VOL. 16, NO. 2, 2017, 11-15
www.fke.utm.my/elektrika
ISSN 0128-4428

ELEKTRIKA
Journal of Electrical Engineering

Modelling Impact of Topography Gradient on Signal Path Loss Along the Road Way for 5G

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Abstract: Prediction of outdoor path loss, *PL*, model is crucial for the design and planning of fifth generation (5G) wireless communication systems. Different propagation models have been proposed to approximate cellular network's coverage for diverse surroundings including for along the road way setting. In Malaysia, Road ways are not entirely on flat terrain with several segments of the roads commonly experience topography elevation. This paper presents simulation studies on the impact of topography gradient towards *PL* for different millimeter wave frequency bands based on available outdoor *PL* models. Three outdoor *PL* models were compared, namely close-in (CI) free space reference distance model, floating intercept model (FI), as well as alpha-beta-gamma (ABG) model. Five millimeter frequency bands at 28, 32, 38, 46 and 73 GHz with different gradients and line-of-sight (LOS) scenarios were investigated in the simulation. *PL* computation using the selected models indicated that topography elevation along roadways may contribute to deviation of no more than 2 dB relative to computation for flat terrain. However, selection of model used may results in different precision in *PL* modeling.

Keywords: mmWave, 5G, outdoor path loss, topography gradient, roadways

1. INTRODUCTION

The proliferation usage of personal communication devices such as tablets, smart phone, plus consumer demand for ubiquitous data access have encouraged carriers to provide higher data rates and improve their service's quality. Fifth generation (5G) wireless technologies are proposed to operate at millimeter wave (mmWave) in order to meet the above-mentioned high data-rates demand and expand capacity of next-generation wireless communication system [1]. Vehicular wireless network is one of the scenarios in which 5G technologies are expected to operate and thus, has been intensively studied [2]. Among the aims are to improve traffic safety and efficiency through exchange of information between vehicles as well as between vehicles and roadsides infrastructure unit wirelessly.

Inter-vehicles signal wave propagation conditions are not easily characterized. Thus, a proper deployment of roadside infrastructures could complement the situation and provide communication coverage where inter-vehicles communication may not be reliable. Light posts have been proposed for the placement of base station transceiver due to its close vicinity to the road side and the possibility to reduce the need to erect new infrastructure by telecommunication operators [3].

Propagation path loss, *PL*, modeling is essential when planning wireless communication network. The developed model could provide easy estimation of *PL* especially for recurring environments with practically similar surrounding. Different outdoor *PL* models have been proposed for mmWave in the literature. These models nevertheless had not considered topography gradient or ground elevation when predicting *PL* [4-12]. Given that certain segment of roadways built would experience elevation [13], it is therefore necessary to determine whether topography gradient could influence *PL* prediction. This paper presents primary investigation on how roadway gradients could affect *PL*, taking into consideration different outdoor *PL* models available, road slope angles as well as potential placement of 5G base station access point (Bs).

This paper is organized as follows: Section 2 provides details on three outdoor *PL* models used in this investigation. Simulation settings for this study are described in Section 3. Next, section 4 presents findings and finally draws conclusion from the results.

2. OUTDOOR PROPAGATION MODELS

Various empirical studies have been conducted by wireless communication research community in characterizing signal wave propagation for different outdoor environments. Commonly, these models put emphasis on the estimation of average signal wave's strength at the receiver-end, *Rx*, for a range of separation distance, *d*, from the transmitter-end, *Tx*. The signal wave attenuation is then represented as *PL*. Friss transmission formula provides the basic mathematical expression used to develop *PL* models. The formulation states that the received power, P_r in dBm for free space condition as [4]

$$P_r = P_t + G_t + G_r - 20\log(\frac{4\pi d}{\lambda}) \tag{1}$$

where P_t is the power transmitted in dBm, G_t and G_r represent *Tx* and *Rx* antenna gain in dBi respectively, d is the wireless link distance, and λ is frequency wavelength. The wavelength is $\lambda=\frac{c}{f_c}$, where c is the speed of light and f_c is the carrier frequency. The *PL* term in Eq. (1) is f_c and d dependent. The *PL* is one of the main parameters describing propagation channel large-scale effects on the received signal at *Rx* as a function of f_c and d [4]. One of the most referred *PL* models is Close-in (CI) model, which has mathematical equation presented below [5]

$$PL^{CI}(f,d)[dB] = FSPL(f,1m)[dB] + 10n\, log_{10}(d) + \chi_{\sigma}{}^{CI} \quad \text{where } d>1\text{m} \qquad (2)$$

where *n* denotes the single model parameter, the *PL* exponent (PLE). The *10n* term describes *PL* in decibels in terms of decades of distances beginning at 1 meter (m). *d* is the 3D *Tx-Rx* separation distance, and $FSPL\ (f, 1\text{ m}) = 20\log_{10}(\frac{4\pi f}{c})$ denotes the free space *PL* in dB at a *Tx-Rx* separation distance of 1 m at the carrier frequency *f*, with *c* being the speed of light. The CI model has only one parameter, *n*, to be optimized and has an intrinsic *f*-dependent *PL* within the 1m *FSPL* value [6]. CI's *PL* also showed excellent parameter stability and accuracy prediction for cases of *d* being outside of the original measurement range compared to other *PL* model [7,8].

Another *PL* prediction model regularly used as benchmark in evaluating proposed mmWave model is *floating intercept* (FI) model that was used in WINNER II and 3GPP channel model [8,9]. The FI *PL* model eliminates the assumption of free space *PL* model at reference distance [10]. The FI equation is given as [4,8,10]:

$$PL^{FI}(d) = 10\alpha\, log_{10}(d) + \beta + \chi_{\sigma}{}^{FI} \qquad (3)$$

with β being the intercept in dB, α is the slope of the line (PLE), and $\chi_{\sigma}{}^{FI}$ is zero mean Gaussian random variable with a standard deviation, σ in dB. This model has no physical basis, but merely fits the best line to measured data to create a floating intercept linear equation model, that is only valid over the specific distance for which measurement were made. α only has a physical meaning similar to PLE, when β is set equal to the free space reference distance close to antenna at *Tx* [8].

An alternative reference *PL* model is Alpha-beta-gamma (ABG) model, given as [11]:

$$PL^{ABG}(f,d)[dB] = 10\alpha\, log_{10}(d) + \beta + 10\gamma\, log_{10}(f) + \chi_{\sigma}{}^{ABG} \qquad (4)$$

where $PL^{ABG}(f,d)$is a *PL* in dB over *f* and *d*, α and γ are coefficients that depend on *d* and *f* respectively, β is an optimized offset value for *PL* in dB. *f* is in GHz, and $\chi_{\sigma}{}^{ABG}$ is shadowing standard deviation describing large-scale signal fluctuation. The range of the three *PL* models above covered frequency range of 28 to 73 GHz [4].

3. SIMULATION SETTINGS

Simulation investigation was intended to demonstrate relationship of roadway gradients toward the *PL*. The simulated environment involved condition where ground elevation take place within a 5G Bs's cell coverage. The range of roadway gradients were defined to be 5°, 10°, and 15° based on observation of five roadways' gradient within Universiti Teknologi Malaysia (UTM) Johor Bahru Campus and guideline of road design by Malaysia Public Works Department (JKR) [14].

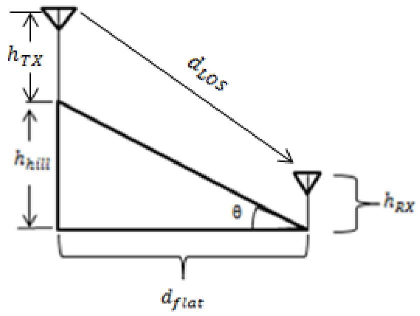

Figure 1: Simulation setting for investigated scenario

Figure 1 shows illustration of the simulated scenario. h_{TX} is height of the *Tx* from ground level to the position of *Tx'*s Bs for the case where the Bs is fixed onto a lamp post. Variation of h_{TX} is between 6 to 14 m. $h_{hill}$is height of ground due to topography elevation, whereas h_{RX} is height of *Rx* or mobile users, fixed at 1.5 from ground level. d_{flat} is flat terrain separation distance between *Tx* and *Rx*, d_{flat} range is beween 0 to 250m, which is close to the expected maximum coverage for a given 5G mmWave Bs [9]. θ is elevation of roadway gradient in degree. The simulation was performed for line-of-sight (LOS) scenario. The simulation asssumed no obstruction between *Tx* and *Rx*. In the *PL* model equation, the parameter *d* is the 3D *Tx-Rx* LOS distance (d_{LOS}).

All the parameters for the CI, FI and ABG models were extracted from the literature. The value of *n* for CI model and value of α and β for FI model were taken from [10], while the value of ABG parameters (α, β, γ) were refering to [12]. The parameters are for LOS condition. These parameter values are shown in table 1. The operating frequencies simulated were 28, 32, 38, 46, and 73 GHz based on proposed frequency bands for 5G from World RadioCommunication Conference 2015 (WRC15).

Table 1: Parameters for simulated *PL* models

***PL* model**	**PLE/ α**	**β(dB)**	**γ**
CI	1.90	-	-
FI	1.76	64.22	-
ABG	2.1	31.7	2.0

In LOS environment, the PLE in CI model is 1.90 and the slope ($\boldsymbol{\alpha}$) of floating-intercept path loss is 1.76. The values are less than 2 due to assumption of ground reflection and multipath components [10]. The simulation study had thus observed impact of different operating frequencies, topography elevation angles, Bs heights, plus the use of different outdoor *PL* models.

4. RESULT AND ANALYSIS

4.1 Investigation on *PL* prediction with various *f*

To analyze the impact of *f* on *PL* prediction, computation of *PL* was performed for the five investigated operating *f* as previously mentioned. Comparisons were made between the three PL models with fixture of gradient at 10°, and h_{TX} at 14m. Figure 2 and Figure 3 depict the simulated PL. The two figures generally show that PL steadily increases with increment of *f*. Largest computed PL values at 73 GHz and d_{flat}=250m were 119dB, 115dB and 107 dB for ABG, CI and FI models respectively. FI PL model calculated the lowest value since the equation is not *f* dependent.

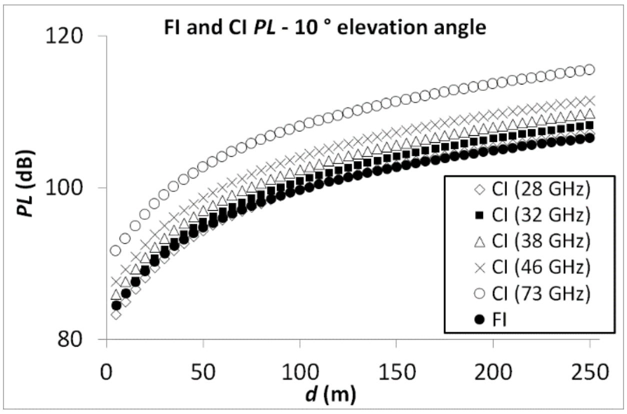

Figure 2: Predicted CI and FI PL values at roadway gradient of 10°, and $h_{TX} = 14m$.

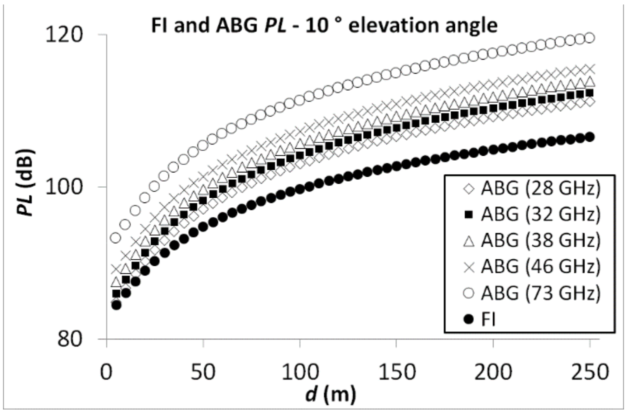

Figure 3: Predicted ABG and FI PL values at roadway gradient of 10°, and $h_{TX} = 14m$.

4.2 Investigation on impact of topography gradient

From preceding results indicating steady increment of PL with *f*, the impact of topography gradients towards PL based on different ground elevation angles was investigated for the two maximum examined range of *f* namely at 28 and 73 GHz. Inspection was done for elevation angle of 5°, 10° and 15°. Figure 4 presents predicted PL using CI and FI models, whereas Figure 5 shows computation results based on ABG and FI models. Computation based on the three PL models demonstrates that d_{LOS} differences due to elevation angles do not contribute to substantial differences pertaining to PL approximation for the two examined *f*. Deviation of PL was found to be less than 1 dB.

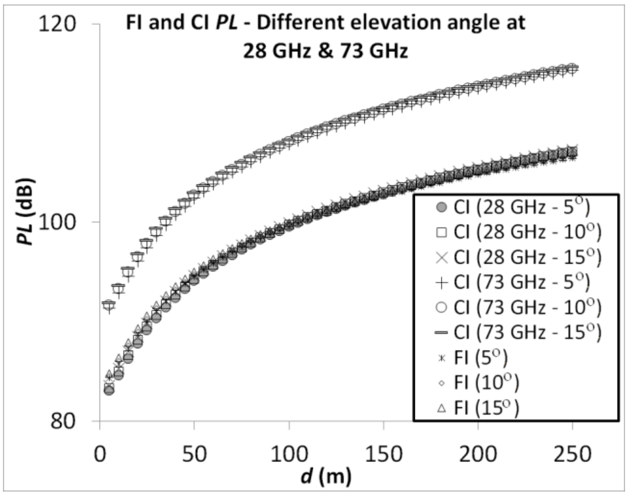

Figure 4: Predicted CI and FI PL values at roadway gradient of 5°,10°,and 15°, and $h_{TX} = 14m$ and *f* at 28GHz and 73 GHz

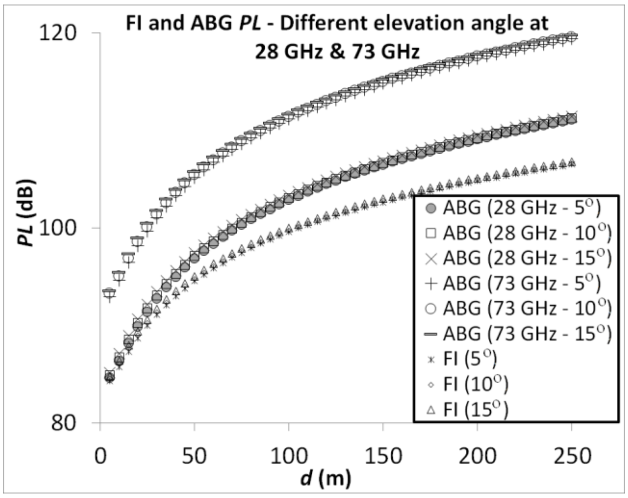

Figure 5: Predicted ABG and FI PL values at roadway gradient of 5°,10°,and 15°, and $h_{TX} = 14m$ and *f* at 28GHz and 73 GHz.

Table 2: Comparison between ABG, CI and FI PL models at 28 and 73 GHz, $d_{flat} = 250m$.

f (GHz)	*PL* model	Degree (θ)		
		5°	10°	15°
28	ABG	111.09 dB	111.23 dB	111.44 dB
	CI	107.02 dB	107.15 dB	107.34 dB
	FI	106.62 dB	106.62 dB	106.79 dB
73	ABG	119.41 dB	119.55 dB	119.76 dB
	CI	115.35 dB	115.48 dB	115.67 dB
	FI	106.50 dB	106.62 dB	106.79 dB

Further assessment based on the predicted PL at 73 GHz is presented in Table 2 for diverse elevation angles and different PL models. The table shows that while elevation angle doesn't influence significantly PL computation, using different PL models could cause predicted PL to be different by 13 dB.

4.3 Investigation on impact of Bs height

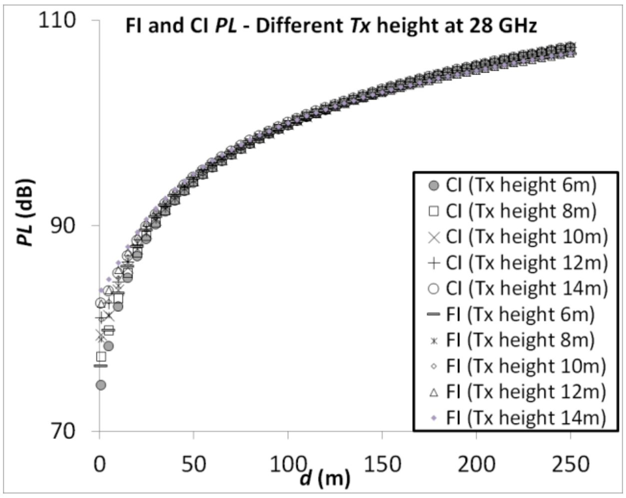

Figure 6: FI and Cl PL values with different height of transmitter, f=28GHz, degree= 15°.

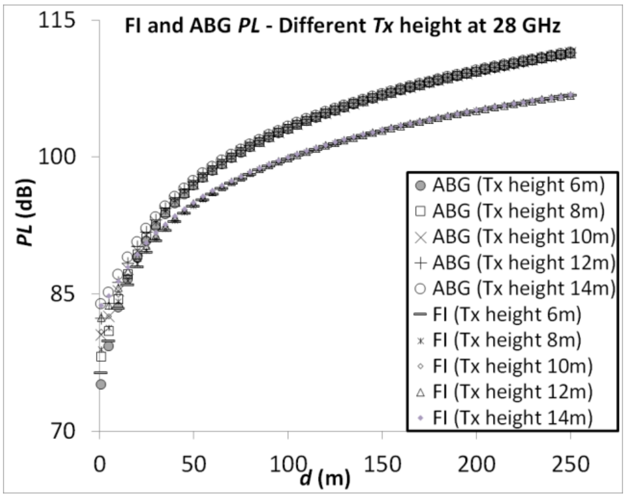

Figure 7: FI and ABG PL values with different height of transmitter, f=28GHz, degree= 15°.

Figure 6 and Figure 7 presents comparison results for the impact of Bs height when fitted onto lightpost-like infrastructure for $h_{TX} = 6$, 8, 10, 12, and 14m. For this comparison, the degree of gradient was fixed to be 15°. From Figure 6, PL difference due to Bs height could be up to 8dB when Rx is close to the Bs. Upon d_{flat} being 10m the difference would drop to about 3dB and would continuously decrease in value to be almost similar when $d_{flat} = 50m$ for the examined h_{TX}. The same trend was observed from Figure 7. Assessment of predicted PL in both Figure 6 and Figure 7 also demonstrate the use of different models could cause differences, up to 9 dB.

5. CONCLUSION

In this paper, simulation studies for investigation of roadways gradient differences impact towards PL prediction was shown. The impact of Bs height and f variations as well as the use of different PL models for the investigated scenarios were also demonstrated. Results indicate that the examined variations may not be significant based on benchmark modeling at mmWave for outdoor case. In addition, the results also suggested that topography elevation cannot be precisely determined based on received signal wave strength at proposed mmWave bands given the small PL differences expected. However, attention may need to be given regarding the PL model opted, which could cause differences of up to more than 10 dB for a particular setting. Results from this simulation could also act as reference should measurement campaign be carried out for validation of these findings.

ACKNOWLEDGMENT

This work was supported by the Ministry of Higher Education Malaysia and Universiti Teknologi Malaysia through the Higher Institute Centre of Excellence - Wireless Communication Centre (HiCOE-WCC) grant, vot R.J130000.7823.4J217.

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