Rain Attenuation Prediction in Tropical Regions using Site Diversity Technique

K. Ravi Teja, B. Alekhya, Ch. Sri Kayya, Praveen V. Naidu

Abstract: Rain attenuation is the main cause for the loss of signals throughout sending or reception over earth’s atmosphere. Moreover raindrops converts the direction of the signal. Rain attenuation changes with change in the frequency and change in the rain rate. As the prediction of rainfall in tropical regions is difficult, design of a terrestrial satellite link without attenuation is a big challenge. In order to design such links, it is essential to predict the attenuation caused by the rain at different frequencies for different rain rates with respect to the regions where the link is to be established. One of the most significant job to examine the impact of rain on the function of the terrestrial microwave link and to estimate the link size required to compensate for this negative impact. This paper presents the analysis of different Rain attenuation prediction models and derives the results for each model with respect to elevation angle. The measured values are compared with the standard ITU-R rain attenuation prediction models. All the observed values can be used to apply site diversity technique and the attenuation value is reduced using site diversity technique.

Keywords—ITUR-R, Rain Attenuation, Terrestrial, Site Diversity, Microwave, Frequency, Prediction.

I. INTRODUCTION

Based on seasonal symptoms and location, rain or stream form may be rain or critical rain. In stratiform, rainfall is low to medium and displays great spatial homogeneity. On the other hand, thermodynamic rain has a radius of 5 km radius, with high rainfall. Rain cells are enclosed by broader zones of stratiform rain. Inhomogeneity of rainfall in rain cells occurs in a very decline, which leads to a cooperative attenuation of signals that follow dissimilar paths. So, if the signal is received by different means, only one of them may be deep fade, which will have little impact on others. Rainfall in both horizontal and vertical directions can predict the complexity of uncontrolled progression. The result is a decrease of satellite-earth microwave signal dissipation, depolarization, and receiver antenna sound. Signal decline for radio-communications schemes working in centimeters and millimeter wave bands Rainfall is one of the main causes, especially in the tropical climate. Rain decline is crucial to designing a ground-satellite radio link at frequencies above 7GHz. These spots can be determined by spots, uniformity and just statistically or experimentally rainfall measurements.

There are two methods of assessing rain deterioration:

- **Physical approach**: This method involves the calculation of the rain attenuation decrease by the practical measure in the laboratory.
- **Empirical approach**: This method uses an effective way of using data from various data bases and uses the length and rainfall rate.

II. PREDICTION OF RAIN ATTENUATION

The brightness of the signal reduces its power when it passes through its medium. It is usually measured in decibels. Spots are adverse when rain is positive. The flow of rain can be calculated from the proportions of the electrically charged flow, which generates the flow of energy as

\[ P(r) = P(0)e^{-\alpha r} \]

The following equations are represent in dBs for the above equation.

\[ P1 = p(0)/p(r) \]
\[ \text{Loss} = 10 \log(p1) \]
\[ = 4.434\alpha \gamma \]

It is called the specific attenuation, \( \gamma \text{(dB/Km)} \). If you know the size and shape distributions [3] from electromagnetic theory, easy to straighten the typical model depends on the rainfall rate:

\[ \gamma = pR^q \]

Here \( p \) and \( q \) constants are provided in the table below.

<table>
<thead>
<tr>
<th>( F ) in GHz</th>
<th>( P )</th>
<th>( Q )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0000387</td>
<td>0.917</td>
</tr>
<tr>
<td>10</td>
<td>0.0101</td>
<td>1.276</td>
</tr>
<tr>
<td>20</td>
<td>0.0751</td>
<td>1.099</td>
</tr>
<tr>
<td>30</td>
<td>0.187</td>
<td>1.021</td>
</tr>
<tr>
<td>40</td>
<td>0.350</td>
<td>0.939</td>
</tr>
</tbody>
</table>

**Table 1**: Values of \( p \) and \( q \) at different frequencies

The value of \( p \) increases while frequency increases, but the \( Q \) is low, the rain deterioration is higher at high frequencies. Some of the symptoms of rain deterioration are as follows:

- Rain attenuation is directly related to improved communication.
- Rain deterioration can be estimated

III. ANALYSIS OF EXISTING PREDICTION MODELS

Rain attenuation patterns for experimentation follow simple procedure. Rain data is collected using a rain gauge. Receives signal from receiver,
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A. MOUPFOUMA’S METHOD

The method has been established by using mostly tropical data. The method requirements elevation angle of the slant path, site height from sea level, etc. Here, the Rain rate is also required for 0.01% and other percent of time to present the idea of modification factor. Predicted attenuation is given by

\[ A(\text{dB}) = \frac{k R^2 a^2 (p2001 / p2000)^{0.38} (L_s/L_r)^{0.15}}{1 + (p2001 / p2000)^{0.38} (L_s/L_r)^{0.15}} \times L_s \]  

where,

- \( m = 1 + 1.4 \times 10^{-4} f^2 \log_e (L_s) \)
- \( f = \text{frequency (GHz)} \)
- \( L_s = \text{slant path length in kms} \)
- \( D = \text{onset time} \)
- \( R = \text{rain rate} \)

Moupfouma has provided the values of \( \alpha \) for different locations throughout the world. Slant path formula is given by,

\[ L_s = \frac{H_R - H_0}{[\sin^2 \theta + 2 \left( \frac{H_R - H_0}{8500} \right)^{1/2} \sin \theta]} \quad \text{for } \theta \geq 5^\circ \]

Here,

- \( \theta = \text{angle of elevation; } \)
- \( H_0 = \text{location height from sea level; } \)
- \( H_R = 0^\circ \text{C height of isotherm.} \)

It should be pointed out that Crane has planned a technique using revised two-component model. However, the method is valid for slant paths only[4].

B. ITU-R MODEL

International telecommunication union radio model is the generally used technique designed for calculating effect of rain and slant path. Main input for these models is time at 0.01% (A0.01) rainfall, which is used to estimate the scattering at other percentages. Since this model accepts a constant reduction factor in calculating the sustained rain altitude and slant path, it will not be an operative method to measure tropical and intermediate regions, as rainfall is potentially variable rainfall with rain intensity. For satellite arguments in different places, rain-specific attention and rain will be calculated using the ITU-R model for changes in the route slant.

Calculation of Rain Attenuation

- **step 1**: calculate the following
  \[ h_R = h_0 + 0.36 \]

- **step 2**: length of Slantpath
  \[ L_s = (h_R - h_s) / \sin \theta \]

\( \theta = \text{angle of Elevation} \)

\( h_s = \text{station height} \)
\( h_R = \text{Horizontal projection of rain height} \)
\( L_G = L_s \cos \theta \)

- **step 3**: Rainfall, R0.01, exceeds 0.01%, with 1-min integration time.
- **step 4**: Specific attenuation
  \[ \gamma R = K (R_{0.01}) \alpha \]
  
where \( K \) and \( \alpha \) shown below and depends mainly on rainfall size distribution, polarization, frequency and height.

\[ k = [k_R + k_H + (k_R + k_H) \cos 2 \theta \cos 2(\pi f)] / 2 \]

\[ \alpha = (k_R + k_H + (k_R + k_H) \cos 2 \theta \cos 2(\pi f)) / 2k \]

- **step 5**: horizontal path adjustment factor is calculated using
  \[ r_{0.01} = 1 / \sqrt{1 + 0.78} \left( \frac{k_R}{k_H} - 0.38 (1 - e^{-2 \gamma \theta}) \right) \]

- **step 6**: Familiar rain-path length
  \[ L_R = L_{0.01} \sin \theta \quad \text{for } \epsilon > \theta \]
  \[ L_s = (h_R - h_s) \sin \theta \quad \text{for } \epsilon \leq \theta \]

\[ \epsilon = \tan^{-1} \left( \frac{h_R - h_s}{L_s / 0.01} \right) \]

- **step 7**: Vertical reduction factor
  \[ V_{0.01} = 1 / \sqrt{1 + \left( \frac{5 \gamma (1 - e^{-0.5 \gamma})}{0.5 \gamma (1 - e^{-0.5 \gamma})} \right)} \]

- **step 9**: Attenuation exceeded for 0.01 percentage
  \[ A_{0.01} = \gamma R L_e \]

- **step 10**: For the calculation of attenuation at 0.001% to 10%
  \[ A_1 = A_{0.01} (P / 0.01)^{-0.365 + 0.022 \ln (P) - 0.045 \ln (P_{2000}) - \beta (1-P) \sin \theta} \]

C. GARCIA LOPEZ MODEL

GL Model is a easy design depending on good database. Rainfall decline and rain intensity are calculated by regressive methods depends on terrestrial regions. Special values are given for different calculations in tropical countries [1].

\[ A(\text{dB}) = k R a L_s / [a \ln \{L_s (h_R + c L_s + d) / e \}] \]

\( R = \text{rain rate (millimetre/hour)} \)
\( L_s = \text{Corresponding path length in km} \)
\( L_s = (h_R - h_s) / \sin \theta \)
\( \theta = \text{Elevation perspective} \)
\( h_s = \text{distance between ground and station in kms} \)

hF= 0° C which is isotope height in kms
a = 0.72  
b = 76  
c = -4.75  
d = 2408  
e = 10000

does the values for India [1].

**D. SIMPLE ATTENUATION MODEL**

SAM is a generally used slant path, clearing indicator models, strati type and tropical varieties of rainfall. In addition to the rate of rainfall at the soil, the deterioration is used to calculate. The rate of rainfall is the simplified logarithmic relationship. In complex rainfall, R> 10 mm / h, when effective rainfall height, HR increases the length of the path slow.

\[
A(\text{dB}) = \gamma L_s \text{ if } R_p \leq 10 \text{mm/hr}
\]

\[
L_s = H_R - H_s / \sin \theta
\]

\[
a = 1 - \exp\{(-a1)\}
\]

\[
a1 = \gamma^{\ln(Rp/10)}
\]

\[
A = \gamma^{a*L_s \cos \theta / a1* \cos \theta}
\]

\[
b = 0.0454545
\]

\[
HR = H_0 \text{ for } R \leq 10
\]

\[
HR = H_0 + \log(R/10) \text{ for } R > 10
\] [1].

**E. HORIZONTAL AND VERTICAL REDUCTION FACTORS**

The horizontal and vertical reduction factors to assess the predictability of the unexpected nature of rainfall events. The horizontal reduction factor of the model is based on the concept of Goddard, each has a virtual link along the radial line, which can propagate a signal to the transmission path.

The vertical and horizontal reduction factors \(r_V\) and \(r_H\) are given as

\[
r_{V0.01} = 1.429 \exp\left(-\left(\frac{1}{\gamma R_{g01} L_g - 0.0251}\right)^2\right)
\]

\[
r_{H0.01} = a L_g^b + c
\]

\[
\alpha = 2.969 \exp\left(-\left(\frac{f - 45083}{23.61}\right)^2\right)
\]

\[
b = -8128 f^{-2.329} - 0.1432
\]

\[
c = -0.00006553 f^3 - 0.005906 f^2 + 0.08657 f + 1.513
\] (30)

\[
L_g = L_G \cos(\theta)
\]

\[
L_g = H_R - H_s / \sin(\theta)
\]

\[
A_{0.01} = \gamma R_{g01} L_g r_{V0.01} r_{H0.01}
\]

\[
\frac{A_{p}}{A_{0.01}} = 0.117 \left(0.637+0.8371 \text{log}(2)\right)
\] [3] (34)

**IV. PROPOSED DIVERSITY TECHNIQUE**

To decrease the effect of rain on communication lines, many prediction models have been evaluated to include fade-mitigation models that have been evaluated. In all the fade mitigation models, site diversity has been recognizes to be the more efficient. The site diversity method is depends on the perception of incomparable nature of rainfall, which happens in the restricted rain cell for a limited kilometers in the horizontal and vertical range.

**SITE DIVERSITY**

Severe rain particles that cause large degrees of value on the ground-empty link often have more than one kilo meter parallel dimensions. Differential systems that can be transmitted with satellite access to alternative land stations At more than 20 GHz frequencies, losses in other ways than rain may also affect site diversity performance[2].

The prediction method defined below applies for balanced and unbalanced methods and computes the common probability beyond the limitations of attenuation. This assessment method is highly accurate and given priority[2].

**Prediction of outage probability due to rain attenuation with site diversity:**

The probabilities given as

\[
P_a(A_i \geq a, A_s \geq a_s) = 100 \times P_a \times P_s \%
\]

These probabilities are:

\[
P_r = \frac{1}{2\pi \sqrt{1-\rho_r^2}} \int_0^\infty \int_0^\infty \exp\left[-\left(\frac{r_1^2 - 2\rho_r r_1 r_2 + r_2^2}{2(1-\rho_r^2)}\right)\right] dr_1 dr_2
\]

Where

\[
\rho_r = 0.7 \exp\left(-d/60\right) + 0.3 \exp\left(-d/700\right)
\]

(37)

\[
P_a = \frac{1}{2\pi \sqrt{1-\rho_a^2}} \int_0^\infty \int_0^\infty \exp\left[-\left(\frac{b_1^2 - 2\rho_a b_1 b_2 + b_2^2}{2(1-\rho_a^2)}\right)\right]/db_1 db_2
\]

(38)

Where

\[
\rho_a = 0.94 \exp\left(-d/30\right) + 0.06 \exp\left(-d/500\right)
\]

And \(P_a\) and \(P_r\) are complementary bivariate normal distributions.

\[
P_{a}^{\text{gain}} = 100 \times Q(R_a) = 100 \times \frac{1}{\sqrt{2\pi}} \int_{R_a}^\infty \exp\left(-\frac{r^2}{2}\right) dr
\]

where

\[
R_a = Q^{-1}\left(P_{a}^{\text{gain}} / 100\right)
\]

i.e.: 

\[
P_{a}^{\text{gain}} = Q\left(lnA_i - \min A_i\right) / \sigma ln A_i
\]

These limitations can be found for every separate
position, or a single position can be used. The rain attenuation vs. annual probability of incidence can be predicted using in this technique defined above.

1. Determine \( P_{\text{rain}} \) (% of time), the probability of rain on the k-th path.
2. Construct the set of pairs \([P_i, A_i]\)
\[ P_i \leq P_{\text{rain}} \]
3. Transform the set of pairs \([P_i, A_i]\) to \( Q^{-1}\left(\frac{P_i}{P_{\text{rain}}}\right), \ln A_i \)

Where
\[
Q(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} e^{-\frac{t^2}{2}} dt
\]

Step 4: Determine the variables \( m_iA_i, \sigma_i A_i \) by performing a least-squares fit to:
\[
\begin{align*}
\ln A_i &= \sigma_i A_i Q^{-1}\left(\frac{P_i}{P_{\text{rain}}}\right) + m_i A_i \\
&\text{for all i}.[2]
\end{align*}
\]

V. RESULTS

The five different models and the exceedance percentage rate taken as input for the corresponding standards values as shown below.

WITHOUT USING SITE DIVERSITY TECHNIQUE

From figs 1, 2, 3, & 4, SAM models have been shown to have a similar performance for almost all frequencies above 10GHz. Attenuation for high rain rates is practically stable. ITU-R model simultaneously develop the attenuation for high rate of rain. Attenuation increased for low rate of rain and almost stable for 30millimeter per hour rate of rain in Garcia-Lopez. The high attenuation values for the models at 40GHz frequency are 37, 33, 17, 12 and 2dB for HORIZONTAL AND VERTICAL REDUCTION FACTORS, ITU-R, GARCIA-LOPAZ, SAM and MOUPFOUMA models respectively.

In the observations from the figs, significantly increases the values exceeding 50mm / h rain rate. The Moufouma model gives a good downturn to all rainfall. SAM, approximately 70mm/hr rainfall rate for Garcia-Lopez techniques is almost the same values of fatigue. From this figures one think is observes that is ITU R and HAVRF models are the best for the communication. Because they have highest attenuation values compared to the others. By using diversity technique we can reduce this high attenuation.

USING SITE DIVERSITY TECHNIQUE
From figs 5, 6, 7 & 8, it can be observed that, using site diversity technique the attenuation value is less compared with the plots from figs 1, 2, 3, & 4.

VI. CONCLUSION

This paper presented a comparison between 5 different models to predict the rain attenuation. The best performing model is Moupouma model where attenuation is less compared to other models. Three successive year’s data in Andhra Pradesh is considered. As frequency increases rain attenuation also increases. This can be reduced by choosing various diversity methods. Site diversity is the best method to be employed. Moupouma, SAM, ITUR, HAVRF and Garcia-Lopez models are observed for various frequencies. If the frequency increase then the attenuation increasing with the frequency. Compared to the ITU-R model, the Moupouma model offered a great deal of disadvantage for various frequencies. The SAM model role is roughly approximate to about 10GHz frequencies. All the five attenuation prediction models can be used to apply site diversity technique to reduce the value of attenuation, it will be reduce the impact of attenuation on microwave signal. The attenuation value is successfully reduced by applying site diversity technique to the prediction models. However, only a three-year rainfall rate can be considered for good results require more data to be monitored and more research is needed to reduce the high rainfall.

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Rain Attenuation Prediction in Tropical Regions Using Site Diversity Technique

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