# PATH LOSS MEASUREMENTS FOR WIRELESS COMMUNICATION IN SOUTH WEST NIGERIA

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**Abstract**

Path loss models are a vital component in planning of wireless communication, as they assist in achieving optimal signal levels in deploying mobile communication base stations. This study compared field-measured data with various propagation models of Walfisch-Bertoni (WB), Dual-Slope (DS) and Vector Parabolic Equation (VPE). Measurements were obtained from three base transmission stations (BTS-1, BTS-2, BTS-3) in a high-density urban environment, in South West Nigeria, using a Mobile Station (MS) setup. The setup consists of a laptop with the Ericsson Test Equipment for Mobile System (TEMS) investigation software, at an operating frequency of 1,900MHz. MATLAB software was used to simulate the path loss for the propagation models. The comparison of the path losses from the measured data and the propagation models showed that the Vector Parabolic Equation model, generally, gave a better prediction of path loss in the study area. The VPE is thus recommended for path loss estimations within the South Western part of Nigeria and other terrains with similar features

**Key Words**: Path loss, propagation, wireless, models, mobile communication.

## Introduction

The performance of mobile communication systems is limited by the signal transmission channel and the path between the transmitter and receiver. Such paths vary randomly from simple line-of-sight to severely obstructed, depending on the location of the transceivers. As against wire channels, it is difficult to analyze the radio channel in wireless media. This is typically done in a statistical fashion based on measurements of any specific communication system (Gibson, 1996). Electromagnetic waves behave differently when propagated through a medium and through the atmosphere so different environments impact wave propagation in different ways (Faruques, 1996). Most cellular radio systems operate in urban environments where there is no direct wave between the transmitter and receiver, but rather integrated waves resulting from diffraction, reflection and scattering, which are the main mechanisms that influence signal propagation. Signal propagation models are traditionally concerned with predicting the strength of the received signal after undergoing various multipath losses (Gibson, 1996). The path loss model prediction for signal strength depends on the reliability of the network and the quality of coverage (Anderson, 2006). With an appropriate propagation path loss model, the coverage area, signal-to-noise as well as carrier-to-interference ratios can be determined easily for a mobile communication system setup (Lee, 1993). Path loss calculations are wireless survey tools used for determining signal strength at various locations, away from the transmitting station. They are increasingly being used to determine possible radio signal strengths before the installation of cellular operation equipment. This is necessary because of the high investment cost in mobile base stations (MBS) (Emagbetere, 2009).

The radio signal path loss will determine many elements of the radio communication system particularly the transmitter power, receiver sensitivity, transmission form and several other factors. As a result, it is necessary to understand the reasons for radio path loss and to be able to determine the level of signal loss for a given radio path (Zakaria, 2015). The signal propagation mechanisms cause distortions of the transmitted signals, resulting in signal fading and propagation losses (Rappaport, 1996). The magnitude of such resulting losses depends on the peculiarity of the propagation environment so various locations will not necessarily have a good fit with the same path loss model. The suitability of a path loss predicting model must take the peculiarities of locations into consideration. It is therefore important to have knowledge of the propagation characteristics of an environment for the designing of any wireless (mobile) communication system in that region (Obot, 2011).

The developed countries have had radio mobile communication since the early 20th century so investigations of the nature of this study have been carried out and different propagation models, as well as model performance, established in such countries. The models were derived to suit specific environmental conditions. Locations and regions with similar environmental features could somewhat apply same models, though not with a 100% fitness certainty (Emagbetere, 2009).

This paper seeks to investigate the suitability of various path loss models as compared with measured data in three locations within Ikoyi, South West Nigeria. Ikoyi is a high-brow urban area in Lagos, South West Nigeria with coordinates 6º27'N 3º26'E. It is populated with a mix of high-rise buildings and bungalows used both for residential and office purposes. It daily experiences very high human and vehicular traffic with commercial activities around the clock. The focus of this study is to determine a suitable model for predicting path loss within the study area. As there is no particular model that is being used for the area.

### *Overview of Propagation Path Loss Models*

Path loss models adopt different approaches in terms of the complexities of mathematical equations and accuracy levels (Jalel, 2013). This study analyses three models, Walfisch and Bertoni, Dual-Slope and Vector Parabolic Equation (VPE) models. The choice of these models is because they have factors that address some of the features of the study area, in predicting path loss.

***Walfisch and Bertoni Model***

This model puts into consideration rooftops and heights of buildings into consideration in predicting received signal strength in a street, using the diffraction phenomenon (Gibson, 1996). It applies to dense urban areas with evenly spaced rows of buildings of uniform height, which act as absorbing screens to the signals. The base station height is considered to be above the average rooftop level. The model considers path loss to be due to three components namely free space loss, loss along the buildings and loss down the street. The path loss, $L_p$, is given by (Parsons, 2000 and Wataru, 2021).

$$L_p = P_0 Q^2 P_1 \quad ...(1)$$

Where $P_0$ is the free space path loss and is given as

$$P_0 = \left(\frac{\lambda}{4\pi d}\right)^2$$

$Q^2$ is the path loss due to propagation over the row of buildings. It is expressed as

$$Q^2 = \left[0.1\left(\frac{\text{Sin}\sigma\sqrt{\frac{d}{\lambda}}}{0.03}\right)\right]^2$$

$$\text{Sin}\sigma = \frac{h_T - H_b}{R}$$

The building spacing is d, $\lambda$ is the signal wavelength, σ is the incidence angle, $h_T$ is the transmitter height, $H_b$ is the building height and R is the distance.

$P_1$ is the signal loss from the rooftop to the street based on diffraction. It is given as

$$P_1 = \frac{\lambda \rho_1}{2\pi^2 (H_b - h_m)}$$

$\rho_1$ is the path distance from the building edge to the mobile station, $h_m$ is the mobile antenna height.

The total path loss is thus given as

$$L_P = \left(\frac{\lambda}{4\pi d}\right)^2 \left[0.1\left(\frac{\text{Sin}\sigma\sqrt{\frac{d}{\lambda}}}{0.03}\right)\right]^2 \frac{\lambda\rho_1}{2\pi^2(H_b - h_m)}$$

$$L_P = \frac{5.51}{32\pi^4} \frac{(h_T - H_b)^{1.8}\rho_1 d^{0.9}}{(H_b - h_m)^2} \frac{\lambda^{2.1}}{R^{3.8}} \quad ...(2)$$

Expressed in decibels, the total path loss is;

$$L_P = 89.5 - 10log\left[\frac{\rho_1 d^{0.9}}{(H_b - h_m)^2}\right] + 21logf_M - 18log(h_T - H_b) + 38logR_k \quad ...(3)$$

$f_M$ is the frequency in megahertz and $R_k$ is the distance in Kilometres.

***Dual-Slope-Model***

This is based on the two-ray model and is suitable for propagations that have a line of light (LoS). The dual-slope model describes the propagation loss, L(d) as a function of distance, d, between the base station and the receiver. The path loss is given by (Oyie, 2018);

$$PL(d) = \begin{cases} PL_1\,(d)[dB], for\ d \le d_{reak} \\ PL_2\,(d)[dB], for\ d \ge d_{reak} \end{cases}$$

$$PL(d) = \begin{cases} PL(d_0) + 10n_1 log_{10} d + L_{m,n_1}(d) & ............ (4a) \\ PL(d_0) + 10(n_1 - n_2)log_{10} d_{brk} + 10n_2 log_{10} d + L_{m,n_2}(d) ... & (4b) \end{cases}$$

PL(d) represents the path loss at any distance *d* between the transmitter and receiver. The path loss (in dB) at the reference point, $d_0$, is given by PL($d_0$), $d_{brk}$ represents the breakpoint distance, $L_{m,n_1}(d)$ is the modal attenuation before the breakpoint, while and $L_{m,n_2}(d)$ is after the breakpoint (they depend on the frequency and antenna heights), $n_1$ and $n_2$ represent the slopes of the best-fit line before and after the breakpoint.

With the transmitter and the receiver antenna heights and the distance between them known, the path loss can be computed based on the two parameters $n_1$ and $n_2$. Normally $n_1 = 2$ and $n_2 = 2$ to 7.

***Vector Parabolic Equation (VPE) Model***

The Vector Parabolic Equation (VPE) is an approximation of the wave equation, which gives room for numerical solutions for long-range forward propagation problems. It is a technique for accurately modelling radio waves that are reflected, diffracted and forward-scattered from irregular terrains with sprawling buildings. It is also important for predicting the effects of these features on the scattered field structure, at high frequencies.

The wave equation is given in terms of the reduced functions thus;

$$\frac{\partial^2 u}{\partial x^2} + 2ik\frac{\partial u}{\partial x} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} = 0 \quad ... (5)$$

The electric field component is

$$E(x, y, z) = u(x, y, z)exp(ikx)$$

Where $exp(ikx)$ is time-harmonic dependent, k is the free space wave number and $U(x, y, z)$is a slow-varying function along x-coordinate

The parabolic wave equation is given as (Zaporozhets, 1999; Pennock, 2010 and Levy, 1992).

$$\frac{\partial u}{\partial x} = -ik\left(1 - \sqrt{1 + X}\right)u$$

With solution $u(x + \Delta x, y, z) = exp(-ik\Delta x)exp(ik\Delta x.Q)u(x, y, z)$

This is the standard parabolic equation.' It is a narrow-angle approximation, which is very accurate at angles within 15" or so of the direction of the x-axis.

***Experimental Setup and Data Collection***

The Mobile Station (MS) setup for data collection consisted of a laptop with the Ericsson Test Equipment for Mobile System (TEMS) investigation software installed on it. An Android mobile handset with the TEMS application was also utilized, while a global positioning system (GPS) receiver was used to obtain the longitude, latitude and altitude of the setup. A 12V dc power inverter was used to provide power during data collection. Three Base Transceiver Stations (BTS) with coordinates A (Latitude –8.744588 and Longitude – 5.72315), B (– 8.647175 and Longitude – 5.64323) and C (Latitude – 8.743406 and Longitude – 5.6141) were utilized for this study. The MS equipment was mounted on a vehicle, which was driven some distance away from the BTS, and the signal strength was measured intermittently

To obtain measurements, a call was initiated from the MS to the BTS and after the call was established, the MS was driven around the BTS and the signal strength measurements were taken from 2 km and in intervals of 100m up to 4 km away from the BTS. The resulting signal strength information over the interface between the BTS and the MS in different radial directions was recorded by the TEMS software. Twenty measurements were taken for each BTS. Google Earth was used to determine the distance between the BTS and MS. The values of the measured signal strengths were converted into path loss using the formula.

$P_L\,(dB) = P_t\,(db) - P_r\,(db)$ . . . . . . . . . (6)

Where $P_L$ is the path loss between BTS and MS in decibels (dB), $P_t$ (dB) is the power of the transmitted signal in decibels and $P_r$ (dB) is the power of the received signal in decibels

***Simulation of Path Loss Model***

Walfisch and Bertoni, Dual-slope and Vector Parabolic Equation propagation models were selected for this study because they are data-dependent and consider some parameters such as which are typical of the study area. The predicted path losses for these models have been simulated using MATLAB software. The simulation parameters are given in Table 1.

**Table 1: Simulation Variables**

| ***Parameters*** | ***Values*** |
|---|---|
| Base station transmitter power | 57dB (m) |
| Transmitter antenna height | 32m |
| Receiver antenna height | 1.7m |
| Operation frequency | 1800mHz |
| Distance between transmitter (Tx) and Receiver (Rx) | 5km |
| Building to building distance | 52m |
| Orientation angle (α) | 65.2° |

**Results Comparison and Analysis**

The path loss for the study area was estimated using the models earlier reviewed and the field measured data from the three BTS locations (BTS1, BTS2 and BTS3). The reviewed models were selected because of their data dependence and path loss prediction being function of several parameters. The measured and predicted path losses are shown in Figures 1 to 4 for the three locations: BTS1, BTS2, and BTS3.

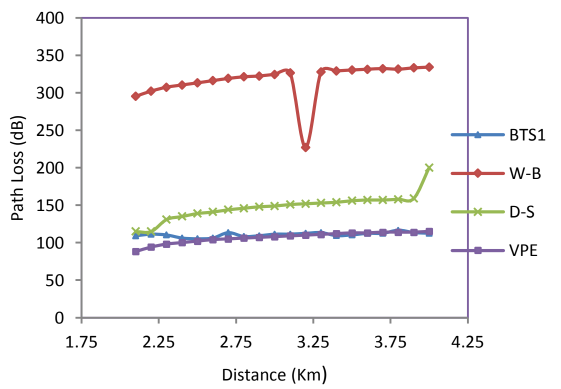


**Figure 1: Comparison between measured and predicted path loss for BTS1**

From Figure 1, a comparison of the model-predicted path loss and the measured path loss for BTS1 shows that the WB and DS model predictions overestimate the path loss, while the VPE gives a good estimation.

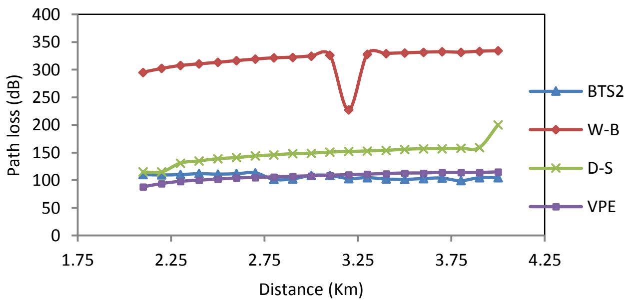


**Figure 2: Comparison between measured and predicted path loss for BTS2**

The path loss estimation for BTS2, as shown in Figure 2, reveals shows that the WB and DS models overestimated the path loss, while the VPE-predicted path loss gave a good estimation when compared with the measured path loss.

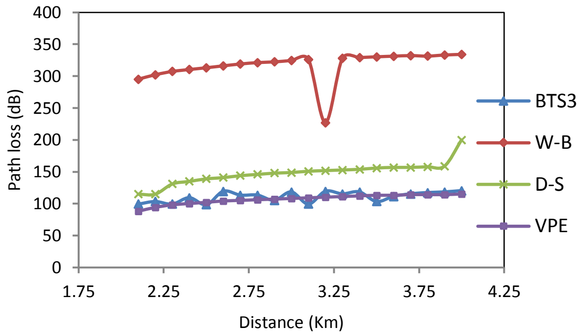


**Figure 3: Comparison between measured and predicted path loss for BTS3**

Figure 3 for BTS3 shows the WB and DS model path losses giving an overestimate of the path loss when compared with the field-measured path loss. The VPE though is seen to have given a good estimation.

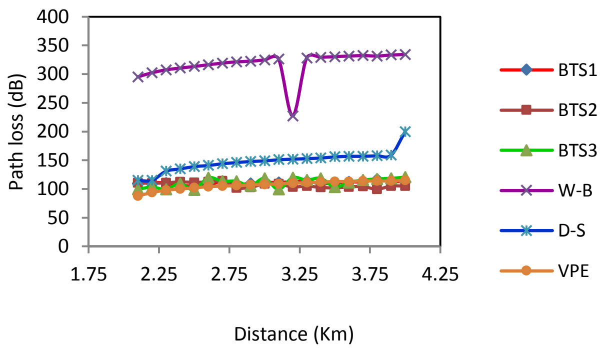


**Figure 4: Comparison between measured and predicted path loss for BTS1, BTS2 and BTS3**

Figure 4 is a combined chart of the path loss estimations for the WB, DS and VPE models and the field-measured path losses from the BTS1, BTS2 and BTS3. It is observed that the Walfisch-Bertoni and Dual-Slope models overestimate the path loss for all three stations, while the VPE model gives a suitable prediction of the path losses. The comparison shows that the VPE is ideal for estimating path loss in the South West part of Nigeria.

**Conclusion**

The path loss for the study area has been estimated using three models, Walfisch-Bertoni, Dual-Slope and the

Vertical Parabolic Equation. The measured results showed that the W-B and DS models overestimated the path losses, while the VPE estimation is quite close to the field-measured path loss. The closeness of the VPE path loss prediction to the measured path losses, therefore, makes it most suitable for path loss estimation and prediction for wireless communication in the South Western part of Nigeria.

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