Channel fading attenuation based on rainfall rate for future 5G wireless communication system over 38-GHz

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ABSTRACT

In this paper, the effect of heavy rainfall on the propagation of a 38-GHz in a tropical region was studied and analyzed. Real measurement was collected, with a path length of 300 meters, for a (5G) radio linkage in Malaysia, installed at the Universiti Teknologi Malaysia (UTM) Johor Bahru campus. The employed system entails an Ericsson MINI-Link 38 E-0.6 mm, with a horizontal polarization (HP) antenna at the top integrated with a rain gauge and a data logger. Daily registered samples with a single minute span, for a full study period of 1 month, were collected and evaluated. The obtained rain rate was found as 56 mm/hr with a specific rain attenuation of 18.4 dB/km for 0.01% of the time. In addition to that, a calculated average rain attenuation of 5.5 dB for the transmission path of 300 meters length, was calculated. Based on these findings, a recommendation to update the International Telecommunication Union (ITU) specification of the rain attenuation for Malaysia is proposed. Based on the results, we suggest shifting the zone classification of Malaysia from zone P to zone N-P. Therefore, accurate design for future 5G systems would rely on more precise estimated attenuation levels leading to enhanced performance.

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1. INTRODUCTION

To establish a good reliable wireless link system, scholars have attended to discriminate, analyze, study, and differentiate fading effects that would mitigate the behavior of signals during the course of propagation. An unlimited number of studies in all dimensions were proposed to set up what exact environmental and climatic parameters may affect the propagation course [1]–[4]. Recent studies found that heavy rainfall would retard the propagation of millimeter-wave (mm-wave) signals via absorption, scattering, depolarization, and diffraction [4]–[6]. This leads to a considerable signal attenuation loss [dB/km] during the course of the actual propagating path length, the so-called physical path length, between transmit and receive antennas. Tropical zones such as Malaysia may suffer from such a scenario whereby the intensity of rainfall is high with large raindrop size. The distribution of the size of raindrops varies with respect to the geographic location where its length scale may be analogous to the radio millimeter waves.

It is anticipated that rain attenuation intensifies as a function of the operating frequency, rain density, and effective propagation length. Consequently, attenuation would lead to the loss of reliability and availability of the link, thus reducing the global performance of the communication system. Due to the aforementioned motives, this issue should be properly addressed during the employment of mm-waves in future 5G systems, particularly in heavy rainfall regions. The attenuation throughout the link path of the mm-waves should be accurately predicted while designing the 5G microwave and mobile radio access links in order to attain improved connectivity and service reliability. The significant influence of rainfall on the electromagnetic wave transmission was the focus of plentiful studies throughout the last decade. The first confident studies based on measurement were conducted by Mueller [7], where he had concluded that the effect of rainfall has more attenuation impact on the mm-waves than the atmospheric attenuation. In addition, the study concluded that the attenuation due to rainfall is on the average of 0.6 dB/mile. Such an early study had pinpointed the rainfall effect on mm-wave propagation. Robertson and King [8] in 1946 addressed the mm-wave attenuation of earlier studies and suggested a new experimental technique, at that time, to investigate attenuation problem. They had concluded that attenuation measurements due to rainfall below 10 mm/hour are somewhat inaccurate. On the other hand, levels of attenuation of more than 10 mm/hour are of more influence. The wavelength used is of more important to specify. For wavelengths less than 3.2 cm, the added loss per mile per millimeter per hour is less than 0.05 dB. Though for wavelengths of 1.09 cm, the added path loss is in the range of 0.3 dB per mile per millimeter per hour. This amount is appreciable as compared to the former wavelength.

As a result of these earlier scholar works, numerous measurement studies were promoted in diverse locations worldwide [9]–[11]. An early study, in the 1990s, was undertaken at the Universiti Teknologi Malaysia (UTM) campus and at the Universiti Sains Malaysia (USM) in Malaysia and had concentrated on rain attenuation over a wireless link [12], [13]. Tangible measurements were collected from quite a few sites at different frequency bands. The implementation conducted in USM [13], had concluded that the parameters κ and β of the φ factor proposed by the International Telecommunication Union (ITU) were not suitable to accommodate the worst-month rain in climatic areas. Instead, it has proposed a new value to represent such losses in these areas.

In the late 90's and early period of the millennium, further studies were conducted and piloted for diverse wireless communication systems all over Malaysia [5], [14]. These studies have led into different considerations with various findings proposals. Scholars in [12] had compared different prediction models for the 15 GHz rainfall case. The suggestion of this study is to adopt the Moupfouma model that is best to predict such attenuation. They have also initially assured that the ITU recommendation for attenuation losses due to rain was not suitable in tropical areas like Malaysia. The case proposed in [12] had compared losses for three different wavelengths, namely the 15 GHz, 26 GHz, and 38 GHz. Multiple models were used including the ITU–Radio communication sector (ITU-R) P.311-13 recommendation. Final assumptions had been made that ITU-R P. 311-13 model was the most accurate prediction algorithm for such losses with minimum mean square error, mean error, and standard deviation [5], [6].

Experimental and theoretical studies suggest the use of frequency bands extending between the 24 to 86 GHz as a preferred range for the operation of the 5th generation systems [5], [6], [15]–[17]. The 15 GHz, 23 GHz, 26 GHz, and 28 GHz are such bands that have been studied comprehensively in many tropical regions such as in Malaysia. Rain fading and attenuation are one of the main factors to be studied and analyzed throughout the occurrence of rain. Research studies confirm that as the operating frequency band increases, rain attenuation gets larger and more severe. This is due to the fact that the operating wavelength would become in the vicinity of the rain drop dimension. Rain drop dimensions with an average of 1.67 mm were reported in such tropical regions [5]. On the other hand, the 38 GHz had attracted global research interest to investigate path loss due to rainfalls. Contrary wise, rain attenuation over 38 GHz has been investigated by several researchers such as that conducted by [18]–[23]. Unfortunately, to the best of our knowledge, this frequency band was not covered and analyzed in tropical regions.

Upon reviewing the open literature, seemingly, the characterization of mm-wave frequencies for the 5G technology in terms of signal propagation properties are not properly performed yet in tropical zones such as Malaysia. To worsen the matter, multiple-input multiple-output (MIMO) is employed within the radio links in that range. Here, multiple transmit and receive antennas are applied to control the multipath propagation modes. The use of such technology improves the performance as well as the capacity of the wireless system [24]–[26]. As a result, the mm-wave band now serves as a primary component in the new 5G wireless technology. Therefore, it is important to grasp the fundamental characteristics of the channel propagation of the proposed new frequency bands in order to deploy the 5G wireless system successfully.

In the current work, real experiments were conducted in order to evaluate the effect of rainfall on the dissemination of mm-waves at 38 GHz over any future 5G radio link in Malaysia, representing a tropical region. Thereafter, calculations were performed to apprehend the propagation behavior of this frequency link as well as to identify the accepted attenuation margin level of the rainfall for the available bands with a specific route length. Data collection was performed utilizing a 5G radio microwave link technology for an effective path length of 0.3 km at Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia. The employed collection setup involves an Ericsson MINI-Link 38 E of 0.6 m horizontally polarized (HP), a rain gauge, and a data logger. Data was taken with a time span of 1-minute for a length of one year. Analyzed results based on simulations were used to evaluate the effect of rain rate and rain attenuation on the dissemination of mm-waves.

Recent climatic changes occurring in many regions worldwide, sets the need to periodically update most existing rainfall system models. One very interesting model which requires modification apprising is the ITU-R model that has been used as a bench mark model for such studies. The results obtained can be used to facilitate the way to modify these ITU-R region classifications. According to the ITU-R model, Malaysia is classified as zone P with regards to the rainfall climatic region. However, based on the present collected measurements and carried analysis, it is suggested that Malaysia should be classified between rain zones N and P. Seemingly, the measured data (for P>0.01%) varied from those predicted by the ITU-R model for zones P and N. The average rain rate (0.01% of the time) throughout the measurement period was reported as 55.5 mm/hr. The rest of the paper is organized as the following: section 2 introduces the most common rainfall models proposed in the literature. In section 3, a measurement system model is presented. Data measurements are analyzed and discussed in section 4. Finally, section 5 concludes the results.

2. RAINFALL SYSTEM MODEL

Rain rate attenuation statistics were studied, analyzed, and modelled by different global algorithm schemes. Consequently, estimating the specific attenuation of the rain is influenced primarily on the rain rate in addition to both the electromagnetic wave polarization state and the regression coefficient of the operating frequency. One of the most pronoun models used to model such attenuation is the ITU-R model. Accordingly, the specific rain attenuation, described mainly by the ITU-R model, is represented as (1):

$$\varphi = \gamma L_{eff} = \kappa R^{\beta} L_{eff} \tag{1}$$

where R and γ are the rainfall rate statistics and the specific rain attenuation, respectively. Both κ and β parameters are subjected to the operating conditions of the system such as the distribution of rain drop size, ambient temperature, operating frequency and the polarization state of the propagating wave. In addition to that L_{eff} is known as the effective path length of the radio link and it usually represents the degree of rain inhomogeneity throughout the propagation path, and is given as (2) [27]:

$$L_{eff} = rL(km) \tag{2}$$

where L is the tangible length between the two transmitting ends, and r is called the reduction factor (distance factor) presented as (3):

$$r = \frac{1}{0.477d^{0.633}R_{0.01}^{0.073\alpha}f^{0.123} - 10.579\left(1-e^{-0.024L}\right)} \tag{3}$$

where f is the operating frequency (GHz), $R_{0.01}$ is the rain rate at 0.01% percent of the time and α is a unique exponent factor for a given specific attenuation model. In the model presented in [28], the distance factor r is presented as (4):

$$r = \frac{1}{1+\frac{L}{L(R)}} \tag{4}$$

where $L(R) = \frac{2636}{R-6.2}$. In [29], another model was developed to evaluate the distance factor r of the path as (5).

$$r = \frac{1}{1+\frac{L}{2.6379R_{0.01}^{0.21}}} \tag{5}$$

Finally, the revised Silva Mello model proposed in [30] concluded a different estimate to the reduction factor r as (6):

$$r = \frac{1}{1+\frac{L}{L_0(R_p)}} \tag{6}$$

where L_0 represents the equivalent dimension of the cell under operation given by $L_0 = 119R_p^{-0.224}$ with R_p the rain rate at p percent of the time. It is intended in the aforementioned models to know the exact distribution of the rain attenuation and rate by obtaining the complementary cumulative distribution function (CCDF). Based on the ITU-R model, both (1) and (2) are used to derive the total rain attenuation parameter $A_{0.01}$ throughout the effective length of the path under operation exceeded for 0.01% of the time as (7).

$$A_{0.01} = \kappa R^{\alpha} r L \tag{7}$$

The total rain attenuation, for the time percentages p between 0.001% to 1% of the time, based also on the ITU-R model given by [27], [31] would be expressed as (8):

$$A_p = A_{0.01} k_1 p^{-(k_2 + k_3 \log_{10} p)} \tag{8}$$

where the variables k_1, k_2 and k_3 are given as (9), (10), and (11):

$$k_1 = 0.07^{k_0}\left[0.12^{(1-k_0)}\right] rL \tag{9}$$

$$k_2 = 0.855 k_0 + 0.546(1 - k_0) \tag{10}$$

$$k_3 = 0.139 k_0 + 0.043(1 - k_0) \tag{11}$$

with k_0 as (12).

$$k_0 = \begin{cases} 0.12 + 0.4 \log_{10}(f/10)^{0.8}, f \geq 10 \text{ GHz} \\ 0.12, f < 10 \text{ GHz} \end{cases} \tag{12}$$

3. MEASUREMENT CAMPAIGN

The measuring system setup consisted of a microwave 5G microwave link utilizing a MINI-Link 38-E unit as shown in Figure 1. Principally, the operations of this system setup are to measure both of the rainfall rate and the rainfall attenuation. The tipping bucket Casella rain gauge, with a sensitivity of 0.5 mm and with an error percentage of ±3%, is the part of the system used to measure the rainfall rate. This gauge records data only during the rainfall time with a record step of a single minute and equipped with an antenna of a gain of 44.9 dBi. The targeted operating frequency of the system was between 37 GHz and 39.5 GHz, centered at 38 GHz. At the receiver, power is also recorded each minute on a daily base. Received data were logged by a logger and monitored on a scheduled base.

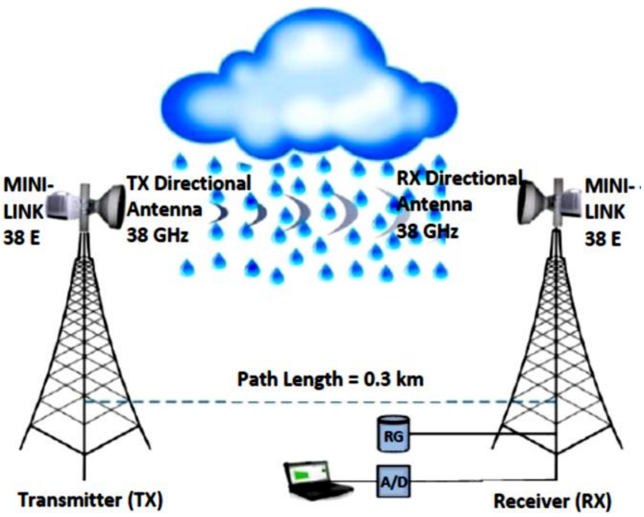

Figure 1. The MINI-Link 38-E unit used in the rain attenuation measurements for the 5G radio link

In order to provide durable link connections during the event of heavy rain environments, both the method of the so-called frequency diversity and the switching method are employed. Measured rain attenuation samples were collected with the help of a microwave link positioned at the UTM Skudai campus with a transmission path length of 0.3 km. The link between the transmit and the receive antennas was established to conduct the experimental set-up and received data samples were manipulated and analyzed. In the next section, the rain rate, attenuation distribution and modelling based on the above mentioned collected data for a duration length of one-month are presented and discussed.

4. DATA MEASUREMENT ANALYSIS AND DISCUSSION

This section presents the experimental 5G microwave radio set-up used to measure both the rain rate and the rain attenuation statistics. As was mentioned, earlier, the measuring system was assembled by the help of the propagation research team, WCC's team, in UTM at Skudai campus, Johor Bahru, Malaysia. The system which is consisted of a 38-E MINI-Link unit, is shown in Figure 1, and it will sample measured data so as to calculate and obtain the CCDF of both the rain rate distribution and the rain attenuation distribution.

4.1. Rain rate distribution

The annual rainfall intensity in Malaysia is relatively high and heavy falls occurs during a full year length. Generally speaking, precipitation levels in Malaysia are distributed and affected by two seasons called the Northeast monsoon and Southwest monsoon seasons. They occur between the months of October-March, and the months of April-September, respectively. It is also worth saying that rainfalls during these monsoons are typical of thunder storm type.

In this paper, the rain rate and the rain attenuation in the month of December were presented and discussed. Real data measurements collected and logged during the month of December are displayed in Figure 2. The first sub plot shows the rain rate recorded per minute with a clear rainfall variation between 29 mm/hr and 123 mm/hr all over the month. The 29 mm/hr rainfall accounts for about 87% of the recorded rain rates, while the rates of 0.5%, 2.5%, and 10% were calculated for the 123 mm/hr, 92 mm/hr, and 58 mm/hr, of rainfalls, respectively. The second sub plot of Figure 2. shows the average rate of rainfall per each day of the month, and it varies between 29 mm/hr and 48 mm/hr.

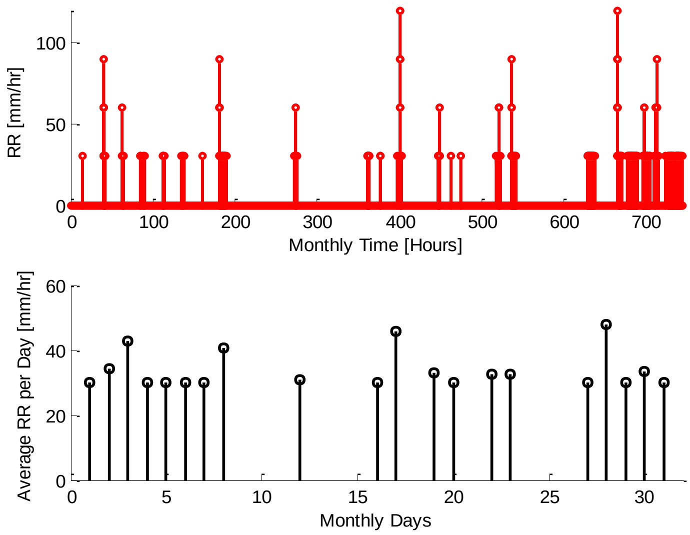

Figure 2. Measured rainfall rate based on 30 days

As an average, the total fall rate during the month of December was recorded around 35 mm/hr, as illustrated in Figure 3. It was also noted that more heavy and intense rainfall usually take place between the period time of 15:00 to 19.00 o'clock, with a worst-case scenario from 17.00-19.00 o'clock, as clarified in Figure 4. Note also that, the rain rate during the time between 15.00 to 19.00 o'clock represents almost around 88% of the total documented rainfalls. It is commendable to say that collected rainfall data (1-minute interval) were used by the ITU-R model to predict the rain rate distribution. According to the ITU-R model, Malaysia is classified as zone P with regards to the rainfall climate. However, based on the present measurement operated in this paper, it is found that Malaysia should be classified between rain zones N and Pas shown in Figure 5 which reports the cumulative distribution of rainfall intensity. Seemingly, the measured data (the case of PT>0.01%) varied from those predicted by the ITU-R model for zones N and P.

The average rain rate (0.01% of the time) throughout the measurement period was 55 mm/hr. This rain rate is used to calculate the attenuation of the rain, in dB, for the link at particular sites.

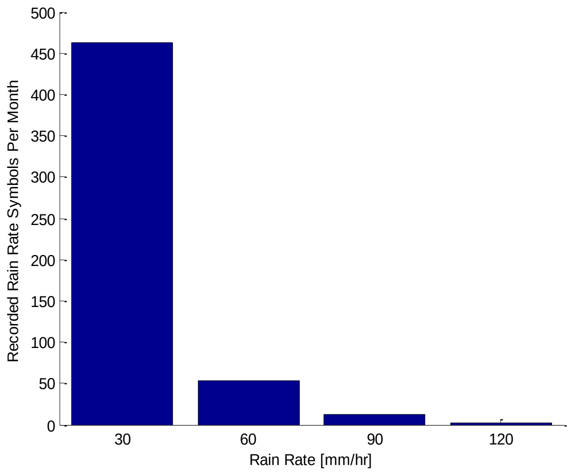

Figure 3. The PDF of the measured rainfall rate

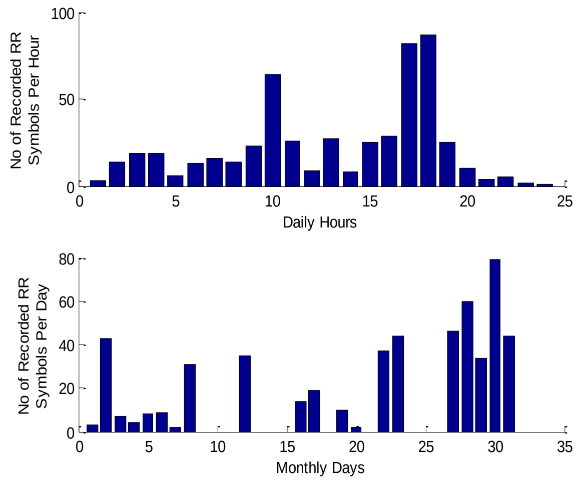

Figure 4. Daily and hourly logged data for a period of one month showing the extreme rainfall times

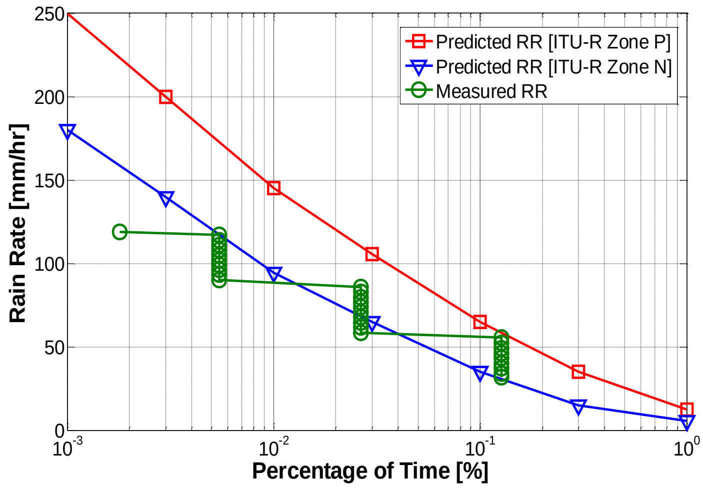

Figure 5. CCDF of the measured rain rate at Skudai campus for one month period

4.2. Rain attenuation distribution

Implementation of the 5th generation mobiles in the mm range is enormously affected by the rain attenuation. This effect may become more intense in countries with annual heavy and high rain levels, especially in the tropical regions. In such a scenario, received signal strength (RSS) will be used as a compensation analyzing method.

Figure 6 illustrates the received signal strength as a function of the rain rate using real collected data for the case of most severely two individual raining days in December. Furthermore, Figure 7 demonstrates how the received signal strength is influenced by the rain rate using real recorded data for the complete month of December. In both of the mentioned figures, Figures 6 and 7, the measured rain rate is presented on the first plot and the received signal strength is shown on the next.

As can be indicated from Figures 6 and 7, the RSS drops significantly in the course of a raindrop and the attenuation further intensifies as rainfall increases. As an example, the attenuation in RSS may reach 15 dB within the measured link distance of 300 meters. Total data rate level, outage probability and connectivity would be affected significantly by such an amount of signal attenuation. Attenuation and losses would increase in the course of heavy rain and all the way during the user mobility.

Obtained daily RSS data were used to calculate and derive the rain attenuation in addition to the percentage of time (PT%). In order to do so, the CCDF everyday recorded data were interpolated to monthly CCDF data by simulation. These monthly rain attenuation CCDF data were plotted in Figure 8 and compared to different ITU-R prediction models for comparison. Anticipated rain attenuation CCDF data is symbolized by the blue line based on the measured RSS records during the entire month of December. For comparison, the rain attenuation CCDF as predicted by the ITU-R model for the same time period is represented by a black line. The green and cyan lines signify the predicted rain attenuation CCDF data for the ITU-R model of zones P and N, respectively.

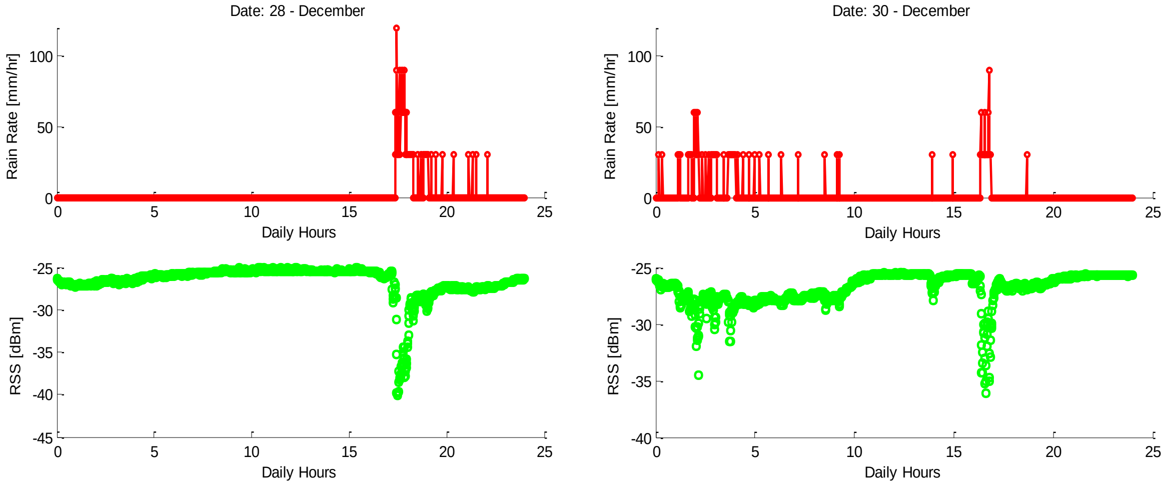

Figure 6. Collected RSS and rain rate for the two worst rainy days in Malaysia

As observed, the rain attenuation loss of 18.4 dB/km is recorded at an operating frequency of 38 GHz and thus is assumed very critical. This level of attenuation would noticeably mitigate the link during the instance of rainy intervals. Meanwhile, the operation of 38 GHz with the 5G schemes in the tropical zones can support microwave signal propagation for short path lengths only.

In order to use 5G systems for longer path lengths, either the antenna gain or the transmit power ought to be compensated consequently to cover the area under concern. On the other hand, measured rain attenuation data would support the claim that this attenuation level is somewhat lower than what was anticipated by the ITU models. As a result, the design of 5G networks should be operated based on more accurate measured data so as to reflect higher system quality and improved system performance.

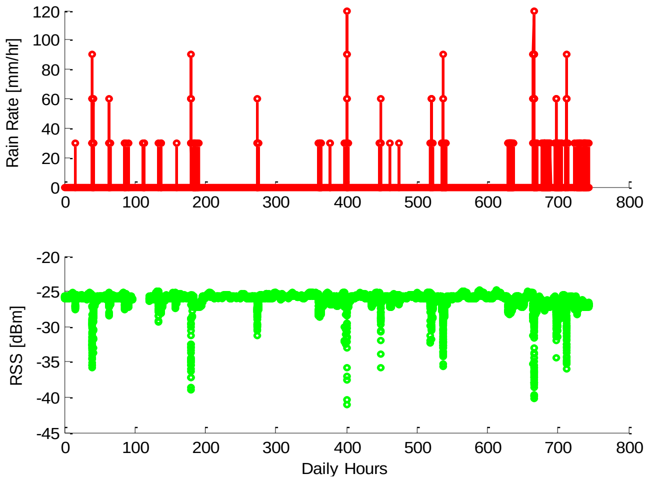

Figure 7. Measured rain rate and RSS for the length of one month at Skudai campus

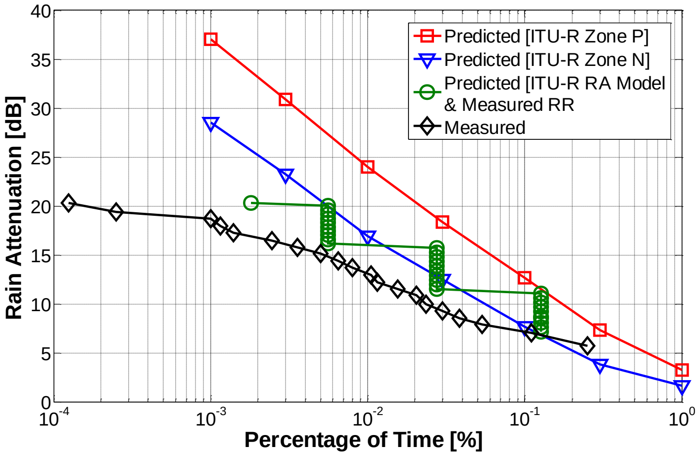

Figure 8. The CCDF of the measured rain attenuation for one month logged data compared to the ITU model at an operating frequency of 38 GHz

5. CONCLUSION

In this proposed paper, real collected rain rate data and evaluated rain attenuation values were analyzed and compared with other widely-used models such as the ITU–models. The experimental procedure was conducted at UTM, Skudai campus, for a period length of one month, with a record span of a single minute. The measurement was conducted with the aid of a 38-E MINI-Link unit operating at 38 GHz. Attenuation of an average of 18.4 dB/km may assumed critical at the 38 GHz operating frequency as rain attenuation value at 0.01% of the time. Furthermore, it was also found that the logged and analyzed rain attenuation in this link is lower than what was anticipated by the ITU-models. Therefore, accurate design for future 5G systems should take into account real measured data that would allow more truthful estimated attenuation leading to enhanced performance. According to our analysis and results, the zone classification of Malaysia should be shifted from zone P to zone N-P. This leads to estimate the attenuation levels accurately which improves the performance of the wireless communication system.

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