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ESTIMATION OF EFFECT OF TROPOSPHERE RAIN ON RADIO LINK IN TROPICAL ENVIRONMENT

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ABSTRACT

Rain has deleterious impact on satellite signal propagation above Ku-band due to scattering and absorption. Numerous Empirical and Non-empirical models are evolved based on measured statistics to estimate the rain attenuation. The day wise, monthly and yearly analysis for 3 years of data is performed in Vaddeswaram. Of the available models, for the tropical region, ITU-R model which uses bulk recorded database clearly underestimates the value. In this paper different attenuation models like ITU-R, RH, SAM and Moupfouma are studied and the results are compared with measured values and analyzed to determine the suitable model for one of the tropical region Vaddeswaram, A.P. It is observed that the average attenuation is around 13.5dB in a year and Moupfouma model is best suited for this region.

Keywords: rain attenuation, effective path length, rain rate exceedance, beacon data.

1. INTRODUCTION

Satellite communications play a major role in revolutionizing the wireless communication systems by providing large bandwidth, high data rates and large area coverage. Earth space path link is subjected to various impairments due to atmosphere. These impairments are due to rain, gases, clouds, snow, fog, amplitude scintillations. Amplitude or phase scintillations are occurred due rapid fluctuations in refractive index of troposphere. Of these the most predominant and prevailing factor that effects link is attenuation due to rain. As the wavelength of the electromagnetic wave approaches to size of a typical raindrop, generally happens when the frequency of above 10GHz, the electromagnetic wave gives up its energy due to scattering and absorption by rain drops. Rain can also lead to depolarization of signal and increase in system temperature. So the estimation of attenuation due to rain has become a crucial part in the link design.

The extent of attenuation in the down link signal alters as the function of parameters like frequency, rain rate, and percentage exceedance of time, latitude and longitude of area, mean sea level height, rain height, elevation angle of antenna, polarization, polarization tilt angle. Among these rain rate is the key parameter.

2. SOURCE OF DATA FOR ATTENUATION STUDIES

The Ku band propagation studies are conducted in K L University (16.44^{o}N and 80.61^{o}E) located in Vaddeswaram of Andhra Pradesh State in India. The climatic behavior of this region is tropical and has nearly a mean annual rainfall of 73.5cms. The rainfall is mainly influenced by southwest and northeast monsoons. The average number of rainy days is 150days/year. The rainfall intensity is more in the monsoon period from July to October and less during summer.

2.1 Beacon receiver setup

The beacon receiver is an offset parabolic reflector antenna of 0.9m diameter and elevation angle of 65.6^{0} and tilt angle 37.4^{0} to receive a signal in the order of 10-13 GHz with vertical polarization from INSAT-4A/GSAT-10 satellites. A single down conversion from 11.7 GHz to a range of 950-2050 MHz is performed by the LNBF converter. The beacon signal EIRP is around 51.2dBW. From August 2012 to Dec 2014, the system recorded the down converted Ku band signal of INSAT-4A beacon at a sampling rate of 0.1Hz.

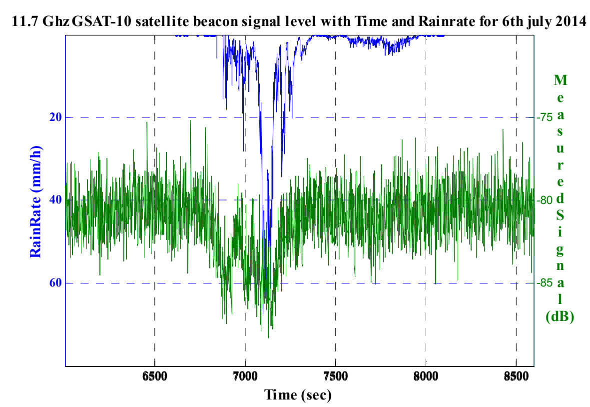

Figure-1. Variation of beacon signal level and rain rate on 6th July with time.

An example of beacon signal received by GSAT-10 on 6th July 2014 with variations in rain rate during the rain event is shown in Figure-1. It can be observed that the signal level is degraded due to the influence of rain.

2.2 Disdrometer

The disdrometer is a laser-optical instrument manufactured by OTT Parsivel. It has a 30mm wide and 180mm long light strip to measure the size and velocity of rain drops. This data can be used to interpret size spectrum, type of precipitation, intensity of precipitation, radar reflectivity, and visibility with a sampling rate of 0.1 Hz. The rainfall rate variations with time recorded on 6th July 2014 is presented in Figure-2. It can be observed that the rain is distributed in the range of 7000 to 8000 sec in the day and highest rain rate is 67.36 mm/hr.

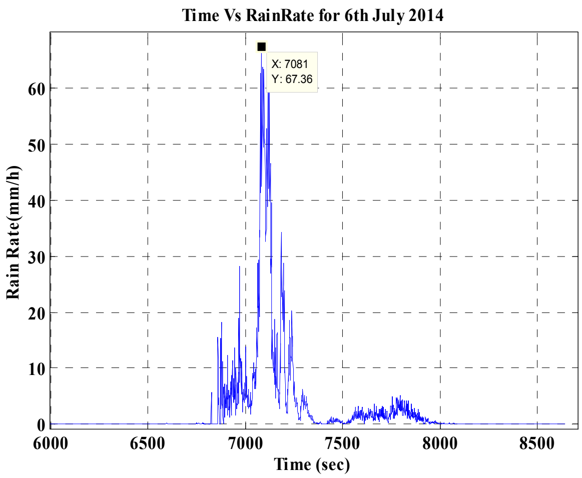

Figure-2. Rain rate variation on 6th July.

Beacon requires preprocessing to be utilized for calculating attenuation in a single day. The subsequent steps are needed to obtain the value.

- Removal of Spurious samples from the signal.
- Estimate the reference level of the signal.
- Attenuation can be calculated as

AdB =Reference signal-Recorded signal

The attenuation variation with the rain rate and time for GSAT-10 beacon signal measured on 6th July 2014 during rain event is presented in Figure-3. The point to be marked here is that attenuation in signal is maximum which is 13.33dB at the highest rain rate of 67.36mm/hr in the entire day.

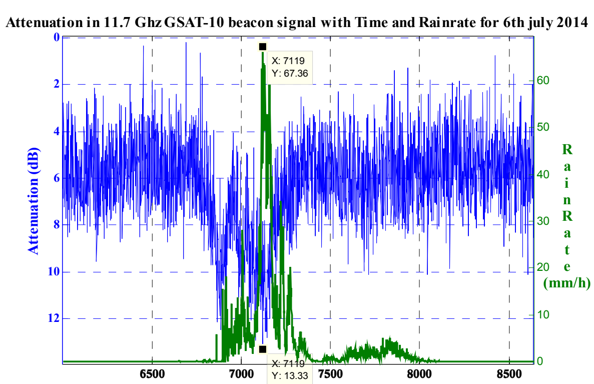

Figure-3. Attenuation variation with rain rate on 6th July 2014.

The subsequent discussion highlights in computing attenuation for a larger period of time (month, year) utilizing different models developed depending on many parameters especially rain rate and effective length excluding the beacon data.

3. RAIN RATE ESTIMATION

As mentioned earlier, rain rate plays a crucial role in attenuation measurement, it is important to estimate rain rate observed for a period of time from the point rain rates recorded by disdrometer. Most of the attenuation models uses rain rate with very less integration time usually in the interval of one minute or less, exceeded as 0.01% ($R_{0.01\%}$). This 0.01% of time corresponds to the allowable outage time in an average year. The integration time used in our studies is 10sec; so that estimation of $R_{0.01\%}$ is accurate the subsequent methods can be adopted for this prospect:

- Conversion of daily or hourly rain rate (longer intervals) to one minute rain rate (shorter intervals).
- Contour maps developed based on rain zone taxonomy by ITU-R.
- Global rain model developed by Crane.
- Rice-Holmberg rain model.
- Power law relationship developed by J.Chebil.

ITU-R model and Crane Global model generally avails database of nearly 30 years and embody ample climatic topography of distant zones. As a result, they rather tend to underestimate the rain rate for a particular site. If the site specific rainfall data is available from the meteorological stations, the conversion of long integration time to concise integration time can be employed. The $R_{0.01\%}$ for our location by ITU-R recommendation is 63.4mm/hr.

Power law relationship developed by J. Chebil can be employed if the mean annual accumulation (M) of the site is available. The power law relationship is as follows:

$$R_{0.01} = \alpha M^{\beta} \tag{1}$$

Where α and β are coefficients calculated by using regression analysis and can be specified as

α=12.2903 and β=0.2973

Rice- Holmberg model employ the parameters like mean annual rain accumulation, thunderstorm component of rain fall.

4. RAIN ATTENUATION PREDICTION METHODS

The prediction of rain attenuation can be done in two methods.

- Physical method
- Empirical method

Physical method approach endeavors to emulate the physical behavior of attenuation process. In this approach not all parameters are considered for attenuation prediction and hence the approach is not mostly used.

Empirical method depends on the rain data collected at specific site or database of meteorological centers. Rainfall rate at 1min or less integration time is necessary for a specific site to estimate attenuation. These models generally estimate attenuation for larger period of time (yearly). Nearly 16 models were proposed based on this empirical approach. Of them only some models can estimate the attenuation accordingly for a particular site as the climatic conditions varies from site to site. So for a tropical region like Vaddeswaram (16^0 44' N and 80^0 61' E) all the models cannot be applied. So the following models are used.

- ITU-R Model
- Rice Holmberg (R-H) Model
- Moupfouma Model
- Simple Attenuation Model (SAM)

Of these four models, ITU-R model is global model which is used for attenuation calculation. The other three models developed to be suitable for tropical regions.

4.1. Basic attenuation equation

Attenuation can be calculated as product of specific attenuation (dB/km) and effective length (km) as follows:

$$A_{0.01} = \gamma_R L_E \text{ dB} \tag{2}$$

Specific Attenuation can be computed by using two techniques:

- Drop Size Distribution and Scattering phenomenon
- Power Law Relationship

Drop Size Distribution and Scattering phenomenon can underestimate the value due to subsequent reasons

- Rain drop is approximated to be Spherical in shape
- The technique is independent of polarization and hence do not differentiate between horizontal and vertical polarizations.

4.1.1 Power law relationship

Power law is the most commonly used relationship to calculate specific attenuation which takes into account, rain rate, frequency, elevation angle, polarization tilt angle, type of polarization and is expressed as follows:

$$\gamma = kR_{0.01}^{\alpha} \tag{3}$$

Where $R_{0.01}$ is Rain rate at 0.01% of time in mm/h, k and α are power law parameters and are defined by ITU-R P.838-3 as follows:

$$k = [k_H + k_V + (k_H - k_V)\cos^2\theta\cos 2\tau]/2 \tag{4}$$

$$\alpha = [k_H\alpha_H + k_V\alpha_V + (k_H\alpha_H - k_V\alpha_V)\cos^2\theta\cos 2\tau]/2k \tag{5}$$

Where

θ represents angle of elevation of receiving antenna

τ represents polarization of receiving signal

K_H, K_V, α_H, α_V are constants of horizontal and vertical polarizations and can be obtained from CCIR tables.

4.2. Rain attenuation prediction models

4.2.1 ITU-R Rain attenuation model

ITU-R model utilizes several recommendations proposed by International Telecommunication Union to estimate the attenuation due to rain.

The main parameters required are $R_{0.01}$, height from sea level (h_s), elevation angle, and latitude. This model utilizes 4 recommendations proposed by ITU-R.

- ITU-R P.839-3 to estimate mean annual rain height[1]
- ITU-R P.837 to estimate $R_{0.01\%}$ [2]
- ITU-R P.838 to estimate specific attenuation[3]
- ITU-R P.618-7 to estimate total attenuation[4]

4.2.2 Rice holmberg model

Rice Holmberg model depends on two different modes of rainfall. It is mainly utilized in the estimation of $R_{0.01\%}$. Mode1 corresponds to convective type of rain fall (thunderstorm) and Mode 2 to stratiform rainfall (uniform). So the total rain rate is sum of these individual modes rate.

Total rain= mode1 rain + mode 2 rain

The key parameter required in R-H model is Thunderstorm Ratio (β) which can be computed as the ratio between mode1 rain fall and total rain.

$$\beta = M1/M \tag{6}$$

The other important parameters required in the analysis are as follows:

P : percentage of a year that point rain rate *R* is exceeded (%)

R : specific rain rate (mm/h)

U : average thunderstorm days expected in an average year

M : average annual accumulation of rainfall (mm)

M_m : highest monthly rainfall observed in 30 consecutive years

Estimated rain rate is relatable to attenuation by Specific Attenuation and Effective length. The rain rate estimates for different percentages of time is shown in Figure-4.

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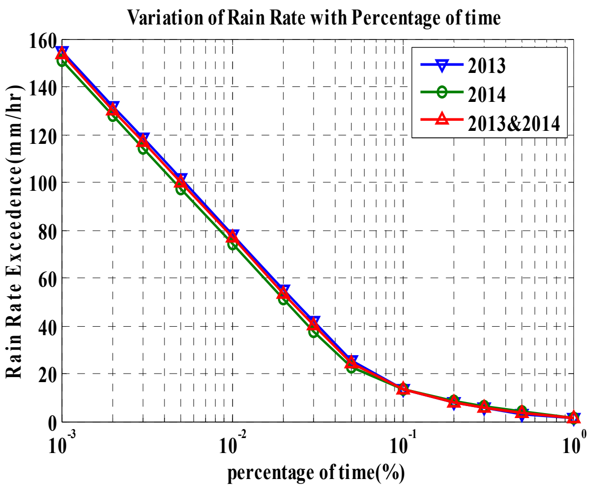

Figure-4. Variation of rain rate with percentage of time.

4.2.3. Moupfouma model

The model is developed to be suitable for tropical region and temperate climates. The model is developed by considering slope shape, rain structure and total propagation path. The model utilizes parameters like $R_{0.01\%}$ by using power law (Chebil's model), specific attenuation calculation by P.838.

4.2.4. Simple Attenuation Model (SAM)

SAM is one of the extensively employed slant-path attenuation prediction models, which encompasses the distinct features of the stratiform and convective (Thunder storm) forms of rainfall. The slant path length depends mainly on the rain height. The rain height depends on the isothermal height and utilizes the recommendation ITU-R P.839-3. The model can also be used for the calculation of point attenuation values. The model utilizes elevation angle, ITU-R P.838 to determine specific attenuation, an empirical constant 'b' for the estimation.

5. RESULTS AND DISCUSSIONS

The above stated models are applied for the rain data recorded for a span of two years by using disdrometer and the comparisons are made for individual year and total span (two years). These are compared with measured attenuation values to determine the suitable model.

5.1. Rain rate estimation ($R_{0.01\%}$)

The Table-1 provides the information about the rain rate $R_{0.01\%}$ for different years by using different rain rate estimation techniques.

Table-1. Rain rates for different years by different Models.

Year	Rain rate ($R_{0.01\%}$) mm/h	
	RH model	Power law
2013	74.2795	88.495
2014	78.2727	86.3
2013& 2014	76.7502	87.3975

From Table-1 it can be clearly observed that the ITU-R P.837 clearly underestimates the annual rain rates of our region.

5.2. Attenuation prediction (Year wise)

Figure-5, Figure-6, Figure-7 gives the comparison between attenuation calculated from ITU-R, SAM, RH; Moupfouma models with measured values at different percentages of time for 2013, 2014 and for 2 years span 2013 & 2014 and can be observed that attenuation decreases with increase in percentage of time.

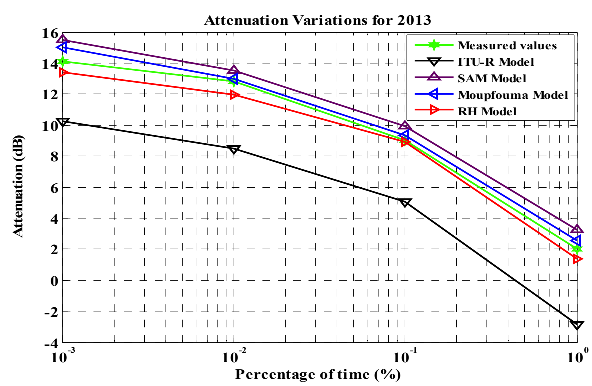

Figure-5. Comparison of different models in 2013.

In 2013, at 0.001% of time, the measured attenuation value is 14.1dB, where the value predicted by ITU-R, R-H, SAM and Moupfouma models is 10.2662dB, 13.3912dB, 15.5070dB, 15.011dB and at 0.01% of time the measured value of attenuation is 12.8dB, where as the value predicted by ITU-R, R-H, SAM and Moupfouma models is 8.5012dB, 11.9874dB, 13.5301dB and 12.9772dB respectively.

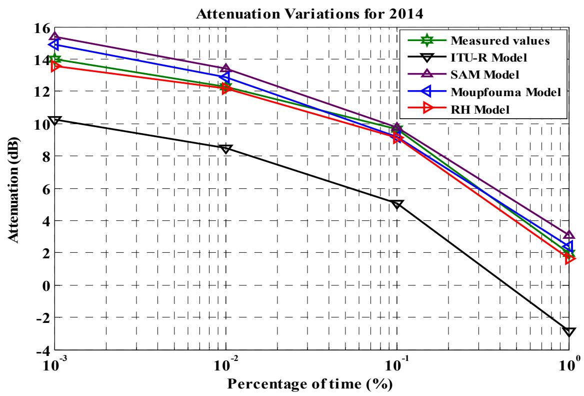

Figure-6. Comparison of different models in 2014.

In 2014, at 0.001% of time, the measured attenuation value is 13.98dB, where the value predicted by ITU-R, R-H, SAM and Moupfouma models is 10.2662dB, 13.5781dB, 15.3835dB, 14.8932dB and at 0.01% of time the measured value of attenuation is 12.31dB, where as the value predicted by ITU-R, R-H, SAM and Moupfouma models is 8.502dB, 12.1959dB, 13.3923dB and 12.8453dB respectively.

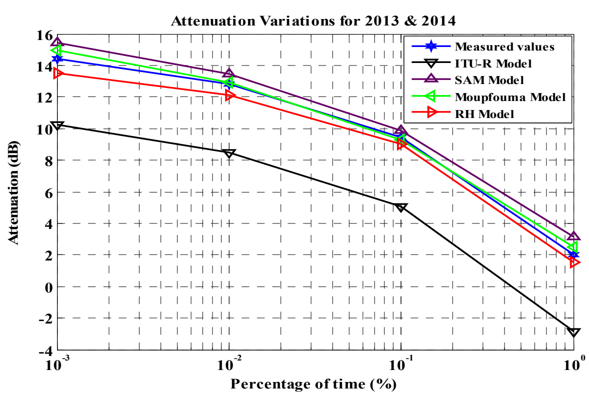

Figure-7. Comparison of different models in 2013 & 2014.

In 2 years span (2013&2014), at 0.001% of time, the measured attenuation value is 14.42dB, where the value predicted by ITU-R, RH, SAM and Moupfouma models is 10.2662dB, 13.5081dB, 15.4457dB, 14.9527dB and at 0.01% of time the measured value of attenuation is 12.8dB, where the value predicted by ITU-R, RH, SAM and Moupfouma models is 8.502dB, 12.1178dB, 13.4616dB and 12.9117dB respectively.

Table-2. Deviations from measured values for 2013.

Models	Deviation (dB) in Attenuation at different percentages of time			
	0.001%	0.01%	0.1%	1%
ITU-R	-3.8338	-4.2988	-3.995	-4.8401
Moupfouma	0.9114	0.1772	0.3249	0.5635
RH	-0.7088	-0.8126	-0.107	-0.627
SAM	1.407	0.7301	0.9351	1.231

Table-3. Deviations from measured values for 2014.

Models	Deviation (dB) in Attenuation at different percentages of time			
	0.001%	0.01%	0.1%	1%
ITU-R	-3.7138	-3.8088	-3.8088	-4.8171
Moupfouma	0.9132	0.5353	-0.4907	0.4272
RH	-0.4019	-0.1141	-0.567	-0.3567
SAM	1.355	0.5923	0.1131	1.0877

Table-4. Deviations from measured values for 2013 & 2014.

Models	Deviation (dB) in Attenuation at different percentages of time			
	0.001%	0.01%	0.1%	1%
ITU-R	4.1538	4.29872	4.405	4.8471
Moupfouma	-0.5327	-0.1117	0.1974	-0.4774
RH	0.9119	0.6822	0.4132	0.482
SAM	-1.0257	-0.6616	-0.4096	-1.1413

- Indicates underestimation, + indicates overestimation

Table-2, Table-3, Table-4 gives the deviation of computed attenuation values by using the four models with measured values. Tables 1, 2, 3 clearly infer that ITU-R model underestimates the measured signal nearly by 4dB in all cases. The deviation through Sam model is nearly +1dB. In cumulative analysis Moupfouma model underestimates in some cases. R-H model slightly deviates (-) but is not reliable because the model is approximated to calculate attenuation for a year without utilizing 30years of database.

5.3. Attenuation prediction (Monthly)

Of the four models, ITU-R and RH models requires a large database (nearly 30 years) to estimate the $R_{0.01\%}$ and hence cannot be utilized to perform the monthly analysis. So SAM model and Moupfouma models are utilized and the rain rate $R_{0.01\%}$ for an average month is estimated by Power law. Figure-9, Figure-0, Figure-10, Figure-11 gives the monthly analysis of attenuation during the months of monsoon with higher rainfall rates in the years 2013 and 2014.

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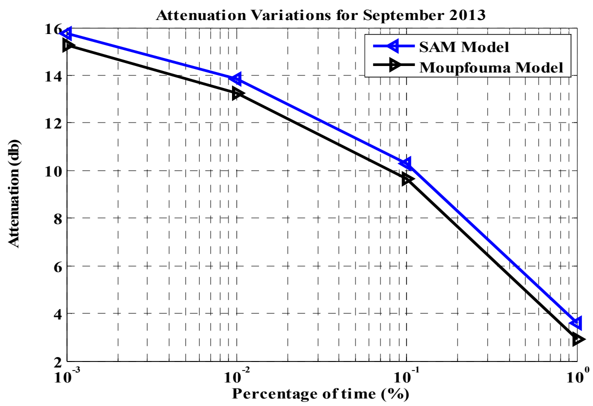

Figure-8. Comparison for September 2013.

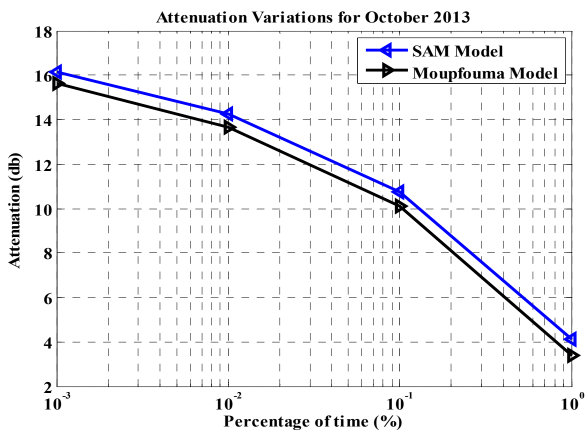

Figure-9. Comparison for October 2013.

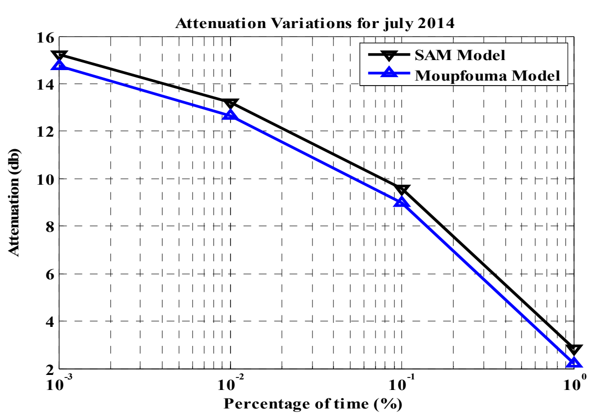

Figure-10. Comparison for July 2014.

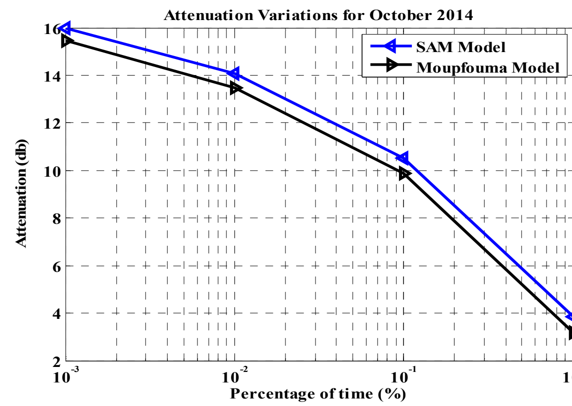

Figure-11. Comparison for October 2014.

5. CONCLUSIONS

Attenuation in Ku band satellite signal due to rain is estimated daily, monthly and yearly. Yearly analysis is performed using ITU-R, SAM, Moupfouma, Rice-Holmberg models and compared with measured attenuation values. Of the four models utilized for yearly analysis, from Table 1, 2, 3 it can be inferred that ITU-R P.618 underestimates and hence needed to be modified in order to be utilized for a tropical region like Vaddeswaram. From Tables 1, 2 it can be observed that Moupfouma model is best suitable to estimate for an year, while for cumulative analysis, it slightly under estimates but provides a better approximation. Similarly in monthly analysis, Moupfouma model is best suited, while SAM model slightly overestimates and can also be observed that these months contribute a major portion in total attenuation predicted in an average year. The attenuation is around 13.5dB in an average year at 0.01% of time and hence mitigation techniques are necessary in this region.

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