Prediction of Time Diversity Gain – Comparison Between ITU-R P.618-13 Using a Concept of Rain Rate with Delay and Synthetic Storm Technique

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Abstract—Future satellite companies will use higher Ka and V bands. Rain fade is the most important issue in establishing reliable communication between Earth and satellites outside the 10 GHz band. The problem is exacerbated in the tropics by significant rainfall throughout the year. One way to deal with rainfall attenuation is to use a time-diversity strategy. Real-time rainfall attenuation data is needed to analyze time variability. However, data from higher frequency bands such as Ka and V bands cannot be used. As a result, the Synthetic Storm Technique (SST) was proposed to convert the measured real time rainfall data into rainfall attenuation data and predict the time diversity gain. The measured rainfall data was converted to rainfall attenuation data using the traditional SST method. Time diversity gains were predicted using Converted rainfall attenuation and the Matriciani model, and the measurements were significantly overestimated. A new concept of realtime rainfall with and without time delay is proposed and used to predict time diversity gain using ITU-R P. 618-13 and the measured rainfall distribution with delay. Therefore, the proposed method recommends using the measured long-term precipitation data to predict the gain from time diversity at the desired frequency.

Keywords—rain rate, rain attenuation, Synthetic Storm Technique (SST), time diversity gain, earth-to-satellite link, ITU-R P.618-13

1 Introduction

In the future, satellite communication will shift to the Ka and V bands, eliminating the utilization of lower frequencies like the C and Ku bands [1]. The existing satellite communication system is dependent on bandwidth and data transmission [2]. Rain, cloud, precipitation, fog, and other environmental propagation deprivations, for example, have a significant impact on higher frequencies. Rain, on the other hand, makes it challenging to methods have been proposed satellite links at higher frequencies [3].

Rain fade is very severe in tropical areas, thus numerous mitigation measures have been proposed to mitigate it, all of which have demonstrated promising results [4].

Since it may be a cost-effective and productive technique for combating rain constriction, the time differing qualities approach is one of the reasonable support methodologies [5], It's moreover utilized in fawning communication to enhance performance over a corrupting connect [6]. Within the existing arrange network, measured rain attenuation information isn't accessible in higher recurrence bands, whereas measured rain rate information is accessible in numerous locales [7]. By changing SST rain rate information into comparable watched rain constriction information, the transient differing qualities for higher recurrence groups may be expanded. SST was built from information collected in tropical environments [8].

Change over the rainfall time series taken by rain intensity at a point during the 1-minute integration period into a longitudinal rainfall series along the line using the estimate of the synthetic storm method used to offset time with distance as shown in equation (1) [9] is a striking example of the basis of the SST established by [10]. SST is a powerful method for calculating time series of rainfall attenuation and long-term probability, daily and service-oriented statistics of reasonable rainfall attenuation [11].

SST not only improves the performance of satellite communication systems, but also makes designs more realistic [12]. Convolution is a mathematical method for solving problems (16). In addition, for time compensation according to distance, the precipitation time series obtained by the rain sensor during the 1-minute integration period in the precipitation spatial series along the line using the synthetic rainfall method estimation is as equation (1).

SST is a effective method for calculating time series of rainfall attenuation and long-term probability, daily and service-oriented statistics of reasonable rainfall attenuation [11]. SST not only improves the performance of satellite communication systems, but also makes designs more realistic [12]. Convolution is a mathematical method for solving problems (1–6).

$$A(X) = K_A \int_0^{L_A} R^{\alpha_A}(X_0 + \Delta X_0, \xi) + K_B r^{\alpha_B} \int_{L_B}^{L_A} R^{\alpha_B}(X_0, \xi) d\xi \tag{1}$$

When it rains, the functional structure of the troposphere is divided into two levels. A is the rainfall layer and B is the molten layer. It can be seen from equation (2). For satellite paths, signal attenuation is determined by the formula:

$$A(t) = K_A R^{\alpha_A}(t) L_A + r^{\alpha_A} K_B R^{\alpha_B}(t)(L_A - L_B) \tag{2}$$

The path distance and specified rain attenuation are denoted by $A(X)$. K_A represents raindrops at 20^0C, whereas K_B represents raindrop size at 0^0C.

The highest limit of layer A's height above sea level is designated by the letter H_A. In equations (3) and (4), it is expressed as $H_A = H_B - h$ km, where h is the melting layer thickness. The formulae $L_A = (H_A - H_S)/\sin(\theta)$ and $L_B = (H_B - H_S)/\sin(\theta)$ are used to calculate the radio path lengths L_A and L_B, where θ is the link of elevation angle and HS is the Earth station's height above sea level, respectively.

$$\Delta x_0 = \Delta L \cos(\theta) = h/\tan(\theta) \tag{3}$$

$$\Delta L = L_B - L_A = \mathrm{h}/\sin(\theta) \tag{4}$$

The equation generates a decaying time series that is correlated with a rainfall rate time series to produce a decaying data set (5). By transforming the Fourier transform theory into the decaying time series of equation (5) and making some assumptions, [15] gives the following equation:

$$A(t) = K_A R^{\alpha_A}(t) L_A + r^{\alpha_B} K_B R^{\alpha_B}(t)(L_B - L_A) \tag{5}$$

The time series of rainfall intensity $R(t)$, like the other parameters, was developed earlier. If the wind speed (v) is close to infinity and the theta angle is not 90 degrees, then this equation can be used. The rainfall attenuation probability distribution is calculated from the probability distribution of the rainfall rate, excluding the additional SST in equation (6).

$$A = [C_0 K_A R^{\alpha_A} + (1 - C_0) K_B (3.134R)^{\alpha_B} B] L^m \tag{6}$$

where C_0 and L are constants in the given scheme and L (km) is the mean long-term slope track of precipitation according to [16]. The values of m used in the following equations are derived from equation (6), where K is a standard constant that converts the rainfall rates for the two precipitation layers A and B shown in the SST to a specific (dB/km) rainfall attenuation [17].

The rain rate statistic study for the Ku band utilizing the SST technology. Figures 2 and 3 show a comparison of rain attenuation using the SST approach to the measured one. It is clear that the SST technique exhibits the same characteristics as the measured one [9]. In addition, the SST predicted attenuation is applied in the time diversity approach.

For each event, the rainfall attenuation statistics for SST are nearly identical to the observed rainfall attenuation statistics [9]. Two peaks were found in Figure 1. SST estimates the main peak rainfall attenuation to be about 13 dB. At the second peak, the observed rain fade price is 10 dB and the SST price is 12.8 dB. The measured rainfall reduction cost at the second peak is 11 dB, but SST estimates it to be around 11 dB. The 30-minute average rainfall attenuation for the first event is 2.755 decibels, which is 3.405 decibels according to the SST calculation. For the second case, the 48-minute mean of the rainfall attenuation time series recorded for the second case is 4.855 dB and predicts an SST of 5.329 dB.

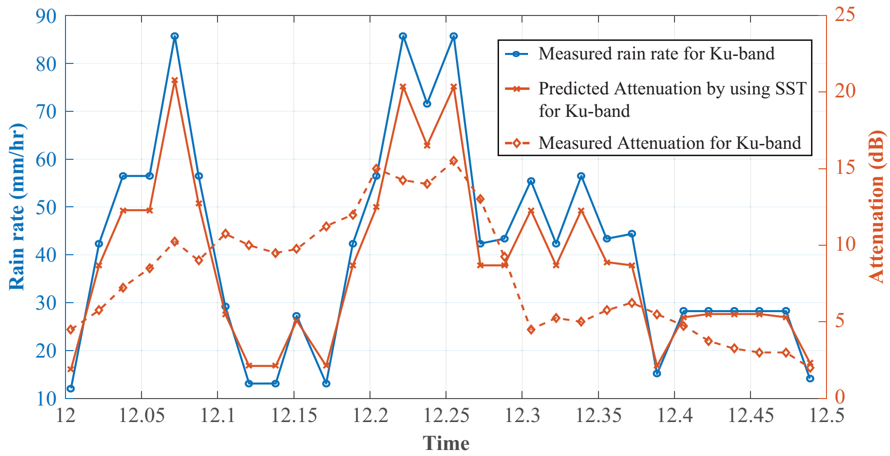

Fig. 1. For a rainy event on August 16, 2012, there was a comparison between rain rate, recorded rain attenuation, and rain attenuation time series converted by SST [9]

2 Time diversity technique

The time delay can range from 1 minute to 1 hour or more, and the same data is retransmitted each time. Temporal fluctuations set up a load on the receiver's memory when a lot of processing time is required [17]. Estimate the time-variety performance using an additional cumulative time-delayed rainfall attenuation distribution function [18].

$$P(A) = P[A(t) > A_{th}, A(\delta t) > A_{th}] \tag{7}$$

While t is regarded a time diversity delay, and $A(t)$ is the rain attenuation value that shifted of t, $A(t)$ is the rain attenuation value that shifted of t. The following is a rewrite of equation (5):

$$P(A) = P[\min(A(t) > A_{th}, A(\delta t) > A_{th})] \tag{8}$$

As a result, the minimal attenuation with variety [18] is as follows:

$$A_{TD} = min[A(t), A(\delta t)] \tag{9}$$

The main rainfall attenuation is 28.24 dB without time delay, but after a delay of 10 minutes to 30 minutes, the maximum rainfall attenuation is 24.35 dB and the minimum rainfall attenuation is 6.68 dB. Figure 2 shows the time diversity method for Earth satellite path signals for rainfall events detected in Malaysia [19–20].

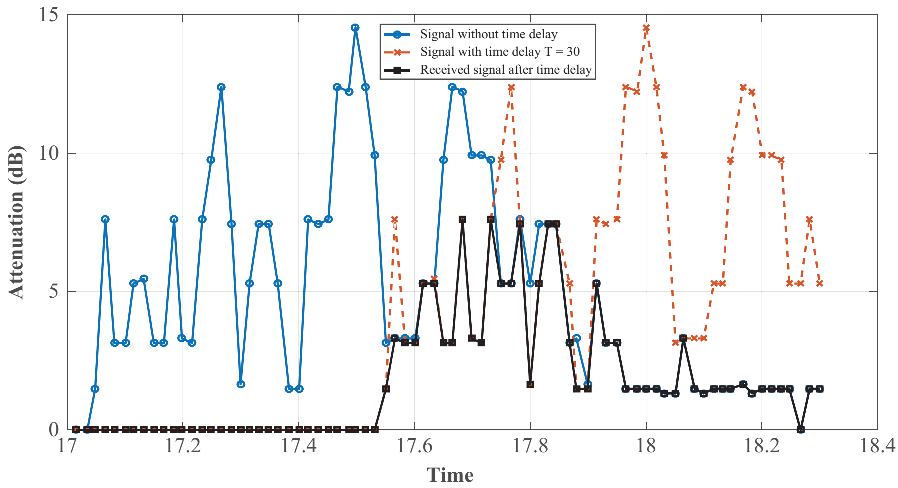

Fig. 2. On the signal of a satellite-Earth link with a rainfall event detected in Malaysia by using time delay method [19,22]

The difference in dB between the cumulative distributions of attenuation and their value with a set time delay is also known as gain of temporal diversity, and it may be represented statistically using the equation provided in (10).

$$G_{TD} = A(t) - A_{TD} \tag{10}$$

where G_{TD} is defined as the gain from time diversity, $A(t)$ is the time decay due to rain, and A_{TD} is the time diversity decay.

Matricciani presented the following rain attenuation gain model based on his measurements in Italy:

$$G = (0.65\,e^{0.036f} + 0.38)(1 - e^{-0.09T(1-e^{-0.44A})})A \tag{11}$$

where G is the attenuation factor, f is the frequency in GHz, T is the delay period, and A is the rainfall attenuation level.

3 Measurement setup

For receiving beacon signal measurement, the rain rate and attenuation distribution, as well as its characteristics, were measured at the University Sains Malaysia (USM), (4.39°N, 100.98°E), at a height above mean sea level of 57 m and a distance of 4.86 km. At 12.255 GHz, with a 40.1° elevation angle, the SUPERBIRD-C signal was received [21,22]. For USM, data on 1-year rain rate and rain attenuation were collected throughout the course of 2009.

4 Result and analysis

4.1 Measured rain attenuation distribution with time delay

The measured rain attenuation is analyzed using equations (7–9) to develop cumulative distribution function. The measured rain rate CDF without delay (T = 0) and with delays of 1, 3, 5, 10, 15, 20, 25 and 30 minutes are shown in Figure 3.

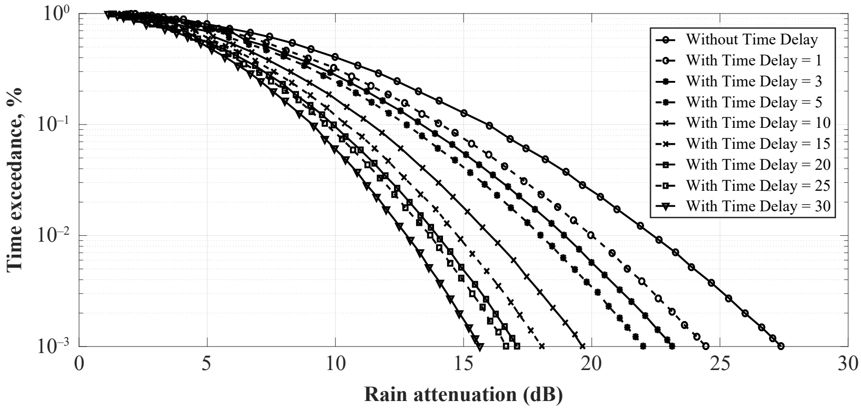

Fig. 3. Measured rain attenuation for several time delays in at USM, Malaysia for the year 2009 by using complementary cumulative function

Without the time diversity approach, the inverse relationship between time delay and excess attenuation for a given percentage of time is 23.6 dB. For time delays 1, 3, 5, 10, 15, 20, 25, and 30 minutes, the rainfall attenuation values are 20, 19, 2, 18, 1, 15. 8, 14.9, 14, 13.8 and 13 dB respectively.

4.2 Time diversity technique by using SST

By following the rain attenuation time series by using SST equation (1–6), is used to make a comparison of the original time series of rain rate and measured rain attenuation time series in Figure 4. It has been observed that pick in the rain rate and pick in the attenuation at 11 m/s are at the same time and it is closer to rain rate. As a result, for 1-year data conversion, a velocity of 11 m/s is used. Furthermore, the most relevant finding is that SST-based attenuation rises fast as a function of observed rain rate [23, 24]. This makes sense because the majority of rainfall in tropical places occurs in short bursts with high intensity.

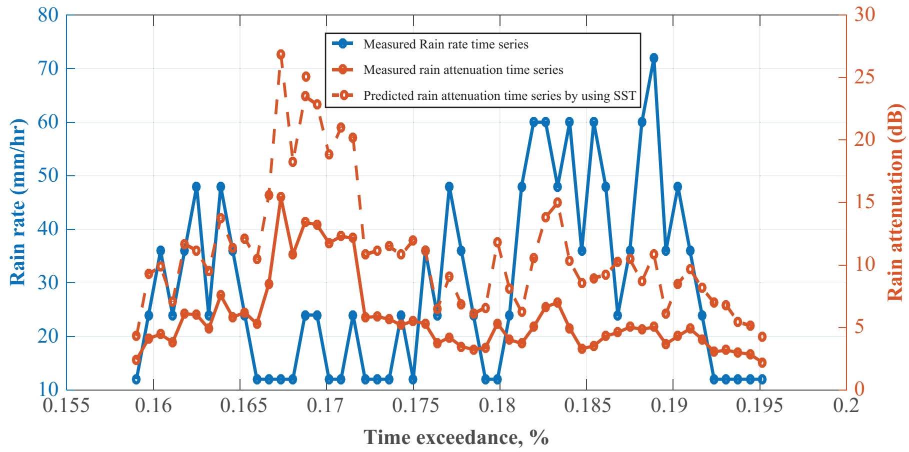

Fig. 4. An example of one event measured rain rate, measured rain attenuation and convert attenuation by using SST

Attenuation converted by SST and T is time regarding days based on a year. For getting the CDF, whole year predicted attenuation data of 2009 converted by the SST have been taken. The SST technique is implemented of time delay method by using equations (1–10). The rain attenuation CDF by converting SST technique without delay (T = 0) and with delays of 1, 3, 5, 10, 15, 20, 25 and 30 minutes are shown in Figure 5.

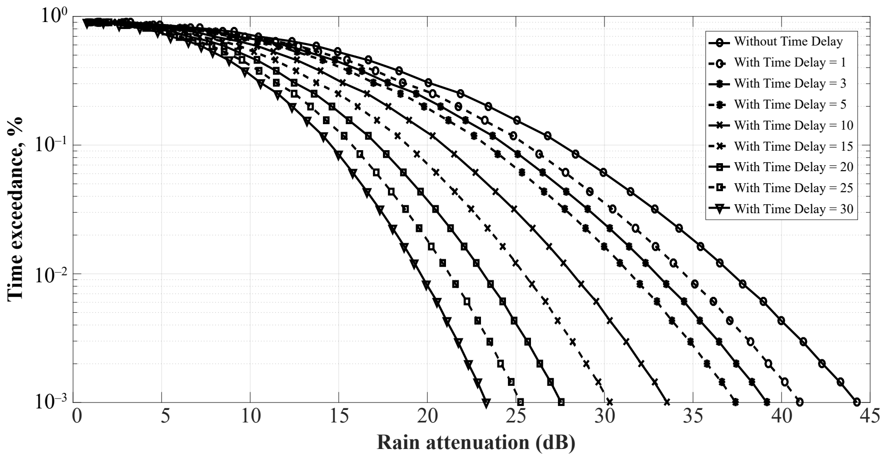

Fig. 5. Cumulative distributions of predicted rain attenuation by using SST for several time delays

Each curve indicates to a specific time delay represents predicted rain attenuation before applying the time diversity technique. In Figure 6 at 0.01 % attenuation without applying time delay technique is 44.8 where the rain attenuation values are 40.8, 39.6, 36.2, 34.3, 30, 26.4, 25 and 23.9 dB for 1, 3, 5, 10, 15, 20, 25 and 30 minute time delay respectively. It is obvious the difference of attenuation by using equation (10) is increasing with delay of time. Simulations using the Synthetic Storm Technique (SST) yielded temporal in non-real-time satellite communications in the frequency range 12 to 100 GHz, variety during rain attenuation [25–27].

Figure 6 presents a comparison of measured, SST, and Matricciani research results with a time delay of 1 to 30 minutes at 0.01 percent. All gain observations show that SST and Matricciani extrapolated gain was higher than measured gain at Ku band.

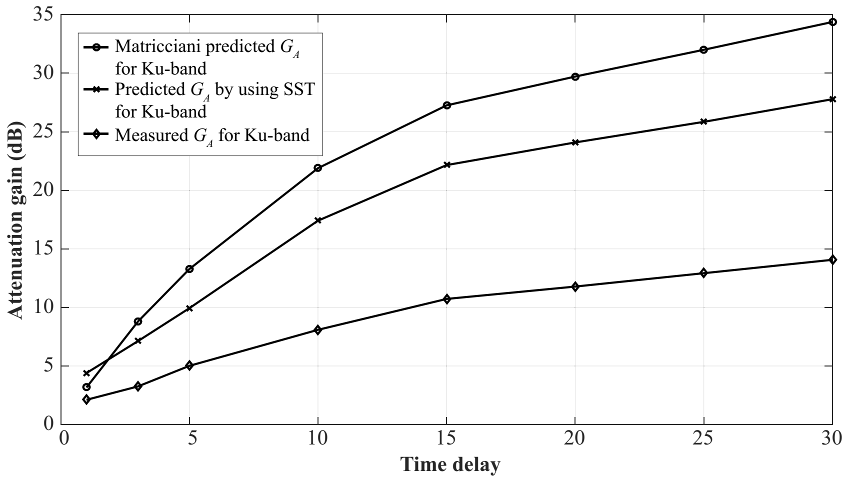

Fig. 6. For 12 GHz, a comparison of SST calculated, Matricciani predicted, and observed gains was made [24]

4.3 Proposed time diversity technique based on ITU-R P.618-13 and rain rate with delay

The rain rate with time delay is proposed based on the real time rain attenuation with time delay concept which are elaborated in equations (7–9). The complementary cumulative distribution function is proposed to be expressed on real time rain rate and the same period with time delay as considered for rain attenuation. The $Rm(t)$ means the real time rain rate and $R(t + T)$ means the rain rate with time delay where the time diversity delay is expressed T. The equation (1 to 3) are proposed based on rain rate time series as follows:

$$P(R) = P[Rm(t) > R] = \int_R^\infty \xi[Rm(t)]dR \tag{12}$$

Where ξ is the rain rate $Rm(t)$ density function, and $P(R)$ is its integral, computed for all time t in the rain rate time series. The proposed expression for the joint distribution is

$$P[Rm(t) > R, R(t+T)R] = \int_R^\infty \int_R^\infty \gamma[R(t), R(t+T)]dR(t)dR(t+T) \tag{13}$$

The joint probability density function γ of $Rm(t)$ and $R(t + T)$ with delay time T is $[Rm, t., R(t + T)]$.

The condition of rain rate with time delay method can be used as the complementary cumulative distribution function to eastimate the implemention of rain rate with time diversity as:

$$R_{TD} = \min[R(t), R(t + T)] \quad (14)$$

The measured rain rate for the year 2009 at USM is analyzed using equations (12–14) to develop cumulative distribution function. The measured rain rate CDF without delay (T = 0) and with delays of 1, 3, 5, 10, 15, 20, 25 and 30 minutes are shown in Figure 7.

For the environmental analysis It has been observed due to heavy rain fall in Malaysia signal becomes drop and heavy attenuation is occurred as a result lots of barrier occurred like economical lose, right information lose coming from the satellite. For the situation basis time delay can be effective with 1, 3, 5, 10, 15, 20, 30 minutes. It has been observed that most of the cases 30 minutes time delay is effective.

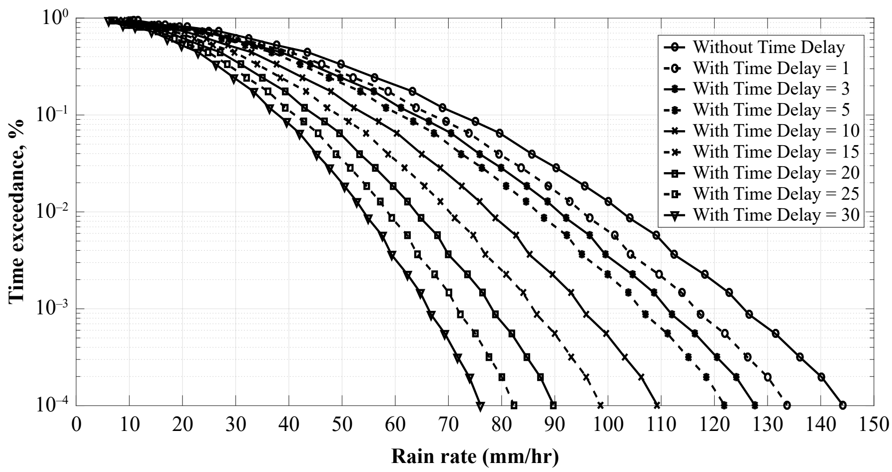

Fig. 7. Cumulative distributions function of measured rain rate with time delays

As a result, the Synthetic Storm Technique (SST) was proposed to convert the measured realtime rainfall data into rainfall attenuation data and predict the time diversity gain. The measured rainfall data was converted to rainfall attenuation data using the traditional SST method. While the rain rate level values are 95, 90, 78, 70, 64, and 59 mm, with time delays of 1, 3, 5, 10, 15, 20, 25, and 30 minutes, the rain rate level values are 95, 90, 78, 70, 64, and 59 mm.

The ITUR P.618-13 forecasting method is used to estimate rainfall attenuation in Earth-satellite links using measured rainfall rates with and without a time percentage overshoot of 0.01%. The satellite is assumed to be SUPERBIRDC with an elevation angle of 40.1°. All signals are treated as horizontally polarized and attenuation is predicted using equation (15–17).

To obtain the specific attenuation, γ_R using the frequency-dependent coefficients [15]

$$\gamma_R = K(R_{0.01})^{\alpha} \tag{15}$$

k and α, these parameters are dependent on frequency, rain temperature, raindrop size distribution, and polarization are given in Recommendation ITU-R P.618-12 [16],

In order to predict attenuation exceeded in 0.01% of an average year, the following formula is used.

$$A_{0.01} = \gamma_R L_E \tag{16}$$

Here L_E is effective path length.

The estimated attenuation to be exceeded for other percentages of an average year, in different percentage, is determined from the attenuation to be exceeded for 0.01% for an average year [15].

$$A_p = A_{0.01}\left(\frac{p}{0.01}\right)^{-(0.655+0.033\ln(p)-0.045\ln(A_{0.01})-\beta(1-p)\sin\theta)} \tag{17}$$

Based on earth-to-satellite prediction model proposed by using ITU-R equation (11–13) [19] and using 0.01% rain intensities of R 0.01% = 102 mm/hr (T = 0), 95 mm/hr (T = 1 min), 90 mm/hr (T = 5), 78 mm/hr (T = 10), 70 mm/hr (T = 15), 64 mm/hr (T = 20), 59 mm/hr (T = 25) and 53 mm/hr (T = 30) the predicted attenuation is shown in Figure 8.

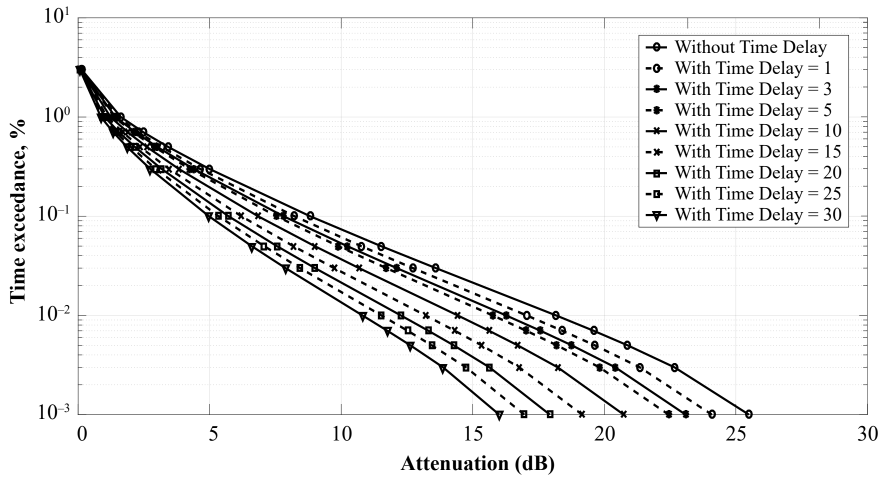

Fig. 8. Cumulative distributions of predicted rain attenuation by using ITU-R for several time delays

Using the time diversity approach, Figure 8 illustrates the forecast rain attenuation distribution. For example, without using the time diversity approach, the rain attenuation level is 25.5 dB at 0.01-time percentage. While the rain attenuation level values are 24, 23.2, 22.8, 20.5, 19.2, 18.3, 17.2, and 16 dB for time delays of 1, 3, 5, 10, 15, 20, 25, and 30 minutes, respectively, with temporal variety.

4.4 Time diversity rain attenuation gain

The time diversity attenuation gain (GA) is predicted by using SST technique as in equations (1–10) and one year measured rain rate. The same is also predicted by Matricciani's prediction model in equation (11). The time diversity attenuation gain is also predicted based on ITU-R P.618-13 as shown in equations (15–17) using new concept of measured rain rate with delay as in equations (12–14). The above three predicted gains are compared with those measured for the same period of time using equations (7–9) and shown in Figure 9.

The most important observation is that the both predicted and measured GA increase rapidly as a function of time delay up to 30 minutes and after 30 minutes delay it is increasing gradually.

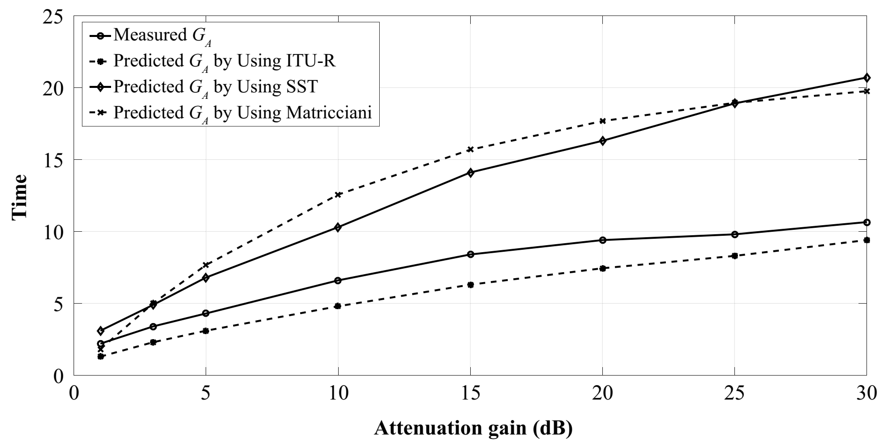

Fig. 9. Comparison among measured rain attenuation gain, predicted rain attenuation gain by using SST, predicted rain attenuation gain by using SST and Matricciani model gain at 0.01% for 12 GHz

The predicted G_A by SST Method is compared with measured G_A and found that after it overestimates from measured G_A. The predicted G_A is 10.4 dB higher than measured one for 30 minutes delay which indicates above 51% error. The predicted G_A by Matricciani using equation () is compared with measured G_A and found that after it overestimates from measured G_A. The predicted G_A is 9.2 dB higher than measured one for 20 minutes delay which indicates above 48% error.

From Figure 9, it is obvious that gain predicted by proposed method is almost similar character with measured gain. It underestimates and maximum 0.8 dB difference is found at delay of 15 minutes which indicates 12% of error.

The comparison of predictions by using SST, Matricciani model and proposed method, the proposed method is found very good agreement with data measurement. And it shows the performance much better than SST and model proposed by Matricciani. Hence the proposed method will be useful in future for modelling of time diversity technique at any higher frequencies by using measured rain rate.

As a result, rain rate with delay can be assumed to represent rain attenuation with delay for the same amount of time at the same place. This assumption is true as long as rain induces attenuation. As a result, it is clear that the time diversity approach may be assessed using a new concept of rain rate, which has been defined as the difference in rain rate with and without time delay, with substantial accuracy, as opposed to being assessed just on the basis of recorded rain attenuation. This notion demonstrates how recorded rain rate may be used to determine attenuation gain at any higher frequency. The following relationship may be used to build the suggested temporal diversity gain model for rain attenuation:

$$GA_{TD\%p} = f\,(R_{m\%p}, T, freq, El) \tag{18}$$

Where $Rm\%p$ = measured rain rate at $\%p$

T = time delay

Freq = frequency of link

El = elevation angle of link

A slight discrepancies in proposed method with measured attenuation gain in Figure 9 may be caused by the elevation angle considered in ITU-R prediction method [13,14].

5 Conclusion

Earth-to-satellite communication technologies are going towards higher and higher frequency bands in the future. Rain fading is the most difficult aspect of developing extremely dependable earth-to-satellite communications above 10 GHz. The problem is exacerbated in tropical areas by the fact that significant rainfall occurs throughout the year. Time variety is considered a cost-effective and efficient mitigation approach to counterbalance the attenuation produced by rain. The improvement in temporal diversity attenuation is thought to be a prerequisite for future high-frequency networks. Synthetic storm approach and Matricciani's model based on recorded rain rate are both approved internationally for predicting this gain. The rain rate and rain attenuation data recorded at Ku-band for a year in Malaysia are presented in this article. Using the SST approach, the recorded rain rate data was converted to rain attenuation data. The temporal diversity gain was predicted using SST converted rain attenuation and Mattriciani's model, and the measurement was found to be greatly overstated, with an inaccuracy of up to 50%. The ITU-R P.618-13 and observed rain rate distributions with delay were used to estimate time diversity gain utilizing a new concept of real-time rain rate with and without time delay. With a 12% inaccuracy, the estimated gain is shown to be close to observations. As a result, utilizing recorded long-term rain rate data, the suggested technique is recommended for more correctly predicting temporal diversity gain at any required frequency.

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