Performance Analysis of Millimeter Wave in Satellite-Earth Systems

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Summary
With rapid advancement in wireless technologies, the demand of increased data rate is materializing. Gbps(Giga bit per sec) rate throughput can be realized using millimeter waves; however, atmospheric attenuations effect on these high frequency waves has not been studied meticulously. Usually satellite-earth link budget calculation does not incorporate these attenuation effects for millimeter waves; the inclusion of these attenuations is unavoidable. In this paper we extend ITU model to millimeter waves and evaluate the performance of LEO Satellite-Earth systems for rain, cloud and gas attenuations. We elaborate the modeled system's various interdependent behaviors for key transmission parameters, satellite-ground station parameters and for atmospheric parameters with meticulous analysis and discussions. Performance of the complete Satellite-Earth System is also simulated for evaluating Eb/No and Bit Error Rate result has been obtained. Finally, the diversity analysis is studied and results are plotted.

Key words:
Atmospheric attenuations, ITU-R model, Rain Fade, Cloud attenuation, Millimeter wave.

1. Introduction

Wireless communication is among the most prodigious contribution of technology towards the advancements of mankind. In contemporary research, among other types of wireless technologies, satellite communication has gained significant importance. With progression of technology, it has become more desirable to send larger amounts of data with respect to time. Millimeter wave[1] in Ku-band, Ka-band and V-band can be used to relay high throughput data. High frequencies also proposes some additional advantages like: greater frequency reuse due to narrow beam width, smaller terminals, larger spectrum availability and better anti-interference properties for frequency hopping and direct spread spectrum [2].

Two types of fluctuations are mainly observed as the signal travels through earth-sky link, namely slow and fast fluctuations [3]. Former is due to the scattering and absorption of signal energy by the particles present in troposphere, especially water drops and oxygen, between earth-satellite link. While, the latter is referred to as scintillation[4] and is typically caused by the rapid variations in signal level attributed to inhomogeneous turbulence in refractive index of the medium present in ionosphere. These impairments are largely affected by the parameters of transmitted signal like its frequency and elevation angle in particular. Ionospheric scintillations contribute predominately toward damping the signal energy at frequencies lower than 3GHz. However, this phenomena becomes negligible for higher frequencies[5]. At frequencies above 10GHz, phenomena like clouds and rain impose serious impact on received signal strength[6]. Consequently, oxygen and water vapors in space effect the signal at further higher frequencies [7].

In the presence of abovementioned atmospheric degradations, in order to insure a minimum outage of the service for a given objective of link availability, there was observed an increased need for developing fade mitigation techniques. Techniques developed for this purpose include power control, diversity, adaptive coding and adaptive modulation [8]. To implement these mitigation techniques it is required to have an efficient fade prediction models that can be able to forecast attenuations caused by atmospheric contents [9]. Researchers have been trying to develop models that can help us predict these attenuations. Prediction models that are widely used include Crane [10], DAH [11], SAM [12] and International Telecommunication Union radio-wave sector ITU-R [13].

In this paper, we use the method proposed by ITU-R to accurately predict rain, cloud, water vapor and oxygen attenuations. Implemented these models using a fourth-generation programming tool; these attenuations depend directly on many parameters and indirectly also on many parameters therefore it is necessary to parametrically evaluate the performance of the system. Instead of linear plots we analyzed system behavior using two dimensional plots.

Rest of the paper is organized as follows. In Section 2 we present theoretical model of atmospheric attenuations added by channel due phenomena like rain, cloud, water vapor and oxygen. Section 3 contains performance analysis of satellite-Earth System in different attenuations then Section 4 includes Eb/No analysis and the Bit Error Rate plot of the complete system. Lastly, a conclusion of the study is given in Section 5.

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2. Attenuation Models

A satellite system consists of earth station, satellite and channel between them. As we move to higher frequencies, other than free space loss, atmospheric phenomena like rain, water vapors, clouds and gasses cause significant degradations in the transmitted signals, traveling through the channel. To produce an effective earth-space communication it is necessary to have appropriate prediction models that could be used to generate accurate propagation data. Following are the explanation of the atmospheric prediction models based on the recommendations of International Telecommunication Union Radio-wave sector (ITU-R).

2.1. Rainfall Attenuation

The extent to which rain absorbs and or scatters signal energy depends upon the amount, size and shape of the droplets, through which the signal passes. Parameters which are required by model include Height of earth station above sea level (h_s), elevation angle (θ), latitude of earth station in degrees (φ), frequency of signal (f) and effective radius of earth (R_e). Rain rate and rain height are two important parameters requires further elaboration.

2.1.1. Rain Rate

Rainfall rate is one of the most important factors in determination of Rain attenuation. Rain rate denoted as $R_{0.01}$ is the rate that exceeds 0.01% of average yearly rain it could be determined using (1) as follows,

$$R_{0.01}(X,Y) = \frac{-B+\sqrt{B^2-4AC}}{2A} \qquad (1)$$

Where,
$A = a.b$
$B = a + c\ln(0.01/P_0(X,Y))$
$C = \ln(0.01/P_0(X,Y))$

and,
$a = 1.09,\ c = 26.02\times b$
$b = \frac{(M_C\ (X,Y)+M_S\ (X,Y))}{21797\times P_0}$

Where p_o is ≥ 0.01. Numerical values of P_r, M_S and M_C in (1) could be determined against our satellite ground station coordinates using model data files available.

2.1.2. Rain Height

Rain occurs at different heights above sea level corresponding to different regions on earth. It has been specified in ITU-R recommended model[14]. A digital map, published by ITU provides the mean annual 0^0C isotherm height above mean sea level (h_0) against the provided latitude $(+90^0 \text{ to} -90^0)$ and longitude $(0^0 \text{ to } 360^0)$. To determine the mean annual height above mean sea level (h_R), the following formula is used.

$$h_R = (h_0 + 0.36) \quad km \qquad (2)$$

2.1.3. Attenuation for 0.01% of Time Precipitation

To compute the total attenuation caused by 0.01% of annual time precipitation [13] we will first calculate the slant-path length (L_s). It is the distance between earth station and rain height if traveled along the elevation angle (θ) as could be observed in Figure 1. It is the measure of the signal traveling through rain and could be determined using the following formula:

$$L_S = \begin{cases} \dfrac{(h_R-h_S)}{\sin\theta} & for\ \theta \geq 5^0 \\ \dfrac{2(h_R-h_S)}{\sqrt{\sin^2\theta + \dfrac{2(h_R-h_S)}{R_e}}+\sin\theta} & for\ \theta < 5^0 \end{cases} \qquad (3)$$

In ITU-R model of rain attenuation has been modified by incorporating an effective slant path for tropical regions where convective rain occurs [15]. Horizontal projection (L_G) of the length which signal travels in rain is determined using (4) as:

$$L_G = L_S.\cos\theta \qquad (4)$$

The values of frequency-dependent rain attenuation coefficients (k, α) for linear and circular polarization is obtained using (5) and (6) as:

$$k = \frac{k_H + k_V + (k_H - k_V).\cos^2\theta.\cos(2\tau)}{2} \qquad (5)$$

and,

$$\alpha = \frac{k_H\alpha_H + k_V\alpha_V + (k_H\alpha_H - k_V\alpha_V).\cos^2\theta.\cos 2\tau}{2k} \qquad (6)$$

Where, k_v, k_h, α_v and α_H are coefficients and constant of vertical and horizontal polarization respectively. Their numerical values could be obtained from [16] for a given frequency.

Rain specific attenuation is determined by (7), using coefficients k, α and rain rate $R_{0.01}$, calculated for 0.01 % of time.

$$\gamma_R = k(R_{0.01})^{\alpha} \qquad (7)$$

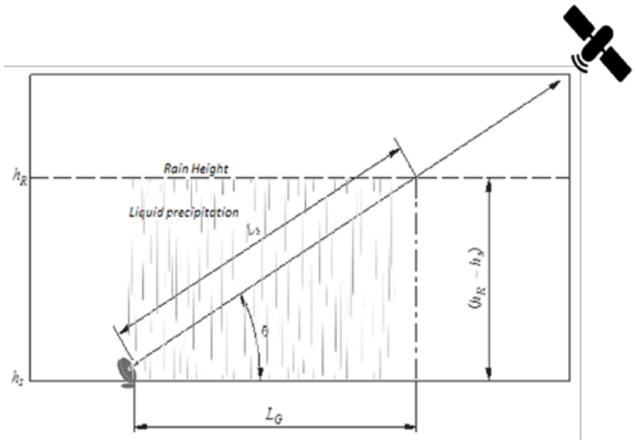

Fig. 1 Rain attenuation

Then horizontal reduction factor, $r_{0.01}$ for 0.01% of time is calculated using (8).

$$r_{0.01} = \frac{1}{1 + 0.78\sqrt{\frac{L_G \cdot \gamma_R}{f}} - 0.38(1 - e^{-2L_G})} \quad (8)$$

To determine the Vertical adjustment factor, we will make the following calculations first:

$$\zeta = \tan^{-1}\left(\frac{h_R - h_s}{L_G \cdot r_{0.01}}\right) \quad (9)$$

Hence for the actual slant-path length L_R would be:

$$L_R = \begin{cases} \frac{L_G \cdot r_{0.01}}{\cos\theta} & if\ \zeta > \theta \\ \frac{(h_R - h_S)}{\sin\theta} & Otherwise \end{cases} \quad (10)$$

If the absolute of the latitude of earth station (φ) is less than 36^0 then:

$$x = 36 - |\varphi|$$

Otherwise,

$$x = 0$$

Now the vertical adjustment factor for 0.01% of time $v_{0.01}$ could be determined by (11).

$$v_{0.01} = \frac{1}{1 + \sqrt{\sin\theta}\left(31\left(1 - e^{-\left(\theta/_{1+x}\right)}\right) \cdot \frac{\sqrt{L_R \cdot \gamma_R}}{f^2} - 0.45\right)} \quad (11)$$

The Effective path length (L_E) in km is the actual distance that rain has to travel through rain before reaching its destination. This could be determined using Equation 12.

$$L_E = L_R \cdot v_{0.01\,(km)} \quad (12)$$

Since specific rain attenuation is denoted as γ_R and effective path length is denoted as L_E. We can predict the attenuation by rain that is exceeded for 0.01% of average yearly time.

$$A_{0.01} = \gamma_R \cdot L_{E\,(dB)} \quad (13)$$

2.1.4. Attenuation Calculation for p% of Time

Percentage by witch rain could be exceeded by its mean yearly value could be less than and up to 5%. We can calculate attenuation for the given percentage of time using the attenuation value for 0.01% of time harnessing the following equation.

$$\beta = \begin{cases} 0 & if\ p \geq 1\% \text{ or } |\varphi| \geq 36^0 \\ -0.005(|\varphi| - 36) & if\ p < 1\%\ \&\ |\varphi| < 36^0\ \&\ \theta \geq 25^0 \\ -0.005(|\varphi| - 36) + 1.8 - 4.25\sin\theta & Otherwise \end{cases} \quad (14)$$

Then,

$$A_p = A_{0.01}\left(\frac{p}{0.01}\right)^{-(0.655 + 0.033\ln(p) - 0.045\ln(A_{0.01}) - \beta(1-p)\sin\theta)} \quad (15)$$

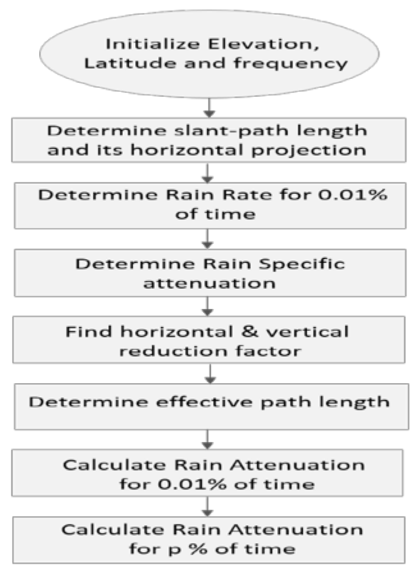

Fig. 2 Rain fade modelling flowchart

2.2. Cloud Attenuation

Presence of clouds in the propagation path of signal cause signal power degradation due to scattering and absorption of electromagnetic energy. Different types of clouds instill different attenuations. Icy clouds cause less attenuations, while warmer climates have thicker clouds hence has more attenuation.

The impairments become significant when we move to frequencies above 10GHz. In addition to transmission parameters like frequency (f) and elevation angle (θ), cloud attenuation also depends on the cloud parameters like average thickness, height, temperature and Liquid Water Content (LCW) of clouds.

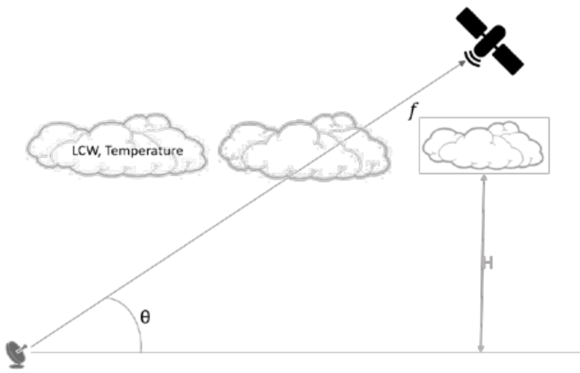

Fig. 3 Cloud Attenuation

Among several models created to estimate cloud attenuation, Salonen Uppalal and ITU-R [17, 18] are the ones that we will be using for our implementation. These two models a similar in terms of procedure but varies in the prediction of LWC of clouds.
The first step is to calculate the principal and secondary frequencies of relaxation using the following equations:

$$fr_{pri} = 20.09 - 142(300/T - 1) + 294(300/T - 1)^2 \qquad (16)$$

And,

$$fr_{\sec} = 590 - 1500(300/T) \qquad (17)$$

Where 'T' is the temperature of clouds in Kelvin. After that we determine the complex dielectric permittivity of water content present in the clouds using the following equation:

$$\varepsilon' = \frac{\varepsilon_0 - \varepsilon_1}{1 + (f/fr_{pri})^2} + \frac{\varepsilon_1 - \varepsilon_2}{1 + (f/fr_{\sec})^2} + \varepsilon_2 \qquad (18)$$

And,

$$\varepsilon'' = \frac{f(\varepsilon_0 - \varepsilon_1)}{fr_{pri}\left[1 + \left(\frac{f}{fr_{pri}}\right)^2\right]} + \frac{f(\varepsilon_1 - \varepsilon_2)}{fr_{\sec}\left[1 + \left(\frac{f}{fr_{\sec}}\right)^2\right]} \qquad (19)$$

$$Where, \quad \varepsilon_0 = 77.6 + 103.3(300/T - 1)$$

$$\varepsilon_1 = 5.48, \qquad \varepsilon_2 = 3.51$$

Cloud specific attenuation coefficient (γ_{clouds}) can then be calculated using the following equation.

$$\gamma_{clouds} = \frac{0.819.f}{\varepsilon''\left[1 - \left(\frac{2+\varepsilon'}{\varepsilon''}\right)^2\right]} \qquad (20)$$

Radiometric or radiosonde measurements are taken to obtain the LWC for a specified region. That LWC could be further used to measure cloud attenuation at any probability.

$$A_{clouds} = \lambda_{clouds}\left(\frac{LWC}{\sin\theta}\right) \qquad (21)$$

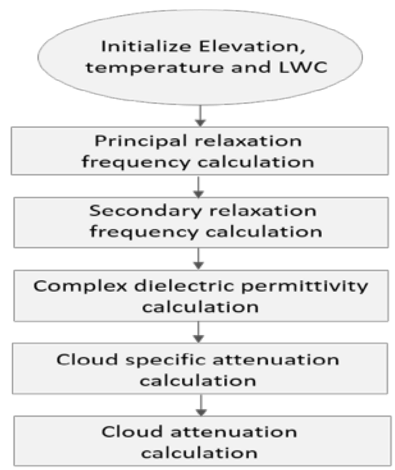

Fig. 4 Cloud Attenuation modelling flowchart

2.3. Gas Attenuation

When the signal propagates through atmosphere its power is degraded owing to the presence of dry air and water vapors in the transmitting medium. Water vapor attenuation is dependent on temperature, content and altitude of vapors and is directly proportional to the temperature and relative humidity of the atmosphere. While in dry air, oxygen processes permanent magnetic moment which interferes the magnetic field of the waves and absorption is also taken place at frequencies above 3GHz [7]. Attenuation due to oxygen remains relatively constant and independent due to its equal distribution in atmosphere.

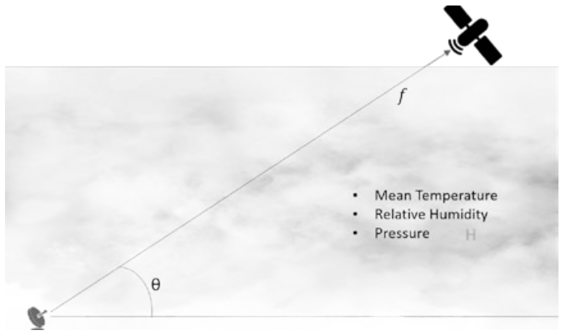

Fig. 5 Gas Attenuation

2.3.1. Specific Attenuation

Oxygen specific attenuation $\left(\gamma_{O^2}\right)$ is solely dependent on the frequency of the traversing signal and could be determined using the following set of equations:

$$\gamma_{O^2}=\begin{cases} f^2p^2\left[\frac{7.2t^{2.8}}{f^2+0.34pt^{1.6}}+\frac{0.62\xi_3}{(54-f)^{1.16\xi_2}}\right]\times10^{-3} & if\ f\le54 \\ \exp\left[\frac{\ln\vartheta_{54}}{24}(f-58)(f-60)-\frac{\ln\vartheta_{58}}{8}(f-54)(f-60)+\frac{\ln\vartheta_{60}}{12}(f-54)(f-58)\right] & if\ 54<f\le60 \\ \vartheta_{60}+\frac{f-60}{2}(\vartheta_{62}-\vartheta_{60}) & if\ 60<f\le62 \\ \exp\left[\frac{\ln\vartheta_{62}}{8}(f-64)(f-66)-\frac{\ln\vartheta_{64}}{4}(f-62)(f-66)+\frac{\ln\vartheta_{66}}{8}(f-54)(f-64)\right] & if\ 62<f\le66 \\ f^2p^2\left[3.02\times10^{-4}t^{3.5}\frac{0.283t^{3.8}}{(f-118.75)^2+2.91p^2t^{1.6}}+\frac{0.502\xi_6(1-0.0163f\xi_7-1.1\xi_7).10^{-3}}{(f-66)^{1.4346\xi_4}+1.15\xi_5}\right] & if\ 66<f\le120 \\ f^2p^2t^{3.5}\left[\frac{3.02\times10^{-4}}{1+1.9\times10^{-5}f^{1.5}}+\frac{0.283t^{0.3}}{(f-118.75)^2+2.91p^2t^{1.6}}\right]\times10^{-3}+\delta & if\ 120<f\le350 \end{cases} \tag{22}$$

Where,

$$p = Pressure/1013, \quad t = 288/Temperature$$

the values of ξ_n, ϑ_n and δ could be obtained using [19]. Path length for oxygen content is determined using the (23).

$$L_{O^2}=\frac{6.1\times(1+z_1+z_2+z_3)}{1+0.17p^{-1.1}} \tag{23}$$

where,

$$z_1=\frac{4.46}{1+0.066.p^{-2.3}}\times\exp\left[-\left(\frac{f-59.7}{2.87+12.4e^{-7.9p}}\right)\right]$$

$$z_2=\frac{0.14e^{2.12p}}{(f-118.75)^2+0.031e^{2.2p}}$$

$$z_3=\frac{0.0114f}{1+0.14p^{-2.6}}\left(\frac{-0.0247+0.0001f+1.61\times10^{-6}f^2}{1-0.0169f+4.1\times10^{-5}f^2+3.2\times10^{-7}f^3}\right)$$

To obtain water vapor specific attenuation, following equation (24) could be used:

$$\left(\gamma_{H^2O}\right)=f^2t^{2.5}\rho\left[\frac{3.98\eta_1e^{2.23(1-t)}}{(f-22.23)^2+9.42\eta_1^2}\left[1+\left(\frac{f-22}{f+22}\right)^2\right]+\frac{11.96\eta_1e^{0.7(1-t)}}{(f-183.31)^2+11.14\eta_1^2}+\frac{0.08\eta_1e^{6.44(1-t)}}{(f-321.226)^2+6.29\eta_1^2}+\frac{3.66\eta_1e^{1.6(1-t)}}{(f-325.153)^2+9.22\eta_1^2}+\frac{25.37\eta_1e^{1.09(1-t)}}{(f-380)^2}+\frac{17.4\eta_1e^{1.46(1-t)}}{(f-448)^2}+\frac{844.6\eta_1e^{0.17(1-t)}}{(f-557)^2}\left(1+\frac{f-557}{f+557}\right)+\frac{8.3328\times10^4\eta_1e^{0.99(1-t)}}{(f-1780)^2}\right] \tag{24}$$

Where,

$$\eta_1=0.955pt^{0.68}+0.006\rho$$

$$\eta_2=0.735pt^{0.5}+0.0353t^4\rho$$

Model then estimates the effective water vapor path length using (25).

$$L_W=1.66\left(1+\frac{1.39\sigma_W}{(f-22.235)^2+2.5\sigma_W}+\frac{3.37\sigma_W}{(f-183.31)^2+4.69\sigma_W}+\frac{1.39\sigma_W}{(f-325.1)^2+2.89\sigma_W}\right) \tag{25}$$

Where,

$$\sigma_W=\frac{1.013}{1+e^{4.902-8.6p}}$$

Finally the gas attenuation (A_{Gases}) for both oxygen and water vapor could be predicted using (26)

$$A_{Gases}=\frac{\gamma_oL_o+\gamma_WL_W}{\sin\theta} \tag{26}$$

3. Performance Analysis and Discussion

This section presents Performance Analysis of Satellite-Earth System using rain, gas and cloud attenuations; there are many parameters in order to depict their behavior on various transmission and satellite ground station parameters. These parameters could be adjusted to obtain optimal values in terms of throughput requirements as well as for reliable Satellite-Earth link.

Rain, cloud and gas attenuations increase as the frequency of the transmitted signal increase as can be seen in Fig.6. We can observe that rain attenuation is negligible (less than 1dB) under 10GHz but as the frequency increases, a drastic increase of about 10dB is observed in rain attenuation, hence above this frequency precipitation causes significant degradation in signal and should be considered while designing the system. Similarly, under 10 GHz cloud attenuation is less than 0.5dB but as frequency goes higher, attenuation of 5dB could be observed. Amount of cloud attenuation always remain lower than that of rain attenuation.

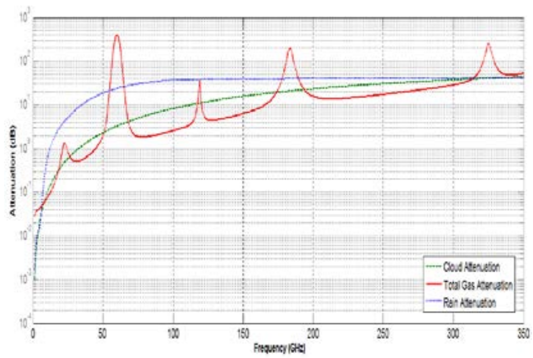

Fig. 6 Attenuations vs. Frequency

On the other hand, gas attenuation heightens smoothly with the increase of frequency but peaks are observed at different points. These peeks are due to the phenomenon of resonance of various substances present in our atmosphere. Resonance of water vapors occurs at 24GHz where attenuation of 0.5dB is observed. While the frequency of 184GHz causes degradation of the order of 80dB. Similarly, for oxygen molecules 60GHz displays catastrophe of 10dB and at 112GHz degradation of 1dB is observed. At aforementioned frequencies, greater amount of signal power is absorbed by these molecules and hence add more attenuation to the signal.

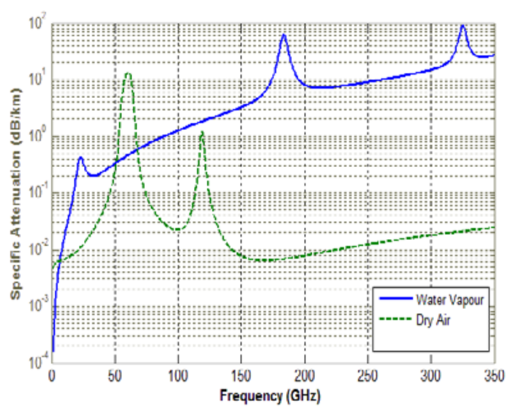

Fig. 7 Specific Gas Attenuation vs. Frequency

The effect of elevation angle of the transmitter or receiver at ground station on rain attenuation increases as the height of rain increases. At 10^0 elevation and 6km rain height attenuation of 80dB is observed. On the other hand, at 60^0 elevation and 2km rain height degradation reduces to 10dB. Hence, if height of rain is greater, lower elevation angles cause larger amount of rain fade in the signal.

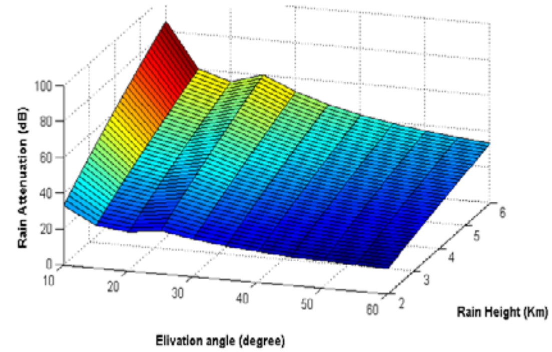

Fig. 8 Rain attenuation vs. Elevation angle and Rain Height

With other parameters fixed if we decrease the annual % of time for which we consider the rainfall, the amount of rain attenuation increases. If we consider 0.01% of mean annual time and 10^0 of elevation angle attenuation of 80dB was observed but attenuation slopes down immediately with the increase in % of time and elevation angle.

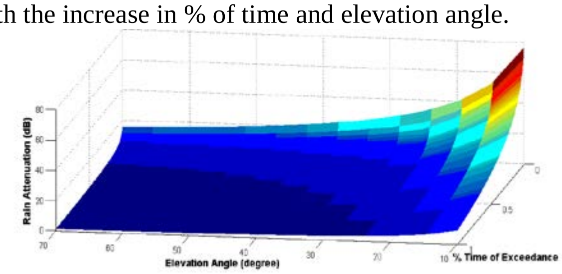

Fig. 9 Rain Attenuation vs. Elevation Angle and % of Time

Rain attenuation is dependent on the rate of rain not the amount of rain. As the rain rate increases, size of rain drops increases and hence the degradation of signal traveling through rain increases. In very heavy rain (140mm/h) attenuation varies from 50dB to 125dB with rain height changing from 2km to 6km. But as Rain rate declines to 20mm/h the attenuation ranges from 10dB to 20dB for rain height from 2km to 6km.

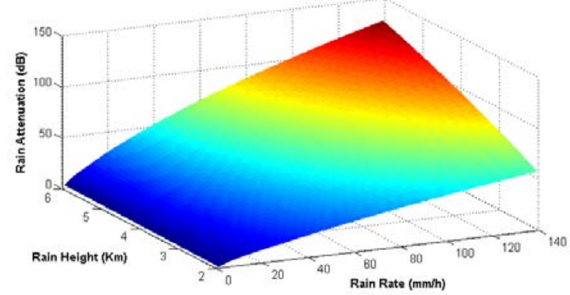

Fig. 10 Rain Attenuation vs. Rain Height and Rain Rate

For a fixed frequency effect of change in Liquid water content and temperature of clouds is directly proportional to the amount of cloud attenuation. Cloud attenuation of

2dB can be observed at 4.5 km/m^2 LWC and 273K temperature. While at higher temperature of 300K and LWC of 1 km/m^2 cloud attenuation is lowered down to 0.25dB. The effect of change is more linear.

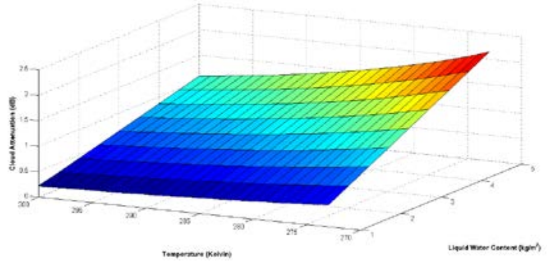

Fig. 11 Cloud Attenuation vs. Temperature and LWC

Increase in pressure and relative humidity of the atmosphere displays a direct relation with the amount of gas attenuation observed by the signal. At 13GHz Gas attenuation of 0.18dB is observed, humidity and pressure being 70% and 1100hPa respectively. More attenuation could be observed of we change the frequency to one of the resonance frequencies. Both of the changing parameters depict a linear relation with the gas fade.

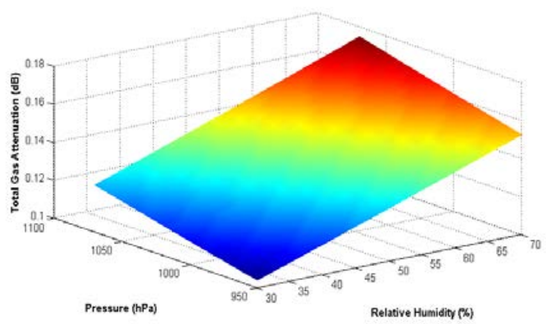

Fig. 12 Gas Attenuation vs. Pressure and relative Humidity

Satellite Ground station parameters like height above sea level and latitude of earth changes the total amount of attenuation observed by the signal. If the station is near the equator of earth i.e. 0 degree latitude, the attenuations are minimum, but as we move towards the poles, signal degradations start increasing and can be observed to be of the order of 36dB in the graph below.

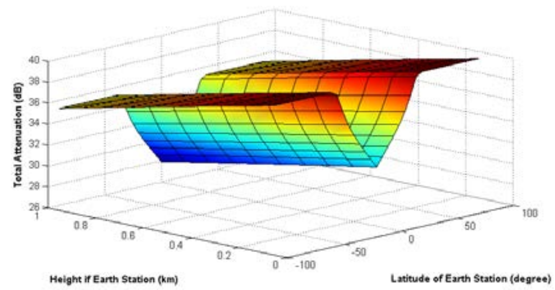

Fig. 13 Total Attenuation vs. Satellite Station Height and Latitude

4. Eb/No Analysis

One of the key parameter of performance analysis of digital communication system is Eb/No. In this section we consider LEO Satellite–Earth System and develop a complete propagation model in MATLAB. Typical parameters considered in our model are shown in the Table I.

Table I: Parameters Used for Satellite-Earth System Model

Parameter	Value
Transmitted Frequency	$30GHz$
Polarization	$Horizontal$
% of Precipitation time	0.01%
Rain Rate	$25\ mm/h$
Rain Height	$3.5km$
Liquid Water Content	$2\ kg/m2$
Temperature	$290\ K$
Relative Humidity	50%
Air Pressure	$1008\ hPa$
Effective Isotropic Radiated Power(EIRP)	$40\ dBW$
Earth Station Latitude	31.47^0
Earth Station Height	$0.2\ km$
Receiver Gain	$40\ dBi$
Elevation angle	$5^0 - 65^0$
Data Rate	Upto 100 Mbps
LEO Satellite Orbit Height	500kms

In our simulation we generated 10^6 random bits. These bits were then modulated using BPSK modulation. Then the amounts of impairments added by the channel were in accordance with the values generated by the prediction model to simulate the transmitted signal. E_b/N_0 is calculated using (27) for complete Satellite-Earth system model.

$$\frac{E_b}{N_0} = EIRP + G_r - FSL - L_A - N_0 - 10\log(R_b) \qquad (27)$$

Where EIRP= Effective Isotropic Radiated Power, FSL= Free Space Loss= $20\log(4\pi d/\lambda)$, L_A is Atmospheric Losses, G_r=Receiver Gain, N_o= Noise Spectral Density and R_b is Bit rate. Typical LEO satellite passes two times in a day in any earth station location. The Elevation angle of the satellite plays an important role in successful satellite data reception. At Low elevation angle the received signal strength may drops below the link threshold value. When at low elevation angle further rain, cloud or gas attenuations causes' significant decrease in signal strength or outages. Thus the inclusion of these attenuations for link margin calculation is very important for 5G systems especially for Satellite-Earth systems. In Figure 14, as data rate is increased, Eb/No is decreasing while at 5^o Eb/No is -130dB and at 10^o Eb/No is -70dB. Thus it is very necessary to include these attenuations model for calculating link margin of Satellite-Earth Systems for better Link reliability. In Figure 15 the Bit error Probability curve is also plotted for measuring end to end performance of our system.BER of 10^{-4} is observed at 8 dB SNR under atmospheric attenuations for the considered system's parameters. The BER performance can be improved by increasing the Eb/No of the Satellite-Earth system.

The attenuation effects can be reduced using mitigation techniques. Diversity techniques are used in order to exploit the attenuation affects. Diversity can be applied in time, frequency or space. We have used ITU-R recommended method for space diversity concept[13] for two ground receivers. The space diversity Space Diversity gain depends upon separation (in km) between the two sites, rain path attenuation (in dB) for a single site, frequency used (in GHz), path elevation angle (in degrees) and angle (in degrees) made by the azimuth of the propagation path with respect to the baseline between sites. As shown in Figure 16 4dB gain in receive signal strength is observed due to space diversity.

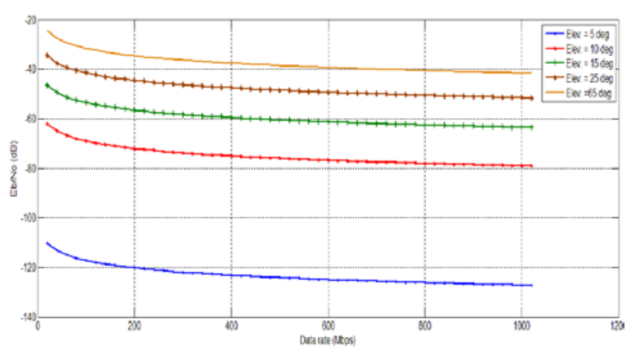

Fig. 14 Bit Energy to Noise ratio vs. Data rate for different Satellite Elevation Angles

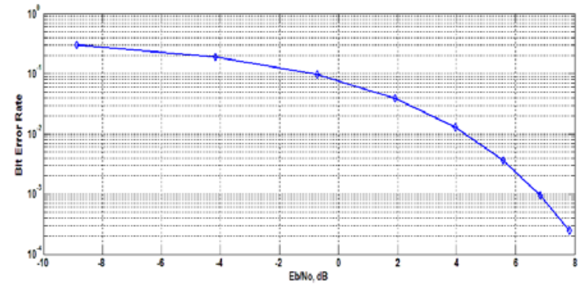

Fig. 15 Bit Error Rate curve for BPSK modulation

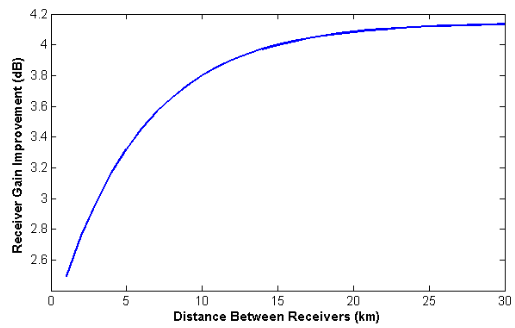

Fig. 16 Space Diversity Gain for two receivers

5. Conclusions

This paper illustrated how satellite radio waves traveling through earth-sky link receives the effect of atmosphere while traveling through stratospheric and Ionospheric layers. Models for the prediction of rain, cloud and gas attenuation were extended for millimeter wave and implemented in MATLAB. Millimeter wave can provide required data rate for future satellite-mobile systems. The effect of various transmission parameters, Satellite ground station parameters and atmospheric attenuations parameters were studied in detail. It was observed that as we moved towards higher frequency bands to attain 5G data rate capabilities, atmospheric fades affected more ferociously, hence we bore higher bit error rate for lower signal to noise ratio.
It was suggested to use communication systems with built in fade mitigation capabilities to cope with these atmospheric attenuations at higher frequency bands. Space diversity was also demonstrated as one of the mitigation techniques and its simulated results displayed the improvement in received power for two receivers.

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