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Original Article

Performance Evaluation of Standard Path Loss Models for Cellular Network Systems

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Abstract - *The quality of signal propagation for any cellular system is based on the terrain where the system is deployed. Also, the distance of the receiving device from the transmitter, the hindrance obstacles at the path of signal propagation, and the frequency are other factors on which the quality of the signal depends. More so, path loss at various distances and frequencies can be related to the environment and can only be evaluated using path loss models with the capacity to predict only the terrain for which it was designed. The existing standard cost231, Okumura, and Free-space models have often been utilized for propagation attenuation estimation during cellular network planning. In this paper, existing standard Okumura-hata, COST231-hata, and Free space models were analyzed and compared with measurement path loss values to ascertain the level of performance between these models at 2600MHz in Port Harcourt, Nigeria. The signal strengths were measured through the drive-test method within six (6) cell sites. It showed that the range of the measured propagation path loss varies from 120-180dB, whereas COST 231-hata, Okumura-hata, and Free space models attained propagation path loss values which vary between 215-255dB, 210-252dB, and 140-162dB respectively in the sites. The free-space path loss model estimated the closest path loss data with measured path loss data as compared to the Okumura model, cost231 model, and measured path loss data. As such, the Free-space model outperformed the Okumura and COST231 models within the study area. The standard COST231 model estimated the highest path loss values. The free-space model proved to be the best that can be suitable within the environment and, as such, should be adopted for cellular network system planning and optimization within Port-Harcourt, Nigeria.*

Keywords - *Performance, Evaluation, Path loss, Models, Cellular network.*

1. Introduction

Call quality can be severely affected by weak signal strength, which could frequently result in a call outage. Weak signals cause the mobile device connection to be unstable, which could also result in poor audio quality, inability to download files, and dropped calls. Several variables, including the distance of the base station from the user, network congestion, and obstacles along the path of signal propagation (such as buildings or topographical structures), can contribute to these unstable conditions. To ensure a consistent and dependable voice and data network, a strong and stable signal must be maintained. To do so, proper cellular network planning and optimization have to be carried out using a path loss model with a high-performance level [1]. A frequency wave can be characterized as transmitting a signal from the transmitter towards the receiver to a communication medium by cellular network. Path loss is basically signal attenuation by which it travels to the receiver from a base station [2]. Path loss models are critical for predicting signal quality variations during spatial propagation in cellular network systems. These models give accurate evaluations for signal coverage area, capacity and quality of services that support cellular network planning and optimization [2]. Recently, various standard models like the Okumura, COST231, and Free-space models have been explicitly considered in scarcely and tensely populated environments propagating path loss evaluation. By using these models, network engineers can accurately predict path loss in several areas, which results in improved performance and reliability of cellular networks, thereby ensuring better user experience as well as connectivity. Propagation path loss estimation can be achieved by applying path loss models [3]. Different existing predicted propagation path loss models exist. Existing path loss models can be formulated using pragmatic, measured data, and the models are commonly utilized in cellular network planning and optimization [4]. Standard path loss models such as COST231 and Okumura models are not very accurate in other areas apart from the environment where the parameters were acquired during the formulation. The propagation path loss can be estimated using standard path loss models based on the distance between the transmitter and receiver antennas as well as the heights [5]. Few of these path loss models are utilized systematically to understand the acquired measured data in the propagating environment.

Scientific researchers have researched various path loss models for path loss prediction in cellular network systems. The measured path loss values have been analyzed and compared with predicted models such as Free-space, COST231-hata, and Okumura-hata [6]. The work aims to analyze and compare standard predicted Free-space, COST231-hata and Okumura-hata path loss models with measured path loss values in order to ascertain the best existing model suited for cellular network planning and optimization within Port Harcourt, Nigeria.

2. Literature Review

[17] analyzed and compared the propagation path loss of standard COST231, Hata, Ericsson and ICC-231 models with path loss calculated from a measured value in Iraq's urban and suburban terrains. When comparatively analyzed, the result showed that Ericsson and Hata's models indicated a small difference from the measured data in the populated urban terrain. In the rural, scarcely populated terrain, the Hata model indicated a high level of accuracy. [15] compared path loss values of COST231-Hata, Hata, free space, SUI, Walfisch-Ikegami, and Ericsson 9999 models. Two different frequencies, 28GHz and 3.5GHz, were considered for the study. The result showed that at lower frequencies, Hata, SUI, and Ericson models were more suitable for 5G wireless cellular networks irrespective of any distance and nature of the terrain, as compared to free space, COST231-Hata, and Walfisch-Ikegami models. Notwithstanding, at 3.5GHz 5G frequency, the SUI model proved to work better than Hata and Ericson 9999 models in both the suburban and urban terrains. But, at higher frequencies, the Ericson 9999 model performed optimally better in the urban terrain, whereas the SUI model proved to be the best in suburban terrain. [7] experimented with path loss estimation at a frequency of 900MHz considering Okumura, COST231, Ericsson, SUI, and ECC33 models for rural, urban and suburban environments in Dar es Salaam, Tanzania. The path losses derived from measured values were relatively compared to the different predicted standard models. It reviewed that ECC-33 was the most suitable in a suburban environment but excessively predicted the path loss within a densely populated environment. It also showed that Okumura, COST231, SUI, and Ericsson models generally predicted the smallest values of path loss in all the terrains.

2.1. Existing Path Loss Models

A convenient way to account for the rigorous characteristics of path loss is based on the path loss model. The reduction of signal strength during space travel can be predicted by utilizing the existing path loss models. Cellular network system design and analysis depend heavily on these models. Because path loss has an impact on the wireless link's quality, capacity, and coverage area, it is a crucial factor to take into account when designing and analyzing cellular network systems [7]. Some of the existing path loss models are detailed below;

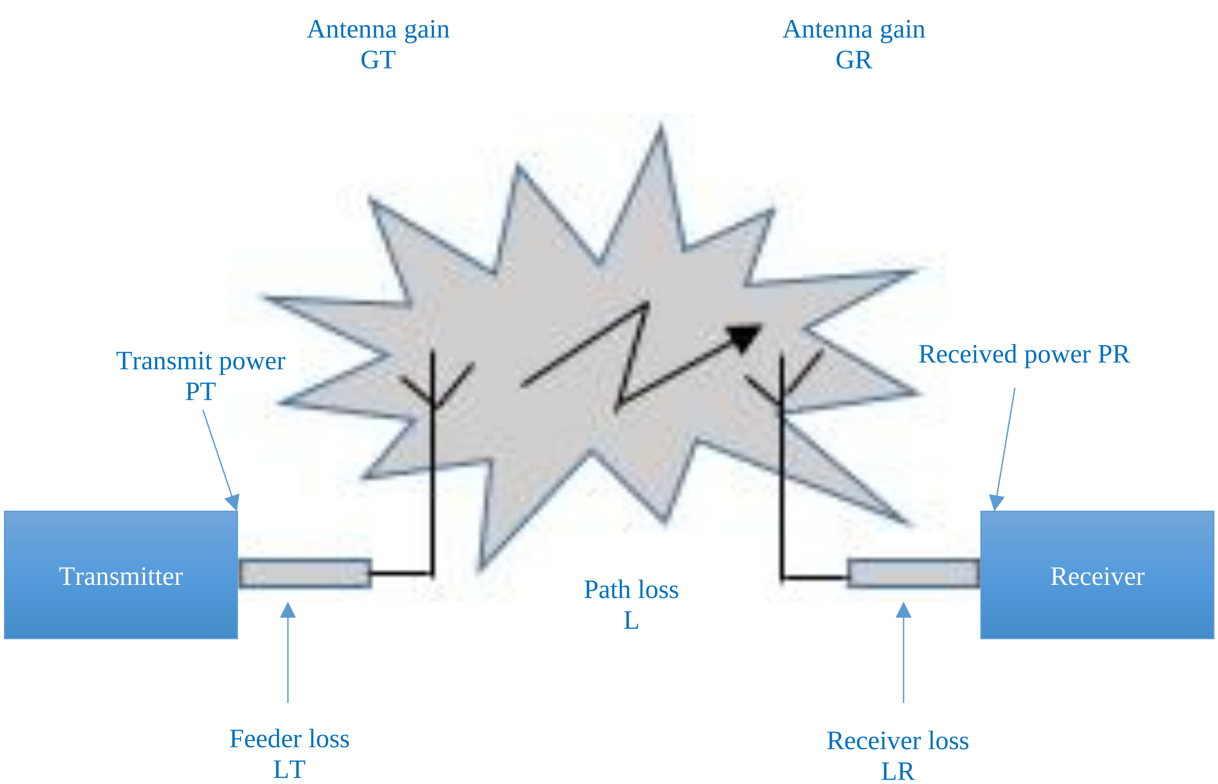

Fig. 1 Free-space signal propagation

2.2. Free Space Model

In cellular networks, the Free-space path loss model is considered a basic idea. As such, it is the foundation of other complex propagation models. The free space model was formulated in an idealized setting environment devoid of obstructions, reflections, or other interference that may cause a radio signal attenuation [18]. Understanding the behavior of radio waves in open spaces is imperative, and this model forms the foundation for more intricate propagation models that take into account multiple variables, such as topography, structures, and atmospheric conditions [17]. Figure 1 basically illustrates the signal propagation path loss of a wireless cellular network system. The receiver power, through the receiving antenna, is related to power density, D_p, of receiving antenna and effective aperture, A_e (which is the proportionality constant) as shown in Equation (1).

$$P_r = A_e D_p \quad (1)$$

Where;

$$D_p = \frac{P_t G_t}{4\pi r^2}$$

$$A_e = \frac{\lambda^2 G_r}{4\pi}$$

Therefore

$$\frac{P_r}{P_t} = G_t G_r (\frac{\lambda}{4\pi r})^2$$

$$P_L = \frac{P_t G_t G_r}{P_r} = \left(\frac{4\pi r}{\lambda}\right)^2 = \left(\frac{4\pi r f}{c}\right)^2$$

$$P_L(dB) = 32.40 + 20\, log\, r + 20\, log\, f \quad (2)$$

Where;

P_r is the receiver power

P_t is the transmitting power

G_t is gain of the transmitter

G_r is gain of the receiver

P_L(dB) is signal path loss in decibels

r is the distance between the receiver and transmitters

f is the transmitting frequency

2.3. Okumura-Hata Model

By using correction factors, Okumura converts urban environments to the other classifications using them as a reference. This is a wise decision because these areas combine the best feature of open spaces—the incorporation of obstacles, while avoiding the significant variability found in suburban environments [8, 9]. The following formula is typically used to calculate Okumura's path loss predictions using Hata's approximations [10]:

$$\text{Urban areas} = P_L(dB) = A_1 + B_2\, log\, r - C \quad (3)$$

$$\text{Suburban areas} = P_L(dB) = A_1 + B_2\, log\, r - D \quad (4)$$

$$\text{Open areas} = P_L(dB) = A_1 + B_2\, log\, r - E \quad (5)$$

Where

$A_1 = 69.60 + 26.2\,0\log(f) - 13.80\log(h_b)$

$B_2 = 44.9 - 6.55\log(h_b)$

$C = 3.2[\log(11.75 h_m)]^2 - 4.97;\ for\ large\ citie, f \geq 300MHz$

$C = 8.29[\log(1.54 h_m)]^2 - 1.1;\ for\ large\ cities, f < 300MHz$

$C = (1.1\log f - 0.7)h_m - (1.56\log f - 0.8)$; for medium to small cities

$$D = 2\left[\log\left(\frac{f}{28}\right)\right]^2 + 5.4$$

$E = 4.78(\log f)^2 - 18.33\log(f) + 40.94$

The model is valid only for $150MHz$ to$1500MHz$; $30m < h_b < 200m$; $1m < h_m < 10m$ and $r > 1km$.

The height above sea level within a range of 3–10 km is known as the base-station antenna height, h_b as a result, h_b may vary slightly depending on the direction of the receiving device relative to the ground level. Measurements also show that range affects this factor. As a result, urban environments are classified as large cities and medium-sized towns, with building heights that are average or more than 15 meters [11].

A city or town's physical and social surroundings, including its roads, buildings, and infrastructure, are what constitute an urban environment when a dense population lives there. Residential, commercial, industrial, and recreational spaces are intricately mixed in these environments [12].

In many situations, especially in suburban environments, Okumura's predictions have proven to be accurate. Other measurements, however, ran counter to these hypotheses; errors are frequently attributed to variations in the study area's characteristics from Tokyo [13].

Although many researchers have tried to fine-tune Okumura's approach to incorporate measured building density, these strategies have not gained widespread traction. Many commercial prediction tools basically work with versions of this model that are tailored to fit the specific areas they serve [14].

2.4. COST231-Hata Model

Okumura model was optimized to accommodate a higher frequency range of $1500MHz < f < 2000MHz$ [15, 16].

$$P_L(dB) = F_1 + B_2\, log\, r - C + C_m \quad (6)$$

Where

$F_1 = 46.3 + 33.9\log(f) - 13.82\log(h_b)$

C is for rural, suburban, or urban, as represented in Equation (3)

$$C_m = \begin{cases} 0\text{ dB}; & \text{rural/suburban environments} \\ 3\text{ dB}; & \text{for city's environment} \end{cases}$$

3. Methodology

3.1. Data Collection/Analysis

The drive test method was adopted for this study, and Reference Signal Received Power (RSRP) was extracted from six commercial cell sites deployed within Port Harcourt, Nigeria. The major equipment used for the signal strength measurement were TEMS Software, a 4G Modem and MTN SIM loaded with internet data, GPS, and MATLAB software for the data analysis.

3.2. Calculation of the Measured Path Loss

Propagation path loss is the term used to describe the reduction in power density of an electromagnetic wave as it passes through space [16].

The signal path loss for measurement data points can be estimated using Equation (7).

$$PL_m(dB) = EIRP(dBm) - RSRP$$

Where

PL_m is the measured path loss

$EIRP$ is the effective isotropic radiated power

$RSRP$ is the measured received signal power or reference signal received power

$$PL_m(dB) = P_t + G_t + G_r - L_{FC} - L_{AB} - RSRP \qquad (7)$$

Where

G_t is antenna gain of the transmitter (dBi)

G_r is antenna gain of the receiver (dBi)

L_{AB} is loss through antenna body (dB)

L_{FC} is the loss through feeder cable (dB)

4. Compared Results and Discussions

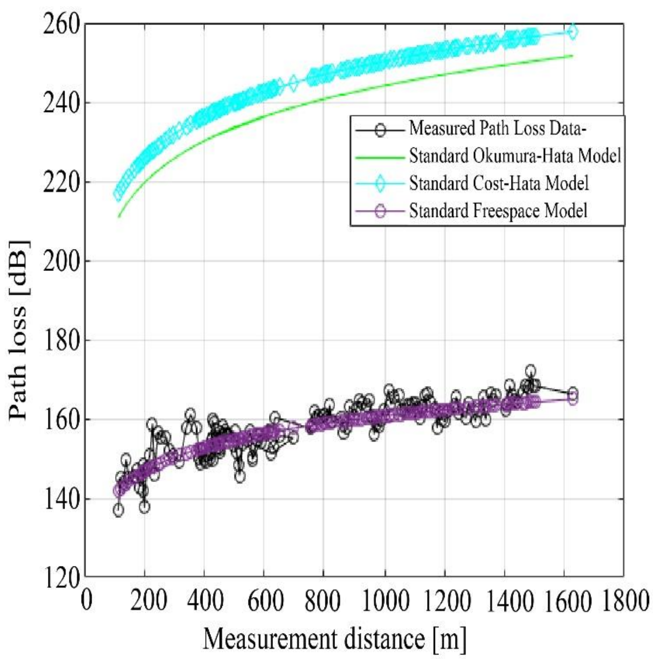

Fig. 2 Compared measured path loss vs standard models in site 1

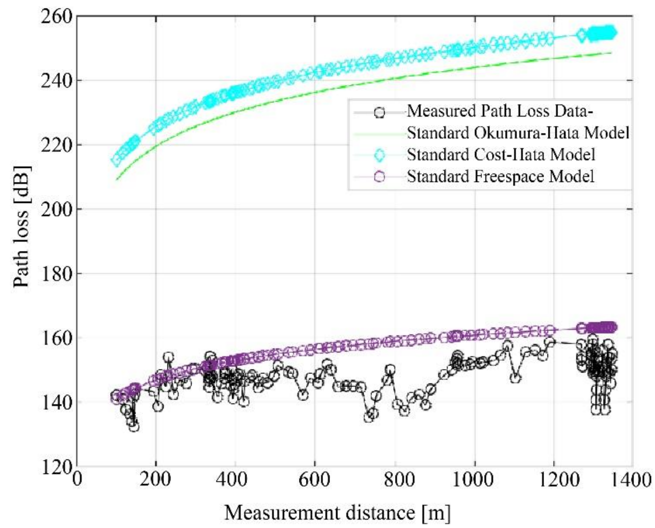

Fig. 3 Compared measured path loss vs standard models in site 2

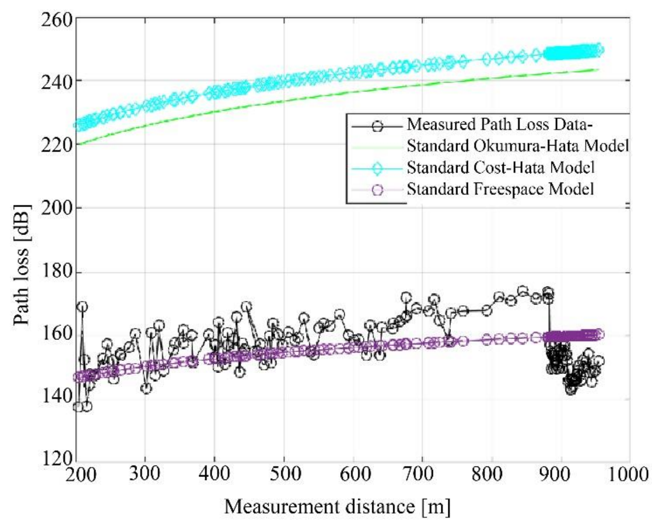

Fig. 4 Compared measured path loss vs standard models in site 3

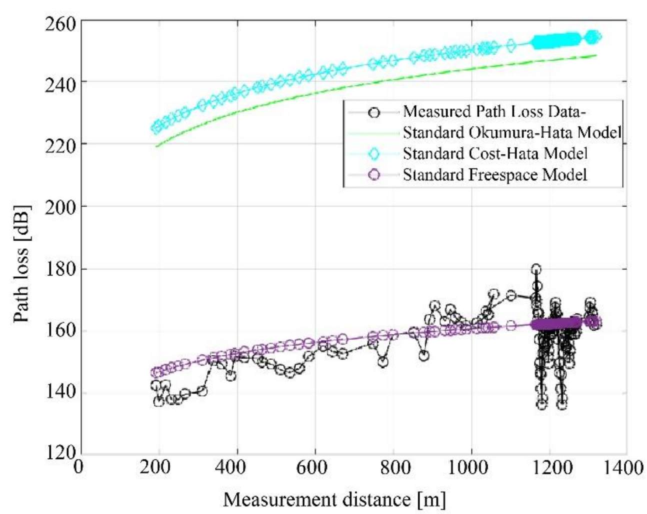

Fig. 5 Compared measured path loss vs standard models in site 4

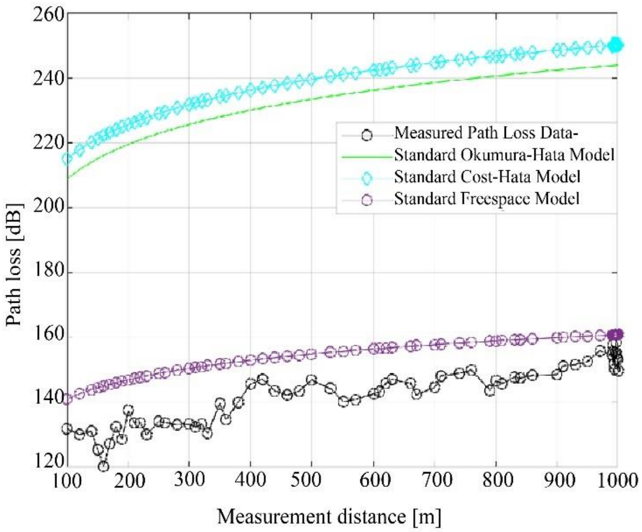

Fig. 6 Compared measured path loss vs standard models in site 5

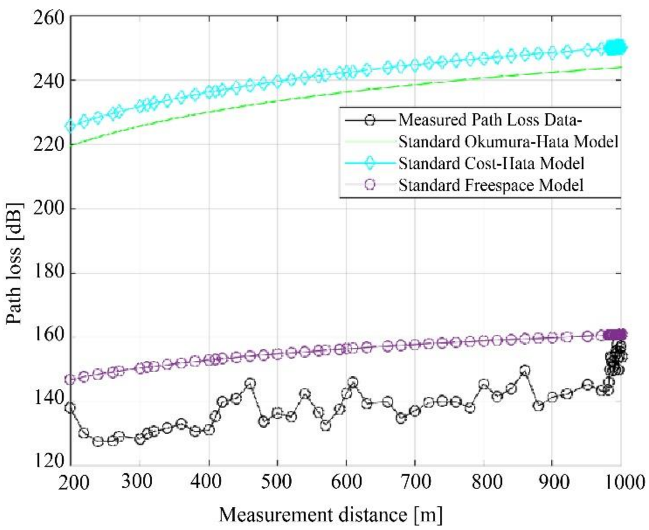

Fig. 7 Compared measured path loss vs standard models in site 6

The analyzed results in Figures 1 to 6 showed that COST231-hata and Okumura-hata models estimated a high value of propagation path loss as compared to the measured path loss throughout the sites. It showed that the range of the measured propagation path loss varies from 120-180 dB. Comparatively, COST231-hata model, Okumura-hata model, and Free-space attained propagation path loss values of 215-249dB, 215-255dB, 225-250dB, 225-255dB, 215-250dB, 225-250dB; 210-252dB, 210-250dB, 220-242dB, 220-249dB, 210-245dB, 220-245dB; 141-165 dB, 140-162 dB, 150-160 dB, 150-160 dB, 140-160 dB, 145-160dB for site 1, 2,3,4, 5 and 6 respectively, when compared with measured propagation path loss values of 138-167dB, 130-160dB, 139-178dB, 135-180dB, 120-160 dB, 125-160dB for site 1, 2, 3, 4, 5, and 6 respectively. Free-space path loss model estimation was the closest to that of the measured path loss values. As such, the free-space path loss model performed much better than the COST231-hata and Okumura-hata path loss models within the study area. Based on the results, it is evident that the propagation path loss values obtained by the Okumura-hata and COST231-hata models were significantly higher than those obtained by the free-space model and field measurements. The physical topographical environment in the areas where the COST231-hata and Okumura-hata models were developed may be responsible for the high propagation path loss values estimated by these models. Consequently, this provides insight into the need to adjust or optimize the current standard models in order to create a cellular communication network system that is dependable and efficient in any given location.

5. Conclusion

This study presented propagation path loss estimated through COST231-hata, Okumura-hata, and Free-space models and these path loss values were compared with measured path loss values considering six cell sites. Both path loss values derived were analyzed and compared using MATLAB software. Based on the observation, it showed that the free space model gives the best result as it estimated a path loss value that was the closest to the measured path loss data. As such, its utilization stands a better chance of achieving a high quality of service during cellular network planning than the COST231-hata and Okumura-hata models within Port Harcourt. So, the application of the free space model can serve as a pathway to resolving the constant weak signal problems faced by mobile users.

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