Comparison Analysis of Hata Model and the Walfisch - Bertoni Model For Propagation Prediction

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ABSTRACT
This research is on comparison analysis of Hata model and the Walfisch - Bertoni model for propagation prediction. It attempts to describe two reliable path loss prediction techniques used in both rural and urban environments, starting with the radio propagation phenomena and fundamental path loss models. A driving test was carried out at Umuahia and Umudike Road, Abia State, Nigeria. The simulation was conducted using Matlab software. The results of the Hata model shows that the path loss has higher values when the frequencies are high and the lower the transmitter heights, the higher the path loss (L) in decibel (dB). The results of the Walfisch - Bertoni model shows that the path loss increases (more shadowing) with increasing frequency. It equally showed that path loss is smaller (less shadowing) for larger building separation distances and larger (more shadowing) for higher buildings. The results of the comparison revealed that for the overall path loss, the more parameterized Walfisch-Bertoni model outperforms the Hata model.

KEYWORDS: Hata model, Walfisch – Bertoni, Propagation, Path loss, Prediction.

1.0 INTRODUCTION

In order for signal transmission to be efficient and reliable, it is crucial to understand the power of the received signal and how it changes at different distances within the base station environment. Wireless signals undergo various propagation mechanisms and are significantly impacted by the surroundings, resulting in a loss of signal power. Path loss refers to the decrease in transmitted power of electromagnetic waves as they travel through space, and plays a key role in analyzing and developing the communication system's link budget. Path loss is affected by factors such as frequency, antenna height, obstructions and reflectors near the receiver, distance between links, and other variables (Ujjawalbahuguna, 2019).

Engineers and scientists use mathematical tools like the propagation path loss model prediction to plan and optimize their wireless communication systems. It is employed to forecast the amount of signal strength or coverage that will be lost at a specific site. For cellular systems, a number of propagation prediction models have been created to estimate important system parameters like antenna heights, frequency, and transmission power. The description of the terrain and the impact of vegetation, which differ greatly from location to location, make it difficult to choose the best model for any given geographic region (Sharma and Singh, 2020). Three types of propagation models exist: deterministic, semi-dispersive, and empirical. Models that are based on measurements, statistical characteristics, and a small number of parameters are called empirical models. The Hata and Okumura models are two examples. Empirical models with deterministic elements are called semi-dispersive models. The Walfish and Bertoni models, as well as the Cost-231 model, are a few examples. Site-specific deterministic models necessitate a great deal of geometry data about a city, a computational report, and a more precise model, (Ubom, *et al.*, 2019).

This study was aimed at carrying out Comparison analysis of Hata model and the Walfisch - Bertoni model for propagation prediction.

2.0. LITERATURE REVIEW

According to a study done in India (Tzaras and Saunders, 2019), Many propagation path loss models have been created over time to evaluate wireless communication systems' performance. Numerous researchers have conducted studies on the behavior of radio waves in various environments under various environmental and geographical conditions in order to achieve high quality service delivery. The resulting models are unique to the relevant environment. Path loss propagation models may produce different results when applied in environments other than the ones for which they were intended.

A study by (Ogbulezie *et al.*, 2020), compared empirical models for cellular transmission in River State, Measured field data were compared with various path loss models. With the aid of a spectrum analyzer, field measurement data were collected at the 900 MHz and 1800 MHz frequency bands in urban, suburban, and rural settings. The results of the ECC-33 and SUI models performed better in urban settings, according to the analysis. The ECC-33, Standard University Interim (SUI), and COST 231-Hata models performed well in suburban areas. In rural areas, the Okumura-Hata and Log distance models performed better.

A study by (Nwalozie *et al.*, 2020),) created a statistical path loss model that could be used in Nigeria's South-South region. They used a live Globacom WCDMA network to gather downlink data at different distances and frequencies (2100 MHz) for their study. MATLAB software was used to compare and simulate the results of the predictions made by three path loss models with the measured path loss. It was suggested that the Cost 231 Hata model be modified for cellular communication in the area because it produced better comparison results.

A study conducted by (Akinwole and Biebuma, 2019) used Ten active Port Harcourt microcells running at 876 MHz provided data for their study. Urban (Category A) and suburban (Category B) environments were distinguished. According to the findings, the Path loss rises by 35 dB in urban areas (Category A) and 25 dB in suburban areas (Category B) per decade, respectively. In order to calculate the differences in path loss between the observed and anticipated values from the Okumura-Hata model, the Mean sq\. Errors (MSE) for urban and suburban terrains were determined to be 10point 7 dB and 13point 4 dB, respectively. According to their opinion, the comparison of the measured values for the two categories and the modified Hata models produced a better outcome, making them useful for use in the study area.

3.0 MATERIALS AND METHOD

3.1 Materials

a. The Hata model

One of the most popular models used in real system design is the Hata model. Because of its accuracy and simplicity, a lot of new models continue to use it as a reference. Carrier frequency f_c in MHz, distance R in km, base station antenna height h_b in m, and mobile antenna height $h_m$in m are the four parameters used by the Hata model to estimate the path loss.

The model is only valid for the parameter ranges 150 MHz ≤ f_c ≤1500 MHz, R >1 km, 30 ≤ h_b ≤200 and 1< h_m <10.

Hata empirically approximated Okumura's graphical path loss data into formulas in the following forms (PranjaliRaturi and Samreen, 2020):

Urban Areas $$L_{dB} = A + Blog_{10}(R), \quad (1)$$

Suburban Areas $$L_{dB} = A + Blog_{10}(R) - C \quad (2)$$

Open Areas $$L_{dB} = A + Blog_{10}(R) - D \quad (3)$$

Where,

$$A = 69.55 + 26.16log_{10}(f_c) - 13.82log_{10}(h_b) - \alpha \quad (4)$$

$$B = 44.9 + 6.55log_{10}(h_b), \quad (5)$$

$$C = 2(log_{10}\left({f_c}/{28}\right))^2 + 5.4, \quad (6)$$

$$D = 4.78(log_{10}(f_c))^2 - 18.33log_{10}(f_c) + 40.94 \quad (7)$$

$$\alpha = 3.2(log_{10}(11.75h_m))^2 - 4.97 \qquad \text{large cities, } f_c \geq 300MHz, \quad (8)$$

$$\alpha = 8.29(log_{10}(1.54h_m))^2 - 1.1 \qquad \text{large cities, } f_c < 300MHz, \quad (9)$$

$$\alpha = (1.11log_{10}(f_c) - 0.7)h_m - (1.56log_{10}(f_c) - 0.8) \qquad \text{small to medium cities} \quad (10)$$

Curves or formulas that are fitted to a set of measurements are typically not valid outside of that measurement range. Because the model is invalid for ranges shorter than one kilometer and less flexible when compared to deterministic models.

b. The Walfisch - Bertoni model

The model represents building rows as absorbing screens with uniform heights and separations between them in densely populated areas. The model's path-loss formulation has more parameters than the Hata model due to its semi-deterministic nature. The path loss is broken down by the model into three parts: loss along the buildings, loss at street level, and loss in free space. The Repeated Kirchhoff Integral for uniform parallel screens, an application of scalar diffraction theory with certain approximations, is the first method used by the model to calculate the loss along buildings, (Sharma and Singh, 2020).

The field at the plane of screen y_{n+1} can be expressed in terms of the incident wave that is approaching the first screen when there are uniform screens with uniform heights ($h_n = 0$). To accomplish this, express each field on a subsequent screen in terms of the field on the one before it. The field for the second screen can be expressed as (Saunders, 2021) in terms of the field above the first screen.

$$E(2d, y_2) = \frac{e^{j\frac{\pi}{4}}e^{-jkd}}{\sqrt{\lambda d}} \int_0^\infty E(d, y_1)\, e^{\frac{-jk(y_2-y_1)^2}{2d}} dy_1 \tag{11}$$

and for the third screen one has,

$$E(3d, y_3) = \frac{e^{j\frac{\pi}{4}}e^{-jkd}}{\sqrt{\lambda d}} \int_0^\infty E(2d, y_2)\, e^{\frac{-jk(y_3-y_2)^2}{2d}} dy_2 \tag{12}$$

and so forth and so on until the last screen y_{N+1}. (13)

$$E((N+1)d, y_{N+1}) = \frac{e^{j\frac{\pi}{4}}e^{-jNd}}{(\lambda d)^{N/2}} \int_0^\infty dy_1 \int_0^\infty dy_2 \int_0^\infty dy_3 \ldots \int_0^\infty dy_N E(d_1, y_1) e^{-j\frac{k}{2d}\sum_{n=1}^{N}(y_{N+1}-y_n)^2} \tag{14}$$

With a parameter,

$$v_n = y_n\sqrt{\frac{jk}{2d}}, \tag{15}$$

and the identity,

$$j = e^{j\frac{\pi}{2}} \tag{16}$$

substituting equation (16) into equation (15) yields,

$$dy_n = e^{j\frac{\pi}{4}\sqrt{\frac{\lambda d}{\pi}}dv_n} \tag{17}$$

and the result can be written as (Mardeni and Kwan, 2019),

$$E((N+1)d, y_{N+1}) = \frac{e^{j\frac{\pi}{4}}e^{-jNd}}{\pi^{N/2}} \int_0^\infty dv_1 \int_0^\infty dv_2 \int_0^\infty dv_3 \ldots \int_0^\infty dv_N E(d_1, y_1) e^{-j\frac{k}{2d}\sum_{n=1}^{N}(v_{N+1}-v_n)^2} \tag{18}$$

The incident plane wave in 2D coordinates can be written as,

$$E(d, y_1) = E_0 e^{-jkr} = E_0 e^{-jk(dcos\delta - ysin\delta)} \tag{19}$$

c. Data Collection Process

A driving test was carried out using a car driven along predetermined routes in the study area of Umuahia and Umudike Road, Nigeria. The drive test survey routes are based on a cell reference's design. A road map for telecommunications that provides drive test routes to cover antenna sectors is called a cell reference. On a laptop with a Global Positioning System (BU353) and a TEMS Mobile Station (Sony Ericsson w995) connected through Universal Serial Board (USB) ports, Transmission Evaluation and Monitoring System (TEMS) Investigation software was used.

Every piece of equipment in the system communicates with each other through the personal computer. The system tracks the location of the Global Positioning Satellites (GPS) while gathering data. This makes it possible for the system to locate the Mobile Station (MS) on the laptop's pre-installed global map. Calls were placed during the data collection process using the MS. The handset was set up to automatically make calls to a fixed destination number while the driver was operating the vehicle. Every call was dropped after a one-minute hold period. After a while, the phone went dead, and then someone else called. Log files were used to store the gathered data so that it could be processed further and processed afterward. The simulation was conducted using Matlab software.

d. The data

The data used for the simulation are as follows:
Carrier Frequency f = 900 MHz, 800 MHz, 1200MHz and 1500 MHz
Transmitter height H_t =30m
Mobile antenna height h_m =1.5m
Building heights H_b=10m and 15m.
Building separation distances d=50 m and 20m

3.2 Method

Figure 1 is the flow chart of the method used in this research.

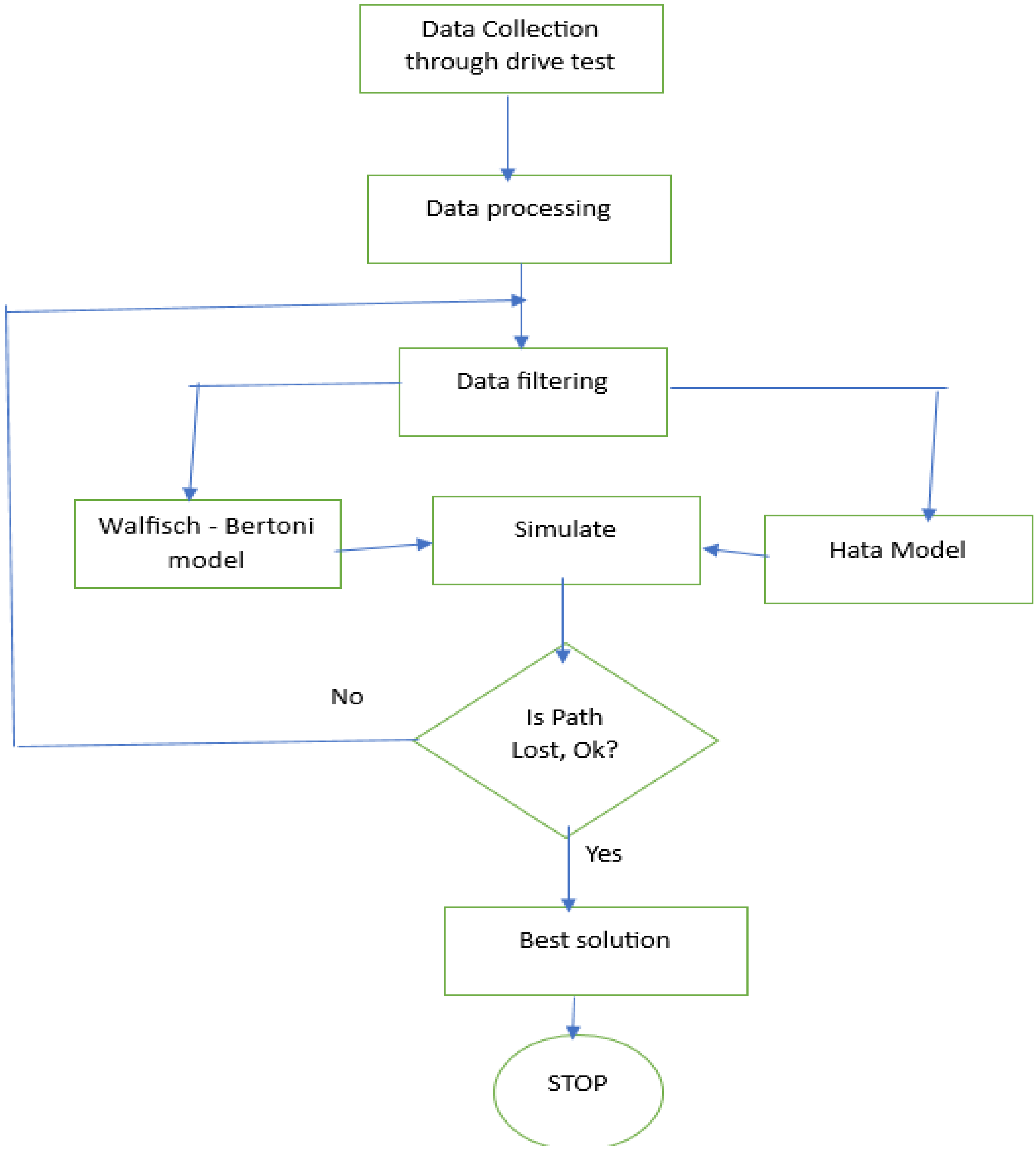

Figure 1: Model flow chart

4.0 RESULTS AND DISCUSSION

a. The Hata model

Figure 2 shows the model for different frequencies in various environments:

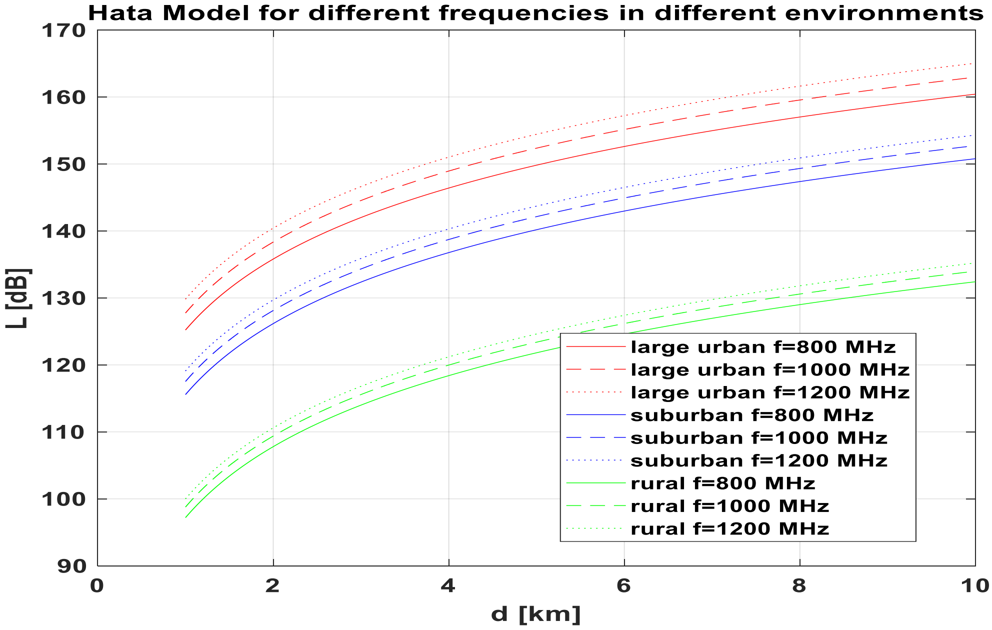

Figure 2: The path loss for different frequencies in different environments.

From Figure 2, at frequency of 1200MHz for large urban, the path loss was at 165dB. At frequency of 1000MHz for large urban, the path loss was at 163dB, while at frequency of 800MHz for large urban, the path loss was at 160dB. At frequency of 1200MHz for suburban, the path loss was at 154dB. At frequency of 1000MHz for suburban, the path loss was at 153dB, while at frequency of 800MHz for suburban, the path loss was at 150dB. Also, at frequency of 1200MHz for rural, the path loss was at 134dB. At frequency of 1000MHz for rural, the path loss was at 133dB, while at frequency of 800MHz for rural, the path loss was at 132dB. By observing the path loss values in Fig. 2, it was clear that the path loss has higher values when the frequencies are high.

Figure 3 shows the model for different transmitter heights in various environments.

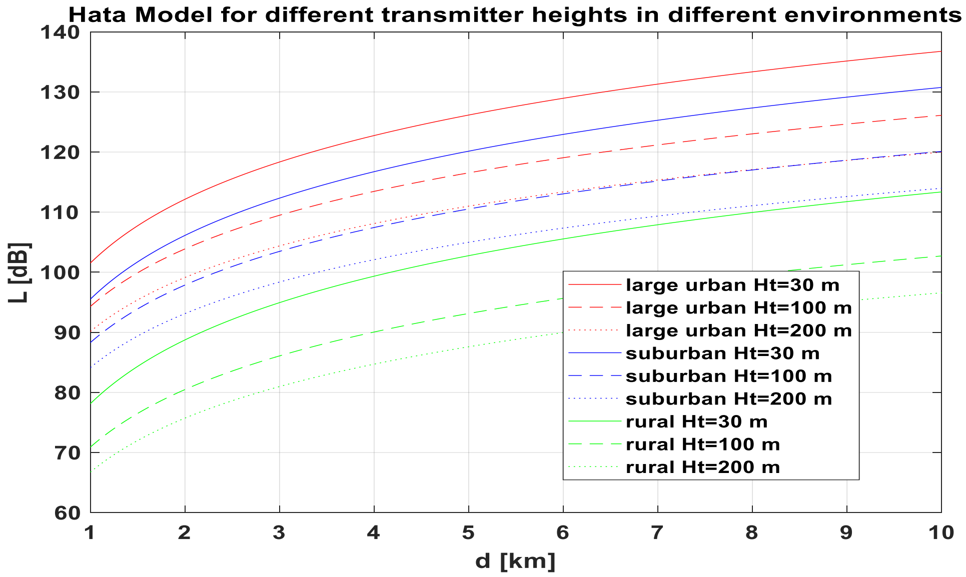

Figure 3: The path loss for different transmitter heights in various environments.

From the graph of Figure 3, it was observed that when the height of the transmitter H_t was 30m, the path loss was at 136dBm, when the height of the transmitter H_t was 200m, the path loss was at 97dBm. Therefore, from the result of Figure 3, it could be seen that the lower the transmitter heights, the higher the path loss L in dB.

b. The Walfisch - Bertoni model

The following figures show the predicted path loss graphs as a function of distance when the propagation occurs along buildings with uniform height and spacing.

Simulations were plotted for various frequencies f, transmitter heights H_t, building separation distances H_d and building heights H_b.

Figure 4 shows the Path loss due to distance and frequency.

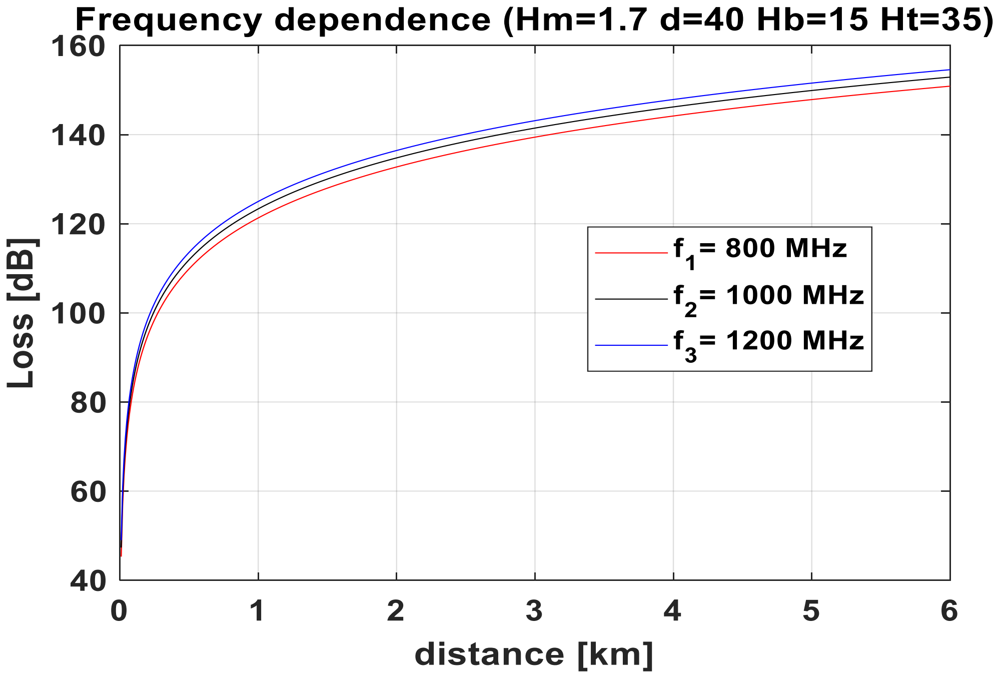

Figure 4: Path loss due to distance and frequency

From Figure 4, the highest Path loss in dB which is 152dB occurs when the frequency was 1200MHz, and the least occur at 150dB when the frequency was 800MHz.

From Figure 4, it was seen that the path loss increases (more shadowing) with increasing frequency.

Figure 5 shows the Path loss due to distance and building separation distance.

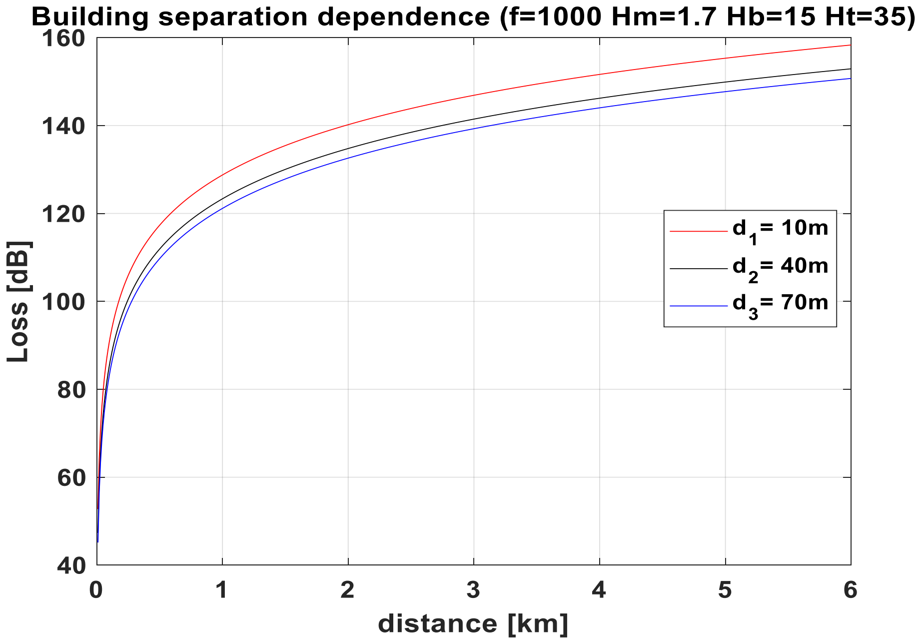

Figure 5: Path loss due to distance and building separation distance

From Fig.5, it was seen that when the distance was 10m, the Path loss was at 158dB. Also, when the distance was 40m, the Path loss was at 155dB while at a distance of 70m, the Path loss was 150dB. The result showed that the path loss is smaller (less shadowing) for larger building separation distances.

Figure 6 shows the Path loss due to distance and building heights.

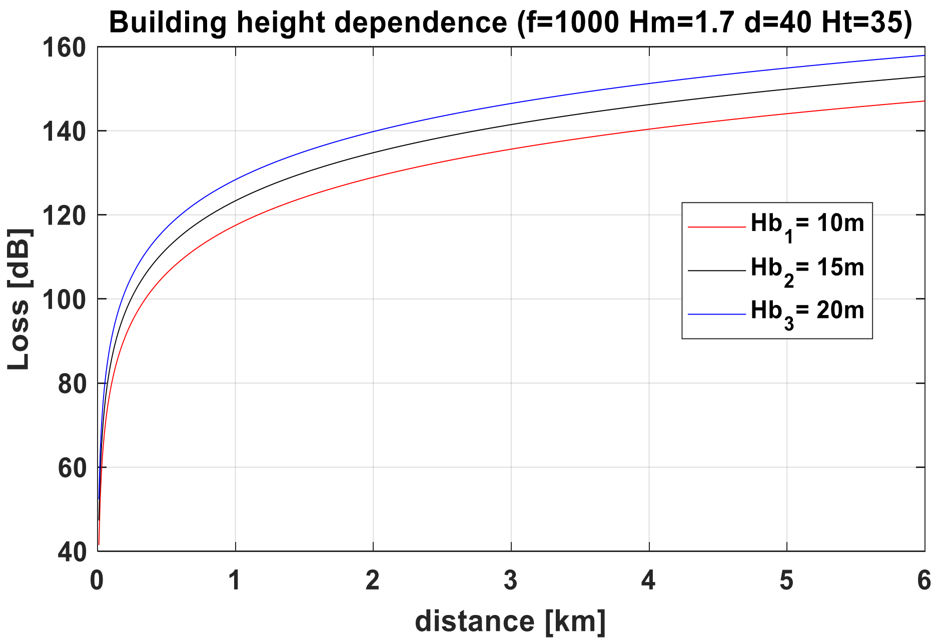

Figure 6: Path loss due to distance and building heights.

From Figure 6, it was seen that when the height of the building was 20m, the Path loss was at 159dB. Also, when the height of the building was 15m, the Path loss was at 156dB while at a height of 10m, the Path loss was 150dB.
The result showed that the path loss is larger (more shadowing) for higher buildings:

c. Comparison of the Hata model and the Walfisch - Bertoni model

A detailed comparison of the proposed models was obtained for three cases where in each case four parameters are fixed and one particular parameter has two values. The distance range for each case was taken as 1 km< R <10 km since the

Hata model is valid in the range of 1 km< R_{HATA} <10km. The building heights H_b were chosen to be smaller than the transmitter heights H_t since this is a must for the Walfisch-Bertoni model to be valid.
In the first case mobile antenna height, transmitter height, building heights and building separation distances were as listed below, and the path loss for the Hata and the Walfisch-Bertoni models were plotted for two different carrier frequencies, 800 MHz and 1500 MHz.

Figure 7 shows the results with the fixed parameters:
Mobile antenna height h_m =1.5m
Transmitter height H_t =30m
Building heights H_b=10m
Building separation distances d=50 m.

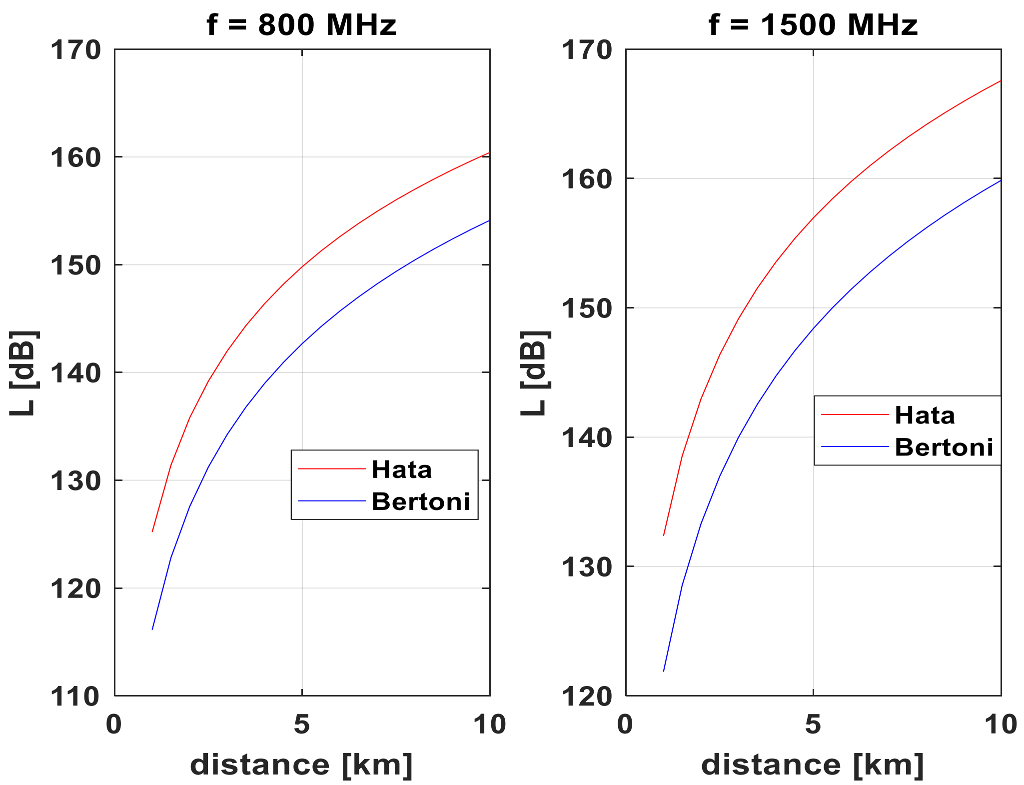

Figure 7: Path loss from the Hata model and the Walfisch-Bertoni model for two frequencies.

From Fig.7, using Mobile antenna height h_m =1.5m, Transmitter height H_t =30m, building heights H_b=10m, Building separation distances d=50 m, and at frequences of 800 MHz and 1500 MHz. At frequency of 800MHz, it was seen that Hata model had a Path loss of 160dB, while Bertoni had a Path Loss of 153dB. At frequency of 1500MHz, it was seen that Hata model had a Path loss of 167dB, while Bertoni had a Path Loss of 160dB. The results showed that at frequences of 800 MHz and 1500 MHz, Hata model had a higher Path loss than that of the Bertoni model.

In the second case frequency, mobile antenna height, transmitter height and building heights were fixed and the path loss for the Hata and the Walfisch-Bertoni models were plotted for two different building separation distances, 20m and 50m. The parameters are:
Carrier Frequency f = 900 MHz
Transmitter height H_t =30m
Mobile antenna height h_m =1.5m
Building heights H_b=10m

Figure 8 shows the results of Path loss from the Hata model and the Walfisch-Bertoni model for two building separations.

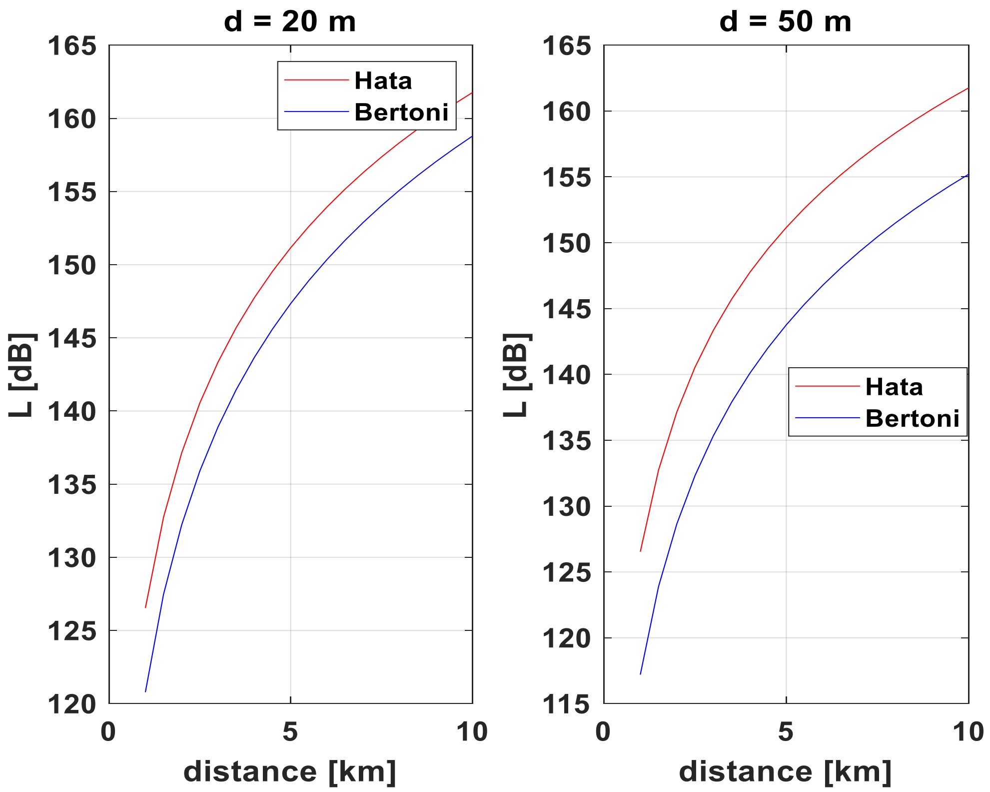

Figure 8: Path loss from the Hata model and the Walfisch-Bertoni model for two building separations.

From Figure 8, using Carrier Frequency f = 900 MHz, Transmitter height H_t =30m, Mobile antenna height h_m =1.5m, Building heights H_b=10m and at separation distances 20m and 50m. At separation distance of 20m, it was seen that Hata model had a Path loss of 162dB, while Bertoni had a Path Loss of 158dB. At separation distance of 50m, it was seen that Hata model had a Path loss of 162dB, while Bertoni had a Path Loss of 155dB. The results showed that at separation distances 20m and 50m, Hata model had a higher Path loss than that of the Bertoni model.

In the third case frequency, mobile antenna height, transmitter height and building separation distances were as shown below, and the path loss for the Hata and the Walfisch-Bertoni models were plotted for two different building heights, 10m and 15m.
The parameters are:
Carrier Frequency f = 900 MHz
Transmitter height H_t =30m
Mobile antenna height h_m =1.5m
Building separation distances d =50 m

Figure 9 shows the Path loss from the Hata model and the Walfisch-Bertoni model for two building heights.

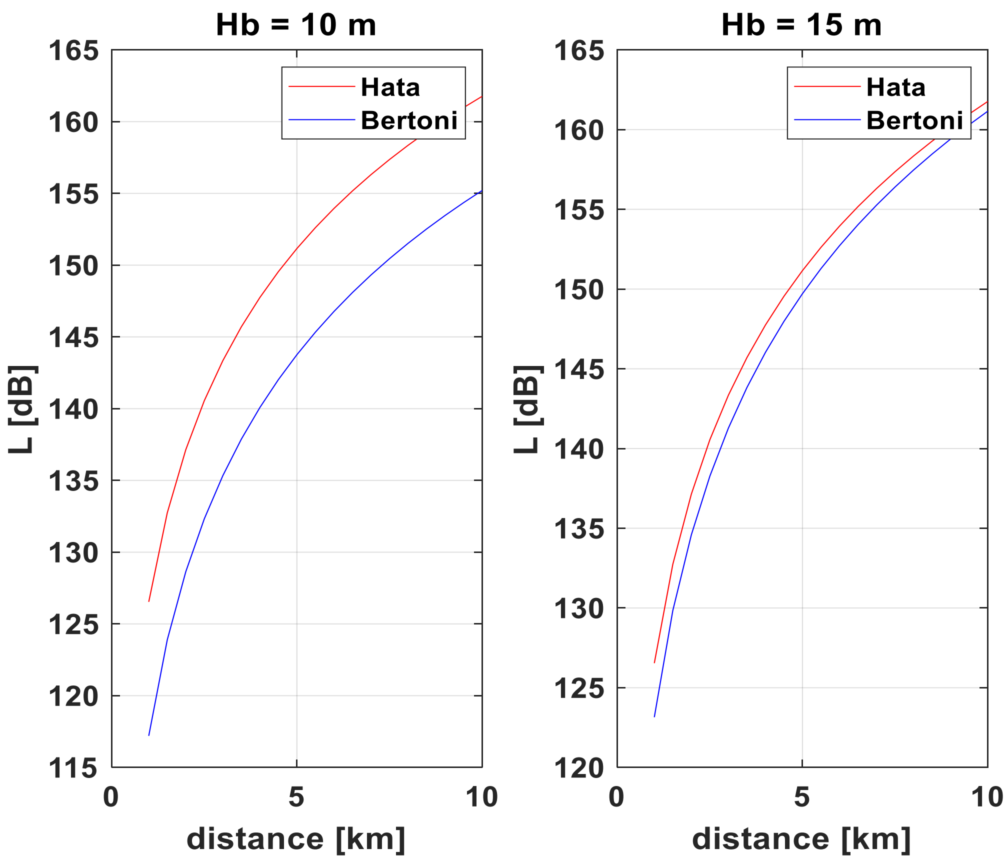

Figure 9: Path loss from the Hata model and the Walfisch-Bertoni model for two building heights.

From Figure 9, using Carrier Frequency f = 900 MHz, Transmitter height H_t =30m, Mobile antenna height h_m =1.5m, building separation distances d =50 m and building heights, 10m and 15m.
At the building height of 10m, it was seen that Hata model had a Path loss of 162dB, while Bertoni had a Path Loss of 155dB. At a building height of 15m, it was seen that Hata model had a Path loss of 162dB, while Bertoni had a Path Loss of 161dB. The results showed that at building heights of 10m and 15m, Hata model had a higher Path loss than that of the Bertoni model.

5.0 CONCLUSION

For mobile radio systems, path loss prediction is essential to both link budget analysis and cell coverage prediction. An increase in subscribers necessitates the addition of more base stations and channels, particularly in urban areas. In contemporary cellular systems, the elimination of interference at the cell boundaries is necessary to achieve high efficiency from the frequency reuse concept.
By employing a precise path loss prediction technique, the cell size can be appropriately determined. This research attempts to describe different reliable path loss prediction techniques used in both rural and urban environments, starting with the radio propagation phenomena and fundamental path loss models. For a thorough comparison, the Hata and Walfisch-Bertoni models—both of which are utilized for UHF propagation in urban settings—were selected. The comparison reveals that for the overall path loss, the more parameterized Walfisch-Bertoni model outperforms the Hata model.

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