SYSTEM MODELLING OF DTH BROADCASTING AT KA BAND MULTIBEAM SATELLITE SYSTEM OVER INDIA

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Abstract: A major application of satellite is broadcasting and in India this is done at Ku band. But with the increase of demand of number of channels Ku band is getting saturated. So, to satisfy this requirement an approach is to go to higher frequency band, i.e. Ka band. As India is allocated with seven fixed GEO locations, so the purpose is to calculate what is the suitable satellite position for India at Ka band, what is the best EIRP available at that position and what will be the smallest ground antenna diameter and satellite antenna diameter at Ka band. Broadcasting is done at 20GHz Ka band downlink frequency. At this frequency, as the signal will face lots of impairments during propagation, so the attenuation caused by variety of factors are discussed here. To overcome the attenuation maximum EIRP is given. The link equation is taken as a reference to calculate quality of the signal, G/T ratio and EIRP of the satellite. The extreme west region of India is being taken as earth station and after some brief calculations all the results are discussed. Out of seven allocated GEO locations, 74ᵒE gives best output in terms of minimum loss & small antenna diameters.

Keyword: EIRP, Rain Attenuation, Free space loss, G/T ratio.

I. INTRODUCTION

India is a large geographical region extending from 8ᵒN to 37ᵒ N latitude wise and 68ᵒE to 97ᵒE longitude wise. To check which location in India will be having less rain attenuation at Ka band, this large geographical region can be divided into small sections each covering 1 deg latitude and 1 deg longitude and at the center of those locations earth stations will be located. So, instead of taking all the earth stations, only one location can be taken arbitrarily as a reference and the same procedure can be applied for rest of the locations. The cross-sectional division has been shown in figure 1. The earth station is taken at extreme west, Bhuj (23.24N, 69.66E). So all the calculations have been done with respect to this earth station. Broadcasting is done at 20 GHz of downlink frequency of Ka band and at this frequency there are several losses which, will be faced by the signal during the propagation.

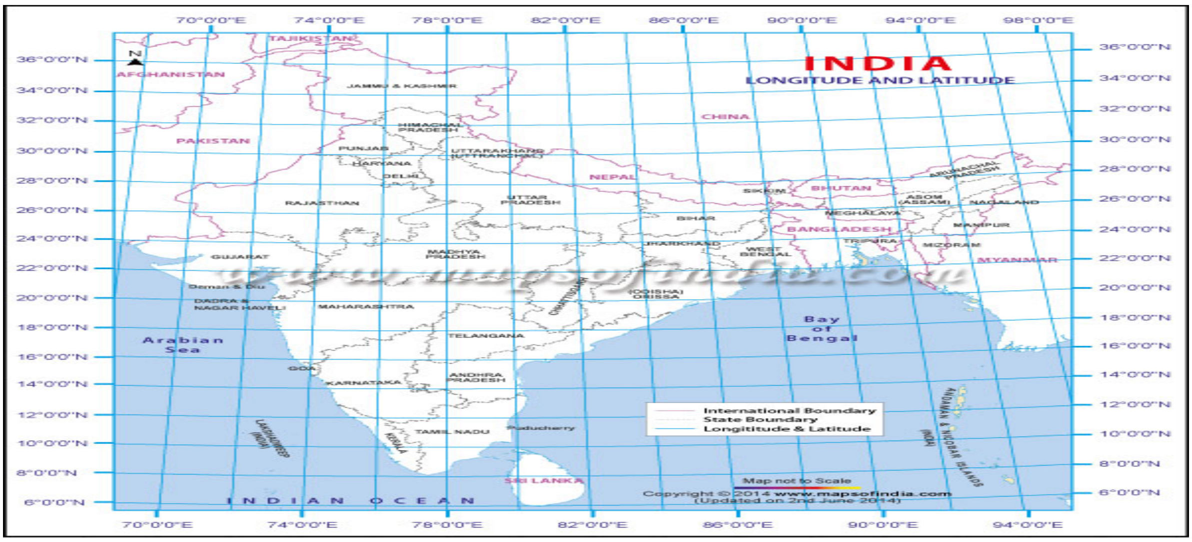

Fig.1 Latitude and longitude division of INDIA

The propagation effect can be described in terms of loss of path. The major loss that the signal will face is due to free space path loss and rain attenuation [1]. So, both the losses have been calculated here for this extreme point [2]. The data is taken from IMD (Indian Meteorological Department) and ITU (International Telecommunication Union). From those calculated values, the position of the satellite, that will give the minimum value will be taken as the best satellite position. Seven fixed GEO locations are 48E, 55E, 65E, 74E, 83E 93E, 112E. Gain to Noise temperature (G/T) ratio calculation is followed by loss calculation which has given a measure about the sensitivity of the receiving earth station. Then relating the link equation, both the satellite antenna and ground antenna diameter is calculated. At first, with a standard value of Travelling Wave Tube Amplifier (TWTA) & gain the satellite EIRP is calculated and then depending upon the smallest diameter of the particular receiving earth station, the satellite EIRP is calculated, followed by calculating the satellite antenna diameter. As a result, at the best satellite position, the maximum EIRP and the minimum antenna diameters (both satellite and ground) that can be seen. The calculations will follow a procedure which is illustrated below.

II. LOSS CALCULATION

II.1 Calculation of Free Space Path Loss (L_{FPLD}):-

When the signal is transmitted from satellite station to earth station, during the transmission it goes through free space, ionosphere and troposphere. The loss that will occur in free space will be called free space path loss which can be calculated from the distance between the earth station location and satellite location as well as from the frequency. The formula [2] used will be:-$L_P=\frac{4\Pi d}{\lambda}$ where **λ** is the measure of wavelength in meters for a given frequency and **d** is the distance between earth station location and satellite location.

The necessary formulas can be derived using the satellite geometry. Here only the final and required formulas are shown [2]. Distance between earth station and satellite station can be expressed as:

$$d= r_s\left[\sqrt{\left[1+\left(\frac{r_e}{r_s}\right)^2-2\left(\frac{r_e}{r_s}\right)\cos(\gamma)\right]}\right] \quad (1)$$

where, r_s= distance of satellite from the center of the earth=42164.17Km.

r_e=radius of earth=6378.137Km.

γ= central angle satellite and the earth station.

By putting the appropriate values, distance can be further modified into,

$$\mathbf{d= 42164.17[1.02288235-0.30253825\cos(\gamma)]^{1/2}\ km.} \quad (2)$$

For downlink frequency of 20GHz, **λ** can be found out as: **λ=$\frac{c}{f}$=0.015m.**

Where, c=velocity of light=3×10^8 m/s.

So, taking these equations free space path loss can be calculated for each earth locations.

II.2 Calculation of Rain Attenuation ($A_{0.01}$):-

After 10GHz, rain attenuation is the most effective one for signal propagation. Rain rate for the extreme earth station has been taken approximately from IMD & ITU. Highest rain fall rate has been taken so that maximum attenuation can be calculated. A brief procedure has been followed particularly to calculate the rain attenuation for the earth station[2]. So, according to the procedure rain attenuation at 0.01% of the attenuation of an average year has been taken. Rain attenuation depends upon rain height which is a function of latitude of the earth station. The relation is shown below [1]:

$$\boldsymbol{h_R=h_O+0.36\ \text{Km.}} \quad (3)$$

Where h_O is the mean annual 0°C isotherm height above mean sea level.

h_O can be calculated from the latitude of the earth station. As this project is based on the geographical region India whose latitude will vary from 8°N to 37°N, so the calculation can be done in the following way:

$$h_O=\begin{cases}5-0.075(L_E-23^o) & for \quad L_E>23^o\\ 5 & for \quad 0^o\leqslant L_E\leqslant 23^o\end{cases} \quad (4)$$

III. G/T RATIO CALCULATION

It gives a measure of the sensitivity of the receiving system. It can be calculated as

$$\frac{G}{T_{TOT}}=10\log(G)-10\ log(T_{TOT}). \quad (5)$$

Normally at high frequency as the losses are more, so to compensate it, high gain is given at the receiving earth station, i.e. of 68 dB. The total noise temperature (T_{TOT}) is the sum of three temperatures, can be expressed mathematically as:-

$$T_{TOT} = T_{Sky} + T_R + T_{Other} \quad (6)$$

- T_{Sky}= Sky Noise Temperature.
- T_R = Receiver Noise Temperature.
- T_{Other}= Other Noise Temperature.

Sky temperature will be calculated separately both for with rain and without rain. The formulas expressing the sky temperature are [6]:

$$\boldsymbol{T_{Sky} = T_{Eff} \times (1 - 10^{-\frac{A_T}{10}}) + T_{CMBT} \times 10^{-\frac{A_T}{10}}} \text{(With rain)} \quad (7)$$

$$\boldsymbol{T_{Sky} = T_{CMBT}} = 2.7\left(\frac{t}{\exp(t)-1}\right) \text{ where } \mathbf{t}=\frac{hf}{2.7\times K} \text{(without rain)} \quad (8)$$

Effective temperature ($\boldsymbol{T_{Eff}}$)represents the attenuation of the signal passing through the medium and taken to be 280K as an average between cold or tropical. Cosmic background noise temperature($\boldsymbol{T_{CMBT}}$) is an EM radiation from no particular source and it depends on frequency. The total attenuation (A_T) which is the sum of atmospheric loss in clear sky (A_{AC}) and the attenuation due to rain($A_{0.01}$) [2]. Rain attenuation has already been calculated for each earth station at different elevation angle. Talking about atmospheric loss, under normal condition, only oxygen and water vapor have a significant contribution in absorption. Other atmospheric gases become a problem in the spectrum above 70GHz. At 20GHz frequency, the atmospheric absorption is very low, i.e. 0.4dB/Km. So, A_T= $A_{0.01} + 0.4$ dB/Km.

Now to calculate the receiver noise, consider the following block diagram [8]:

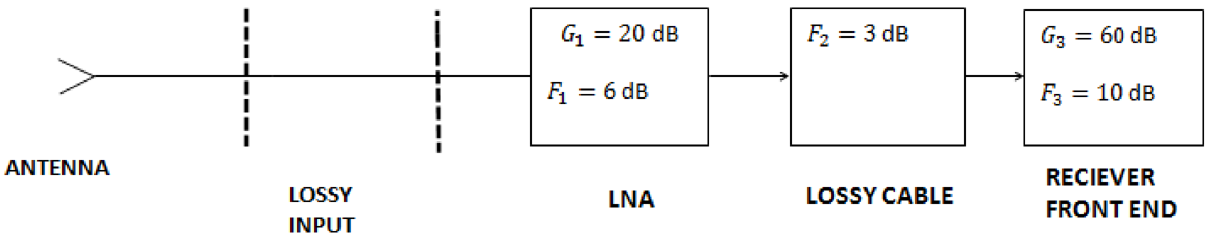

Fig. 2 Signal Propagating in a Noisy Environment

In the above system, all the parameters are defined here and some of them are already assumed values:-

- $\boldsymbol{T_{LNA}}$= Low Noise amplifier Temperature=110 K.
- $\boldsymbol{G_{LNA}}$= Gain of low noise amplifier= 20 dB=100
- $\boldsymbol{T_C}$= Line and cable temperature= $T_{Eff} \times (NF - 1)$= 280 × (1.99-1) =278.67 K.
- NF (F_2) = Noise Figure of line and cable=3 dB =1.99
- $\boldsymbol{G_C}$= Gain of the line and cable loss = 1 dB=1.25
- $\boldsymbol{T_{RF}}$= Temperature of the receiver front end =1000 K.

So, taking all these constraints the receiver noise temperature can be calculated as follows:

$$\boldsymbol{T_R = T_{LNA} + \frac{T_C}{G_{LNA}} + \frac{T_{RF}}{G_{LNA}G_C}} = 110 + \frac{278.67}{100} + \frac{1000}{100\times1.25} = 120.78\text{K}. \quad (9)$$

Considering the other noise temperature (T_{Other}) that occurs in a receiving system, it can be expressed as the sum of three temperatures that are most likely to occur.

$$\boldsymbol{T_{Other} = T_{Spill} + T_{sl} + T_{in}}. \quad (10)$$

- T_{Spill}= Noise temperature due to ground radiation (spillover & scattering)
- T_{sl}= Noise temperature due to side lobe of the antenna
- T_{in} = Noise temperature due to interference from nearby systems.

Spillover noise temperature is both from ground and the antenna and is seen at all the line of sight around the antenna reflector [7]. Scattering noise will occur when the radio energy after hitting a particle, is redirected back from its original path without loss of energy. So the combined value will be 6k at Ka band. Side lobe attenuation occurs as antenna manufacturers have to reduce the gain of the side lobes to levels that are below main beam. This temperature is around 3K at Ka band. Interference noise will occur if any nearby systems will be there whose value is around 7K. So, the other temperature will be calculated as:-

$$\boldsymbol{T_{Other} = T_{Spill} + T_{sl} + T_{in}} = 6\text{K}+3\text{K}+7\text{K}=16\text{K}$$

and the total system temperature can be summed up as follows:-

$$\boldsymbol{T_{TOT} = T_{Sky} + T_R + T_{Other} = T_{Sky} + 120.78K + 16K.}$$

IV. ANTENNA DIAMETER AND SATELLITE EIRP CALCULATION

Ground station antenna diameter is always desirable small in size. For this, maximum satellite EIRP has to be provided. Again maximum satellite EIRP means high satellite antenna gain which results in minimum satellite antenna diameter [10]. Two cases are here: first to keep satellite EIRP constant, ground antenna diameter will be calculated and second is to keep ground antenna diameter constant, calculating satellite EIRP and thereby calculating satellite antenna diameter.

IV.1 Variable Ground Antenna Diameter:

Small ground antenna diameter requires large EIRP. EIRP as the sum of transmitter antenna power and transmitter antenna gain. As satellite is the transmitter so, TWTA and antenna gain is discussed here. Commercially available TWTA (Travelling Wave Tube Amplifier) is having a standard value of 200W applicable for Ka band [11]. Satellite transmitter antenna gain depends on the beam width or foot print of the satellite. The beamwidth will be calculated using satellite antenna geometry assuming India as a cross-section of 5 deg×5 deg latitude longitude, then approximately 16 beam widths are required and earth stations are located at the margin of the footprint of the satellite. The beamwidth is calculated using satellite geometry as 0.88^{o} and there by gain as 45.42 dBi using the formula $\boldsymbol{G = \frac{27000}{\alpha^2}}$[10] where α is the beamwidth. So, EIRP as a whole can be taken as 68.43 dBW.

The link equation that relates these parameters is written below as:

$$\frac{C}{N_o} = \frac{EIRP \times G_r}{KTL_{FPLD} \times A_{0.01}} \quad (11)$$

Where the parameters are:

- $\boldsymbol{G_r}$= Receiver antenna gain which can be equated to $\eta\left(\frac{\pi D}{\lambda}\right)^2$.
- D= Diameter of the antenna.
- λ = Wavelength of the signal.
- η= Efficiency of the system is taken to be 60% as small size antennas called VSATs are taken.
- $\boldsymbol{A_{0.01}}$= Attenuation due to rain.

The assumed parameters are $\boldsymbol{\frac{E_b}{N_O} = 5dB}$ and Bit rate (R_b) = 27Msps= 74.31 dBHz.

So, from the link basic transmission link equation, antenna diameter can be calculated.

IV.2 Variable EIRP and Antenna Diameter:

Considering a constant ground antenna diameter, satellite EIRP can be calculated depending upon rain attenuation and free space path loss. So, choosing the smallest ground antenna diameter at best GEO satellite position will give the maximum EIRP and there by satellite antenna diameter can be calculated using the link equation.

V. TABULATION

Here the four earth stations are tabulated with all necessary columns which indicate all the results that discussed above such as free space path loss at downlink frequency, rain attenuation, best satellite position, G/T ratio, ground antenna diameter, satellite EIRP and satellite antenna diameter.

Name of the state: Gujarat

Location of the earth station: Bhuj (23.24N & 69.66E)

- Average annual rain fall rate:$\boldsymbol{R_{0.01}}$ = 45.00mm/hr.
- Height above mean sea level: $\boldsymbol{h_s}$=110m=0.110Km.
- Specific attenuation along the path: $\boldsymbol{\gamma_r}$=k$(R_{0.01})^{\alpha}$ dB/Km=0.0691×$(45)^{1.065}$=3.98 dB/Km.

Case-1:

Sl. No	l_S	γ in degrees	D in Km.	L_{FPLD} in dB	θ in degrees	3 dB in degree	Satellite Antenna Gain in dB	$A_{0.01}$ in dB	$\frac{C}{N_o}$ In dB	EIRP in dBW	Ground Antenna Diameter in m
1	48E			209.79				18.36			0.85
2	55E			209.73				17.83			0.79
3	65E	2.5	35793.15	209.68	87.05	0.88	45.42	17.47	79.31	67.18	0.75
4	74E			209.68				17.47			0.75
5	83E			209.72				17.71			0.78
6	93E			209.81				18.70			0.88
7	112E			210.08				23.72			1.63

So, as the best GEO satellite position is 74E, so, the smallest antenna diameter required to design satellite station is 0.75m. Here comparatively a large ground antenna indicates increase in the rain attenuation.

Case-2:

Sl. No	l_S	Ground station antenna diameter	L_{FPLD} in dB	$A_{0.01}$ in dB	$\frac{C}{N_o}$ In dB	EIRP in dBW	TWTA Power In dBW	Gain in dB	Satellite Antenna Diameter in m
1	48E		209.79	18.36		68.28		46.52	1.30
2	55E		209.73	17.83		67.69		45.93	1.22
3	65E	0.75	209.68	17.47	79.31	67.28	21.76	45.52	1.16
4	74E		209.68	17.47		67.28		45.52	1.16
5	83E		209.72	17.71		67.56		45.80	1.20
6	93E		209.81	18.70		68.65		46.89	1.36
7	112E		210.08	23.72		73.96		52.20	2.51

VI. SIMULATION

Both the free space los & rain attenuation have been shown in simulation environment. From figure 3, it is concluded that there is not much fluctuation in the individual losses if the satellite locations are compared. 74°E satellite is giving the minimum losses in both free space loss & rain loss. The least values of free space path loss & rain attenuation are 209.68 dB & 17.47 dB respectively.

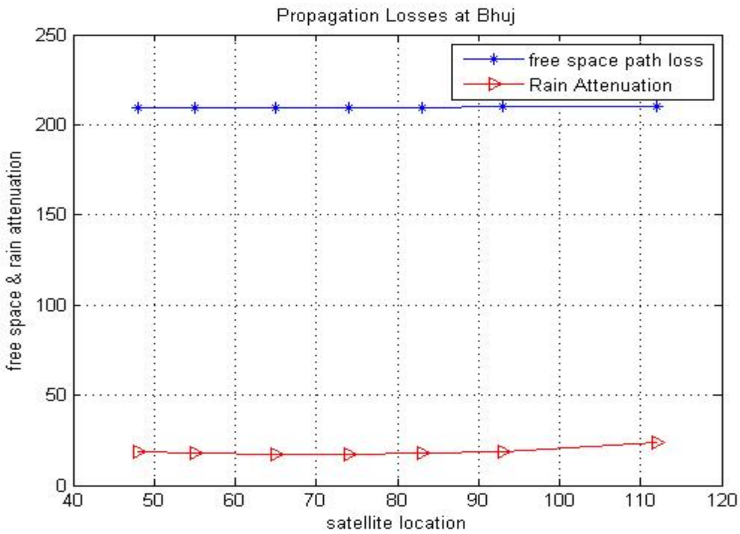

Fig. 3 Propagation Loss Comparison at Bhuj

VII. PROBABLE EXTENSION

This project is based on the calculation of rain attenuation, G/T, antenna diameter, EIRP for an availability of 99.9% of an average year. Similarly, the same parameters can also be calculated for some other parameters, i.e. 99.7%, 95% etc. This project can also be extended to the uplink frequency where VSAT system can be designed by adopting the same procedure. The only difference is the frequency & EIRP used, as higher frequency will result in higher losses. The other calculations will be done by following the above procedure.

VIII. CONCLUSION

From the above discussion, it is cleared that at Ka band, rain attenuation is the second major loss that the signal will face during the propagation. Out of seven fixed allocated GEO satellites, 74^{o}E satellite will give the minimum loss. The maximum EIRP of the satellite is 67.18 dBW which results in 0.75 m satellite antenna diameter & 1.16 m ground earth station antenna diameter. This same procedure can be applicable for rest of the earth station locations if chosen.

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