Impact of Link Elevation Angles on Rain Attenuation Statistics in Heavy Rain Region Predicted Using the Synthetic Storm Technique

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***Abstract*—In the absence of measured rain attenuation, prediction models are the best way to estimate statistics of rain attenuation. Synthetic Storm Technique (SST) model is one of the solutions to obtain time series of rain attenuation. By using SST, we will investigate the impact of link elevation angle on the prediction models; in particular, the results show that time series of rain attenuation at low elevation angles deviate significantly from those at high elevation angles. In addition, higher frequencies show considerably higher attenuation than lower frequencies. This is particularly severe in a tropical and equatorial region where the rainfall rate is higher with respect to the temperate region.**

***Index Terms*—Elevation Angle; Path Length; Rain Attenuation; Synthetic Storm Technique.**

I. Introduction

Attenuation induced by rain in the troposphere is considered as one of the most dominant impairment to the satellite propagation link particularly at above 10 GHz of operating frequency. Its impact is even more severe at low elevation angles with longer path length, as the link experiences inhomogeneous rain spatial distribution along the Earth-space path [1-2] as shown in Figure 1 [3]. Besides this, such link elevation may also lead to higher attenuation level, due to convective precipitation events (limited spatial area, with short duration and intense showers). In fact, in heavy rain regions such as tropical and equatorial areas, the contribution of convective events is definitely prevailing over stratiform rain events. [2-5]. Hence, it is worth to investigate the combined effect of frequency and elevation angles in heavy rain regions by means of the well-known physical prediction model named Synthetic Storm Technique (SST) [6]. One of the main advantages of the SST model is its ability to reproduce the dynamics of rain attenuation time series using local one-minute rain-rate time series as input. Such method is always preferable for the accurate statistical prediction in heavy rain region as the input to the model are local values which retain the real physical dynamics characteristics of precipitation in that particular region. Furthermore, the SST model has been extensively validated and widely accepted in the tropical/equatorial region [7]. This work investigates the impact of rain attenuation as a function of link elevation in equatorial Johor, Malaysia by means of the SST model. The remainder of the paper is structured as follows: Next section first reports the statistical analysis of rainfall rate in this particular area, followed by the rain event based comparison with respect to different elevation angle, while the subsequent section presents the analysis from the statistical point of view. Last part of the paper deals with the investigation of the effective path length as the impact of elevation angles and eventually draws some conclusions.

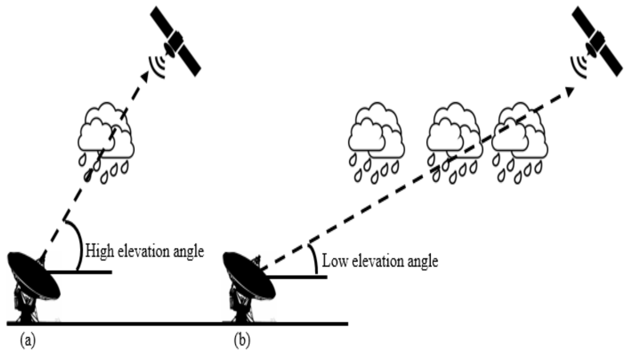


Figure 1: Different path length geometries as a function of link elevation angles. (a) High elevation angle (b) Low elevation angle [3]

II. Statistical Analysis of Rainfall Rate

Complimentary Cumulative Distribution Function (CCDF) of rain rate is one of the essential parameters required by most of the attenuation prediction models. Figure 2 shows the CCDF of rain rate collected from 2D-Video-Disdrometer at Universiti Teknologi Malaysia (UTM) spanning over one year from July 2015 to Jun 2016. The details of disdrometer and data processing can be found in [8]. The results show that ITU-R P.837-6 [9] model slightly overestimates measured result at a high percentage of time starting from 0.1 to 1%, but underestimates measured rain rate at a lower percentage of time up to 0.02%. However, the comparison shows the measured results matched well with ITU-R P.837-6 model at 0.06% of the time.

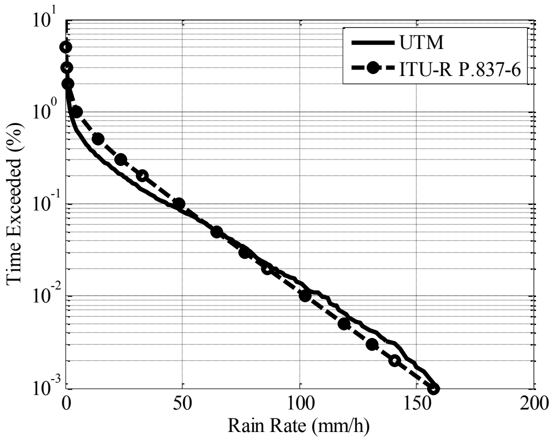


Figure 2: CCDF comparison of rainfall rate between data collected at UTM and predicted by ITU-R P.837-6 model.

III. Comparison of Rain Attenuation Time Series for Different Elevation Angles

Elevation angle plays an important role in determining rain attenuation level. Different elevation angles may have a huge impact on the prediction of rain attenuation, as rain is not evenly distributed over a wide range of area especially when the elevation of the earth-space link is low. Figure 3 shows the times series of rain rate collected from video disdrometer for a rain event on 1 July 2015 (local time) whereas Figure 4(a) to 4(c) shows time series of rain attenuation predicted by SST model [6] for elevation angles of 75^0, 50^0 and 20^0, respectively. Comparison of rain attenuation time series between Ku-band (12.2 GHz) and Ka-band (20.245 GHz) are also included. It is interesting to note that time series of rain attenuation for high elevation angle (75^0) follow closely the trend of rain intensity. For instance, at 2.07 am, the intensity of a rain event shows 24 mm/h and SST gives about 5 dB of attenuation level at Ku-band frequency, and about 12 dB at Ka-band frequency. This indicates that the signal propagated through the Earth-space path is highly impaired by rain attenuation, especially at higher frequencies band. On the other hand, it is found that time series of rain attenuation at low elevation angle (20^0) do not strictly follow the trend of rain intensity as shown in Figure 4(c). The results show the duration of the fade event is longer than that of the rain event; this is due to the movement of the rain cells along the (longer) propagation path, that still introduce attenuation even if the rain gauge detects no rain at the location of the ground station.

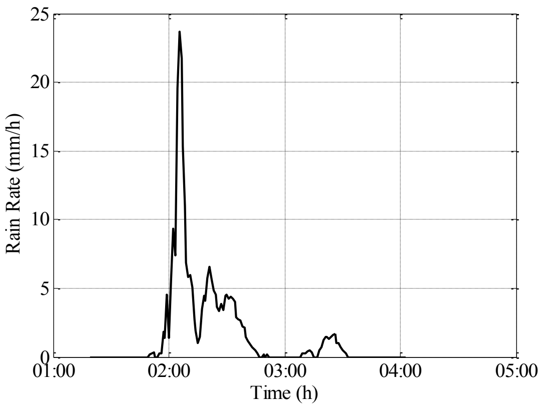
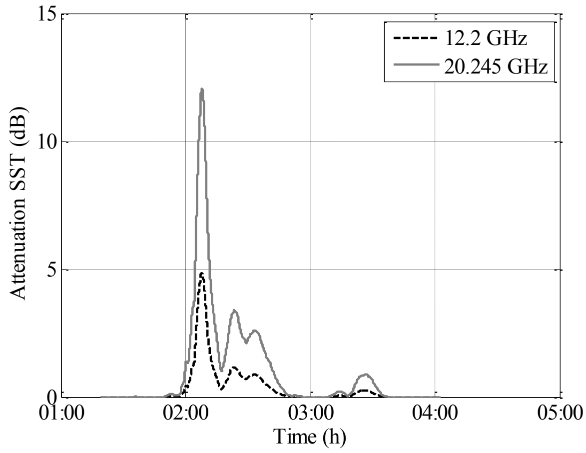
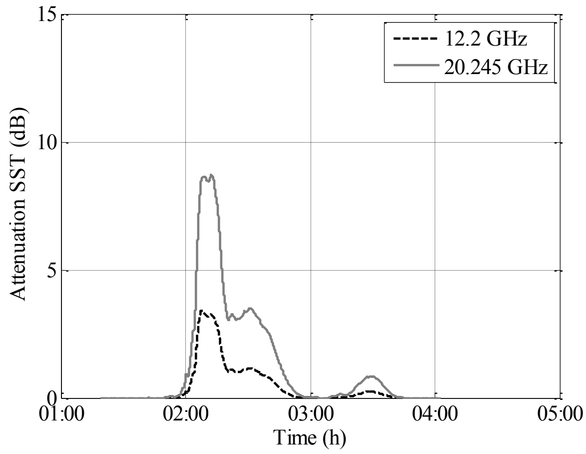


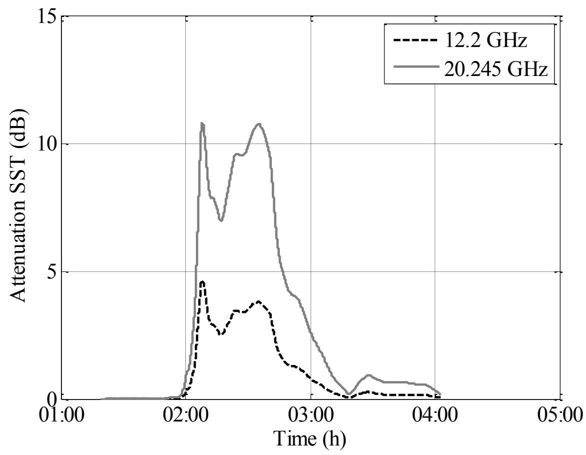
Figure 3: Time series of rain fall rate collected on 1 July 2015.



(a)



(b)



(c)

Figure 4: Time series of rain attenuation predicted by SST model for Ku (12.2 GHz) and Ka (20.245 GHz) band. (a) for elevation angle of 75^0, (b) for elevation angle of 50^0 and (c) for elevation angle of 20^0.

IV. Statistical Analysis on Different Elevation Angles

In order to show the impact of elevation angle on the predictions obtained through the SST model, Figure 5 presents the comparison of CCDFs of attenuation for elevation angle from 20^0 to 80^0 with 10^0 increment. It is clearly shown that at low elevation angles a higher level of attenuation is experienced, for a given probability level.

However, not much of increment was found for elevation angle from 50^0 to 80^0 and nearly identical for 70^0 and 80^0. A similar trend happened to predictions from ITU-R P.618-12 [10] model as shown in Figure 6. As high as 45 dB of attenuation at 0.1% of time exceeded was found at an elevation angle of 20^0 while 40^0 to 70^0 show constant rain attenuation of about 25 dB. The details of comparison of rain attenuation statistic at 0.1% of time exceeded can be found in Table 1. For instance, at an elevation angle of 20^0, rain attenuation at 0.1% is 40.25 dB and 45.06 dB for prediction from SST and ITU-R model respectively whereas only 19.68 dB and 24.55 dB at 50^0. Such huge difference (about 20 dB) needs to be further confirmed by measurements which are currently collected at the ongoing campaign in UTM.

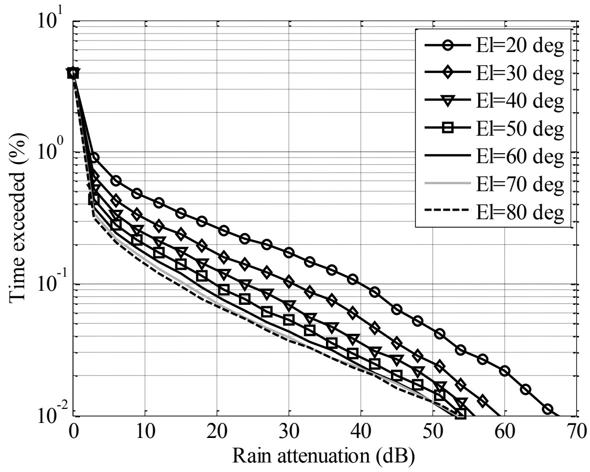


Figure 5: CCDF of rain attenuation predicted by SST model at 20.245 GHz.

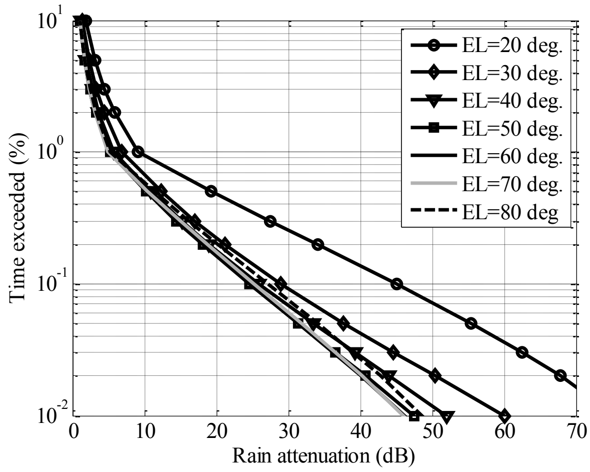


Figure 6: CCDF of rain attenuation predicted by ITU-R P.618-12 model at 20.245 GHz.

Table 1
Cumulative Rain Attenuation Exceeded For 0.1% Of Time for Different Elevation Angle.

Elevation angle	20^0	30^0	40^0	50^0	60^0	70^0	80^0
SST (dB)	40.25	30.71	24.08	19.68	17.28	15.6	14.41
ITU-R (dB)	45.06	28.89	25.94	24.55	24.71	25.25	27.20

V. Dependence on Path Length

Effective path length is referred to the actual extent of rain that affects the received signal and it is used in ITU-R P.618-12 model in the estimation of rain attenuation ($A_{0.01}$) at 0.01% of the time. According to ITU-R P.618-12 recommendation model, effective path length (L_E) can be estimated through a power-law relation as [10]:

$$L_E = \frac{A_{0.01}(t)}{kR\alpha} \quad (1)$$

Where k and α are the parameters of power-law relation to calculate specific attenuation (γ) based on ITU-R P.838-3 [11] model and R is the local precipitation rate at 0.01% of the time. Figure 7 shows the value of the path length derived from ITU-R model and compared with SST model. At low elevation angle (10^0), the longest effective path length derived by ITU-R is about 8.5 km whereas 7 km estimated by SST. The effective path length derived from the SST model is slightly lower than that of the ITU-R model from 10^0 to 30^0 of elevation angles, but it larger in the range 30^0 to 70^0. The length reduces to about 4 km and 4.5 km at 70^0 for SST and ITU-R model, respectively. Overall, the effective path length increases when the elevation angle decreases. This indicates that the received signal at low elevation angle link may suffer from severe attenuation due to its longer effective path length.

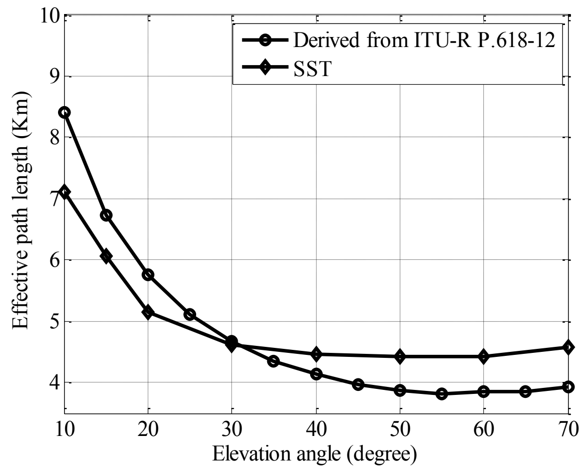


Figure 7: Effective path length as a function of elevation angle. Comparison between SST and ITU-R model.

VI. Conclusion

This contribution focuses on the impact of rain attenuation in equatorial Malaysia as a function of link elevation angle, investigated by means of the SST model. Rain attenuation time series and their statistical distribution are synthesized by the SST model using one-minute local rain-rate time series as input. Both, event-based and statistical analyses showed that as the link elevation angle decreases to 20°, the impact of rain attenuation increases significantly, while for higher elevation angles (i.e 40° to 80°) there are negligible statistical differences. Such results are closely related to the value of effective path length. These preliminary results suggest that the use of prediction model for low elevation angle application system such as Low Earth Orbit (LEO) satellite should carefully consider the significant impact of rain attenuation particularly in heavy rain region.

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