



Fine-tuned Cost231 Path Loss Model for Kampung Banyok, Sarawak

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ABSTRACT

This paper presents a fine-tuned Cost231 Path Loss model based on the propagation measurements performed at 2.4 GHz WiFi transmission in Kampung Banyok. There are a few limitations appeared on conventional Free Space Path Loss model (FSPL) in which performance parameters such as terrain conditions, absorption from obstacles and geographic area factors were not considered in the model for outdoor path loss prediction. Therefore, this study aims to modify the existing Cost231 Path Loss Model for predicting signal strengths using the least square method (LSM). The fine-tuned Cost231 Path Loss model can help telecommunication providers to deliver satisfactory network services by investigating suitable wireless equipment and access point locations before actual implementation on selected site. The accuracy of the proposed fine-tuned Cost231 Path Loss model was determined using Mean Absolute Percentage Error (MAPE) and Root Mean Square Error (RMSE) using the measured data collected from Kampung Banyok. The results show that the MAPE and RMSE of the fine-tuned model are 1.87% and 1.92 dBm for Kampung Banyok, which indicates that the fine-tuned model can provide better accuracy than the conventional FSPL and Cost231 Path Loss models.

1. Introduction

In order to achieve full coverage by 2030, Sarawak government want to expand the coverage in rural areas as part of the government's effort and initiative [1]. To achieve this goal, radio frequency planning is needed. Path loss information is needed in frequency planning. One of the major challenges faced in implementing communication systems in rural areas include less subscribers than urban areas. Thus, leading to lower return in investment for the wireless infrastructure installed. Therefore, the implementation of the license-free wireless transmission system which allows reasonable coverage such as 2.4 GHz Wi-Fi might be a feasible option to provide internet access in rural areas. Before actual implementation or deployment of such transmission systems, the rural areas path loss should be studied. Path loss models, also known as propagation models are required for wireless network planning to support the analysis and design of network topologies. These path

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loss models are used for predicting the received signal strength (RSS) at specified distances. They may or may not include factors such as transmit power, base station height and antenna gain etc [2-5].

Path loss models were derived based on different conditions. They are categorised into deterministic, empirical and semi-empirical models. Empirical models such as Free Space Path Loss (FSPL), Egli, Okumura and Hata are derived based on measurements and observations. They are also derived based on existing equations. The measurements obtained from urban, sub-urban and rural areas can be used to derive most of the empirical models. Semi-empirical models combine the empirical and deterministic models. The commonly used semi-empirical models are Walfisch-Bertoni, Cost231 Path Loss and Cost-Walfisch-Ikegami models.

The Cost231 Path Loss model was developed by the European Cooperative for Scientific and Technical research [6-7]. It is an extended version of Hata Model. The model is applicable to frequency range from 1500 MHz to 2000 MHz. Although Cost231 Path Loss Model frequency is only restricted until 2000 MHz, Cost231 Path Loss estimation can cover up to 2300 MHz. Moreover, Mardeni and Priya [8] had used this model for frequencies more than 2300 MHz.

Based on study by Akande *et al.*, [7], the Cost231 Path Loss Model is given by:

$$PL_{Cost231}(dB) = 46.3 + 33.9 \log_{10} \left(\frac{f}{MHz} \right) - 13.82 \log \left(\frac{h_B}{m} \right) - a \left(\frac{h_R}{m} \right) + \left(44.9 - 6.55 \log \left(\frac{h_B}{m} \right) \right) \log_{10} \left(\frac{d}{km} \right) + C_m \quad (1)$$

where d is the distance between the antennas in km , f is the transmit frequency, h_B is the base station antenna height and h_R is the mobile station antenna height. C_m is the constant offset which gives 0 dBm for suburban and rural areas, and 3 dBm for urban areas. $a(h_R)$ is the correction factor depending on the area. It is given by Equations (2) to (4).

For suburban or rural area,

$$a(h_R) = (1.1 \log f - 0.7)h_R - (1.56 \log f - 0.8) \quad (2)$$

For urban area,

$$a(h_R) = 8.29(\log 1.54 h_R)^2 - 1.1; (f \leq 300 MHz) \quad (3)$$

$$a(h_R) = 3.2(\log 11.75 h_R)^2 - 4.97; (f \geq 300 MHz) \quad (4)$$

The path loss in each area is unique and it is impossible to fully control the environment to ensure strong signal strength. Therefore, this paper aims to introduce a fine-tuned Cost231 Path Loss model to predict the path loss for the 2.4 GHz WiFi transmission for a village in one of the divisions in Sarawak using the least square method (LMS) with RSS obtained from Kampung Banyok in Sibu for site testing. Concentrated wooden house in Kampung Banyok makes the selected site more suitable for the license-free WiFi transmission system deployment. Kampung Banyok covers an area of 0.132 km². It is surrounded mostly by trees, and situated near the Rajang River. The latitude and longitude of the village are 2° 15' 48.39" and 111° 48' 41.32" [9].

The objectives of this research are:

- To obtain the actual path loss by measuring the Received Signal Strengths (RSS) from the physical testing in Kampung Banyok.
- To generate the fine-tuned Cost231 model using the LSM based on the physical testing results.

- To evaluate the accuracy of the fine-tuned Cost231 Path Loss model against the conventional FSPL and Cost231 Path Loss models.

2. Path Loss Testing and Models

There are a few path loss models which can help to precisely determine the number of access points required for providing coverage in a given area which leads to achieve a simple estimation for network planning purpose. In this section, a review of WiFi path loss prediction models are provided.

2.1 Free Space Path Loss Model

The FSPL model derives from the Friis transmission model [3]. The FSPL is given by:

$$PL_F(dB) = 20 \log_{10}(d) + 20 \log_{10}(f) + 20 \log_{10}\left(\frac{4\pi}{c}\right) - G_T - G_R \quad (5)$$

where, d is the distance between the antennas in meter, f is the signal carrier frequency in MHz, c is the light speed in vacuum, G_T and G_R are the transmitter and receiver antenna gains. The FSPL model estimates the attenuation of the radio energy between two antennas under the line-of-sight (LOS) path through free space. The FSPL model is suitable to be used for the 2.4GHz and 5GHz WiFi frequency. However, the FSPL does not include the power losses in the antennas and assumes the polarization of the antennas is the same in which there are no multipath effects.

2.2 Two-ray Path Loss Model

The two-ray prediction model is a multi-path propagation model that considers a direct and ground reflected propagation path for the experimental setup. There is a direct path from a transmitter to the receiver without obstacles whereas another wave is assumed to be received after being reflected by the ground surface.

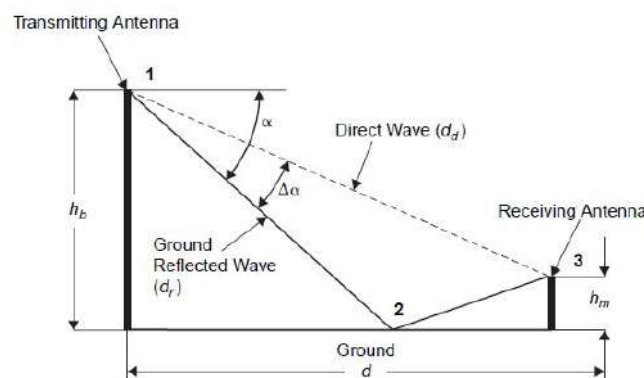


Fig. 1. Two-ray ground reflection model [10]

The assumptions related to the base station height h_b , mobile station height h_m , the angle between the direct (d) and reflected paths ($\Delta\alpha$), and reflecting surface are of significance. Following these assumptions, h_b and h_m should be much smaller than the separation distance d . $\Delta\alpha$ is assumed to be less than $\pi/8$, and the reflecting surface is assumed to be flat. The model showed the

power decrease proportionally to an inverse of fourth power of d for any distance d greater than \bar{d} which is referred to as the critical distance and given as

$$\bar{d} = \frac{4h_b h_m}{\lambda} \quad (6)$$

where $\lambda = \frac{c}{f}$ is the wavelength of the transmission, c is the speed of light and f is the transmission frequency.

The two-ray path loss is given in [10] can be expressed in dB as

$$PL_{2\text{-ray}}(dB) = 20 \log \left[\frac{d^2}{h_b h_m} \right]^2 \quad (7)$$

2.3 Log-distance Model

The Log-distance Path Loss model is derived from FSPL. The Log-distance Path Loss model is used to predict the propagation loss for a wide range of environments. It is assuming an exponential relationship between incremental path loss and distance [11].

$$PL(d) \propto \left(\frac{d}{d_0} \right)^n \quad (8)$$

which d indicates the distance in meter, d_0 is a reference distance and n is the attenuation factor. From the above relationship the path loss model is defined by:

$$PL(d)[dB] = PL(d_0)[dB] + 10n \log_{10} \left(\frac{d}{d_0} \right) \quad (9)$$

For a given distance d , the path loss in this model is observed at a reference distance d_0 and the additional loss could be imposed by (8). The attenuation factor n can be found experimentally by considering different building types. The model encompasses random shadowing effects due to signal blockage by any obstacles such as trees or buildings. Therefore, it is also referred as log normal shadowing model.

2.4 ITU-R Model

The ITU (International Telecommunication Union) radio propagation model was developed to estimate the path loss in a closed area delimited by walls that suited the WLAN operating frequency from 900MHz to 100GHz [12]. The path loss model is.

$$PL_{ITU}(dB) = 20 \log_{10}(f) + N \log_{10}(d) + P_f(n) - 28 \quad (10)$$

where d indicates the distance in meter, N is the distance power loss coefficient, f is the signal carrier frequency in MHz, P_f is the floor penetration loss factor, and n is the number of floors between access point and terminals.

This path loss model is suitable to approximate the total path loss an indoor link may experience based on the appliances designed for indoor use.

2.5 The Young Model

The radio propagation model proposed by Young, is based on the data collected in the outdoor environments over a wide frequency range, from 150MHz to 3.7GHz to model the behaviour of cellular communication system in 1952.

The formula of the Young model is:

$$PL(d) = \frac{d^4}{G_t G_r (h_t h_r)^2 \beta} \quad (11)$$

where d indicates the distance in meter. G_r and G_t stand for the antenna gains and h is the height (indices t and r indicate a transmitter or receiver). The parameter β is called the clutter factor and is experimentally obtained. Supposing that the antennas of the transmitter and receiver are similar and have the gain $G_t = G_r = 1$ and that both are placed at the same height $h_t = h_r = 1$, then the formula above can be simplified into:

$$PL(d) = \frac{d^4}{\beta} \quad (12)$$

or, expressing in dB as

$$PL(d)[dB] = 40 \log_{10}(d) - 10 \log_{10}(\beta') \quad (13)$$

2.6 Cost231 Model

Some of the path loss models used for rural and suburban areas are Lee, Okumura, Cost231 path loss model or Cost231-Hata model [6-7], [9], [13]. In the study by Onipe *et al.*, [13], a specific correction factor is used for rural or suburban areas in the path loss formula. These models cater for areas or distances larger than Kampung Banyok.

The Cost231 model in (1) was first developed for path loss estimation in rural area ($C_m = 3dBm$) and urban area ($C_m = 0dBm$) using empirical and deterministic approach. Compared with the free space model, the Cost231 model provides more feasibility in path loss study by considering the antenna heights. By adjusting C_m and the correction factor $a(h_r)$, Cost231 model can be adopted into different studies based on specific urban or rural classification. The recommended carrier frequency range for this model is in between 1500H and 2000MHz. There were extensive studies conducted in a range of 2360 to 2390MHz for WiMAX path loss prediction [9]. The optimised model was developed for suburban and open urban environments using the standard deviation error analysis with Stanford University Interim (SUI) Model.

Several researchers have fine-tuned path loss models using LSM. This method was used by [7][14] to fine-tune the Cost231 Path Loss model. 900 MHz & 1800 MHz frequency were used in the research. The result showed that the fine-tuned Cost231 Path Loss model was a suitable model compared with the original Cost231 Path Loss model [14]. In [14], the authors did not show the fine-tuned Cost231 Path Loss model equation. However, the fine-tuned model returns an improved root mean squared error (RMSE) in comparison to the original model. The drive tests in [7] and [14] were conducted in Nigeria rural areas. The empirical Cost231 model was built using commercial frequencies spectrums such as 2G GSM and 4G LTE networks spectrum which the derived models are not suitable to be used for WiFi or 5G network planning in rural areas. In this project, WiFi frequency spectrum 2.4GHz was

used to conduct the drive tests and the existing Cost231 was fine tuned based on the site testing RSS measurement for the better use of the outdoor WiFi network implement on the targeted site.

The Log-distance model is designed mainly for indoor path loss estimation due to the attenuation factor is needed by considering building types. Although the ITU-R model is an indoor propagation model, there are a few drive tests carried out for this propagation model with low prediction errors for the urban residential environment [12]. There were a few modifications introduced on the original ITU-R model for adopting this indoor propagation model into urban propagation model. The Young model is an urban propagation model which performs modelling of the cellular communication systems's behaviours in large cities with tall structures. In fact, the clutter factor β is used to represents losses due to buildings rather than terrain features and the Young model is not a specific prediction method. Therefore, the Young model is not suitable for rural/remote area path loss estimation. FSPL is a simple path loss model, which assumes Line of Sight (LOS) in between the transmitter and receiver. However, FSPL will not consider terrain conditions, absorption from obstacles and reflections from surfaces. FSPL is an empirical model in which the parameters will be determined based on the site measurement.

Unlike FSPL, the Cost231 model will take the antenna heights and type of area as a part of the correction factors as the semi empirical model. Therefore, the Cost231 model is selected to perform the outdoor path loss prediction. However, the Cost231 model was originally used for indoor path loss estimated. Therefore, the research aim of this project is to fine tune the Cost231 model for outdoor path loss prediction using the RSS collected from the selected site. The proposed fine-tuned Cost231 is suitable to be used for the outdoor path loss estimation compared with other indoor/outdoor path loss models.

3. Problem Formulation

In this paper, the parameters of the fine-tuned Cost231 model were determined based the physical measured data from Kampung Banyok by using the LSM. The environmental influences from Kampung Banyok were considered as a part of errors during the LSM optimization process to improve the prediction accuracy of Cost231 model as observed from the measured data. The accuracy of the fine-tuned Cost231 model will be evaluated using MAPE and RMSE compared with conventional Cost-231 and FSPL models.

The conventional Cost231 path loss model in (1) can be rewritten into

$$PL_{Cost231}(dB) = a + b \log_{10} \left(\frac{d}{km} \right) \quad (14)$$

where

$$a = 46.3 + 33.9 \log_{10} \left(\frac{f}{MHz} \right) - 13.82 \log \left(\frac{h_B}{m} \right) - a \left(\frac{h_R}{m} \right) + C_m$$

$$b = 44.9 - 6.55 \log \left(\frac{h_B}{m} \right)$$

According to Mardeni and Priya [8], the LSM is the most suitable method for fine-tuning path loss model. The environmental impacts can be embedded into the Cost-231 model using optimized statistical tuning approach. The mean square error function reduced the difference between actual data and calculated data. The LSM was used by Imoize and Ogunfuwa [14] to fine-tune path loss

models. The LSM given in the study by Akande *et al.*, [7] is referred to in this research though the path loss models and frequency bands are different.

The fine-tuned Cost231 model is represented by

$$PL_{new}(dB) = a_{new} + b_{new} x \quad (15)$$

where a_{new} and b_{new} are new parameters to be determined based on the Kampung Banyok measured data. x is $\log_{10} \left(\frac{d}{km} \right)$.

The LSM error function can be calculated as follow:

$$E(a_{new}, b_{new}) = \sum_{i=1}^5 (PL_{mi} - PL_{newi}) \quad (16)$$

$$= \sum_{i=1}^5 (PL_{mi} - (a + bx_i))$$

Squaring the error function gives

$$E(a_{new}, b_{new})^2 = \sum_{i=1}^5 (PL_{mi} - (a_{new} + b_{new}x_i))^2 \quad (17)$$

The partial derivatives of (17) are

$$\frac{dE(a_{new}, b_{new})^2}{da} = -2 \sum_{i=1}^5 (PL_{mi} - (a_{new} + b_{new}x_i)) \quad (18)$$

$$\frac{dE(a_{new}, b_{new})^2}{db} = -2 \sum_{i=1}^5 x_i (PL_{mi} - (a_{new} + b_{new}x_i)) \quad (19)$$

In order to determine the optimized parameters a_{new} and b_{new} , both partial derivatives (18) and (19) are set to zero for minimum error.

From (18),

$$-2 \sum_{i=1}^5 (PL_{mi} - (a_{new} + b_{new}x_i)) = 0$$

$$\sum_{i=1}^5 PL_{mi} - \sum_{i=1}^5 a_{new} - \sum_{i=1}^5 b_{new}x_i = 0$$

$$a_{new} = \frac{\sum_{i=1}^5 PL_{mi} - b_{new} \sum_{i=1}^5 x_i}{5} \quad (20)$$

From (19),

$$-2 \sum_{i=1}^5 (x_i PL_{mi} - a_{new} x_i - b_{new} x_i^2) = 0$$

$$\sum_{i=1}^5 x_i PL_{mi} - a_{new} \sum_{i=1}^5 x_i - b_{new} \sum_{i=1}^5 x_i^2 = 0 \tag{21}$$

Substitute (20) into (21),

$$\sum_{i=1}^5 x_i PL_{mi} - \frac{1}{5} \sum_{i=1}^5 x_i \left[\sum_{i=1}^5 PL_{mi} - b_{new} \sum_{i=1}^5 x_i \right] - b_{new} \sum_{i=1}^5 x_i^2 = 0$$

$$\sum_{i=1}^5 x_i PL_{mi} - \frac{1}{5} \sum_{i=1}^5 x_i \sum_{i=1}^5 PL_{mi} + b_{new} \frac{1}{5} \sum_{i=1}^5 x_i \sum_{i=1}^5 x_i - b_{new} \sum_{i=1}^5 x_i^2 = 0$$

$$\sum_{i=1}^5 x_i PL_{mi} - \frac{1}{5} \sum_{i=1}^5 x_i \sum_{i=1}^5 PL_{mi} + b_{new} \left[\frac{1}{5} \left(\sum_{i=1}^5 x_i \right)^2 - \sum_{i=1}^5 x_i^2 \right] = 0$$

$$b_{new} = \frac{5 \sum_{i=1}^5 x_i PL_{mi} - \sum_{i=1}^5 x_i \sum_{i=1}^5 PL_{mi}}{5 \sum_{i=1}^5 x_i^2 - \left(\sum_{i=1}^5 x_i \right)^2} \tag{22}$$

Reobtain a_{new} in (20)

$$a_{new} \sum_{i=1}^5 x_i = \sum_{i=1}^5 x_i PL_{mi} - b_{new} \sum_{i=1}^5 x_i^2$$

$$a_{new} = \frac{\sum_{i=1}^5 x_i^2 \sum_{i=1}^5 PL_{mi} - \sum_{i=1}^5 x_i \sum_{i=1}^5 x_i PL_{mi}}{5 \sum_{i=1}^5 x_i^2 - \left(\sum_{i=1}^5 x_i \right)^2} \tag{23}$$

From the new parameter formulas in (22) and (23), the fine-tuned Cost231 model in (15) can be determined using measured distance and RSS from the site testing.

4. Methodology

The Figure 2 shows the layout of the actual physical testing in Kampung Banyok. For the measured data collection, the physical site test setup used the outdoor router Tenda V03(1) as the transmit end to provide long distance wireless solution with EAP110 as the access point. Tenda V03 is a customer premises equipment (CPE) that can be pole or wall mounted [15]. The EAP110 from TP-link helps to broadcast the existing WiFi network outdoors [16]. The end mobile user was connected to the access point for the RSS measurement.



Fig. 2. Diagram of testing setup for Kampung Banyok

The RSS measurements were collected at distances of 40 m, 80 m, 120 m, 160 m and 200 m along the red line in Figure 2 every 5 minutes. The maximum distance was 200 m because EAP110 provides wireless coverage up to 200 m. The data transmitted were random signal from the router (build-in function). The RSS measurements were recorded every 5 minutes using the network performance measurement tool in the mobile phone.

The RSS used in this paper was obtained on 16th September 2020 at site. The testing was conducted in the afternoon. The weather was fair with temperature ranging between 34.4° and 39.5° Celsius and humidity, from 50% to 65%. The parameters used for the site testing are tabulated in Table 1.

Table 1
 Parameters used in the physical testing

Parameters	Kampung Banyok
Wireless standard	802.11n
Frequency	2.4 GHz
Measured distance	40m 80m 120m 160m 200m
Transmitter (EAP110) Antenna Gain	6 dBi
Transmitter Power	20dBm
Transmitter Height	4m
Receiver (Mobile phone) Antenna Gain	1 dBi
Receiver Height	1.5m
Modulation Type	64-QAM 5/6
Channel Width	40MHz

Ten RSS measurements were taken for each distance. As the RSS fluctuates in between 2 dB and 3 dB for each distance, the 10 measurements for each distance were averaged. The average RSS were used in Equation (24) to determine the path loss based on measurement from site testing.

$$PL = P_T + G_T + G_R - RSS - A \tag{24}$$

where P_T is the transmitted power in dBm, G_T is the transmitter antenna gain, G_R is the receiver antenna gain and A is the cable loss. CAT5 ethernet cables were used in this site testing. The length of the cables is less than 100m. Therefore, cable loss can be ignored following the ANSI/TIA/EIA-568-A, Commercial Building Telecommunication Standards [17].

The accuracy of the path loss models is determined by RMSE and MAPE. RMSE is widely used by researchers [7-8]. It is also known as root mean square deviation. RMSE shows the error between measured path loss and path loss calculated from the models. The equation is given as [18- 20]:

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (PL_m - PL_c)^2}{N}} \tag{25}$$

where PL_m is the measured path loss, PL_c is the predicted path loss and N is number of samples. Here, the PL_c is PL_{new} when the fine-tuned model is considered and $PL_{cost231}$ when the unturned model is used.

MAPE were commonly used to measure the prediction accuracy of the proposed forecasting method in statistics [21-25]. The MAPE was used by [13] to measure the accuracy of the selected path loss models and the equation is given as:

$$MAPE = \frac{100\%}{N} \sum_{i=1}^N \left| \frac{PL_m - PL_c}{PL_m} \right| \tag{26}$$

The FSPL in (9) and Cost231 path loss in (1) were used as reference models to compare the accuracy of the fine-tuned path loss model in (19) using RMSE and MAPE.

5. Results and Discussion

The RSS and PL_m obtained from the physical testing are given in Table 2. The PL_m values were calculated using Equation (24). On the whole, the RSS values decrease when distance increases. The difference between the maximum and minimum RSS for each distance is 2dB except at 120m, where 3dB difference is noticed. The path loss increases with distance since the average RSS decreases with distance.

Table 2
 RSS (dBm) and PL_m (dB) obtained from physical testing for distances 40m to 200m

No.	40m	80m	120m	160m	200m
RSS 1	-56	-59	-66	-72	-78
RSS 2	-54	-60	-66	-72	-79
RSS 3	-54	-60	-69	-73	-79
RSS 4	-55	-61	-68	-74	-79
RSS 5	-55	-61	-68	-74	-78

RSS 6	-55	-60	-67	-73	-78
RSS 7	-55	-60	-67	-73	-77
RSS 8	-55	-60	-68	-74	-78
RSS 9	-54	-60	-67	-73	-78
RSS 10	-56	-60	-67	-73	-79
Average RSS (dBm)	-54.9	-60.1	-67.3	-73.1	-78.3
PLm (dB)	81.9	87.1	94.3	100.1	105.3

Based on the measured data, the following fine-tuned Cost231 path loss model was proposed using Equations (15), (22) and (23):

$$PL_{new}(dB) = 126.54 + 33.40 x \quad (27)$$

For comparison, the conventional free space and Cost231 models were determined based on parameters in Table 1. The in tuned Cost231 model can be rewritten as the following equation

$$PL_{cost231}(dB) = 152.59 + 40.96 x \quad (28)$$

Table 3 provides the RSS and path losses using the fine-tuned Cost231 model in Equation (27), conventional free space and conventional Cost231 as in Equation (28). Figures 3 and 4 are based on the information in Table 3. The proposed fine-tuned Cost231 path losses model is closer to the measurements than other path loss models.

Table 3
 RSS (in dBm) and path losses

Distance (m)	40	80	120	160	200
$PL_{new}(dB)$	79.9	89.9	95.8	100.0	103.2
RSS from PL_{new} (dBm)	-52.9	-62.9	-68.8	-73	-76.2
$PL_F(dB)$	65.1	71.1	74.6	77.1	79.1
RSS from PL_F (dBm)	-38.1	-44.1	-47.6	-50.1	-52.1
$PL_{cost231}(dB)$	95.3	107.7	114.9	120	124
RSS from $PL_{cost231}$ (dBm)	-68.3	-80.7	-87.9	-93	-97

The path losses based on the fine-tuned Cost231 model are similar to the measured path loss calculated using Equation (24). They differ slightly due to rounding off. The difference between PL_m and FSPL ranges from 16 to 26dB. The path losses based on the original Cost231 model are between 15.48dB and 20.79dB higher than the fine-tuned Cost231 model. The original Cost231 led to a less accurate prediction of the village's path loss may be due to two criteria for using this model are not met. Firstly, the model accommodates distance of more than 200m according to [7]. Secondly, the base station height should be 30m to 100m [7]. Based on Equation (14), both the a and b terms are affected by the base station height.



Fig. 3. Measured path loss, calculated and simulated path losses for Kampung Banyok

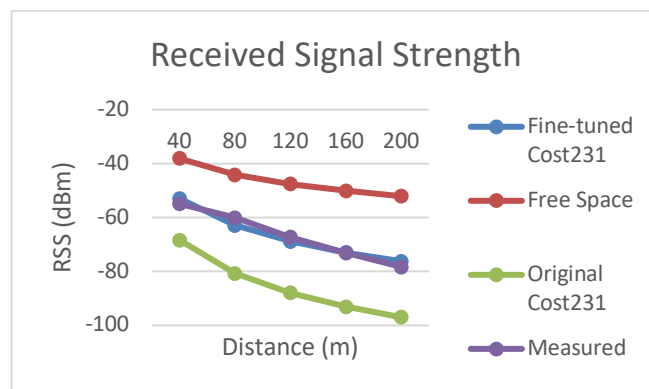


Fig. 4. RSS based on site testing, fine-tuned and untuned path losses models

The MAPE and RMSE values for the fine-tuned and untuned path loss models are shown in Table 5. The MAPE of the fine-tuned Cost231 path loss model is 1.87% and compared to 21.53% for FSPL. As such, the FSPL model prediction is not reliable as it does not take into account other factors of path loss such as the height of transmitter and receiver station. The RMSE for PL_{new} is 1.92 dBm which means that the prediction based on this model fulfills the 10dB RMSE requirement for rural or suburban area. Based on the MAPE and RMSE of PL_{new} , the fine-tuned Cost231 path loss model is very accurate as a prediction model.

Table 5
 MAPE and RMSE of the path loss models

Path Loss Model	PL_{new}	PL_F	$PL_{cost231}$
MAPE (%)	1.87	21.53	19.90
RMSE (dBm)	1.92	20.70	18.84

From Equations (27) and (28), the a and b terms of the fine-tuned Cost231 are lower than those based on the original Cost231 model. The constant a term in both models contribute mainly to the path loss. As observed in Tables 6 and 7, the a term is greater than the path loss for both tuned and untuned models. As the distances used in this paper range between 40 and 200m, the bx term leads to negative values which causes reduction to the a term and leading to the path loss obtained. These negative bx values tend to lessen in the increase path loss when the distance increases as shown in Figure 5 and Figure 6. Thus, resulting in the fine-tuned model producing a lower estimated path loss

than the original Cost231 model for the distances considered. By comparing the original Cost231 model in Table 7 to the fine-tuned Cost231 model in Table 8, the a and b terms in the untuned Cost231 model are 26.05dB and 7.56dB higher than those of the fine-tuned model. This indicates that correction factors of 26.05 and 7.56 should be introduced to the untuned model to allow a more accurate prediction in path loss and RSS as showed in Figure 3 and Figure 4.

$$PL_{new}(dB) = PL_{cost231}(dB) - 26.05 - 7.56x \tag{29}$$

Table 6
 Original Cost231 parameter terms contribution

d (m)	a term	b term × log10(d/km)	PL (dB)
40	152.59	-57.259	95.331
80	152.59	-44.929	107.661
120	152.59	-37.716	114.874
160	152.59	-32.599	119.991
200	152.59	-28.629	123.961

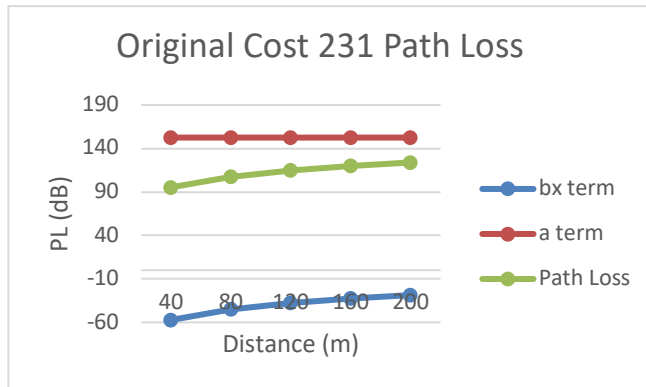


Fig. 5. Trend of the Original Cost231 parameter terms

Table 7
 Fine-Tuned Cost231 parameter term contribution

d (m)	a term	b term × log10(d/km)	PL (dB)
40	126.54	-46.691	79.849
80	126.54	-36.636	89.903
120	126.54	-30.755	95.785
160	126.54	-26.582	99.958
200	126.54	-23.345	103.194

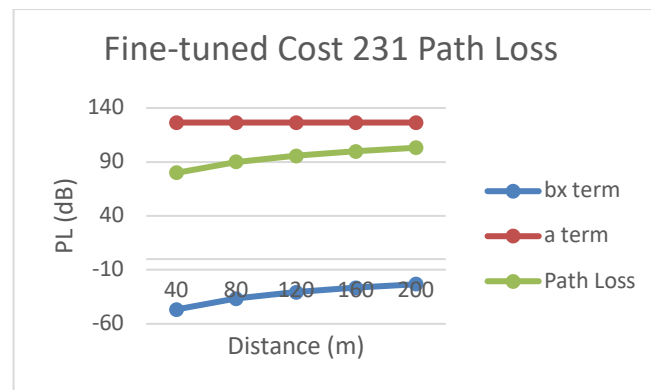


Fig. 6. Trend of the Fine-Tuned Cost231 parameter terms

6. Conclusion and Future Work

A fine-tuned Cost231 path loss model based on LSM and actual site testing data for a village in Sarawak is introduced. Though the Cost231 model should not really be used to predict the path loss in Kampung Banyok as two of the criteria are not fulfilled, the Cost231 model can still be fine-tuned using the LSM based on actual measurements to provide a more suitable path loss model for the said village. The MAPE and RMSE of this path loss model show considerable improvement over the FSPL and unturned Cost231 models as they are lower. From this model, it is found that the distance term contributes to the variation or increase in path loss when distance increases.

Currently, the proposed Cost 231 path loss model coefficients were fine-tuned based on the site testing data collected from Kampung Banyok. In order to compare and analyses the capability of the proposed path loss model in prediction accuracy, it would be better if more site testing can be conducted on different rural areas follow their landscape conditions such as mountain, river, lake or forest. The research work can also be further improved by collecting certain quantities site testing data under different weather conditions and variation to the physical set up such as different heights or antenna gains. These important factors can also be used for better fine-tuning the path loss estimation model and investigate their impact on the RSS for the targeted site.

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