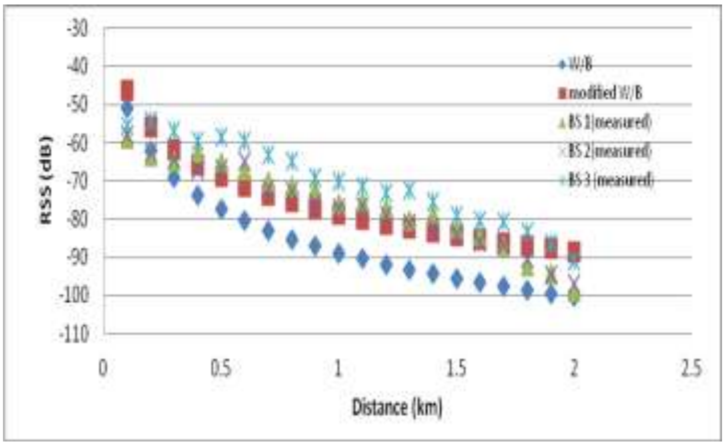

Figure 3(c): Comparison of original W/B model and the modified signal pathloss prediction with measured data in location 3

Shown in figure 4 (a, b) and table 1 (a, b) are root mean square error (RMSE) and relative error (RE) computation results obtained between the measured pathloss data and the results of the modified W/B model in comparison with that of the original model in the three study locations. From table 1, few points can be drawn. The calculated RMSE and RE of modified W/B pathloss model, which ranged from 5.47-14.09 dB and 3.96-10.81% respectively, with measurement data, have reduced to 4.88-7.88 dB and 2.77-8.53%, all compared to the original model. These performance improvements reveal a closer agreement between the modified W/B model and the measurements.

Table 4.5: RMSE and re of w/b model in comparison with measured pathloss data before and after modification

	RMSE Before modification			RMSE after modification		
Location	BS 1	BS 2	BS 3	BS 1	BS 2	BS 3
Benin	10.27835	6.000804	7.118139	7.532402	4.948292	6.41352
P/Harcourt	7.315548	9.586893	7.498731	5.777528	6.507872	6.450969
Uyo	9.910601	7.362285	9.890975	6.825131	6.239924	6.762281
	RE before modification			RE after modification		
Location	BS 1	BS 2	BS 3	BS 1	BS 2	BS 3
Benin	8.339102	4.512429	5.13252	5.476544	2.776905	3.641594
P/Harcourt	5.694344	7.872961	5.595454	3.878041	4.684862	3.890758
Uyo	8.076184	5.419595	8.046214	5.219357	3.795512	4.958755

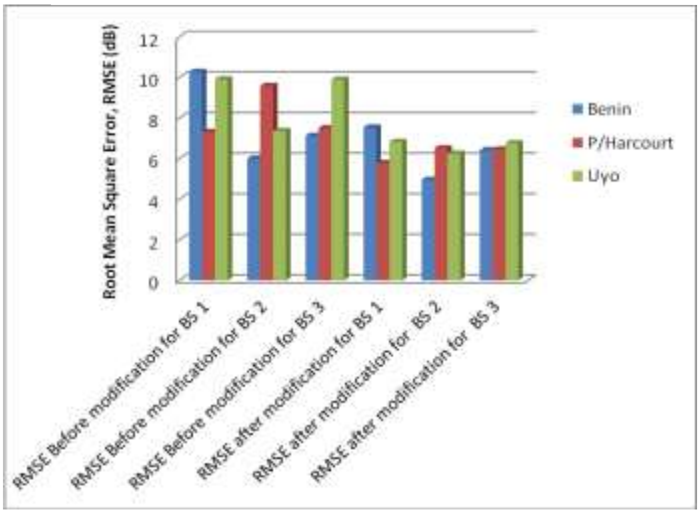

Figure 4 (a): RMSE computation results obtained for W/B model before and after modification in the three study locations

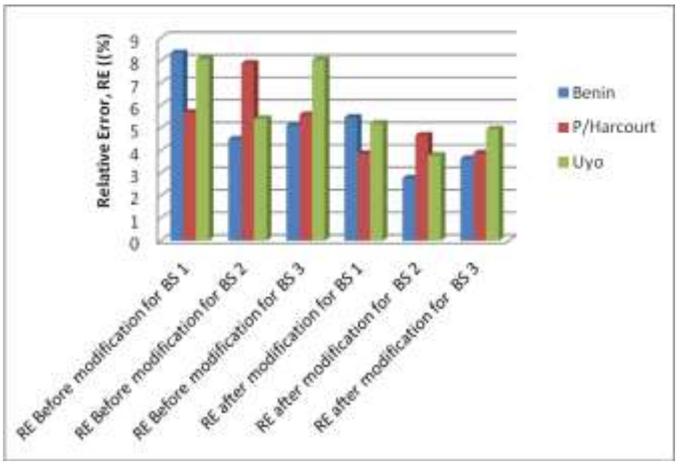

Figure 4 (b): RE computation results obtained for W/B model before and after modification in the three study locations.

Conclusion

In the implementations of wireless network, wave propagation pathloss models are necessary to determine signal propagation characteristic through a medium. Propagation study provides an estimation of signal characteristics. This paper proposed a new enhanced W/B pathloss model based on signal strength measurement campaigns conducted in two CDMA2000 networks transmitting at 800MHz frequency band in South-South, Nigeria. In this enhancement method, W/B is modified to incorporate secondary knife edge diffraction and multipath reflection loss due to the buildings and objects nearest the mobile down the street. The proposed pathloss models indicate improved prediction accuracy compared to the original W/B model in terms of root mean square and relative error analysis

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