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Analysis of the Synthetic Storm Technique Using Rain Height Models to Predict Rain Attenuation in Tropical Regions

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***Abstract*— This paper aims to investigate the utilization of the Synthetic Storm Technique (SST) to convert rain rate time series to rain attenuation time series using the ITU-R P.839, Stutzman and Bryant rain height models. Furthermore, the study aims to compare the actual rain attenuation with that predicted by the SST using the three above-mentioned rain height models based on rain rate and rain attenuation both measured concurrently. The study relies on rain rate time series and rain attenuation time series measured at University Science Malaysia (USM) campus (4.390 N, 100.980 E). The study found that the higher the rain rate, the higher is the percentage error for the SST predicated rain attenuation using the three above-mentioned rain height models as compared with measured rain attenuation. However, it is observed that when the Stutzman model applied as part of the SST model, the prediction is more accurate of the three rain height models.**

Keywords- Synthetic Storm Technique; rain height models; rain rate time series; rain attenuation time series.

I. INTRODUCTION

At high frequency, Satellite - earth link experiences dispersion due to rainfall, this is more severe in tropical regions. Future direction of satellite communication systems is geared towards utilizing higher and higher frequencies, such as Ka and V-bands. Accordingly, the loss and degradation of the link path from the satellite to ground stations are severely affected by tropical rain events. Numerous empirical prediction models aiming to estimate rain attenuation were proposed in the temperate regions based on measured data. The majority of these present models do not perform well in high rainfall regions [1], such as the tropical country of Malaysia. One of these models is the SST, which is a vastly used technique by many researchers [2-4]. However, when evaluated in Malaysia using the ITU-R P.839 model, it was found that the results were close to the actual attenuation in low rain rate but were overestimated in medium rainfall and extremely overestimated in high rainfall rate. Therefore, this method needs to be modified in order for it to be applicable to Malaysia. Rain height is one of the many factors used to estimate effective length path of satellite-earth link. Several models were proposed to predict rain height, such as recommendation ITU-R P.839, Stutzman model and Bryant model.

This paper aims to investigate the use of these models in predicating the length of the slant path for satellite-earth link, so that they can be used in the SST model. Therefore, the study aims to compare the actual rain attenuation with that predicted by the SST using three different rain height models based on actual rainfall rate both measured concurrently. Rain attenuation and rain rate measurements were conducted at USM campus (4.390 N, 100.980 E) located in Tronoh, Perak, which experiences very heavy rainfall frequently. The receiver antenna was pointing towards Superbird-C at 40.1 elevation angle and diameter size of 2.4 m and the beacon signal frequency is 12.255 GHz. The data logging system has a sampling rate of one sample per second and the rain gauge is of 1-min integration time. Section two of the paper provides a brief background on the rain height models, whereas, the third section offers concise description of the SST. Results are introduced and analyzed in section four. Finally, section five concludes the paper.

II. BACKGROUND ON RAIN HEIGHT MODELS

The prediction models being used to predict the signal attenuation encompass the various location specific meteorological factors; and rain height is one such factor. Rain height can be defined as the height of the top of the rain column above the mean sea level. Another definition, considers rain height to represent the boundary between the rain region and the snow region and it often corresponds to the 0°C isotherm.

Many rain height prediction models have been developed to estimate the effective length path of satellite-earth communications. These models are as follows:

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A. *ITU-R 839 Model*

ITU-R Recommendation 839-0, supplies a technique to determine 0°C isotherm height above sea level [5]. The model is formulated in the following equation:

$$H_R = \begin{cases} 5 & \varphi < 23 \\ 5 - 0.0075(\varphi - 23) & \varphi \geq 23 \end{cases} \tag{1}$$

where H_R represents the mean rain height above mean sea level and φ is the latitude of the Earth station.

B. *ITU-R 839-4*

Recommendation ITU-R P.839-4 provides a method to predict the rain height for propagation prediction models. The difference between the effective rain height and the freezing height is taken to be 360 meter [5]. The model is expressed as follows:

$$H_R = h_o + 0.36 \ \ km \tag{2}$$

where h_0 is the mean C isotherm height above mean sea level.

C. *Stutzman model*

Based on measured data, the model introduced by Stutzman proposes empirical expressions for effective rain height using the following equation [6]:

$$H_R = \begin{cases} h_0 & R < 10 \\ h_0 + \log(\frac{R}{10}) & R \geq 10 \end{cases} \tag{3}$$

D. *Bryant model*

Bryant proposed model uses measured rain-rate to estimate rain height by applying the following equation. [7]

$$H_R = h_o + 0.0005 * R^{1.56} \, km \tag{4}$$

where R is rain rate, mm/h

Since, both the ITU-R 839-0 and ITU-R 839-4 models are very similar in terms of their structure; the study will rely on the earlier version of the model, which is ITU-R 839-0. Moreover, the Stutzman and Bryant models will be used as well in the analysis of the synthetic storm technique to predict rain attenuation in tropical regions.

III. SYNTHETIC STORM TECHNIQUE

The Synthetic Storm Technique [2] is a technique used to transfer actual rain rate time series into rain attenuation time series. In the dearth of authentic beacon data, SST is a helpful tool to generate rain attenuation from rain rate for any slant path satellite-earth link with elevation angle higher than 10°, using any frequency and polarization, at any location. The model requires the speed (m/s) of rain cells, the length of link path between satellite and base station (km) and the rain rate time series which was measured at the desired site. The model consists of two layers, namely, the rain layer (layer A) and the melting layer (layer B), which presents the vertical structure of precipitation as shown in Fig. 1. The signal of rain attenuation is calculated as follows:

$$A(x) = K_A \int_0^{L_A} R^{\alpha_A}(x_0 + \Delta x_0, \xi) d\xi + K_B r^{\alpha_B} \int_{L_A}^{L_B} R^{\alpha_B}(x_0, \xi) d\xi \tag{4}$$

where A (x) is the rain attenuation caused by the rain rate at a specific point along the rain path length L (km), and ξ is the distance measured along the satellite path. The parameter values of K and α depend on the electromagnetic wave, frequency and polarization, and raindrop size distribution. They are estimated by ITU-R 838, for water temperature of 20°C, and estimated for 0°C, by Maggiori [8]. For more details about the SST, please refer to [8 ,9].

The rainy path can be calculated using the following equation:

$$L = \frac{H_R - H_s}{\sin(\theta)} \tag{5}$$

where H_R represents H_A which is the height above sea level of the upper limit of layer A, as well as H_B, which is the height above sea level of the upper limit of layer B. H_S is the height above sea level of the Earth station.

According to [2] the signal of rain attenuation time series, which is induced on satellite - earth link by rain time series is given by the following equation:

$$A(t) = K_A R^{\alpha_A}(t) L_A + r^{\alpha_B} K_B R^{\alpha_B}(t)(L_B - L_A) \tag{6}$$

where R(t) is rain rate time series. L_A and L_B are the radio path lengths and are given in Equation (5).

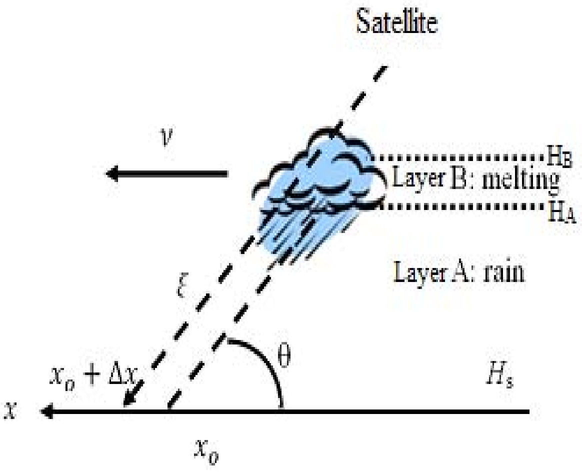

Figure 1. Illustrates the structure of the SST model with the two-layers of rainfall and the earth- satellite link.

IV. RESULTS AND DISCUSSION

Conversion from rain rate time series to rain attenuation time series was performed by using the Synthetic Storm Technique method using Equation (2). Equations (3 and 4) were used to calculate the radio path lengths L_A and L_B respectively. The specific attenuation of melting region (B) is constructed according to [8] and the values for coefficients k and α are taken to be 0.220 and 1.1668 respectively. Also, the k and α values which are related to rainy layer (A) selected to be 0.0257 and 1.623 respectively. As originally proposed in [2] the rain advection velocity is assumed v=10 m/s.

In Fig. 2 and Fig. 3, measured beacon rain attenuation and that predicted by the SST using different rain height models for 12.255 GHz are plotted with respect to time using measured rain rate time series. It is observed that there is a good correlation between the measured rain rate and the measured rain attenuation. Predicted rain attenuation time series using the SST method followed the measured rain attenuation time series in both events. Fig. 2 shows several peaks, which illustrate a comparison between the actual rain attenuation and that converted by the SST model based on the three used rain height models. The first peak shows the values of rain attenuation predicted by the SST model, which are close to 45.8, 52.5 and 42.2 dB using the ITU-R 839, Bryant and Stutzman models respectively. However, the actual rain attenuation measurement is about 22 dB. Moreover, the predicted value of rain attenuation observed in the last peak is about 74, 101.4 and 72.5 dB using the three rain height models of ITU-R 839, Bryant and Stutzman respectively, while the actual rain attenuation measurement is close to 22 dB. Fig. 3 shows that the highest value of measured rain attenuation reaches to 29 dB while the SST prediction is close to 74, 101.4 and 72.5 dB using the ITU-R 839, Bryant and Stutzman models successively. In addition, the value of the lowest peak of measured rain attenuation reaches to 18 dB while the SST prediction is close to 20.2, 20 and 17.5 dB using the ITU-R 839, Bryant and Stutzman models successively.

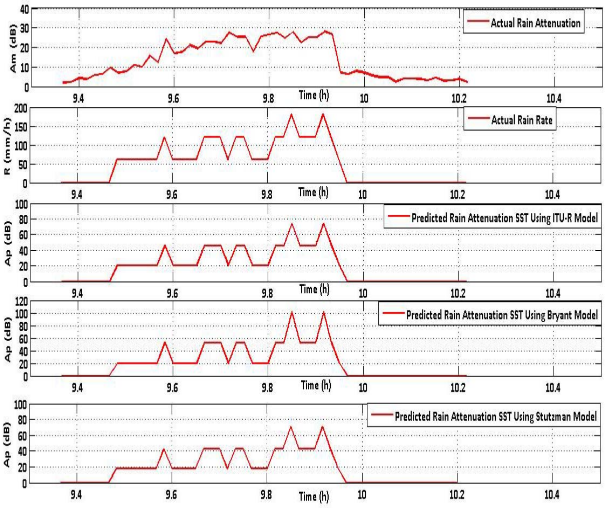

Figure 2. Comparison between measured rain attenuation and that converted by the SST using different rain height models to calculate the length of slant path for a rainy event on 9/8/2009.

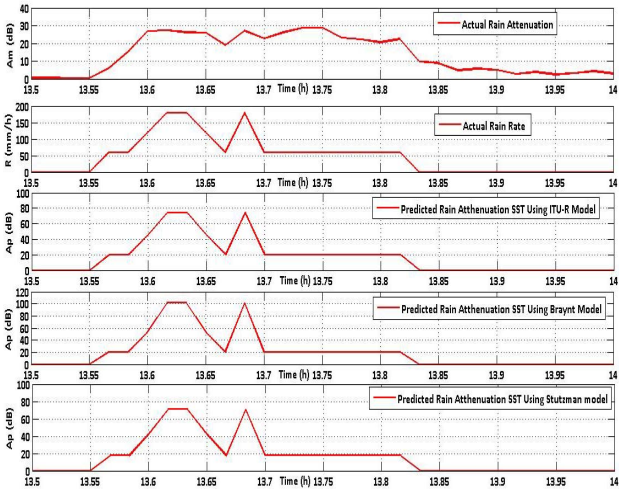

Figure 3. Comparison between measured rain attenuation and that converted by the SST using different rain height models to calculate the length of the slant path for a rainy event on 26/8/2009.

One month statistics of average measured rain attenuation for August 2009 and predicted rain attenuation by the SST model using three different rain height models to estimate rain height are presented in Table 1. Moreover, the difference between measured and predicted rain attenuation for several values of rain rate, mm/hr is shown in Table I. It is clear from the first and second row of Table I that the value of SST predicted rain attenuation for 30 and 60 mm/h is close to actual attenuation with a preference for the Stutzman model, which gives a lower percentage error. The difference between measured rain attenuation and the SST predications is high when the rain rate equals 90 mm/h. They are 12.62, 14.53 and 9.26 dB for ITU-R 839, Bryant and Stutzman models respectively. These values reflect a percentage of error, which are as follows: 63.1%, 72.65% and 46.3% respectively. For the last three rows of table 1, it is clearly evident that the higher the rain rate, the higher is the percentage error for the SST predicated rain attenuation as compared with measured rain attenuation. Moreover, it is also observed that the Stutzman model when used as part of the SST model is the most accurate of the three rain height models when comparing its values with those of measured rain attenuation.

The percentage error (E) between the measured attenuation (Am) and the predicted attenuation (Ap) is calculated based on the following equation [9]:

$$E = \frac{A_p - A_m}{A_m} \times \% \tag{7}$$

TABLE I. COMPARISON BETWEEN MEASURED RAIN ATTENUATION AND THAT CONVERTED BY THE SST MODEL USING VARIOUS RAIN HEIGHT MODELS

R (mm/h)	**A_m (dB) Average**	**A_{SST} (Original)**	**Error (%)**	**A_{SST} (Bryant Model) (dB)**	**Error (%)**	**A_{SST} (Stutzman Model) (dB)**	**Error (%)**
30	7.7	8.91	15.71	8.36	8.57	7.21	6.36
60	18	20.21	12.28	20	11.11	17.47	2.94
90	20	32.62	63.1	34.53	72.65	29.26	46.3
120	22	45.82	108.27	52.57	138.95	42.17	94.11
150	25	59.63	138.52	74.66	198.64	55.94	123.76
180	29	74	155.17	101.43	249.75	72.48	149.93

V. CONCLUSIONS

This paper focused on the applicability of the SST model in Malaysia using three rain height models, namely the ITU-R 839, Bryant and Stutzman models. The SST was used to generate rain attenuation time series by relying on rain rate data measured for one month in USM campus. The converted rain attenuation time series using the three rain height models were then compared with the measured rain attenuation at 12.255 GHz recorded at Satellite Lab, USM. The study found that the SST method using the Stutzman rain height model shows closer results when comparing with measured rain attenuation. Hence the Stutzman rain height model with modification is recommended to use in SST method.

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