A Hybrid Model for Path Loss Estimation in Avenue Environment

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Abstract

Diverse propagation mechanisms complicate propagation analysis and modeling for a foliage condition. Therefore, a simpler optimized hybrid propagation model, which maintains or improves accuracy but preserves a cooperative relationship with physics, would be insightful. We evaluate an approach for developing a radio-wave propagation prediction model in an avenue area by combining the path loss in free space and environment parameters. It is demonstrated that this two-mechanism hybrid model can provide an accurate fit to the profile of through forest propagation over a long distance, which is impossible with the definitive radiative energy transfer model. The predicted model results were validated using radio-wave propagation in the FM band measurement data. The results obtained from the developed Free-Med model will differ slightly from the measurements under the avenue environment compared to the free space path loss model, Okumura-Hata path loss model, and the Perez-Vega path loss model, as can be seen from the values of the variables MAE and RMSE, which are 1.4966 [dB] and 1.8288 [dB], respectively.

Keywords: Path loss estimation, Avenue environment, Radio wave propagation

1. Introduction

The propagation of radio waves in very high frequency (VHF) bands is always the cornerstone and recreate a significant part of general communications. VHF is the radio frequency scope from 30-300 MHz, which covers television and frequency modulation (FM) radio broadcasts at 80-108 MHz [1] and can provide audio and information services using the existing FM bands and channel spacing [2]. In recent years, the radio system's quality and coverage have been significant issues for conception and development. In supplement to communication, the FM technique can furthermore be applied in diverse applications such as sending photo information on the FM radio broadcasting infrastructure [3], sharing time data through another FM broadcasting channel [4], FM radio source localization application [5], and passive radar system based on FM radio system [6].

However, the system's quality and efficiency depend on the signal parameter, signal intensity level, signal-to-noise ratio, and coverage of the area used. Therefore, it is essential to consider a system's propagation features through a medium for the estimation of the signal parameters accurately [7] and to understand how signals are attenuated over distance in a realistic environment [8]. In addition, network engineers require techniques for accurately mapping the coverage area of existing and planned networks. The radio propagation models can be used to represent the radio wave's behavior when transmitted from transmitter to receiver and indicate the association of the space between transmitter and receiver and path loss, which are connected closely to specific propagation conditions [9].

Developing and improving mathematical models to describe radio propagation properties are based on signal magnitude measurements under diverse conditions. Over the years, researchers have performed experimentations to estimate radio propagation underneath distinct requirements and environmental aspects, such as The outdoor measurement campaigns for 5G system at 32 GHz [10], the measurement of path loss on the ground-to-air path using a drone-based measurement system [11], the vegetation loss measurement at D-band frequencies [12], the signal propagation at ground level [13], open-space static measurements in a stadium [14], the empirical neat ground path loss modeling in a forest at VHF bands [15], the radio propagation dynamics in the forest [16], the network deployment in snowy environments [17] and the device-to-device communication in forest terrain [18]. Distinct environments will instantly impact the propagation of radio waves. Therefore, tests were carried out in each country to acquire knowledge and aspects that are appropriate and consistent with the validity in each area, such as the path loss measurement in a Brazilian Atlantic rainforest urban site [19], in New York City [20] and in Amazonian border region [21].

Because the individual model has distinct features and implementation, numerous investigators have resembled model performance based on measures in further environmental requirements, such as the comparison of path loss models for UHF/VHF bands [22], the measurements and models for signal attenuation in vegetated areas [23] and the efficacy of some unpopular path loss propagation models [24]. However, the values obtained from measurements often need to be more precise from the model, which has a continuous curve. Therefore, analyzing the measured values using graphing processes is essential to construct a mathematical model appropriate for actual usage, as shown by [25] and [26]. Furthermore, the radiation model must provide accurate loss prediction, even for specific conditions. Therefore, there is an attraction to a more accessible propagation model that can be empirical and should yield better results [27]. Some path loss effect technique employs a free-space path loss (FSPL) and a practical path loss model [28] or a simplified model for path loss computation [29]. From the research mentioned above, the authors have yet to find any specific research on tree-covered landscapes on the sides of roads, which will directly affect the radio reception performance of the equipment in the vehicle. This research is, therefore, comparable to pilot research for an in-depth study of the issue.

This article proposes the development of a simple and accurate model established on the combination of an empirical path loss model and a free-space path loss model to enhance the overall prediction accuracy in an avenue environment. The novelty and the key contributions of our work are listed as follows:

1. We have developed a path loss prediction model for analyzing radio wave propagation through an avenue environment. The paths electromagnetic waves travel through free space and trails through trees are interpreted according to the terrain in an avenue area.

2. We have adjusted the attenuation prediction parameters to suit the experimental terrain as a standard for further model development.

The rest of this paper is organized as follows: the propagation loss and empirical formula are presented in Section 2. The propagation measurements are proposed in Section 3. The results and discussions are presented in Section 4. Finally, conclusions are drawn in Section 5.

2. Propagation Loss and Empirical Formula

The radio propagation models represent the manners of the radio waves when they are transmitted from transmitter to receiver and demonstrate the relationship between the space between transmitter and receiver and path loss, which are correlated closely to the specific propagation environment.

2.1 Free Space Path Loss

The considerably uncomplicated wave propagation matter is direct wave propagation in free space. In this particular case of line-of-sight propagation, there are no obstacles due to the earth's character or other barriers. Next, we suppose radiation from an isotropic antenna. This sort of antenna is thoroughly omnidirectional, radiating uniformly in all directions. While there is no such thing as a purely isotropic antenna in practice, it is a functional, theoretical concept. The received power P_r at the receiving antenna (mobile station), located at a distance d from the transmitter (base station) is given for free space propagation as [30]:

$$P_r = P_t \left(\frac{\lambda}{4\pi d}\right)^2 G_t G_r \tag{1}$$

If other losses (not related to propagation) are also present, we can rewrite Equation (1) as:

$$\frac{P_r}{P_t} = \left(\frac{\lambda}{4\pi d}\right)^2 \frac{G_t G_r}{L_o} = \frac{G_t G_r}{L_{p,\mathrm{fspl}} L_o} \tag{2}$$

where P_r, P_t, λ, G_t, G_r, d, L_o and $L_{p,\mathrm{fspl}}$ are received power, transmitted power, wave length, gain of the transmitting (base station) antenna, gain of the receiving (mobile) antenna, antenna separation distance between transmitter and receiver, other losses expressed as a relative attenuation factor and free space path loss, respectively. The free space path loss is often expressed as an attenuation in decibels [dB] as follows:

$$L_{p,\mathrm{fspl}}(\mathrm{dB}) = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right) = 32.44 + 20\log_{10} f + 20\log_{10} d \tag{3}$$

where f is the carrier frequency in [MHz] and d is the separation distance in [km]. The free space path loss is fundamental to consider the effects and losses caused by wave propagation through space. But in more complicated environments, it is essential to consider other impact factors to make the computation and analysis of results additionally accurate.

2.2 Okumura-Hata Path Loss

One of the well-known empirical models for propagation loss is Okumura-Hata model, which is based on experimental data. What is taken into account besides the general equation is the correction factor a. The standard formula for propagation loss for urban area L_{urban} is obtained by [31] and [32] as follows:

$$L_{p,\mathrm{urban}}(\mathrm{dB}) = 69.55 + 26.16\log_{10} f - 13.82\log_{10} h_b - a(h_m) + (44.9 - 6.55\log_{10} h_b)\log_{10} d \tag{4}$$

where $a(h_m)$ in [dB] is the correction factor for the mobile station antenna height h_m in [m]. The parameters f, h_b and d are the frequency in [MHz], the base station antenna height in [m] and the distance in [km], respectively. The correction factor for vehicular station antenna height in the case of a medium-small city can be determined as follows:

$$a(h_m) = (1.1\log_{10} f - 0.7)h_m - (1.56\log_{10} f - 0.8) \tag{5}$$

Due to the distinct environments between urban and rural areas, an open area correction factor for adjusting accuracy has been added to the equation to simulate the propagation loss in open spaces. So that we get the propagation loss as follows:

$$L_{p,\mathrm{hata}}(\mathrm{dB}) = L_{p,\mathrm{urban}} - 4.78(\log_{10} f)^2 + 18.33\log_{10} f - 40.94 \quad (6)$$

In this model, the height of both the receiving and transmitting antennas has been increased. as well as coefficients for adjusting the accuracy of the model to be more in line with the actual usage environment.

2.3 Perez-Vega Path Loss

A computational path loss model developed by Perez-Vega and Zamanillo is one of a simple propagation model for VHF and UHF bands. It allows the estimation of median path loss, received power, or electrical field strength which usually is sufficient in many practical applications. The model is independent of frequency and is applicable to outdoor environments. Path loss in dB can be calculated as [33] and [34]:

$$L_{p,\mathrm{perez}}(\mathrm{dB}) = 10\, n\log_{10}(d) + L_{p,\mathrm{fspl}} \quad (7)$$

The value of n intrinsically embeds the effects of all propagation mechanisms: attenuation, diffraction, reflection, etc. The best fit was obtained with a polynomial model of fourth degree with the form:

$$n = \sum_{i=0}^{4}\sum_{j=0}^{4} a_{ij}\, h^i d^j \quad (8)$$

where h is the height of transmitting antenna in [m] a d is the distance in [km]. The coefficients a_{ij} are given by [33]. The value of the variable was obtained by adjusting the accuracy of the curve using a processing program, which will be more complex in actual use.

2.4 Proposed Free-Med Model

Each model has limitations that depend on the propagation environment and experimental setup, which cannot model the path loss. They are mainly based on the distance between the transmitter and receiver. Then, modifying the accuracy with specific properties for each environment and terrain condition is essential. For example, in this research, we desire to construct a characteristic of a road-like area with trees on the sides. This environment is typical in the region and directly affects communication by propagating radio waves to conventional cars. Therefore, we proposed a so-called Free-Med model, a path loss model combining the FSPL model using the distance of a free space area and an empirical path loss model for an avenue area.

Due to their high efficiency in losing estimation and low mathematical complexity, empirical models are highly appreciated in radio-wave propagation dimensioning. Among them is the Modified Exponential Decay model (MED), one of the considerably widely employed due to the high levels of precision when determining canopy losses, as shown by [35] and [36]. Propagation models that calculate path loss or characterize attenuation in radio wave propagation play an essential role in the deployment of broadcasting signals in diverse large-scale contexts. The MED model can be calculated as follows:

$$L_{\mathrm{med}} = \alpha f^{\beta} d^{\gamma} \quad (9)$$

where L_{med} is the excess path loss in [dB], the parameter α, β, and γ are fitted values f is the frequency in [MHz], and d is the distance in [km].

The parameters were developed employing the geographic coordinates of the transmitter (Tx) and receiver (Rx) antenna locations, as depicted in Fig. 1, we define the total attenuation of Free-Med model $L_{\text{free-med}}$ in terms of:

$$L_{\text{free-med}} = L_{d,\text{fspl}} + L_{d,\text{tree}} = 20\log_{10}\left(\frac{4\pi d_{\text{fspl}}}{\lambda}\right) + \alpha f^{\beta} d_{\text{tree}}^{\gamma} \quad (10)$$

where d is expressed in [km] and f is the frequency expressed in [MHz]. The height of the transmitting antenna is represented by h_a in [m], where variable h_t in [m] represents the height of the surrounding trees, with $\theta = \arctan(h_a/d)$, $d_{\text{fspl}} = (h_a - h_t)/\sin\theta$, and $d_{\text{tree}} = h_t/\sin\theta$.

The highlight of this model is the inclusion of the efficiency of the wave propagation equation through free space and taking into account the changes in electromagnetic waves as they journey through a forest medium, which will change with the frequency, and the space traveled through the trees. In addition, all variables will vary depending on the distance between the wave source and the receiver's position.

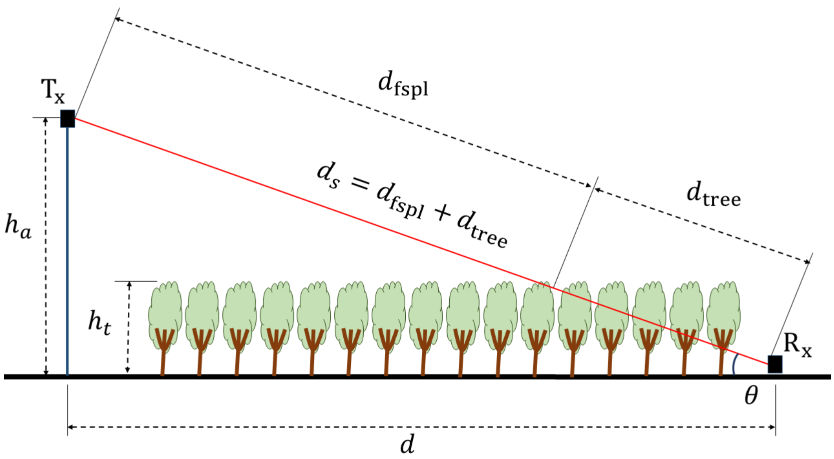

Fig. 1 Developed Model Geometry

3. Propagation Measurements

The research focuses on radio wave propagation affected by the typical road environment in the region. Avenues are streets or paths bordered on both sides by uniform rows of trees or separated by a row of trees in the middle. The trees on both sides of the track are planned to be planted at equal intervals and the same age with approximately the same planting quality. Trees of one tree species are usually used.

3.1 Measurement Scenario

The propagation measurement campaign was accomplished in an avenue environment in Nakhon Nayok, Thailand, as presented in Fig. 2. The dominant tree species were the Thai Pterocarpus macrocarpas and Thai Samanea. The measurements were performed along a straight route, as illustrated with the yellow line in Fig. 2(a). This experiment will use accurate radio signals from an FM radio station adjacent to the road where the measurement begins at the coordinates (14.279301, 101.162881), as demonstrated in Fig. 2(b). Along the route from the starting point to the endpoint at coordinate (14.221812, 101.151023), which has a total distance of 6.5 [km], the signal strength at the receiver will be estimated every 100 [m]. At all measurement locations, the moderate heights of trees h_t varied from 7 to 10 [m]. Therefore, the distance between the trees is approximately the same size at about 5 [m], as displayed in Fig. 2(b). Measurement data were acquired during the season, when the trees had leaves in damp weather conditions.

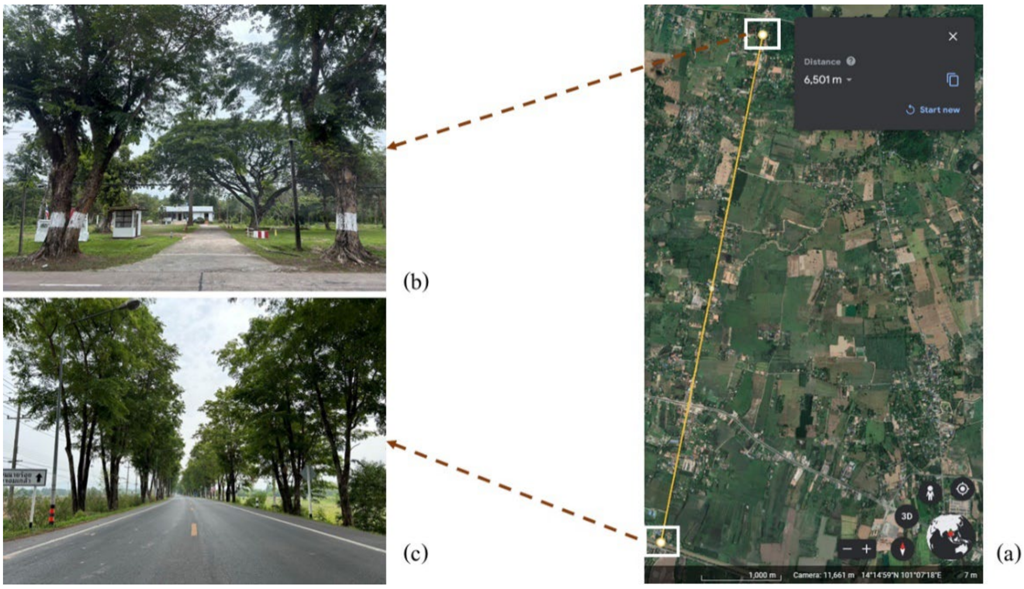

Fig. 2 The measurement site: (a) Measurement path form www.google.com, (b) Starting point and (c) Endpoint

3.2 Measurement System Description

The FM radio station generates a broadcasting signal in transmission using the carrier frequency of 89.75 MHz that is amplified and transmitted by an antenna located on a mast at the height of 20 [m], as depicted in Fig. 3(a) and Table 1. The measurement system employed is based on the Keysight FieldFox Handheld Analyzers N9913A (30 kHz to 4 GHz) utilized as the receiver (Rx), as depicted in Fig. 3(b). The receiving system is climbed on an automobile with a receiving antenna height 1 [m] and located at a distance from the line of trees along the road of 2 [m]. The experimental movement will stop at each measurement point to ensure signal stability. Besides that, this process can reproduce the signal received by the car's audio system.

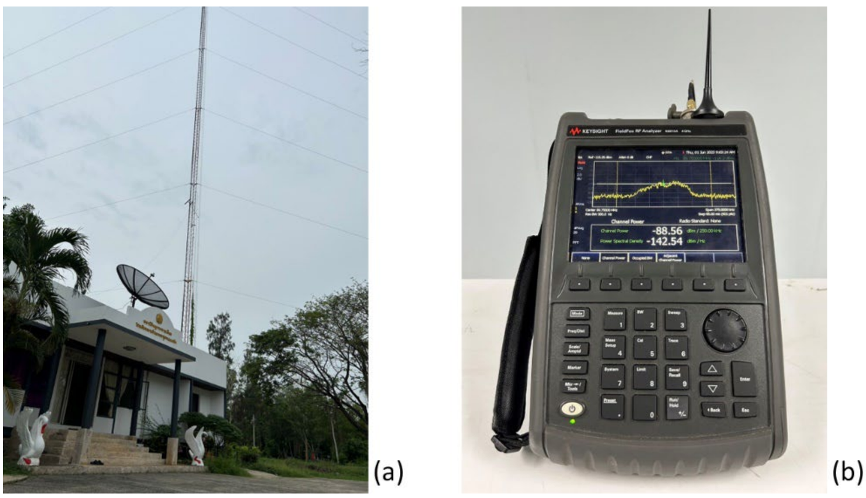

Fig. 3 System Description: (a) Transmitter antenna and (b) Keysight FieldFox Handheld Analyzers N9913A

Table. 1 Experimental setup

Description	Value
Tx Hight (above ground)	20 [m]
Rx Hight (above ground)	1 [m]
Frequency	89.75 [MHz]
Ground distance	0 – 6.5 [km]

3.3 Prediction Model Accuracy

The prediction errors between the measurements and the models were quantified with the mean absolute error (MEA) and the root-mean-squared error (RMSE).

$$\mathrm{MAE} = \frac{i}{N}\sum_{i=1}^{N}|x_i - m_i| \tag{11}$$

$$\mathrm{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - m_i)^2} \tag{12}$$

where N is the total number of measurement points, m_i and x_i are measurement and predicted values at the i^{th} measurement point in [dB], respectively [37].

4. Results and Discussions

This study's results can be divided into two parts: The first part is the results obtained from simulation by computer programs according to various models presented above. The second part is the outcomes received from the measurement experiment in the natural environment and then applied as a model to simulate the consequences of the typical avenue's environment in the region.

Fig. 4 illustrates the values obtained from the simulation using the free space path loss model $L_{p,\mathrm{fspl}}$, the Okumura-Hata path loss model $L_{p,\mathrm{hata}}$ and the Perez-Vega path loss model $L_{p,\mathrm{perez}}$ compared to measurements. The x-axis represents the ground distance between the antenna mass and the position of the received antenna mounted on the vehicle. The y-axis displays the path loss in dB. The circle shows the data obtained from each measurement. The measurement locations are 100 meters apart, totaling 65 measurement points. The dotted line represents the simulation results using the free space path loss model according to Equation (3). The dashed line represents the simulation results based on the Perez-Vega path loss model according to Equation (7). The curves indicate that the actual measurement values are distinct from those acquired from both models, as expected. The graphs and the measured values demonstrate that the loss trend in radio wave propagation over different distances is in the same approach. But there are differences in the range from about 1 [km] up. To improve this accuracy, the researchers present a model for calculating the effects of wave propagation in free space and the attenuation effects of trees and environments in the experimental area according to Equation (10). The dash-dot graph in Fig. 4 displays the free space part of the variable $L_{d,\mathrm{fspl}}$. It can be seen that this value is less than the value obtained from the free space path loss model $L_{p,\mathrm{fspl}}$ because the propagation distances in the air defined in each model are dissimilar.

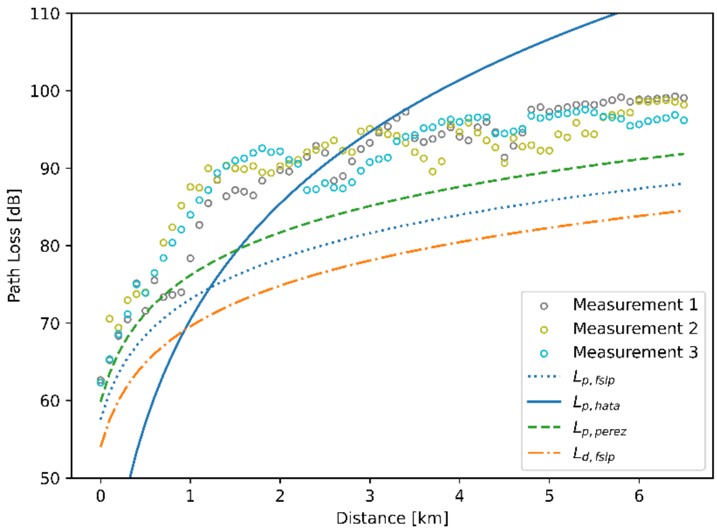

Fig. 4 Comparison between path loss models and measurements

The difference between the experimentally measured value and the variable $L_{d,\text{fspl}}$ in the proposed model can be used to estimate the correct variable value $L_{d,\text{tree}}$, as shown in Fig. 5. As for the variables $L_{d,\text{fspl}}$, only the distance d_{fspl} traveled by electromagnetic waves through unobstructed space is considered, and separating the part that spreads electromagnetic waves through the tree is represented using variable $L_{d,\text{tree}}$. Fig. 5 depicts the distinction ΔL_d between the values acquired from each measurement and the variables $L_{d,\text{fspl}}$ in the developed model. In the next step, these values are used to discover relevant function variables $\alpha f^{\beta} d_{\text{tree}}^{\gamma}$. In this research, we have applied a curve-fitting technique to discover the most correlated curve optimization that finds an optimal set of parameters for a specified function that agreeably suits a given set of observations. The dash-dot line in Fig. 5 displays the outcomes acquired when the variable set is provided the following values α = 0.1431, β = 1.0151 and γ = 0.0826.

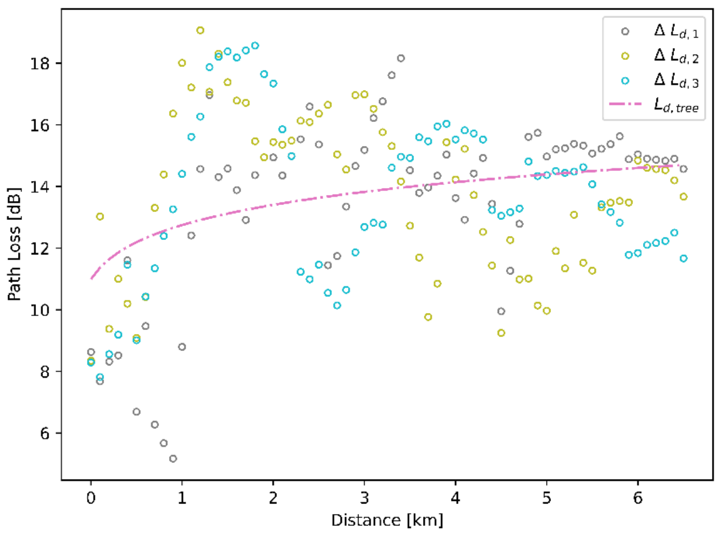

Fig. 5 The distinction ΔL_d and curve optimization with α = 0.1431, β = 1.0151 and γ = 0.0826

Fig. 6 compares the experimentally average measured values, the free space path loss model $L_{p,\text{fspl}}$, the Okumura-Hata path loss model $L_{p,\text{hata}}$, the Perez-Vega path loss model $L_{p,\text{perez}}$, and the developed Free-Med path loss model $L_{\text{free}-\text{med}}$. It can be seen that the dotted line is comparable to the series obtained from the other two models. The improvement in accuracy is evident from the tolerance values shown in Table 2. When using the free space path loss model, the MAE and RMSE values are 10.1407 [dB] and 10.3463 [dB], respectively. These are lower than the results from the Okumura-Hata model, which have MAE and RMSE values of 59.0248 [dB] and 60.2650 [dB], respectively. In the case of the Perez-Vega model, the MAE and RMSE values based on measurement results are 6.7061 [dB] and 6.9729 [dB], respectively. The results from the developed Free-Med model show a slight difference from the measurements, as indicated by the MAE and RMSE values of 1.4966 [dB] and 1.8288 [dB], respectively.

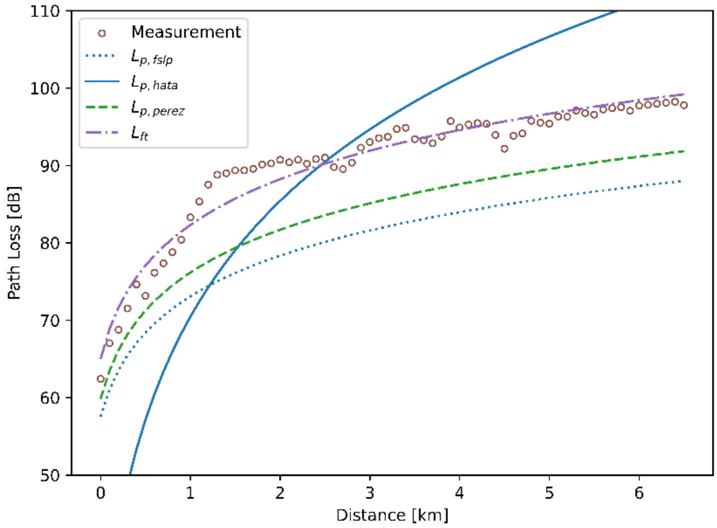

Fig. 6 Comparison between the others path loss models, developed path loss model and measurements

Tab. 2 Model performance

Model	MAE [dB]	RMSE [dB]
Free Space	10.1407	10.3463
Hata	59.0248	60.2650
Perez	6.7061	6.9729
Free-Med	1.4966	1.8288

5. Conclusion

In this paper, a novel prediction model for path-loss estimation in avenue environments has been proposed. A measurement campaign has been carried out at a frequency of 89.75 [MHz]. The experiment utilizes the signal from the radio station and employs the receiver antenna at the vehicle's height. So, the position of the transmitter antenna exceeds the size of the trees, and the receiver antenna is below the peak of the trees. In contrast with most well-known empirical models, the proposed model determines the transformations in propagating waves as they travel through a free space and forest medium, varying with the frequency and distance traveled through both mediums. Furthermore, the experimental results demonstrate that the values obtained using our developed model are more accurate than other general models. Therefore, creating a model suitable for operating conditions by analyzing the propagation of waves in free space and areas with characteristic obstructions permits modeling to be precise and provide results roughly the value obtained from the measurement.

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