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Effects of Different Losses on Satellite Systems

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Abstract*: Satellite signal quality during propagation degrades due to absorption, scattering of the particles in space. For high information rate satellite technologies, this degradation significantly affects the received information. This degradation also depends on the link, atmospheric losses. Rain, cloud imposes a major effect on signal attenuation above 10 GHz frequencies. Low elevation angle transmission during rain, condensed clouds increases the effective path length and causes degradation in the received signal level. The change of transmitted signal parameters like frequency f and elevation angle θ, impacts atmospheric impairments considerably. In this paper, effects free space loss, rain attenuation and cloud attenuation are studied in the frequency range of 10-50 GHz for lower elevation angles. The link calculation method is used for determining free space loss. The ITU-R Rec. P.837-4 and ITU-R Rec. P.676-11 are used for calculation of rain and cloud attenuations respectively. The results of these three losses are plotted and tabulated using MATLAB software.

***Keywords*: cloud attenuation, elevation angle, free space loss, propagation, rain attenuation, satellite link.**

I. INTRODUCTION

Satellite communication is mainly used in mobile and wireless communication applications for all locations on the earth. It covers wide area of the earth using one satellite. Satellite technology is showing new ways in the use of orbital space and radio spectrum resources. It substitutes the voice, video and data communications, networking to distant places without even basic infrastructure. Satellite system plays an important role in providing the global coverage for all types of communications. Satellites are a key component of the world's communication infrastructure for a majority of the countries. Recently, multi beam, regenerative satellites and onboard processing are attracting means for reducing the size and cost of the earth stations [1].

Next generation satellite operating in mm Wave band (above 30 GHz) needs more bandwidth and suffers severe attenuation. So, this band needs higher spectral efficiency and abundant spectral resources. Antenna arrays using smart beam selection algorithms can be used for mitigating millimeter Wave signal attenuation [2]. Satellite systems basic principle of operation is high exceedance probability (=1%) and economic link margins. Signal-to-noise ratio of these systems is required to achieve a lower BER of 10^{-10} (bit error ratio of ten to the power minus ten) with suitable coding techniques.

Communication between the RF terminal and the satellite is governed with electromagnetic wave propagation principles. International Telecommunication Union (ITU) and its committees and conferences allocates frequency bands. Using frequency reuse technique satellites will communicate with a number of ground stations operating with the same frequency and transmits in narrow beams. Two stations with same frequency and separated far enough apart can receive different messages. Satellite antennas are designed in such a way that using the same reflector they have to transmit several beams in different directions [3]. Propagation impediments in the troposphere are the major limiting factors for the high frequency range transmission. Even though, small earth terminals are more attractive for consumer and transportable applications but difficult to provide sufficient link margin for propagation related outages. Millimeter range satellite systems has more weather attenuation and atmospheric effects than C- (6/4 GHz) and Ku- (14/12 GHz) bands [4]. In the design of centimeter links, in spite of the rain attenuation effects, the optimum working efficiency of satellite path should be with 99.99% availability. Accurate estimates of the propagation impairments of the link quality, availability fields are the essential features for the reliable design of communication systems and the efficient use of the electromagnetic spectrum. This paper deals with different impairments of propagation such as free space loss, rain attenuation and cloud attenuation and its impacts on satellite links.

II. METHODOLOGY

A communication link in a satellite consists of Uplink transmitter - from an earth station to the satellite and Down link transmitter - from the satellite to the earth station. Uplink, downlink equations are essential for calculating the system performance. Carrier to noise spectral density ratio at uplink represented as shown below

$$(C_u / N_{ou}) = (WP_T G_T G_{Ru} \lambda^2) / ((4\Pi R_u)^2 K T_d L_d) \quad (1)$$

or in terms of dB

$$(C_u / N_{ou}) = P_{T\,dBw} + G_{T\,dBi} + G_{u\,dBi} + 20\log(\lambda/4\Pi R_d) + 10\log(W/KT_d) + 10\log(1/L_d) \quad (2)$$

where C_u – Input power(Receiver), N_{ou} – Noise spectral density, P_T – Transmitting antenna power, G_T – Antenna gain, R_u – Distance of earth station to satellite, λ – wave length,
G_{ru} – Satellite receive antenna gain, T_d –Noise temperature(uplink), K – Boltzman constant ($1.38 * 10^{-23}$ [JK^{-1}]), W – antenna efficiency, L_d – additional losses.

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These six elements are useful for calculating the carrier to noise power spectral density ratio. The first, second terms stands for effective isotropic radiated power (EIRP), free space loss respectively. The last one shows additional losses which are attenuations due to propagation conditions in troposphere (like rain, atmospheric gases and clouds and fog). The difference between uplink and downlink is in the numbers and the emphasis.

III. RESULTS

The atmospheric loss is the result of attenuation of atmospheric gases, water (rain, clouds, snow and ice) [5]. The results of free space loss and water losses for several of elevation angles (path distance) and frequencies from 10 GHz to 50 GHz using MATLAB software are shown below. The ground station assumed to be situated at Visakhapatnam, India and receives signal from number of GEO satellites with the elevation angles ranges from 10° to 30°.

A. Free Space Loss Versus Elevation Angle

The free space loss FLS mainly depends on frequency, distance (d) between the earth, satellite stations [6] [7]. The distance of satellite path also depends on elevation angle

$$d = \sqrt{((R+h)^2-(R\cos\theta)^2)} - R\sin\theta \quad (3)$$

where Radius of Earth(R) = 6371 km, Satellite orbit height(h)= 36,000 km, EA or θ – the elevation angle

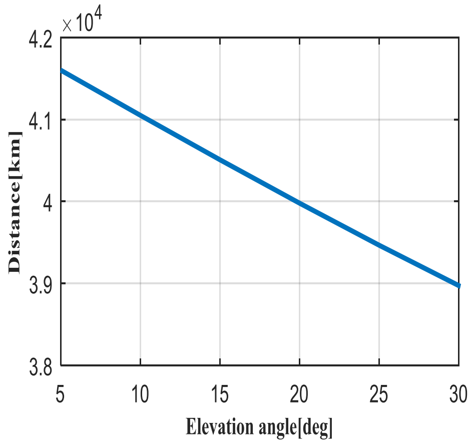

Fig. 1. Elevation angle Vs Distance of Earth satellite path

The equation for free space loss can be described as follows

$$FSL = 20\log(d) + 20\log(f) + 20\log(4\Pi/c) \quad (4)$$

From the Fig1 the distance of satellite path decreases with the increase in elevation angle. The difference between 5^0 and 30^0 is around 2631 km. The free space loss value increases with the frequency, decreases with the elevation angle. The elevation angles considered for this study were 10^0,20^0,30^0 and frequencies around 10-50 GHz as shown in Fig2. For a path of 50 GHz and 99.99% of time availability the system requires 60 dB excess margins.

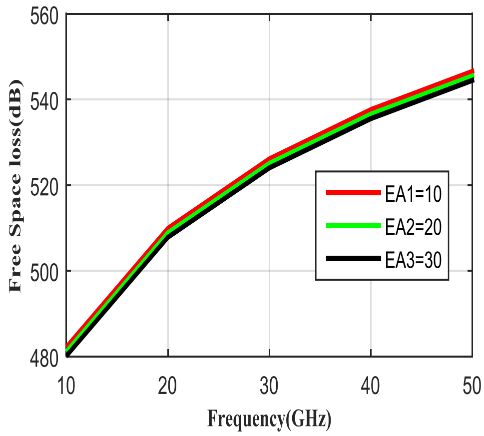

Fig. 2. Frequency Vs Free space loss

B. Rain Attenuation Versus Elevation Angle

Rain is a weather phenomenon that greatly affects in the propagation of radio waves. Above 10 GHz, the attenuation by the interaction of the propagating waves and the rain droplets becomes significant for both terrestrial radio links and satellite links [8] [9] [10]. The specific attenuation of rain depends on the values of temperature, terminal velocity and shape (mainly radius) of the raindrops. ITU-R Rec. P.618-13 [11] is the best performing model of rain attenuation for the frequencies up to 50 GHz. ITU-R P.837-4 [12] can be used to measure from the global maps, where rain intensity distributions are not available. This recommendation is used for the performance of rain attenuation models without substantial degradation. The rain height (h_R) above the mean sea level can be obtained from the ITU-R Rec. P.839-4 [13]

$$h_R = h_0 + 0.36 \quad (5)$$

h_0 –0°C isotherm height [km].

For θ ≥ 5° the slant-path length

$$L_s = (h_R - h_s) / \sin\theta \quad (6)$$

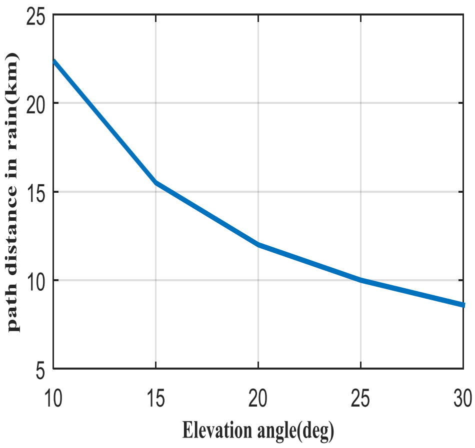

Fig. 4. Effective path length during rain

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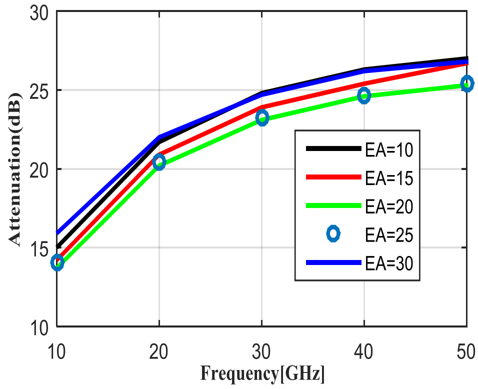

Fig. 5. Rain Attenuation for satellite paths

Attenuation $A_{0.01}$ exceeded for 0.01% for an average year

$$A_{0.01}[\text{dB}] = \gamma_R L_E \quad (7)$$

L_E – Effective path length, γ_R –Specific attenuation,

$$\gamma_R = K R_{0.01}^{\alpha} \quad (8)$$

$R_{0.01}$ – 0.01% exceedance rainfall rate (with an integration time of 1 min)

K, α – Regression coefficients.

The effective path length in rain decreases almost 15 km with the increase of 20^0 elevation angle. For lower elevation angles the values of effective path length are higher as shown in Fig.4. Fig.5 shows the variation of attenuation due to rain with frequency, elevation angle. As, the frequency increases the attenuation values increases with almost 14 dB difference between 10-50 GHz range. Attenuation decreases with increase elevation angle almost 1-2 dB for these range of frequencies.

C. Cloud Attenuation Versus Elevation Angle

For higher frequency clouds consist of suspended water droplets of smaller size than the wavelength. Clouds attenuation is highly variable and depends on the liquid water content [14] [15] [16]. Existing models for computing attenuation are ITU-R Rec. P.676-11 [17], Rec. P.840-6 [18]. In these models cloud attenuation is function of the liquid water content(LWC), frequency(f), elevation angle(θ) and dielectric constant of the water(ϵ). The cloud attenuation model is mainly based on the Salonen & Uppala and ITU-R models [19].

The equations for principal, secondary relaxation frequencies are shown below

$$fr_{pri} = 20.09 - 142(\Lambda - 1) + 294(\Lambda - 1)^2 \quad (9)$$

$$fr_{sec} = 590 - 1500(\Lambda - 1) \quad (10)$$

where $\Lambda = 300/T$ and T = temperature in Kelvin.

Complex dielectric permittivity of water contents (ϵ^1, ϵ^{11})

$$\epsilon^1 = (\epsilon_0 - \epsilon_1) / [1+(f/fr_{pri})^2] + (\epsilon_1 - \epsilon_2) / [1+(f/fr_{sec})^2] + \epsilon_2 \quad (11)$$

$$\epsilon^{11} = f(\epsilon_0 - \epsilon_1) / fr_{pri}[1+(f/fr_{pri})^2] + f(\epsilon_1 - \epsilon_2) / [1+(f/fr_{sec})^2] \quad (12)$$

where $\epsilon_0 = 77.6 + 103.3(\Lambda - 1)$, $\epsilon^1 = 5.48$, $\epsilon^{11} = 3.58$

Rayleigh approximation is valid for calculating water content per unit volume for clouds (<200 GHz) consisting of small droplets (< 0.01cm). The specific attenuation of a cloud is

$$\gamma_{clouds} = 0.819f / \epsilon^{11} [1-((2+\epsilon^1)/\epsilon^{11})^2] \quad (13)$$

$$A_{clouds} = \gamma_{clouds} [LWC/\sin\theta] \quad (14)$$

LWC value ranges from 1 to 3 g/m^3

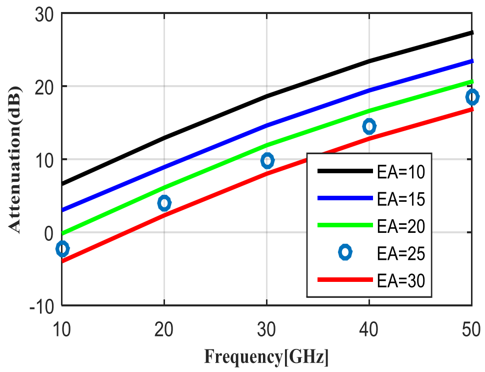

Fig. 6. Cloud Attenuation for satellite paths

Cloud attenuation values with the varying frequency, elevation angle is shown in Fig.6. The cloud attenuation increases around 6 dB, and decreases with elevation angle around 2-4 dB with the increase of 10 GHz frequency.

Over all the experimental results of three losses are tabulated in Table I

IV. CONCLUSIONS

The free space loss, rain attenuation, cloud attenuation effects on satellite link were studied for the 10 – 50 GHz frequency range, lower elevation angles. The distance of satellite path decreases with elevation angle. The satellite path distance difference between the elevation angles is around 2631 km. Rain attenuation was calculated using the recommendations of ITU-R P.837-4, ITU-R Rec. P.839-4. Cloud attenuation was calculated with the help of ITU-R Rec. P.676-11, Rec. P.840-6. With the change of elevation angle the attenuation values increases due to rain by 14 dB, cloud by 6 dB respectively, whereas the effective path length in rain decreased by 15 km for the frequency of 50 GHz, 0.01% of time. Measured attenuation distribution of satellite path values under the influence of atmospheric events increase significantly above the frequencies of 10 GHz. It can be concluded that all these three losses increase significantly for lower elevation angles and higher frequencies.

Table- I: Values of different losses

	Free Space loss(dB)			Rain attenuation(dB)			Cloud attenuation (dB)		
EA(θ)	f =10^0	f=30^0	f=50^0	f =10^0	f=30^0	f=50^0	f =10^0	f=30^0	f=50^0
10	485.6	520	545.3	15.2	24.5	27.8	8.4	18.2	28.4
20	483.3	518.8	542.9	13.8	22.1	25.1	-1.7	12.3	21.8
30	481.7	515.6	541.2	15.8	24.7	27.9	-2.5	7.4	17.4

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