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# Rain attenuation statistics over 5G millimetre wave links in malaysia

**Mustafa Ghanim[1], Manhal Alhilali[2], Jafri Din[3], Hong Yin Lam[4]**
[1,2,3]Wireless Communication Centre, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, Malaysia
[4]Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Hab Pendidikan Tinggi Pagoh, Malaysia

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**ABSTRACT**

Millimetre wave band is a solid contender to be utilized for the future 5G wireless systems deployment. Rain-induced attenuation is a major disadvantage at these frequencies. This paper presents statistics of rain-induced attenuation and rainfall data for two years of horizontally polarized links propagating at 38 GHz and 26 GHz over a terrestrial path link of 301 meters. From the analysed datasets, a rain rate around 116 mm/h exceeded at 0.01% of the time of an average year, while the links recorded 16 and 9.5 dB at the same percentage of time for 38 and 26 GHz respectively. The study aims to identify the prediction model that deliver most reasonable predictions for 5G links operating in Malaysian tropical climate. ITU-R P.530-17, Mello's, and Ghiani's models were all examined. Using ITU-R model, relative error margins of around 3.8%, 30% and 49.7% alongside 22.3, 9.5, 33% were obtained in 0.1%, 0.01% and 0.001% of the time for 26 and 38 GHz respectively. Curiously, ITU-R model demonstrates better predictions to measured rain attenuation with lower error probability. This study highlights the need for new prediction models for short path-length 5G links and helps to improve the design of terrestrial links operating at millimetre wave frequencies in tropical regions.

***Corresponding Author:***

Jafri Din,
Wireless Communication Centre, Faculty of Electrical Engineering,
Universiti Teknologi Malaysia,
81310 Johor Bahru, Johor, Malaysia.
Email: jafri@utm.my

## 1. INTRODUCTION

For the currently deployed 4th generation of wireless communications, excess attenuation due to rain can be neglected. However, the demand for greater bandwidth by telecommunication providers requires the move to higher frequency bands in the implementation of the next 5th generation (5G) wireless communication [1]. In tropical regions, the occurrence of rain is more frequent, and the effect on radio links becomes dramatically high for frequencies above 7 GHz, due to higher rain intensities [2], [3]. Therefore, it is fundamental to precisely predict rain-induced attenuation for the planning and design of higher capacity point-to-point 5G radio communication system [4]. The 1-minute rain rate statistics and the rain rate exceeded at a certain percentage of the average year are the most broadly utilized parameters to determine the rain-induced attenuation [5], [6]. Numerous models have been created utilizing these parameters to predict the rain-induced attenuation. However, the majority of these models are conducted and focused on the temperate regions [7]. This could create an issue when applied to the tropical countries due to higher rain rates in tropical regions in comparison to temperate regions. To that end, A campaign to measure the rain attenuation statistics was carried in Universiti Teknologi Malaysia (UTM) [8]. Some of the most widely used prediction models are empirically based, which uses historical databases for given geographical regions [9], while others are physically based, designed to recover the physical attenuation process, which in turns requires more parameters and longer time to process [10]. Many studies have analysed rain attenuation extensively and various models to overcome the issue have been developed [9]-[12] that primarily enhance the ITU-R P. 530-17 [13] for specific scenarios.

This study investigate three established rain attenuation models, selected to address different types and assumptions used while designing the models, namely, ITU-R P. 530-17 [13] which is the most widely used, Mello model [9] which is usually used in tropical regions, Ghiani's model [14] which is a new physical based model.

The following sections are organized as follow: In Section 2, prediction models used for the estimation of rain attenuation are briefly discussed. Followed by the system setup, and data collection procedure is discussed. Result and discussion section summarize the accuracy of prediction models. Finally, a conclusion is given in Section 5, and the possible future research based on the findings is presented.

## 2. RAIN ATTENUATION PREDICTION MODELS

Rain-induced attenuation usually presented as the product of rain specific attenuation $\gamma_R$ (dB/km) and the effective propagation path-length $d_{eff}$(km) [15]. The rain-induced attenuation, $A$ (dB), above $p$ percent of time is then defined as:

$$A = \gamma_R \, d_{eff} = \gamma_R \, d * r \tag{1}$$

where $d$ is the actual path-length in km, and $r$ is path reduction factor at $p$ percentage of time.

In the ITU-R recommendation P.838–3 [15], the technique to calculate the specific attenuation from the rain intensity was described. The specific rain attenuation, $\gamma_R$ (dB/km) is computed from the rain rate $R$ (mm/ h) exceeded at $p$ percent of the time by applying the power-law relationship as,

$$\gamma_R = kR^{\alpha} \tag{2}$$

where, $k$ and $\alpha$ are frequency dependent coefficients. These constants can be found in the recommendation tables. Due to the rainfall non-uniformity along the propagation path, a reduction factor of the actual link path-length is presented to reduce the effective path length [10]. However, for shorter links the reduction factor takes values larger than unity, to overcome the model's initial design assumptions. Each model addresses this problem in different way. In this paper three different models included, those of the ITU-R Model [13], Mello's model [9], Ghiani's model [14], these models are briefly explained in the following subsections.

### 2.1. ITU-R P.530.17 Model

The ITU-R recommendation [13] presents the rain attenuation, as described earlier in 2, depending on the path reduction factor, which considers the time-space variability of rain intensity along path. The following reduction factor is presented

$$r = \frac{1}{0.477d^{0.633}\, R_{0.01}^{0.073\propto} f^{0.123} - 10.579(1 - \exp(-0.024d))} \tag{3}$$

where $r$ is the distance factor, $f$, is the frequency in GHz, $d$, is the distance. The maximum value of $r$ is capped at 2.5.

The resulted rainfall attenuation value exceeded at 0.01% of the time in an average year, is scaled by an empirical formula to other percentages of time between 1% and 0.001% by using the following equation:

$$\frac{A_p}{A_{0.01}} = C_1 p^{(} C_2 + C_3 \log 10p) \tag{4}$$

where,

$$\begin{cases} C_1 = (0.07^{c_0})\left(0.12^{(1-c_0)}\right) \\ C_2 = 0.855C_0 + 0.546(1 - C_0) \\ C_3 = 0.139\, C_0 + 0.043(1 - C_0) \end{cases} \tag{5}$$

And,

$$C_0 = \begin{cases} 0.12 + 0.4(\log_{10}\left(\frac{f}{10}\right)^{0.8} \ f \geq 10GHz \\ 0.12 \ f < 10GHz \end{cases} \tag{6}$$

This model is recommended to be used worldwide, by providing locally measured rain rates, or by using ITU-R maps, it can help in the prediction for any frequency between 1 and 100 GHz with path-lengths up to 60 km.

### 2.2. Mello's Model

This model uses multiple non-linear regressions to obtain the required numerical coefficients from rain rate and rain cell diameter. And was initially designed using the databanks provided the ITU-R. Mello [9] have used similar procedure as done in [13] which is used by the presented ITU-R model, and overcome the limitation of the ITU-R model by using the complete rainfall distribution as the models input, and keep using the reduction factor parameters from the ITU-R model. In order to correct these limitations, a new effective rainfall rate coefficient ($R_{eff}$) was developed., which helps to predict the rain-induced attenuation complementary cumulative distribution function (CCDF) instead of a single percentage of time, and can be computed as:

$$A_p = \gamma_R . d_{eff} = k(R_{eff}(R,d))^{\alpha} \frac{1}{1+\frac{d}{d_0(R)}} \tag{7}$$

where,

$$d_{eff} = \frac{1}{1+\frac{d}{d_0}} d = rd \tag{8}$$

here $d$ is the link path-length, $r$ as presented earlier, the path reduction factor. The definition for $R_{eff}$ and equivalent rain cell diameter $d_0$ is then given by:

$$R_{eff} = 1.763R^{0.753+\frac{0.197}{d}} \tag{9}$$

$$d_0 = 119R^{-0.244} \tag{10}$$

Multiple nonlinear regressions are used to obtain the numerical coefficients in (9) and (10), using the databanks provided the ITU-R.

### 2.3. Ghiani Model

Ghiani [14] has developed novel physically based approach to model the rain attenuation affecting terrestrial links. This model is devised by simulating the interaction between terrestrial links and synthetic rain maps, which are specifically exploited to investigate the path reduction factor, considering the spatial inhomogeneity of rainfall along the link. The accuracy of the proposed model was tested against the MultiEXCELL-derived rain attenuation statistics and against the independent set of experimental data included in the DBSG3 database made available by ITU-R. The rain attenuation exceeded with probability $p$ in an average year can be calculated as

$$A(p,d) = KR(p)^{\propto} d\left[a(d)e^{-b(d)R(p)} + c(d)\right] \tag{11}$$

where $R(p)$, extracted from the local input rain rate complementary cumulative distribution function (CCDF), is the rain rate exceeded with probability $p$, coefficients $a, b,$ and $c$ are defined as:

$$\begin{cases} \mathrm{a} = -0.8743e^{-0.1111d} + 0.9061 \\ \mathrm{b} = -0.0931e^{-0.0183d} + 0.1002 \\ \mathrm{c} = -0.6613e^{-0.178d} + 0.3965 \end{cases} \tag{12}$$

## 3. SYSTEM SETUP AND DATA COLLECTION

Two experimental millimetre wave links operates at 26 and 38 GHz were mounted at UTM Johor campus [5]. The links were set between the roof of microwave lab and the second transceiver was installed on a telecom tower with a path-length between the two antennas of 301 meters. Both antennas are covered by radomes to prevent wetting antenna conditions. The Automatic gain control output level of the antenna unit is then connected to a PC using a data acquisition system and the sampling interval was set to 1-second. The logged data then stored into databank using C language written. The data was collected over duration of 24 months and a satisfactory data availability of 99.95% was achieved.

A tipping-bucket rain gauge with tip size of 0.2 mm was set up on the same roof. The rain gauge added a time stamp for each tip with 0.1 second resolution. Similar method to calculate 1-minute rain rate used in [16] is used for to present the data in 1-minute integration time. For 0.01% of the time the 1-minute rain rate was found to be around 116 mm/h at the measurement site. Figure 1 show the rain-induced attenuation versus rain rate for both investigated links of 38 and 26 GHz. The attenuation reaches up to 25 dB on the 38 GHz link, and 16 on the 26 GHz link. This highlight that even with short link distance, that will be used for 5G applications, the rain attenuation should not be underestimated.

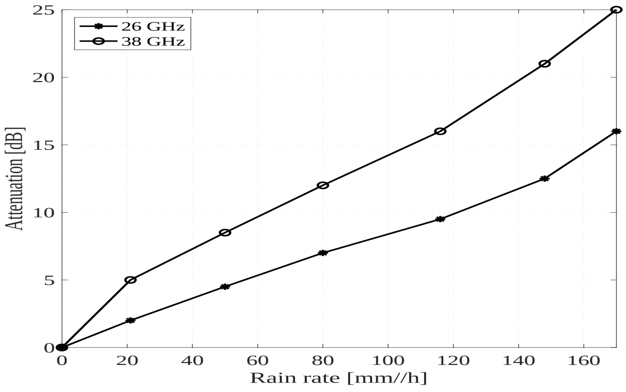

Figure 1. Distribution of rain attenuation versus rain rate

## 4. RESULT AND DISCUSSIONS

Figure 2 presents the prediction error plots of ITU-R Model versus rainfall rates for 38 and 26 GHz under horizontal polarization respectively.

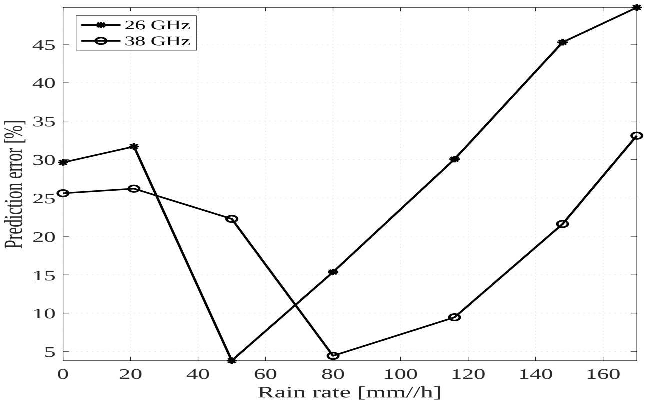

Figure 2. ITU-R P.530-17 prediction error with rain rate

It was found that the error in prediction is higher for 38 GHz link as compared to 26 GHz. The prediction error increases with higher rain rate, due to the initial design of the model based on the data bank from temperate regions, where the rain rates will not reach these high values.

Figure 3 present comparison between the measured values for 38 and 26 GHz links, and the selected attenuation models. The ITU-R prediction slightly overestimated the rain attenuation and the highest disparity was 8 dB at 38 GHz link. The disparity might be due to the fact that the initial design factors investigated to predict the rain attenuation in the model have not considered the propagation tropical rain.

Additionally, ITU-R P. 530-17 is designed for link with path-length longer than 1 km. ITU-R P.530-17, and Ghiani's models give closer estimates to the measured CCDFs of rain attenuation. Large overestimate is shown by Mello's model. The ITU-R model prediction was the most suitable and generated fewer disparities between measured rain attenuation values and the predictions in comparison to other models.

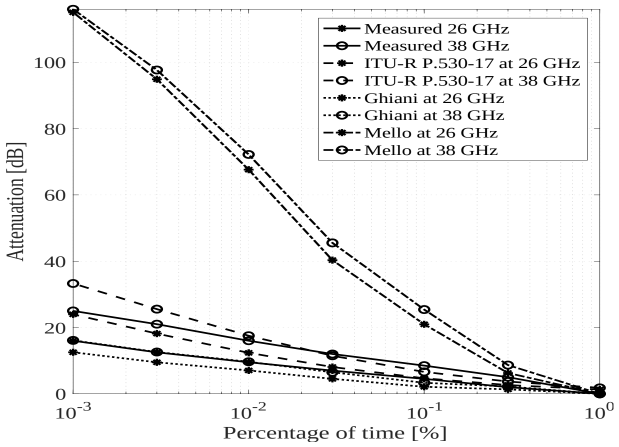

Figure 3. CCDF of rain attenuation compared with prediction models at various time percentages for 38 and 26 GHz

The Mello model shows excessive overestimation. As an example, Mello predicts 25.4, 72.2, 116 dB at 0.1%, 0.01%, 0.001% of the time for 38 GHz link, this might be due to the design of the model based on long-path links. Table 1 shows the measured and predicted attenuation values for 26 and 38 GHz links at critical percentages of the time.

Table 1. Attenuation Values for 0.1, 0.01, 0.001% of the Time for 26 and 38 Ghz Links

| | 26 GHz | | | | 38 GHz | | | |
|---|---|---|---|---|---|---|---|---|
| Time percentage (%) | measured (dB) | ITU-R (dB) | Ghiani (dB) | Mello (dB) | measured (dB) | ITU-R (dB) | Ghiani (dB) | Mello (dB) |
| 0.1 | 4.5 | 4.67 | 2.12 | 20.96 | 8.5 | 6.6 | 3.31 | 25.4 |
| 0.01 | 9.5 | 12.35 | 7.04 | 67.61 | 16 | 17.51 | 9.65 | 72.2 |
| 0.001 | 16 | 23.97 | 12.52 | 115.1 | 25 | 33.27 | 16.11 | 116 |

The relative error figure ($\varepsilon(p)$), is presented to measure the appropriateness for each of the model. And further comparisons are done through the calculation of Standard Deviation (STD) and Root Mean Square (RMS), to examine the performance of the ITU-R, Mello's, and Ghiani's models. The error figure used to examine the accuracy of the prediction models is given by:

$$\varepsilon(p) = \frac{A_{p,predected} - A_{p,measured}}{A_{p,measured}} \times 100 \tag{13}$$

The calculated $\varepsilon(p)$, Standard Deviation (STD) and Root Mean Square (RMS) means for each model are listed in Table 2 for 26 and 38 GHz respectively.

As can be noted from the table, Mello's model shows higher relative error compared to ITU-R model and Ghiani's models, which is apparent with the increased STD and RMS values. For that, ITU-R, Ghaini's models give better prediction alongside the measured rain attenuation.

Table 2. Percentage Error Obtained Over the Interval 0.001–1% for 26, 38 Ghz

| | 26 GHz | | | 38 Ghz | | |
|---|---|---|---|---|---|---|
| | ITU-R | Ghiani | Mello | ITU-R | Ghiani | Mello |
| $\boldsymbol{\varepsilon(p)mean}$ | 29.3 | 32.2 | 406.43 | 1.8 | 46.4 | 218.8 |
| RMS | 32.8 | 33.9 | 479.26 | 21.8 | 47.3 | 273.1 |
| STD | 16.4 | 11.4 | 174.5 | 23.8 | 10.1 | 116.9 |

## 5. CONCLUSION

Based on the presented results for the described experiment on 26 and 38 GHz links, the rain rate and the induced attenuation are presented for 5G short path-length links. Three well established rain attenuation models were used to compare the predicted results with the measured data. The presented comparison shows that ITU-R P.530-17 model was the most appropriate to be used under the link specification and tropical climate, by giving closer predictions to the measured rain induced attenuation. However, for the lower frequency 26 GHz, the prediction error was slightly lower in comparison with 38 GHz, this might be due to the differences in rain drop size distribution effects on higher frequencies. Additionally, fewer error at low exceedance of time for all the models, and the error increase with time percentages, indicate the differences between the measured and predicted values as the models were initially designed for temperate regions. Ghiani's model followed the ITU-R with close estimate to the measured rain attenuation. In addition, the performed error analyses showed similar judgment. Mello's model fails to adapt to the shorter link path, as it was empirically designed. The study highlights the need for a model that cover shorter path-length 5G links and designed especially for tropical regions. The results presented here could help in the design of a better rain attenuation prediction models for terrestrial links operating at higher frequencies in the tropics.

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