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PERFORMANCE ANALYSIS OF 5G PATH LOSS MODELS FOR RURAL MACROCELL ENVIRONMENT

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ABSTRACT: 5G networks are expected to use the Millimeter Wave (mmWave) frequency band and this frequency provides wider bandwidth allowing a better quality of service to be offered to the users. However, the mmWave frequencies may lead to a higher path loss due to several factors including blockages,rain and atmosphere. Therefore, to allow optimal positioning of the 5G base stations, the study of path loss model in this 5G mmWave frequencies is crucial. This paper investigates the 5G path loss models as well as their parameters that are most suitable for cross-polarized antennas under rural macrocell environment in Malaysia. Path loss models namely Close In Free Space Reference Distance Path Loss Model (CI) model, and Alpha Beta Gamma (ABG) or Floating Intercept (FI) Model along with their parameters achieved from the previous studies were evaluated by comparing the parameters and models that are closest to the sampled path loss when using antennas that have different patterns and polarizations in an open-source simulator. Results obtained indicate that FI model can be adapted to the majority of the environment where this model showed the lowest Root Mean Square Error (RMSE). The study of path loss models by using advanced simulator or field measurement, and studies on other rural areas from other states in Malaysia will be considered in future works.

ABSTRAK: Rangkaian 5G dijangka menggunakan jalur frekuensi Gelombang Milimeter (mmWave) dan frekuensi ini menyedia jalur lebar yang lebih lebar membolehkan kualiti servis yang lebih baik untuk para pengguna. Walau bagaimanapun, frekuensi mmWave mungkin menyebabkan kehilangan penyebaran yang tinggi disebabkan beberapa faktor seperti halangan, hujan dan atmosfera. Oleh itu, untuk membolehkan stesen pangkalan 5G berada dalam kedudukan optimum, kajian model kehilangan penyebaran dalam frekuensi mmWave untuk rangkaian 5G ini sangat penting. Kertas ini menyiasat beberapa model kehilangan penyebaran rangkaian 5G serta parameter yang paling sesuai untuk antenna polarasi-silang dalam persekitaran sel makro luar bandar di Malaysia. Model-model kehilangan penyebaran iaitu Model Kehilangan Penyebaran Berdekatan Ruang Bebas Bersama Rujukan Jarak (CI), dan Model Alpha, Beta, Gamma (ABG) atau dipanggil Model Pintasan Apungan (FI) telah dinilai dengan membandingkan beberapa parameter dan model yang paling hampir dengan kehilangan penyebaran yang sudah disampel apabila menggunakan antenna yang mempunyai corak dan polarasi yang berbeza melalui simulator sumber-terbuka. Kajian ini mendapati bahawa model FI boleh diadaptasi ke persekitaran majoriti di mana model ini menunjukan prestasi statistik punca min ralat kuasa dua (RMSE) yang terendah. Kajian model-model kehilangan penyebaran ini akan mempertimbangkan penggunaan simulator yang canggih atau pengukuran lapangan, dan juga kawasan luar bandar di negeri-negeri lain di Malaysia untuk kerja masa akan datang.

KEYWORDS: *5G networks; path loss modelling; rural macrocell*

1. INTRODUCTION

The Fifth Generation (5G) network is expected to provide a better quality of multimedia services for significantly larger number of mobile phone users [1,2]. To achieve this expectation, the standardization bodies proposed the Millimeter wave (mmWave) frequencies (i.e. the frequency range of 3 GHz to 300 GHz) to be used for the 5G given that the lower range of frequencies are mostly congested [2,3]. However, it was found in a number of studies that the mmWave has implementation issues especially in terms of path loss. For example, the study conducted by [4] shows that path loss in mmWave frequency at shorter distance under non-line of sight (NLOS) condition is above 100 dB. This indicates that mmWave frequencies is very sensitive to certain factors such as rain, atmosphere and blockages [5]. Based on this observation and given the importance of path loss in the network planning for optimal installation of 5G base stations, path loss needs to be accurately modelled.

There are a number of well-known path loss models proposed for use in the 5G networks. The basic path loss models include Close-in Free Space with Reference Distance (CI), and Alpha, Beta, Gamma (ABG) or Floating Intercept (FI) [1,6]. The majority of the other path loss models are derived by modifying the values of the path loss parameters of these basic models. However, it is difficult to obtain the optimal values of path loss parameters due to several factors such as different areas and countries, environment, and type of antennas. This lead to inaccurate optimal values of path loss parameters been established. Given this limitation, this paper will focus on finding the optimal values of path loss parameters in Malaysia context.

Besides the limitation previously stated, another limitation include the existing studies did not highlight the type of antenna polarization been used as well as the line of sight (LOS) or NLOS conditions been assumed. For instance, research conducted in [4] focus on different polarizations at LOS condition but fail to state the antenna polarization type use at NLOS condition. Another example is the work in [7] that do not mentioned the antenna polarization type been used. Given the newly stated limitation, this paper will be investigate on the 5G path loss model for the case of cross-polarized antennas. Cross-polarized antennas can be described as a polarization type where the transmitter transmits different polarization to the receiving antenna. According to [8], multiple and reconfigurable polarization of antennas (which includes cross-polarized antennas) will be used for 5G network implementation. Therefore, this shows the importance to study on 5G path loss model for cross-polarized antennas.

Besides the limitations on antenna polarizations, limited studies have been conducted in rural macrocell areas. Only research in [9] and [10] focused in this type of area. However, these two researches focused for CI model and its modification only. There could be possibility that FI or ABG models could be suitable for this area. Therefore, this research will utilizes these path loss models to identify whether these models are suitable for rural macrocell areas in Malaysia. Rural macrocell can be defined as larger coverage of cell sizes for undeveloped and less populated areas[11]. Although most 5G path loss studies were conducted in urban areas, the study for rural areas seems to be important as 5G network will also be implemented in rural areas in near future. Hence, by combining all the limitations of the existing studies, this paper will investigate the performance of 5G path loss models based on their optimal values of path loss parameters for cross-polarized antennas in Malaysia's rural macrocell environment. It should be noted that identification of the optimal values of the path loss parameters will be based on the values achieved from previous studies [4,6,7,9,10,12-14].

The remaining sections of this paper is described as follows. Section 2 explains the well-known path loss for 5G networks followed by Section 3 that highlights on the research methodology. Section 4 analyzes the results obtained while conclusion and improvements of this research are discussed in Section 5.

2. WELL-KNOWN PATH LOSS MODELS FOR 5G NETWORKS

The basic path loss models investigated in this paper are Close-In Free Space Reference Distance Path Loss Model (CI) and Floating Intercept or Alpha-Beta-Gamma Model (FI or ABG). Each model is described next.

2.1 Close-In Free Space Reference Distance Path Loss Model (CI)

The first basic path loss model for 5G networks is CI path loss model where this model depends on the frequency and it is obtained by applying the CI reference distance upon law made by Friis as below [1]

$$PL^{CI}(f_c, \mathrm{d}_{3D})[\mathrm{dB}] = FSPL(f_{c,} 1m) + 10n\log_{10}(d_{3D}) \quad (1)$$

where, n is the path loss exponent (PLE) found by measured data error minimization to Eq. (1), where d_{3D} is the seperation distance and it is must greater > 1m and FSPL(f_c, 1m) is the free space path loss equation at 1m given as below

$$FSPL\ [dB] = 32.4 + 20\log_{10}(\mathrm{f_c}) \quad (2)$$

where f_c is the carrier frequency.

The CI model is simple and accurate as it requires to optimize the PLE value only and it offers similar prediction of path loss to the measured path loss [6,13]. As an evidence, results obtained in [10] showed that when modelling the path loss at LOS settings using CI model, the result were almost identical to the measured path loss and hence indicating CI model is very accurate model under LOS. However, the weakness of this model is that the transmitter power needs to be standardized so that same PLE can be achieved at the same frequency [15].

2.2 Floating Intercept or Alpha-Beta-Gamma Model (FI or ABG)

The ABG model is determined by finding the best fit values for error minimization between model and the measured data. This is by introducing the α, β, and γ parameters. The equation for this model is as follows [6]

$$PL^{ABG}\left(f_c, d\right)[dB] = 10\alpha^{ABG}\log_{10}(d) + \beta^{ABG} + 10\gamma^{ABG}\log_{10}(f_c) \quad (3)$$

where α^{ABG} and γ^{ABG} are coefficients indicating the path loss dependence on distance and frequency, respectively, β^{ABG} is an optimized offset path loss value in dB, d is separation distance between receiver and transmitter in meters and f_c is the carrier frequency in GHz. When γ^{ABG} is 0, this model becomes Floating Intercept (FI) as follows:

$$PL^{FI}\left(f_c, d\right)[dB] = \alpha^{FI} + 10\beta^{FI}\log_{10}(d) \quad (4)$$

where α^{FI} and β^{FI} are the same parameter described as β^{ABG} and α^{ABG} respectively.

Sun et al. state that ABG or FI offers slightly improved accuracy of measured path loss [14]. Whereas [6] shows that ABG or FI model able to give good prediction at short range compared to CI model. However, the good prediction at short range only works at specific measurement range. Furthermore, ABG or FI model is difficult as it requires optimization of two or three parameters compared to CI.

2.3 Related Works Using CI and FI or ABG Models

A number of studies extended the basic path loss models for use in the outdoor 5G networks. For example, Third Generation Partnership Project (3GPP) and 5G Channel Model (5GCM) proposed their own path loss based derived from the CI and ABG models [1]. The advantage of their proposed path loss model is that the model can be used in the frequencies ranging from 6 GHz to 100 GHz and without modification on the values of the path loss parameters (i.e. PLE). However, this proposed model assumed the usage of omnidirectional antennas. It should be noted that the directional antennas will be considered for implementation in the 5G networks [8]. Directional antenna is the antenna pattern that makes an antenna to transmit or receive signal at a specific directions. While omnidirectional antenna is defined as an antenna patterns that make an antenna to transmit and receive signal at all directions.

Rappaport et al. [1] stated that the predicting of path loss on the basis of omnidirectional antenna as a replacement for directional antennas is not effective unless understanding on the modelling of the directional antenna patterns and true spatial and temporal multipath channel statistics are achieved. Zhao et al. [7] argues that similar parameter values of PLE, α, and β cannot be achieved under LOS condition when the CI and FI or ABG models are utilized for different antenna patterns. This might be due to the antenna gain of the omnidirectional antenna is independent as compared to the directional antennas and therefore lead to the omnidirectional antenna obtained lower path loss. Consequently, the results obtained by Zhao et.al support the argument made by Rappaport et al. with respect to the ineffectiveness for assuming the omnidirectional antennas as the replacements for directional antennas [1,7]. Given that the polarization method was not mention in the Zhao et.al, this becomes one of the limitations of their work.

To address the limitation faced by Zhao et al., [4] investigated the impact of using cross polarized antennas on path loss. This paper compares [4] and [7] given that these two works use similar frequency and identify that cross-polarized antenna requires higher parameter values of PLE, α, and β. This is probably due to higher path loss obtained by cross-polarized antennas in [4] compared to the unknown polarization used in [7]. This indicates that different antenna polarization requires different parameters values of PLE, α and β. This research [4] however, did not mention the polarization use for NLOS condition and investigation of antenna polarization in NLOS condition is important given the sensitivity of mmWave to blockages.

In regards to path loss study for rural macrocell areas, research in [10] investigated CI path loss model at 73 GHz frequency at rural macrocell area and obtained PLE of 2.16 and 3.04 for LOS and NLOS respectively. When the results obtained in [10] are compared with [4], it is observed that the PLE obtained in [10] is slightly lower than in [4] although the research in [10] uses higher frequency than the research in [4]. This is probably due to higher transmitter height used in [10] which causes the path loss measured in [10] to be lower than [4]. Nevertheless, the researchers in [10] used unknown polarization and focus

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at CI model only. Better results can be obtained if known polarization and other models are used.

3. RESEARCH METHODOLOGY

This chapter describes the methodology used for this research. The methodology of this research begins with the description on how the path loss samples is collected and ends with how the path loss models are benchmarked using Root Mean Square Error (RMSE) calculation.

3.1 Research Flow

The research begins with the collection of path loss samples by using a simulator called NYUSIM [15]. This software is very popular given that several researches had used this software for 5G path loss study as discussed in [16] and [17]. This is probably because NYUSIM is an open-source simulator and provides samples that are similar to field measurements of signal levels as claimed in [15]. Thus, these advantages motivates the usage of NYUSIM for this research. For further information on how NYUSIM works, it can be referred in [15].

Due to the time constraint and given the main aim of this research, this paper only considers path loss (PL) figure (the values obtained from the figure will become the path loss samples) in Power Delay Profile (PDP) output, though a number of output were generated from the software. One of the disadvantages of the NYUSIM is that only the PL figure of CI model was generated. This does not fulfil the aim of this paper where investigation of other basic path loss models need to be conducted. Therefore, additional results of other basic path loss models described in Section 2 will be plotted by using MATLAB software.

Fig. 1: Location for path loss samples collection for rural macrocell area.

Besides that, another disadvantage of NYUSIM is that this simulator is not a map-based channel simulator. This may lead to inaccurate values of path loss sample collection. Furthermore, these inaccurate values may contradict to the one of the NYUSIM's advantages which is to provide samples that are similar to field measurements. Therefore, a thorough geographical studies were conducted to identify the rural macrocell area in Malaysia to be as the reference location for collecting path loss samples. Based on the assistance of Google Earth, the chosen location is depicted in Fig. 1 where it is located in Tanjong Karang, Selangor. The reason for choosing this area is because this area is not similar to other rural areas in Malaysia where it is not covered by dense foliage. Therefore, input parameter of foliage loss provided by NYUSIM can be ignored for collecting path loss samples for this location. This is because, when testing the performance of NYUSIM, it is found out that less number of output samples especially for PDP output can be taken from this simulator when higher rain rate and foliage loss are considered for path loss study.

Table 1 describes the relevant parameters that will be used for processing path loss samples. This table has been categorized into two categories which are Channel Parameters, and Antenna Properties. It should be noted that some of the parameters used were based on weather websites on 6th April 2019, guidelines from Ericsson and International Telecommunication Union (ITU), some parameters in [13] and what is provided by NYUSIM [18-20].

Table1: Simulation parameters for path loss samples collection [13,18-20]

Environment	**Rural Macrocell**
Location	Tanjong Karang, Selangor
Channel Parameters	
Frequency (GHz)	40
Scenario	RMa
Conditions	LOS and NLOS
Distance (m)	100 to 10000
TX Power (dBm)	40 dBm
Antenna Height (m)	35
Barometric Pressure (mbar)	1011
Humidity (%)	88
Temperature (°C)	26
Rain Rate (mm/hr)	90
Polarization	Cross Polarized
Number of RX Locations	20
Antenna Properties	
Array Type	Uniform Rectangular Array
Number of TX Antenna Elements, Nt	16
Number of RX Antenna Elements, Nr	16
Number of TX Element Per Row,Wt	8
Number of RX Antenna Elements Per Row, Wr	8
TX Antenna Azimuth Half-Power Beam Width (HPBW),°	7.8
TX Antenna Elevation HPBW,°	7.8
RX Antenna Azimuth HPBW,°	7.8
RX Antenna Elevation HPBW,°	7.8

After the path loss samples using the parameters provided in Table 1 have been collected, the path loss samples are then extracted into MATLAB software for path loss modelling. The modelling of path loss are based from the models described in Section 2 alongside with the parameters from the previous studies [4,6,7,10,12-14]. Thereafter, the optimal parameters (parameters showing the closest plot to the path loss samples) from each path loss models are identified by observing the output plot from MATLAB. The predicted path loss values with their optimal parameters are compared with the path loss samples on the basis of Root Mean Square Error (RMSE) calculation. The calculation of RMSE are as below:

$$RMSE = \sqrt{\frac{\sum_{n=1}^{N}(\mathrm{PL}_{\mathrm{sampled,n}} - \mathrm{PL}_{\mathrm{predicted},n})^2}{N}} \tag{5}$$

where $PL_{sampled}$ is the path loss samples, $PL_{predicted}$ is the predicted path loss obtained from the path loss models and N is number of samples obtained from the path loss samples. Based on equation (5), the path loss model with respect to the identified parameters that has the lowest RMSE indicates that this model has the closest path loss prediction. Thus, this model is chosen as the suitable model to be used for 5G networks in rural macrocell environment in Malaysia. Calculation on RMSE percentage degradation between identified model and the suitable model is also conducted. The reason of conducting this calculation is to see how much the RMSE of other identified models are degraded from the RMSE of the suitable model. The percentage degradation is depicted on equation (6) below.

$$\text{RMSE Degradation (\%)} = \frac{|\, RMSE_{IdentifiedModel} - RMSE_{SuitableModel} \,|}{RMSE_{SuitableModel}} \text{ x } 100 \tag{6}$$

where $RMSE_{IdentifiedModel}$ is the RMSE of the other identified models and $RMSE_{SuitableModel}$ is the lowest RMSE identified from each models.

As a summary for this section, it is described in a form of research flow as shown in Fig. 2.

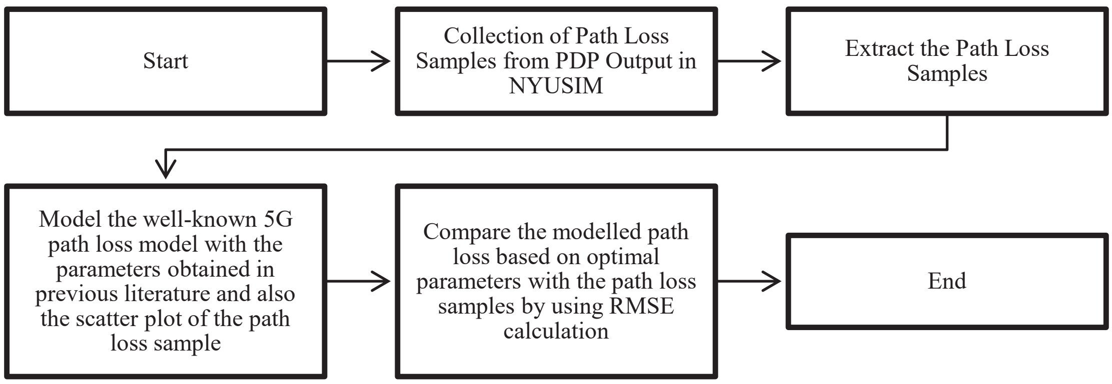


Fig. 2: Research flow for finding the accurate path loss model for 5G networks in rural macrocell environment in Malaysia.

4. RESULTS AND DISCUSSION

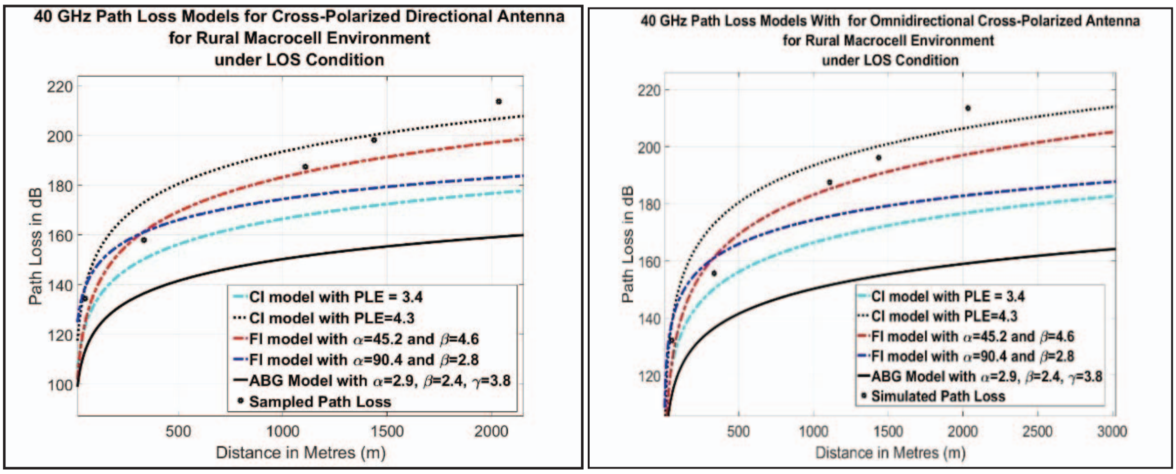
This section contains results obtained via simulation being compared with the path loss samples obtained via measurement. The parameters of path loss models obtained from the previous studies that are closest to the path loss samples are identified and later analyse based on RMSE calculation so as to identify path loss model with the most optimal parameter for different scenarios in rural macrocell environment in Malaysia. The scenarios studied include LOS or NLOS condition and cross-polarized antennas with respect to directional and omnidirectional patterns. Directional and omnidirectional patterns are considered because according to [13], directional antenna is used to cope with the feature of beamforming and beam combining techniques for implementing 5G networks, while omnidirectional antennas is studied because wireless user equipment (UE) uses this antenna pattern as UE needs to receive signal from all directions. Thus, showing that these two antenna patterns are required in the implementation of 5G networks.

The authors in [13] further defined the conditions where LOS is a condition where a clear propagation path occurred between transmitter and receiver while NLOS is a condition where transmitter and receiver are obstructed by blockage and there is no clear path of propagation between them. Thus, from the description of these two conditions, in real time, 5G users will always move from one location to another leading to changing condition of LOS or NLOS based on user's location.

Given the popularity of CI and ABG or FI models alongside with their parameters from [4,6,7,10-14], these basic path loss models are studied in this paper.

4.1 Analysis of Path Loss Model for Rural Macrocell in Malaysia at LOS Condition

Simulation results of path loss models alongside with the scatter plot of the path loss samples for rural macrocell environment under LOS condition at 40 GHz is shown in Fig. 3. It was observed that there are four parameters that are closest to the path loss samples for cross-polarized antennas with different patterns. For CI model, the PLE parameters that are closest to the path loss samples are 3.4 and 4.3. FI model that have α value of 45.2 dB with β value 4.6 and α value of 90.4 dB with β value of 2.8 are observed to be the closest to the path loss samples. Meanwhile, the parameters of ABG model that are closest to the path loss samples have values of α, β and γ that equal to 2.9, 2.4 dB and 3.8 respectively. For CI and FI models, the values of the parameters were similar to [4] while for ABG model, the values obtained were similar to [12]. These two studies were conducted based on field measurement in Malaysia and probably have the same environmental condition set in the NYUSIM for this paper.



(a) Directional cross-polarized antenna under LOS condition.

(b) Omnidirectional cross-polarized antenna under LOS condition.

Fig. 3: 40 GHz rural macrocell simulated path loss model alongside scatter plot under LOS condition.

Thereafter the RMSE calculation was performed so as to find the most optimal parameters of path loss model for rural macrocell in Malaysia. Table 2 showed that different path loss models are suitable for cross-polarized antennas with different antenna patterns. The suitable path loss model for directional pattern is CI model with PLE of 4.3 while FI model with α and β parameters of 45.2 dB and 4.6 is suitable for omnidirectional pattern. Referring to Table 2, for directional pattern, CI model with PLE of 4.3 has the lowest RMSE of 8.60 dB compared to other models with respect to different values of parameters. The reason why this model has the lowest RMSE probably because the PLE of 4.3 gives closer prediction of path loss when the separation distance are at 53.3 m, 1436.2 m and 2034.1 m as observed in Fig. 3(a). Compared to FI model with α and β parameters of 45.2 dB and 4.6 which scores the second lowest of RMSE (i.e. 7.33% degradation as compared to the RMSE obtained by CI model with PLE of 4.3), the β parameter of this model can only give two predicted path loss values that are closest to the path loss samples which is when the location of the receiver are 1109.4 m and 1436.2 m away from the transmitter. Thus, showing that CI model with PLE of 4.3 is suitable due to the number simulated/predicted path loss that are closer (smaller value of RMSE) to the path loss samples. Furthermore, CI model with PLE of 4.3 which was proposed in [4] also can be adapted for path loss modelling for rural macrocell environment in Malaysia under LOS condition when using Cross-Polarized Directional antenna.

Referring back to Table 2, FI model with α and β parameters of 45.2 dB and 4.6 have the lowest RMSE among the other models for omnidirectional pattern which is around 8.72 dB. Based on observation in Fig. 3(b), this model obtained the lowest RMSE probably because at distance of 1109.4 m, the β parameter of 4.6 obtained from this model provide closer predicted path loss values to the path loss samples where the difference between predicted path loss and path loss samples is around 2.22 dB. Compared to CI model with PLE of 4.3, where at 1109.4 m, larger difference value between the measured and predicted values of path loss was observed in which the difference is 7.85 dB. Hence, contributing to CI model with PLE of 4.3 to have slightly higher RMSE than FI model with α and β parameters of 45.2 and 4.6. Furthermore, the findings achieved by [4] is suitable to be adapted in Cross-Polarized antenna for LOS rural macrocell environment by using CI model with 4.3 PLE for directional type and FI model with α and β parameters of 45.2 dB and 4.6 for omnidirectional type.

Table 2: RMSE value for rural macrocell environment under LOS condition

Polarization	**Antenna Pattern**	**RMSE [dB]**				
		CI Model		**FI Model**		**ABG Model**
		PLE 3.4	PLE 4.3	α[dB]= 90.4 and β= 2.8	α[dB]= 45.2 and β = 4.6	α = 2.9, β [dB]= 2.4 and γ= 3.8
Cross-Polarized	**Directional**	22.80	8.60	17.24	9.23	37.45
	RMSE Degradation (%)	165.28	-	100.49	7.33	335.65
	Omnidirectional	21.99	9.83	17.05	8.72	36.47
	RMSE Degradation (%)	152.06	12.71	95.43	-	318.08

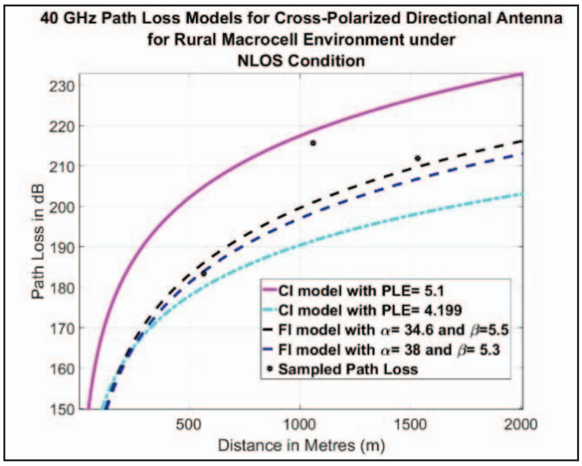
4.2 Analysis of Path Loss Model for Rural Macrocell in Malaysia at NLOS Condition

The results of path loss samples and the simulated path loss models with the best chosen parameters for rural macrocell environment in Malaysia under NLOS condition is shown in Fig. 4. It is observed in the figure that there are four parameters that have the closest prediction to the path loss samples. Parameters of CI model that are closest to path loss samples have PLE of 5.1 and 4.199 which were achieved in [4] and [7] respectively. Parameters α equal to 34.6 dB with β equal to 5.5 and parameters α of 38 dB with β of 5.3 of FI model are the closest to the path loss samples and the values of these parameters came from the research made in [13]. ABG model is excluded because most of parameters from this model of the previous studies give poor prediction of path loss under NLOS condition. Therefore, the only parameters that give closer prediction to the path loss samples obtained in this paper are the parameters α equal to 34.6 dB with β equal to 5.5 and parameters α of 38 dB with β of 5.3 of FI model and PLE of 5.1 and 4.199 of CI model.

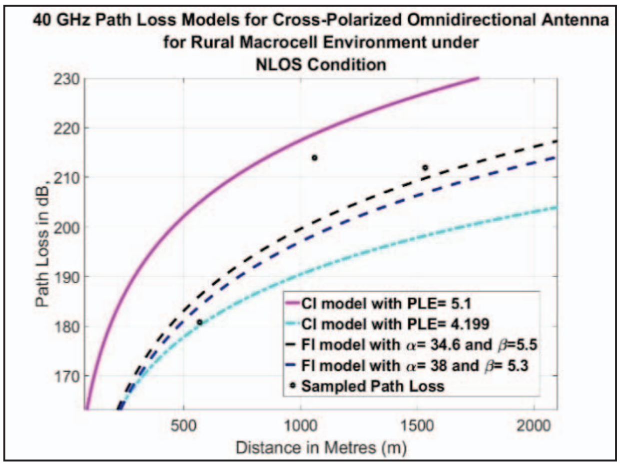
However, to simplify the process of finding the suitable path loss model based on the identified optimal parameters for Malaysia's rural macrocell environment under NLOS condition, RMSE calculations were conducted which are shown in Table 3 respectively. FI model with parameters α equal to 34.6 dB and β of 5.5 are suitable as it has the lowest RMSE around 8.70 and 8.14 for directional and omnidirectional respectively. The reason is because the parameter β of this model provide the smallest average of difference between the measured and predicted path loss for all distances measured (ADMPPL). This average is calculated as below.

$$\text{ADMPPL} = \frac{\sum_{i=1}^{N} |(\text{PL}_{\text{Predicted}})_i - (\text{PL}_{\text{Sampled}})_i \,|}{N} \text{ [dB]} \tag{7}$$

where $PL_{Predicted}$ is the predicted path loss in dB, $PL_{Sampled}$ is the sampled path loss, and N is the number of sampled path loss obtained in the NYUSIM simulator. The reason for utilizing Eq.(7) is because each identified path loss model has some predicted values that are close to the sampled path loss at certain distances. For instance and as tabulated in Table 5, using Cross-Polarized Omnidirectional antenna, CI model with PLE 4.199 gives closer prediction at 567.9 m where the difference between predicted path loss and path loss samples is around 0.71 dB, compared to FI model with α equal to 34.6 dB and β equal to 5.5 where the difference is around 5.28 dB. However, the latter model gives closer prediction of path loss when the receiver is at 1533.9m where the difference between predicted path loss and the sampled path loss is around 2.08 dB compared to the former model where difference is 13.69 dB. These examples leads to the requirement of using Eq.(7) for better justifications on why FI model with α equal to 34.6 dB and β equal to 5.5 has the lowest RMSE. Based on Table 6 and referring to omnidirectional type as an example, using equation (7), the average for this suitable model is 6.76 dB compared to the second lowest path loss which is FI model with α equal to 38 dB and β equal to 5.3 where the average difference around 7.93 dB. Thus, this lowest ADMPPL gives the former model to have lowest RMSE and leads to this model to have the best fit of slope to the path loss samples. Further, the results obtained also agree with the statement made by [14] as path loss prediction made by the FI model with parameters α equal to 34.6 dB and β of 5.5 give slight accuracy to the sampled path loss.



(a) Directional cross-polarized antenna under NLOS condition.



(b) Omnidirectional cross-polarized antenna under NLOS condition.

Fig. 4: 40 GHz rural macrocell simulated path loss model under NLOS condition.

Table 3: Sampled path loss and predicted path loss results for rural macrocell environment under NLOS condition

Polarization	**Antenna**	**Distance [m]**	**Sampled Path Loss [dB]**	**Predicted Path Loss [dB]**			
				CI Model		**FI Model**	
				PLE 4.199	PLE 5.1	α[dB]= 34.6 β = 5.5	α [dB] = 38 β = 5.3
Cross-Polarized	**Directional**	567.9	183.5	180.10	204.91	186.08	183.98
		1060.2	215.7	191.48	218.74	201.00	198.35
		1533.9	211.9	198.21	226.92	209.82	206.85
	Omni-directional	567.9	180.8	180.09	204.91	186.08	183.98
		1060.2	213.9	191.48	218.74	201.00	198.35
		1533.9	211.9	198.21	226.92	209.82	206.85

Table 4: RMSE value for rural macrocell environment under NLOS condition

Polarization	**Antenna Pattern**	**RMSE [dB]**			
		CI Model		**FI Model**	
		PLE 4.199	PLE 5.1	α[dB]= 34.6 β = 5.5	α [dB] = 38 β = 5.3
Cross-Polarized	**Directional**	16.18	15.20	8.70	10.44
	RMSE Degradation (%)	85.96	74.65	-	19.95
	Omnidirectional	15.17	16.63	8.14	9.62
	RMSE Degradation (%)	86.40	104.36	-	18.17

Table 5: Difference of sampled path loss and predicted path loss results for rural macrocell environment under NLOS condition

Polarization	Antenna	Distance [m]	| Sampled Path Loss - Predicted Path Loss | [dB]			
			CI Model		FI Model	
			PLE 4.199	PLE 5.1	α[dB]= 34.6 β = 5.5	α [dB] = 38 β = 5.3
Cross-Polarized	**Directional**	567.9	3.4	21.41	2.58	0.48
		1060.2	24.22	3.04	14.7	17.35
		1533.9	13.69	15.02	2.08	5.05
	Omnidirectional	567.9	0.71	24.11	5.28	3.18
		1060.2	22.42	4.84	12.9	15.55
		1533.9	13.69	15.02	2.08	5.05

Table 6: ADMPPL calculation results as to find justification on why FI Model with parameters of α equal to 34.6 dB and β = 5.5 has the lowest RMSE for rural macrocell environment under NLOS condition

Polarization	Antenna Pattern	RMSE			
		CI Model		FI Model	
		PLE 4.199	PLE 5.1	α[dB]= 34.6 β = 5.5	α [dB] = 38 β = 5.3
Cross-Polarized	**Directional**	13.77	13.15	6.46	7.63
	Omnidirectional	12.27	14.65	6.76	7.93

4.3 Analysis of Suitable 40 GHz Path Loss Models for Rural Macrocell in Malaysia

After finding out the suitable parameters of path loss models for cross-polarized antenna under LOS and NLOS conditions for rural macrocell in Malaysia, a summary of these suitable models is tabulated in Table 7. The table shows the most effective model that provide good path loss prediction is FI model and only CI model is obtained in Cross-Polarized Directional Antenna under LOS condition. This is probably because the various β parameter values of FI model obtained in the previous studies give the best fit of slope to the scatter plot of the path loss samples for most antenna patterns polarizations. Therefore, the results shown in Table 7 validates the statement made by [14] that ABG or FI model offers slightly improved accuracy of the path loss samples.

Another finding is that most of the suitable path loss models have the same parameter values for the case of different antenna patterns under NLOS condition. This is probably due to the slight difference of path loss samples when directional and omnidirectional patterns are used. Thus, these findings are in line with the findings obtained in [7] when using Cross-Polarized antenna with different patterns under LOS condition whereas results from NLOS condition differ from this study.

Table 7: Summary of path loss models suitable for rural macrocell environment in Malaysia

Condition	Antenna Pattern	Model	Parameters
LOS	Directional	CI model	PLE 4.3
	Omnidirectional	FI model	α[dB]= 45.2 and β = 4.6
NLOS	Directional	FI model	α[dB]= 34.6 and β = 5.5
	Omnidirectional	FI model	α[dB]=34.6 and β = 5.5

5. CONCLUSION AND FUTURE WORKS

This research aims to study the performance of 5G path loss models based on their optimal parameter values for cross-polarized antennas in Malaysia's rural macrocell environment. Results show that when tested in LOS and NLOS conditions with different antenna patterns, the FI model with their respective parameters is the most suitable model to be used for the majority of the scenarios of rural macrocell in Malaysia whereas CI model only can be used for Cross-Polarized Directional antenna under LOS scenario only. This is because the suitable models score the lowest RMSE compared to all models. Besides that, similar parameter values of FI model can be used for different antenna patterns under NLOS condtion only as small difference of sampled path loss values were obtained for both Cross-Polarized Directional and Omnidirectional antennas. As a conclusion, the results obtained from this research can be recommended to be standardized for Malaysia's 5G implementation for rural macrocell areas when using cross polarized antennas as the parameter values of the basic path loss models are from the studies made from previous researches.

This research can be improved by using map-based simulator or field measurements as the total number of path loss samples taken is less than 10 samples and at inconsistent distance intervals. This due to NYUSIM placed the receivers at unknown and random locations and at distances that causes the sampled path loss value to exceed the threshold limit set by this simulator. Thus, new weakness on using NYUSIM is found based on this findings. Other than that, the results could also be better if more locations of rural macrocell areas in Malaysia are tested. This is to ensure that the path loss models that are suitable for other rural macrocell areas are similar to the suitable models obtained in this research. Therefore, the results obtained in this research can be more accurate if large number of path loss samples is obtained through known locations and consistent distance intervals and tested in various rural macrocell locations in Malaysia.

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REFERENCES

[1] Rappaport TS, Xing Y, MacCartney GR, Molisch AF, Mellios E, Zhang J. (2017) Overview of millimeter wave communications for Fifth-Generation (5G) wireless networks-with a focus on propagation models. IEEE Transactions on Antennas and Propagation, 65(12): 6213-6230.

[2] Mitra RN, Agrawal DP. (2015) 5G mobile technology: A survey. ICT Express, 1(3): 132-137. https://doi.org/10.1016/j.icte.2016.01.003

[3] Prabu RT, Benisha M, Bai VT, Yokesh V. (2016) Millimeter wave for 5G mobile communication application. In Proceedings of 2016 2nd International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB), 27-28 February 2016, Chennai, India; pp. 236–240.

[4] Al-Samman AM, Hindia MN, Rahman TA. (2016) Path loss model in outdoor environment at 32 GHz for 5G system. In Proceedings of 2016 IEEE 3rd International Symposium on Telecommunication Technologies (ISTT), 28-30 November 2016, Kuala Lumpur, Malaysia; pp. 9–13.

[5] Andrews JG, Buzzi S, Choi W, Hanly S, Lozano A, Soong ACK, Zhang JC. (2014) What will 5G be? IEEE Journal on Selected Areas in Communications, 32(6):1065-1082.

[6] Sun S, Rappaport TS, Rangan S, Thomas TA, Ghosh A, Kovacs IZ, Rodriguez I, Koymen O, Partyka A, Jarvelainen J. (2016) Propagation path loss models for 5G urban micro-and macro-cellular scenarios. In Proceedings of 2016 IEEE 83rd Vehicular Technology Conference (VTC Spring), 15-18 May 2016, Nanjing,China; pp.1–6.

[7] Zhao X, Li S, Wang Q, Wang M, Sun S, Hong W. (2017) Channel measurements, modeling, simulation and validation at 32 GHz in outdoor microcells for 5G radio systems, IEEE Access, 5:1062-1072.

[8] Gupta A, Jha RK. (2015),A survey of 5G network: architecture and emerging technologies. IEEE Access, 3:1206-1232.

[9] MacCartney GR, Rappaport TS. (2017) Study on 3GPP rural macrocell path loss models for millimeter wave wireless communications. In Proceedings of IEEE International Conference on Communications, 2017, 21-25 May 2017, Paris,France; pp. 3–9.

[10] MacCartney GR, Rappaport TS. (2017) Rural macrocell path loss models for millimeter wave wireless communications. IEEE Journal on Selected Areas in Communications, 35(7): 1663-1677,

[11] Rural Area. [https://www.nationalgeographic.org/encyclopedia/rural-area/].

[12] Al-Samman AM, Rahman TA, Hindia MHDN, Daho A, and Hanafi E (2018) Path loss model for outdoor parking environments at 28 GHz and 38 GHz for 5G wireless networks. Symmetry, 10(12):1-15. doi: 10.3390/sym10120672.

[13] Rappaport TS, MacCartney GR, Samimi MK, Sun S. (2015) Wideband millimeter-wave propagation measurements and channel models for future wireless communication system design. IEEE Transactions on Communications, 63(9): 3029-3056.

[14] Sun S, Rappaport TS,Thomas TA, Ghosh A, Nguyen HC, Kovacs IZ, Rodriguez I, Koymen O, Partyka A. (2016) Investigation of prediction accuracy, sensitivity, and parameter stability of large-scale propagation path loss models for 5G wireless communications. IEEE Transactions on Vehicular Technology, 65(5): 2843-2860.

[15] Sun S, Maccartney GR, Rappaport TS. (2017) A novel millimeter-wave channel simulator and applications for 5G wireless communications. In Proceedings of IEEE International Conference on Communications, 21-25 May 2017, Paris, France; pp.1-5 .

[16] Reddy MMP. (2018), The effect of cross polarization and co polarization on channel modeling in 5G Communications. International Journal for Science and Advance Research in Technology, 4(3):53-58.
Retrieved from http://ijsart.com/Content/PDFDocuments/IJSARTV4I321194.pdf

[17] Budalal AA, Islam MR, Habaebi MH, Rahman TA. (2018) Millimeter wave channel modeling - present development and challenges in tropical areas. In Proceedings of the 2018 7th International Conference on Computer and Communication Engineering (ICCCE), 19-20 September 2018, Kuala Lumpur,Malaysia; pp.23–28.

[18] Weather Forecast. Available: https://www.worldweatheronline.com/
[19] Characteristics of Precipitation for Propagation Modelling P Series Radiowave Propagation. [https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.837-6-201202-S!!PDF-E.pdf]
[20] Advanced Antenna Systems for 5G Networks. [https://www.ericsson.com/4a8a87/assets/local/reports-papers/white-papers/10201407_wp_advanced_antenna_system_nov18_181115.pdf]