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An Investigation on Effects of In-Leaf and Out-of-Leaf Conditions on Propagated Radio Broadcast FM Signal

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ABSTRACT

The daily increasing desire for the right information at any place, anytime, and anywhere by people has made broadcast media indispensable media for disseminating information to the public. Propagation models are deployed in planning and designing wireless communication systems. Different environments do require a unique propagation model. In this paper, least squares regression analysis was utilized to create the path loss models for the in-leaf and out-of-leaf conditions of a teak (Tectona grandis) plantation. The developed model was found to be more suitable compared to the existing Weissberger's and COST235 models because it gives the least difference in root mean square error of 3.9 dB in the two scenarios compared to COST 234 and Weissberger, which stand at 11.2 dB and 10.8 dB, respectively, and the developed model was closer to the assessed path loss obtained from the measurement carried out. The results of the study establish a standard model that can be deployed in the effective planning and design of wireless communication links for very high bands within the radial distance in the tropical rain forest of 30m to 45m foliage depth. This study confirms the need for distinctive models for radio signals at different locations under different conditions.

Keywords: Propagation Model, Path Loss, Root Mean Square Error, FM, Coverage Areas.

1 Introduction

The wireless signal strength of propagated radio waves from the transmitter to the receiver usually decreases as the distance between the transmitter and the receiver increases [1]. This is because, in a wireless communication system, the transmission and reception of radio signals through the wireless channel are usually affected by both environmental and physical factors. These environmental and physical or geographical factors negatively affect the maximum range of the signal as well as limit the quality of service (QoS) of the communication system [2]. This is because as the radio signal propagates outwardly from the transmitting antenna, the radio signal strength is dispersed over an increasingly greater area, which causes the radio signal to attenuate as it travels away from the transmitter. This attenuation grows gradually with distance, resulting in a rapid reduction in radio signal strength as the signal propagates far from the transmitting antenna. The presence of vegetation along the radio propagation path has been observed as one of the environmental factors causing significant attenuation of radio signals propagated from radio stations. In addition, the presence of vegetation along the radio propagation path has been observed as the major problem responsible for much of the reduction in the radio signal coverage area or range [3]. This reduction in radio signal coverage range, or attenuation, occurs normally as a result of scattering, absorption, reflection, and diffraction, which propagated radio signals usually suffer from when traveling from the transmitter to the receiver [1],[2]. As reported by these authors, reflection, diffraction, and scattering are major propagation mechanisms that impact radio wave propagation in wireless communication.

In wireless communication, radio signal reflection occurs when a propagating radio wave impinges upon an obstruction or obstacle that has very large dimensions compared to the wavelength of the propagating radio wave. On the other hand, diffraction happens when an electromagnetic wave that is traveling between the transmitter and receiver comes into contact with an obstruction that is impermeable and larger than the wavelength of the propagating electromagnetic wave [4]. According to Huygen's principle, secondary waves are produced behind the obstructing body even though the transmitter and receiver are not in the line of sight (LOS) [5]. Primarily, diffraction explains how radio waves travel in both rural and urban environments without LOS paths. This process, according to [4], is also called shadowing since the diffracted wave can reach a receiver even when it is shadowed by any obstruction. Similarly, scattering occurs when the medium through which the electromagnetic wave travels or propagates consists of obstacles with dimensions that are small compared to the wavelength of the propagation signal. Most often, as reported by [5], scattered waves are usually produced by rough surfaces, small obstacles, or irregularities in the channel. In addition, in practice, vegetation, lampposts, street signs, and stairs within buildings can induce scattering in radio communication signals. According to [6], quantitative knowledge of the excess propagation loss experienced by radio signals due to the presence of leaves or foliage is important in planning a communication link in any vegetated channel. Research conducted by [7] on individual trees revealed that as trees develop leaves, there is an increase in the additional attenuation observed across them. The study observed a significant difference in propagation loss between the states when the tree is in-leaf compared to when it is out-of-leaf, which is primarily attributed to the presence of leaves. Furthermore, the experiment demonstrated that when the tree is in full leaf condition, leaves contribute to a larger percentage of the overall attenuation. However, the research did not explicitly state that leaves have a substantial impact on radio waves, especially at microwave frequencies. To predict the best behavior of radio

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broadcast FM signals in Teak (*Tectona grandis*) plantations, a propagation model was created using three existing FM (modulation) broadcasting stations in Ondo State, Nigeria. The study involved assessments and measurements of the three FM radio station signals and the modeling of an appropriate model for in-leaf and out-of-leaf. Condition. The effectiveness of radio propagation is determined by essential factors such as distance, transmission power, antenna gain, and terrain. To ensure optimal signal quality within their coverage area, radio stations must have knowledge of the terrain. This understanding is crucial for enhancing the signal quality and meeting the recommended signal levels of 60 dB for urban FM broadcasting stations and 48 dB for rural FM broadcasting stations, as outlined in the 5th edition of the Nigerian broadcasting code [8]. Moreover, radio stations should consider the reduction in signal strength during the rainy season, which typically ranges between 3 and 5 dB compared to the dry season [9]. Therefore, for the planning and designing of radio stations and wireless communication systems located within the tropical rainforest region covered by this study, they can predict propagation loss for their service area using the path loss model developed in this study. Section 3 provides all-inclusive information on all the steps taken to complete the study. The remainder of the work is arranged as follows for both a reasonable and sequential presentation: A quick summary of the important material is presented in Section 2. Section 3 provides wide-ranging information on the method used to conduct the study. In Section 4, the results are given and discussed, and Section 5 concludes the study with a summary of the results.

2 Concept and Evaluation of Related Studies

The propagation model is a mathematical formula that empirically describes how radio wave propagation changes with frequency, distance, and other factors [10]. Since the route loss experienced along any radio link is the most important factor in determining the propagation of the link, radio propagation models frequently focus on predicting the area of coverage for a transmitter or modeling the distribution of signals over different places. [2],[4] opined that radio propagation models play a vital role in designing wireless communication systems and employed least squares regression analysis to develop a versatile propagation model for very high-frequency broadcasting radio stations in vegetation and/or rocky environments. The developed model was later evaluated by comparing its path loss prediction result with two existing path loss models in the literature. The results of the comparative performance analyses show that the two existing models predict the highest difference in propagation path loss compared with that from the developed least squares regression model. The generated model outperformed the projected value favorably for every route and the whole coverage area of the transmitter station used as a case study, according to the comparison between the two. Also, the study's findings support those of other researchers who have concluded that no single propagation model can perfectly account for all topographies, uses, and environments. [11] Carried out exponential models of the signal strength of a television station in Nigeria. In the paper, the line of sight and signal strength of ultra-high frequency (UHF) television signals in Osun State, Nigeria, were investigated. Regression analysis was performed to identify the exponential models that may be used to calculate signal strength for a given line of sight at the authorized routes in the state after propagation curves for the signal along various routes were plotted. However, the work covers much of the urban centers [10]. A study on the electric field strength distribution of UHF television signal propagation in Ekiti State Adopting the free space path loss model, the findings show the field strength distribution of the broadcasting station in major towns and villages, its elevation pattern, and the many levels of coverage that its residents can access there. Fagbohun is silent on the propagation through foliage accuracy and reliability prediction model for microcellular urban propagation environments; the work is mainly for mobile wireless networks. [12] Carried out a comparative analysis of path loss prediction models for urban microcellular environments. Path losses were predicted using the three path loss prediction models: free space, Hata, and Egli. The estimated route loss values and actual measured data from a Visafone base station in Uyo, Nigeria, were contrasted. According to the comparative analysis, free space, Hata, and Egli had mean square errors (MSE) of 16.24 dB, 2.37 dB, and 8.40 dB, respectively. According to the findings, Hata's model is the most. [9] In a review of radio wave constriction in forest environments, the classic analytical methods of propagation loss modeling and prediction are described first. And suggest that the difference in path loss for trees in-leaf and out-of-leaf is about 3 to 8 dB in the UHF and VHF bands. This provides data on the physical processes that radio waves undergo when propagating through a forest. However, the paper does not specify the specific woodland. In order to determine the RF loss through packed eucalyptus leaves as a function of the effective water path of the waves at a frequency of 2.4 GHz, [13] developed a plane wave model that includes a calculation of the water content of leaves. When the water content of the leaves is given as an effective water path (EWP) in millimeters, there is a positive non-linear connection between the RF loss in decibels (dB) and the latter. It was suggested that more research be done to connect this mathematical model of radio propagation to actual measurements of water content and RF loss through whole trees with a view to evaluating plant water status for monitoring plant physiology. [14] Carried out experimental studies of radio wave attenuation were carried out in a tomato greenhouse using a network of wireless sensors that sent a signal in the 2.4 GHz ISM band. There is a sizable margin of uncertainty between the recorded attenuation data and the values of the current empirical vegetation attenuation models. A regularized regression approach based on the modified exponential decay model (EDM) was used to reduce the number of variables and construct an empirical model. Unlike Weissberger's model, which included the height of the nodes' antennas (both for transmitting and receiving), this model is more straightforward since, as predicted, the height variable has a greater influence on attenuation than the distance variable. It was advocated that to utilize new empirical models and to understand how the model will act if the device moves in accordance with a particular plant development, it is critical to explore the compensating component of the suggested modified equation derived from the modified exponential decay model (MED) in future studies. The proposed empirical foliage loss models for the horizontal propagation path can be classified as the modified exponential decay (MED) models, as well as the Weissberger model [15]. ITU Recommendation (ITU-R) model [16], the COST235 model, the fitted ITU-R (FITU-R) Model [17], the modified gradient model, such as the maximum attenuation (MA) model, the nonzero gradient (NZG) model, and the dual gradient (DG) model The exponential decay model was first proposed by Weissberger, and its main modified versions include the ITU-R model, the COST235 model, and the FITU-R model. In general, the exponential decay model, as reported in [12], is expressed in Eq. (1).

$$L(dB) = A * F^{B} * {d_t}^{c} \quad (1)$$

F stands for frequency in MHz, and d is the depth of the tree in meters. Where A, B, and C are the fitted parameters from a variety of experiments with regression techniques. Depending on the frequency, kind of foliage, and propagation methods, among other factors, many parameter values have been suggested. The simplicity of the exponential decay model is a plus, but a significant disadvantage is that [18] findings about measurement geometry and foliage size are ignored.

3 Methodology

The steps employed in this study are presented in Fig. 1.

3.1 Data Collection

Table 1 lists the distinguishing information about the three FM radio stations' transmitters, including their site coordinates, transmitter frequency, transmitter aerial height, and other relevant details. Experimental Set-up and Measurement Techniques

For the three radio station coverage zones, site surveys and route planning were done. The elevation and latitude of each location where measurements were collected were determined using the Germin GPSMAP 78s Global Positioning System. The line-of-sight distance (in km) to the transmitting antenna was also calculated using this information. A BC-1173 field strength meter and a 10 dB gain 75-ohm dipole antenna were used to test the strength of the signal. Adaba 88.9 FM's transmitter output power was kept constant (upon request) at 15 kW, and Orange FM's transmitter output power was kept at 15 kW. The received signal strength was measured between the hours of 8 a.m. and 6 p.m. each day between the months of December and June, at a height of 6 feet above the ground. Six measurements were taken at the same location each month, each no more than 5 km apart. The data collection at the Teak (*Tectona grandis*) Plantation is depicted in Fig. 2.

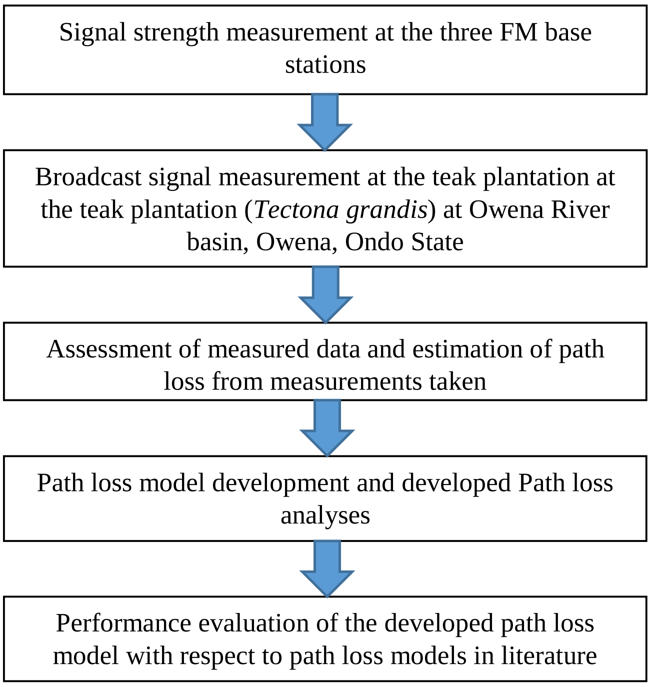

Fig. 1 Research Methodology

Table 1 Transmitter Data

S/N	PARAMETER	ADABA FM	ORANGE FM	POSITIVE FM
1	Frequency of operation	88.9 FM	94.5MHz	102.5MHz
2	Frequency Bandwidth	200 kHz	300 KHz	500 KHz
3	Transmitter Power(maximum)	35 KW	35 KW	35 KW
4	Transmitting Power (actual)	25 kW (71%)	15 kW	15 kW
5	Maximum Deviation	295 kHz	250 kHz	220 kHz
6	Antenna Gain	85.6 dB	96.8dB	98.6 dB
7	Antenna Polarization	Vertical	Vertical	Vertical
8	Antenna Maximum Height	250m(800ft)	150m(500ft)	200m(700ft)
9	Maximum elevation	427m	276m	482m
10	Coordinates	LAT7.324390, LON 5.125180	LAT 7.29025 LON5.193556	LAT 7.253056 LON 5.131083

(a) (b)

Fig. 2 (a) Out-Of-Leaf Data Measurement at the Teak Plantation (*Tectona Grandis*) (b) In-Leaf Data Measurement at the Teak Plantation (*Tectona Grandis*)

3.2 Path Loss Model Development for Conditions for Being In and Out of Leaf

Radio signal travels through the Teak (*Tectona grandis*) tree plantation as well as the ground-level bushes in forest zones, there is significant restriction and spreading of the transmitted radio signal to the headset. The signal will be significantly constrained because of potential communication connection incursions this is frequently overlooked when designing communication frameworks. In the absence of moisture, the Teak (*Tectona grandis*) tree plantation foliage offers little resistance, but following rainstorms, the trees in the plantation and other elements of the Teak (*Tectona grandis*) tree plantation mature. This affects how the wave is attenuated when it passes through the Teak (*Tectona grandis*) tree plantation. Following the broad contours of the optimization technique and learning from the analysis of the previously established model [9], the surplus Eq. (2) represents the extra attenuation caused by the Teak (*Tectona grandis*) tree plantation.

$$P_l = A * f^B * {d_t}^c \quad (2)$$

Based on observed data from the three FM radio stations used at 88.9 MHz, 94.5 MHz, and 102.5 MHz, the three variables A, B, and C in Eq. (2) were experimentally optimized by least squares regression techniques. Since measurements made in the plantation of teak (Tectona grandis) trees reveal a linear connection between the relevant LOS due to distance and the projected project signal loss, stands for the frequency of operation, stands for the teak (Tectona grandis) depth in meters, and is propagation loss.

3.2.1 Out-of-Leaf Propagation Model

The empirically optimized constants through least squares regression methods of the out-of-leaf measured data are shown in Eq. (3).

$$P_{l(out\ of\ leaf)} = 0.5934 * f^{0.2441} * {d_t}^{0.9840} \quad (3)$$

3.2.2 In-Leaf Propagation Model

The empirically optimized constants through regression methods of the in-leaves measured data are shown in Eq. (4).

$$P_{l(in\ leaf)} = 0.6213 * f^{0.5440} * {d_t}^{0.6443} \quad (4)$$

It is necessary to establish how much the signal loss propagation model hinges on other factors, such as the operational frequency, the location, and the depth of the Teak (*Tectona grandis*) tree plantation. The difference between the signal strength predicted by the developed model and the actual signal recorded in this dependency is measured by the root mean square error (RMSE). By comparing the anticipated errors of the various propagation models with the supplied measurement data, accuracy is evaluated. The computed RMSE values were derived using Eq. (5).

$$S = \sqrt{\frac{\Sigma_{i=1}^{K}(P - M)^2}{k}} \quad (5)$$

Thus, for a total of k data points, P stands for the developed model value, and M is the measured data of propagation loss *i*.

3.3 Propagation Model in Literature

The following traditional path loss models are contrasted with the measurement-based path loss model developed in this study.

3.3.1 Weissberger Model and COST 235 Model

When a signal path is obstructed by dense, arid, in-leaf trees prevalent in temperate locations, Weissberger's modified exponential decay model is suitable [9],[15] and is stated in Eqs. (6) and (7) [9]. Also applicable is the COST235 model, as stated in Eqs. (8) and (9) [19].

Out of Leaf

$$P_{ld} = 1.33 * f^{0.284} * {d_t}^{0.588} \quad (6)$$

In-Leaf

$$P_{fW} = 0.45 * f^{0.284} * d_t \quad (7)$$

Out-of-Leaf

$$P_{ld} = 26.6 * f^{-0.2} * {d_t}^{0.5} \quad (8)$$

In-Leaf

$$P_{fW} = 15.6 * f^{-0.009} * {d_t}^{0.26} \quad (9)$$

4 Results and Discussion

The standard evaluation tests conducted on the developed propagation model are covered in this section. There are two broad classifications for the tests. The tests used to gauge how well the developed model performed when applied under the in-leaf and out-of-leaf circumstances of the Teak (*Tectona grandis*) tree plantation make up the first class. Subsection 4.1 provides the results of these evaluations. The second phase of the performance evaluation test that was carried out included a comparison of the developed propagation path loss, estimated results from the developed model, and two more models from the literature.

4.1 Measurement Analysis

By correlating the path loss estimation with the path loss that was observed during measurement in the Teak (*Tectona grandis*) tree plantation, the performance of the developed propagation model was evaluated in this subsection. The extracted results from the measured data were used to plot the graph for the three radio stations.

Their assessment of the measured signal data was done to determine the level of obstruction by the Teak (*Tectona grandis*) trees along the LOS of the three radio station signals. From Fig.

3, Fig. 4, and Fig. 5, it is clear that both measured and estimated data obey the Friis transmission Eq. (10) [20].

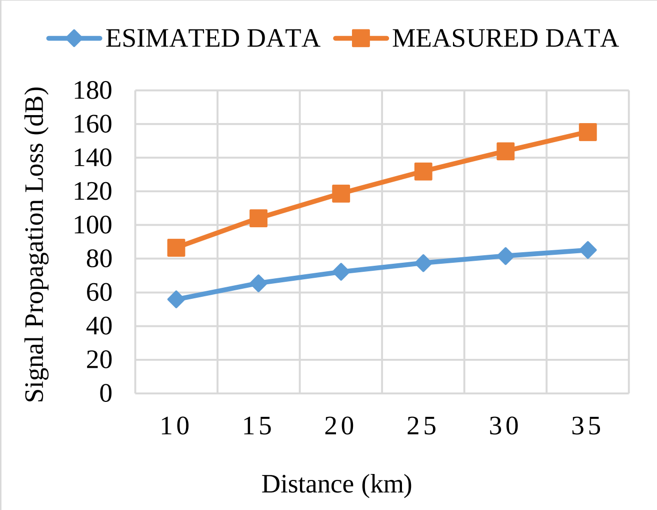

Fig. 3 Adaba FM Signal Propagation Loss

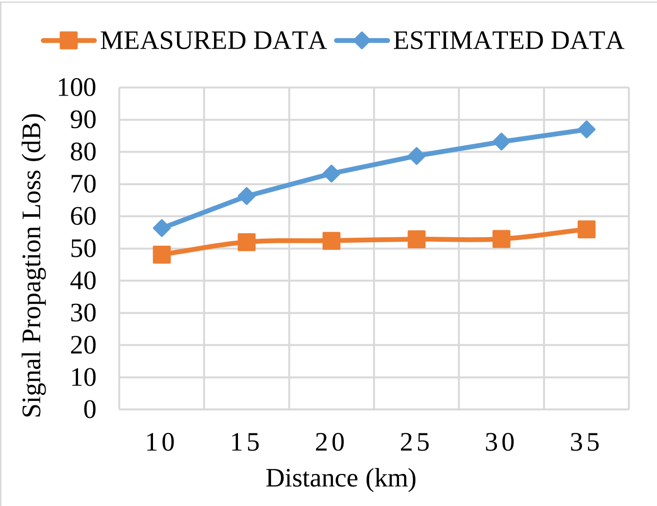

Fig. 4 Orange FM Signal Propagation Loss

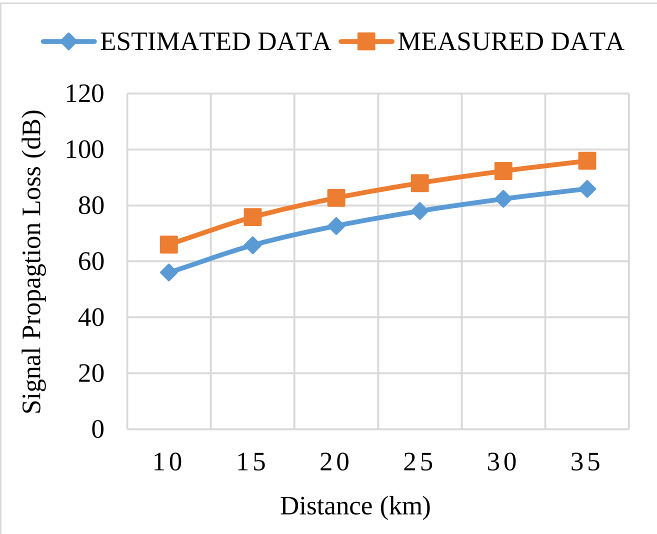

Fig. 5 Positive FM Signal Propagation Loss

The developed model prediction estimates are congruent with the estimated data from measurements.

$$P_l = 10 \log \left(\frac{4\pi d}{\lambda}\right) \tag{10}$$

When representing the reduction in signal strength caused by distance, this cluster dataset does not provide a precise depiction of what occurs under the two distinct situations of the teak trees' in-leaf and out-of-leaf circumstances at the Owena Dam River Basin.

4.2 Assessment of the Developed In-Leaves and Out-of-Leaf Model

By contrasting the model that was created with the existing Weissberger and COST235 models, the model that was developed was validated. The model that was created was applied to the teak (*Tectona grandis*) plantation in the Owena Dam River Basin of Ondo State to determine the route loss with the help of the canopy under the distinct circumstances of in and out-of-leaf.

And all were subjected to the root mean square error test. When regression analysis is performed, the result is a model that predicts the value of the response variable based on the value of the predictor variable. Calculating the root mean square error, a statistic that shows how far projected values are from the observed values on average, is one technique used to judge how "well" the model fits a specific dataset of the Teak (*Tectona grandis*) plantation at the Owena Dam River Basin of Ondo State and other similar environments.

4.2.1 In-Leaf Model Assessment

There's a slow degradation or dissipation of the signal with increasing depth of the teak (*Tectona grandis*) plantation due to the thickening of the teak tree foliage canopy disturbing point-to-point connection or direct or line-of-sight communication and shading the radio waves from the receiver antenna. For the in-leaf model, the values of variables A, B, and C in the preceding model Eq. (2) have been correspondingly regulated to 0.2113, 0.5644, and 0.6733. Observations reveal that when the teak (*Tectona grandis*) has enough leaf on its branches during the time of year when it rains, the variation that was found in the calculated path loss has been addressed, as shown in Fig. 5. The computed RMS error is 11.3 dB between the developed model predictions and the actual recorded data. When compared to the recorded data, COST 234 and Weissberger yield respectively 15.7 dB and 11.6 dB. Fig. 5 shows the measured data, the decay model, and the developed model. This demonstrates that the created model works better in the teak (*Tectona grandis*) plantation's in-leaf circumstances.

4.2.2 Out-of-Leaf Model Assessment

When there is no rain or during the dry season, the foliage provides little resistance. Hence, there is little disturbance to point-to-point connection, direct or line-of-sight communication, and shading of the radio waves from the receiver’s antenna. The values of variables A, B, and C in the preceding model Eq. (2) have been correspondingly regulated and Fig. 6 illustrates how the developed model performs admirably in contrast to COST 234 and Weissberger. Calculations show that there is an RMSE error of 7.4 dB between the model predictions and the measured dataset. When compared to the observed data, COST 234 and Weissberger yield 4.5 dB and 22.4 dB, respectively. Fig. 7 shows the observed data, the decay model, and the created model. The variance in RMSE value of the developed model plants in and out-of-leaf circumstances in the teak (Tectona grandis) plantation at the Owena Dam River Basin of Ondo State, when contrasted with COST 234 and Weissberger, which stand at 11.2 dB and 10.8 dB, respectively, This demonstrates the developed model's superior performance in both situations as well as across the teak tree's diverse depths, which is proof of its appropriateness for these species of trees in the tropical rain forest.

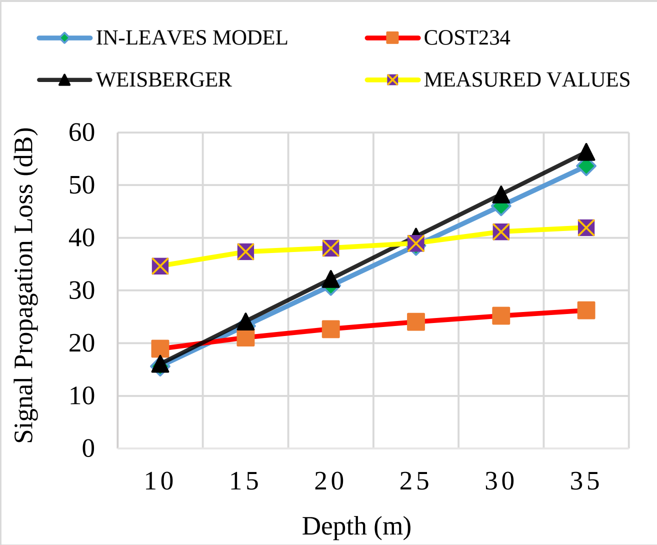

Fig. 6 In-Leaf Propagation Loss

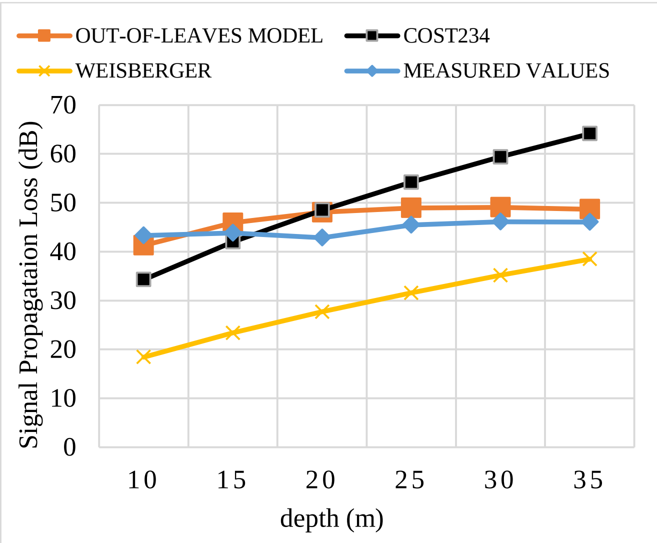

Fig. 7 Out-Of-Leaf Propagation Loss

4.2.3 Propagation Loss for Three FM Stations

To assess the level of impact of obstruction by the teak (*Tectona grandis*) tree plantation at the Owena River Basin of Ondo State on the three FM station signals used as the case study for this research along the line-of-sight path of the radio station signals and confirm the usefulness of the developed model. The developed in-leaf and out-of-leaf propagation models were applied to the data set of three FM stations used for this study. Fig. 8 illustrates how the depth and amount of foliage in the teak (*Tectona grandis*) tree plantation affect the amount of attenuation that occurs there when the teak (*Tectona grandis*) tree plantation is in its in-leaf state. The three FM stations behave quite differently when the plantation is not in leaf, as shown in Fig. 9, and the amount of attenuation is significantly lower than it was when the plantation was fully covered in foliage. In both the in-leaf and out-of-leaf circumstances, the newly developed prediction model performed better than the COST 234 and Weisberger models. Its root mean square error difference was just 3. 9 dB, compared to discrepancies of 11. 2 dB and 10. 8 dB for the COST 234 and Weissberger models, respectively.

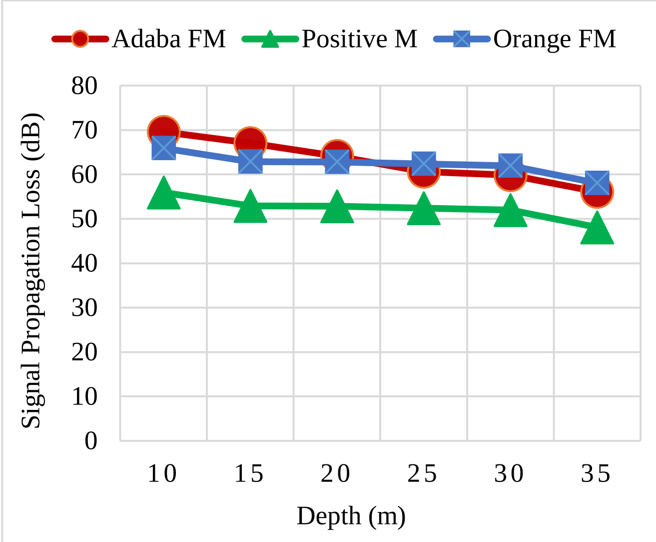

Fig. 8 In-Leaf Propagation Loss for the three FM stations

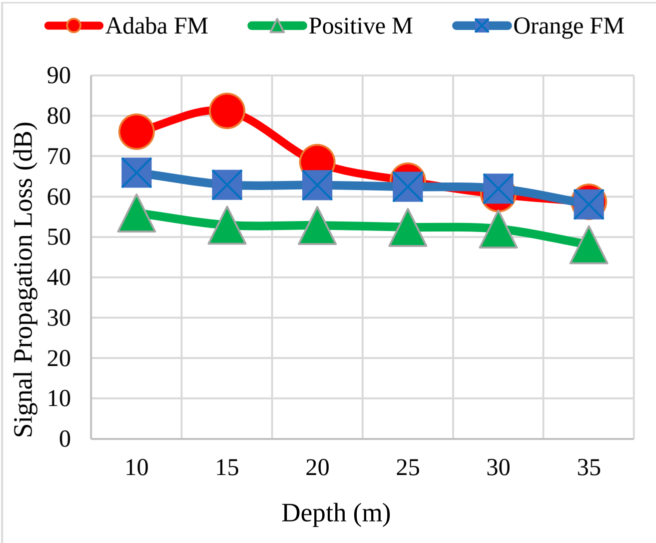

Fig. 9 Out-of-Leaf Propagation Loss for the Three FM Stations

5 Conclusion

Adaba 88.9 MHz, Orange 94.5 MHz, and Positive 102.5 MHz FM Broadcast Station power density (attenuation or signal strength) are observed to decrease along part of their broadcasting area at the Teak (*Tectona grandis*) tree plantation at the Owena River Basin of Ondo, according to the results of field measurements taken and the analysis of the measured signal strengths. but it was primarily influenced by the amount of leaf on the branches of the Teak (*Tectona grandis*) tree plantation, the depth of the teak tree, as well as the altitude and location of the teak tree relative to the three FM radio stations. The newly designed propagation prediction model was discovered to be more appropriate when compared to the two reference prediction models of COST 234 and Weissberger because it gives the least difference in root mean square error of 3.9 dB in the two scenarios, as opposed to COST 234 and Weissberger, which stand at 11.2 dB and 10.8 dB, respectively, and because The newly designed propagation prediction model was more in line with the assessed dataset obtained from the carried out measurement.

6 Recommendations

Distance, transmission power, antenna gain, and terrain are the fundamental factors that determine the effectiveness of radio propagation. It is necessary that radio stations know the terrain of their coverage area to know how to improve the quality of their signal within the primary coverage area in order to meet the recommended level of 60 dB for urban FM broadcasting stations and 48 dB for rural FM broadcasting stations as stipulated in the 5th edition of the Nigerian broadcasting code and be cognizant of the drop in their signal strength during the rainy season, which must be between 3 and 5 dB of the signal strength during the dry season. Therefore, during the planning and designing of radio stations and wireless communication systems that fall within the tropical rainforest area covered by this study, they can predict propagation loss for their service area using the path loss model developed in this study.

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