Estimation of Bit Error Rate for Satellite Communication in Ka-band under atmospheric disturbances for India

Alpesh H. Dafda (First/Main/Corresponding author) and Dr. Kishor G. Maradia

Alpesh H. Dafda - Research Scholar (EC Engineering), Gujarat Technological University, Ahmedabad, Gujarat, India (email: sadafda@gmail.com)

Dr. Kishor G. Maradia - Prof. and HOD (Electronics and Communication Engg.), Government Engineering College, Sector-28, Gandhinagar, Gujarat, India (email: kgmaradia@yahoo.com)

Abstract:

In satellite communications, the Ka band allows higher bandwidth communication, and is going to be used in the impending next satellite series. Unlike the Ku and the C bands, however, it is far more endangered to signal attenuation under rainy conditions. Atmospheric disturbances affect the satellite signals causing BER to increase. These disturbances cause propagation impairments. Many models are developed to predict atmospheric disturbances for India, but very few are verified and implemented. An estimation model is developed for the estimation of BER under atmospheric disturbances for India. Values of mean Rain, Cloud and Gaseous attenuation is applied in the estimation model for monsoon JJAS months (June, July, August and September) for Ka-band downlink (20.2 GHz) for five different cities of India so as to cover all five zones of India (North, West, Central, East and South India). It is found that the BER is highest for East India and lowest for North India. These BER estimations will be helpful for designing different fade mitigation techniques for Ka-band satellite communication for India.

Keywords:

Estimation of BER, Atmospheric disturbances, Satellite Communication, India, Rain-Cloud and Gaseous attenuation, Ka-band downlink (20.2 GHz), JJAS months (June, July, August and September) months, ITU-R model, QPSK/BPSK, 8-PSK, 16-PSK, Digital modulation, 99.99% link availability.

I. Introduction

As the satellite signal passes through the communication link its strength and quality degrades due to the particles in space **[1]**. The degradation worsens with the presence of atmospheric disturbances like rain, cloud and gases. Current day advances in Satellite Communication requires higher information rate and high bandwidth. The degradation affects the received information significantly. There are two types of signal fluctuations, fast and slow. Fast fluctuations are called scintillations. Scintillations are having greater effect on signal frequencies below 3 GHz. However, this effect becomes negligible as the frequency increases **[2]**. Slow fluctuations are due to the absorption and scattering of the signal energy by the particles, mainly water droplets, in the satellite-earth station communication link. Slow fluctuations cause serious impact on satellite signal attenuation above 10 GHz due to rain and clouds **[3]**. The dry air (oxygen) and water vapour have a significant effect at higher signal frequencies **[4].**

For tropical country like India, the attenuation due to rainfall is very heavy. Also clouds and gaseous attenuation can cause significant attenuation. This attenuation is very high for Ka-band satellite communication. Hence a proper estimation of signal strength is required under atmospheric disturbances so that proper fade mitigation technique (FMT) can be designed. This paper describes the estimation of Bit Error Rate (BER) for Ka-band satellite communication under atmospheric disturbances for five different cities/regions/zones of India so as to cover whole of India. These zones are North India (New-Delhi), West India(Ahmedabad), Central India(Bhopal), East India(Kolkata) and South India(Bengaluru).

II. Estimation Model

To estimate BER for different locations of India, we need to design a generalized model for estimation which will provide us different steps of estimation. Figure 1 below shows the projected estimation model.

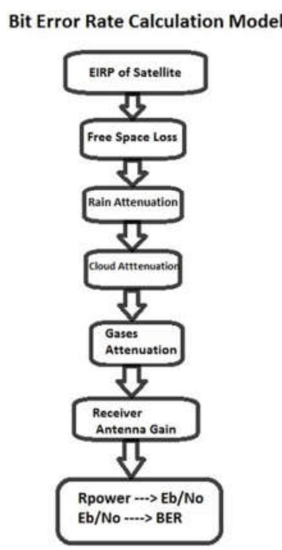

Figure 1: Bit Error Rate Calculation model

For estimation of BER for India, Ka-band downlink frequency of 20.2 GHz is used. The estimation/calculations are done using MATLAB **[5]**. The design link is from the satellite to the earth station. Hence first step is to provide Effective Isotropic Radiated Power (EIRP) of the satellite. The range of EIRP is from 30 to 100 dBW **[6]**. The value of EIRP chosen is 90 dBW.

Next step is to calculate the Free Space Loss. The free space loss is given by **[7]**,

$$L = 20Log(\frac{4\pi d}{\lambda}) \qquad ....(1)$$

Where L is the path loss in dBs,

d is the distance between satellite and earth station,
λ is the wavelength of the signal in use.

Hence we can see that FSL increase with the increase in frequency or conversely decrease in the wavelength. FSL depends on the frequency and is relatively constant.

Next steps are to calculate Rain attenuation, Cloud attenuation and Gaseous attenuation. Calculation were carried out for JJAS (June, July, August, September) monsoon months for India, as major atmospheric disturbances affecting Ka-band communication occurs during monsoon months in India. For these calculations, five different cities of India were chosen so as to cover five zones (North, West, Central, East and South India). These cities are New-Delhi (North India), Ahmedabad (West India), Bhopal (Central India), Kolkata (East India) and Bengaluru (South India). Biggest city of south India-Chennai was not chosen as it receives its maximum rainfall through northeast monsoon during the months of October to December **[8]**, while primary monsoon season of Bengaluru is June to September **[9]**.

Following parameters are used for the calculation of Rain, Cloud and Gaseous Attenuation at 20.2 GHz Ka-band downlink frequency for different cities of India. The parameters for all cities have been taken from Satellite Earth Stations of respective cities.

Parameters	**New Delhi**	**Ahmedabad**	**Bhopal**	**Kolkata**	**Bengaluru**
Latitude(deg)	28.61 °N	23.02356 °N	23.26 °N	22.34 °N	13.0361 °N
Longitude(deg)	77.23° E	72.515 °E	77.40 °E	88.29 °E	77.5708 °E
Station height above MSL(m)	293	48.77	50	6.5	902.25
Antenna Polarization angle(deg)	19.6°	21.7°	45°	45°	45°
Antenna Elevation angle(deg)	56.4°	63°	62.50°	59.24°	74.1298°

Table 1: Important parameters applied for Calculation of Rain, Cloud and Gaseous attenuation

Rain attenuation is calculated from rainfall data of 64 years (1951-2014) from IMD website **[10]** and using Kothyari and Garde equation **[11]** to calculate rainfall intensity in mm/hour and applying it in ITU-R model **[12]**, **[13]**.

Mean cloud and gaseous attenuation is calculated using **[14]**. The values of average rain, cloud and gaseous attenuations obtained along with total mean attenuation are shown in table 2.

Location	**Mean Rainfall (mm/hr)**	**Mean Rain Attenuation (dB)**	**Mean Cloud Atten. (dB)**	Mean Water Vapor Atten. (dB)	Mean Dry Air(Oxygen) Atten (dB)	**Total Gaseous Atten.(dB)**	**Total Mean Attenuation (dB)**
New Delhi	40.92	23.12	0.3380	0.4823	0.0436	0.5259	**23.98**
Ahmedabad	41.56	25.22	0.3160	0.4595	0.0407	0.5003	**26.03**
Bhopal	43.88	25.58	0.3174	0.4182	0.0409	0.4591	**26.35**
Kolkata	47.96	26.74	0.3277	0.6218	0.0422	0.6640	**27.73**
Bangalore	37.58	23.46	0.2927	0.5065	0.0377	0.5442	**24.29**

Table 2: Mean attenuation due to atmospheric disturbances for India**[14]**

The receiver input antenna gain (G_r) is assumed to be 230 dBi, and the value of Noise spectral density is taken as $N_0 = 10^{-7}$ **[15]**. The received power at earth station is calculated using,

$$R_{power} = EIRP + G_r - FSL - L_a - L_s \qquad \text{.............(2)}$$

Where *FSL* is calculated using equation 1 above and L_a is given by,

$$L_a = L_{rain} + L_{cloud} + L_{gas} \qquad \text{................(3)}$$

L_{rain}, L_{cloud} and L_{gas} for a particular city are taken from table 2 above. L_s is system losses which is assumed to be 2 dB **[16]**. System losses include receiver feeder loss(RFL), antenna misalignment loss(AML) etc. Next the E_b/N_0 is calculated using equation 4 below for different bit rates (*brate*) of 30, 50, 70, 90 and 110 Mbps.

$$E_b/N_0 = R_{power} - N_0 - 10*10Log_{10}(brate) \qquad \text{..........(4)}$$

Now, the probability of bit error for a general M-PSK modulation is given by

$$BER = P_b = \frac{1}{k} erfc\left[\sqrt{\frac{kE_b}{N_0}} sin\left(\frac{\pi}{M}\right)\right] \qquad \text{...........(5)}$$

Here *k* is bits per symbol given by,

$$k = log_2(M) \qquad \text{.........(6)}$$

For 8-PSK, M=8 and for 16-PSK, M=16 **[17]**. In the case of QPSK/BPSK modulation and AWGN channel, the *BER* as function of the E_b/N_0 is given by:

$$BER = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_0}}\right) \qquad \text{.........(7)}$$

III. Results and Conclusions

Figure 2 shows the E_b/N_0 vs BER curve for New-Delhi for atmospheric disturbances for JJAS months. As can be observed from the figure, the BER is lowest for QPSK/BPSK modulation and is highest for 16-PSK modulation system. The values of 8-PSK modulation obtained are in between the values of QPSK/BPSK and 16-PSK modulation. As expected for digital modulation, with the increase in bits of modulation, the transmission capacity/bit rate increases but the BER also increases simultaneously.

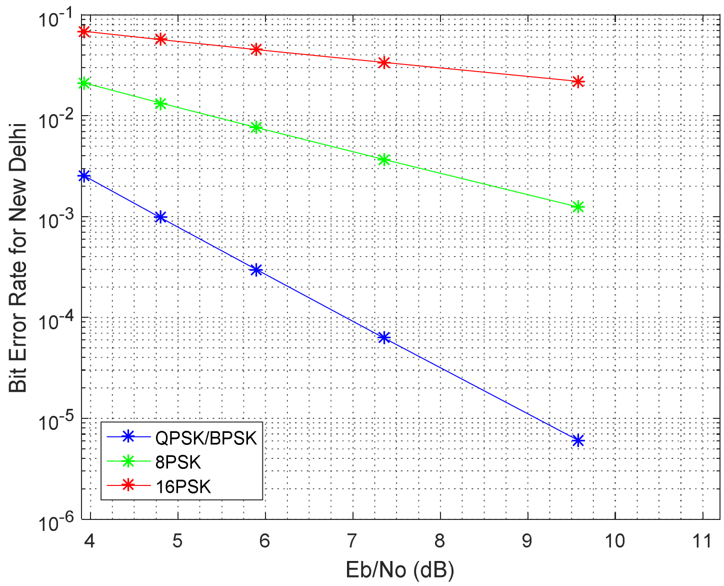

Figure 2: E_b/N_0 vs BER curve for JJAS months for New-Delhi

Similarly figure 3, 4, 5 and 6 shows the BER curves for Ahmedabad (West India), Bhopal(Central India), Kolkata(East India) and Bengaluru(South India) regions of India.

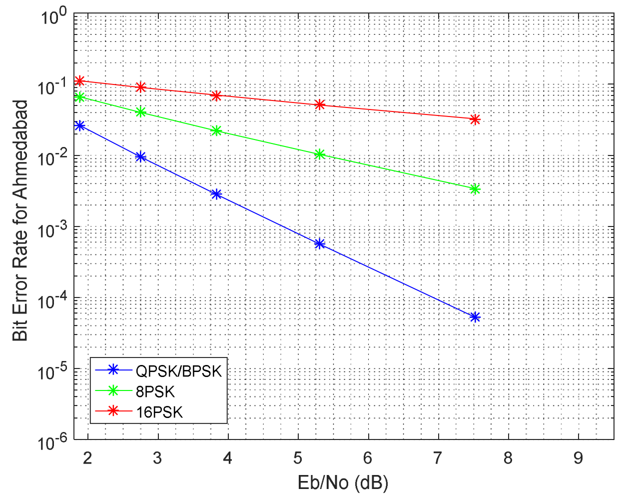

Figure 3: E_b/N_0 vs BER curve for JJAS months for Ahmedabad

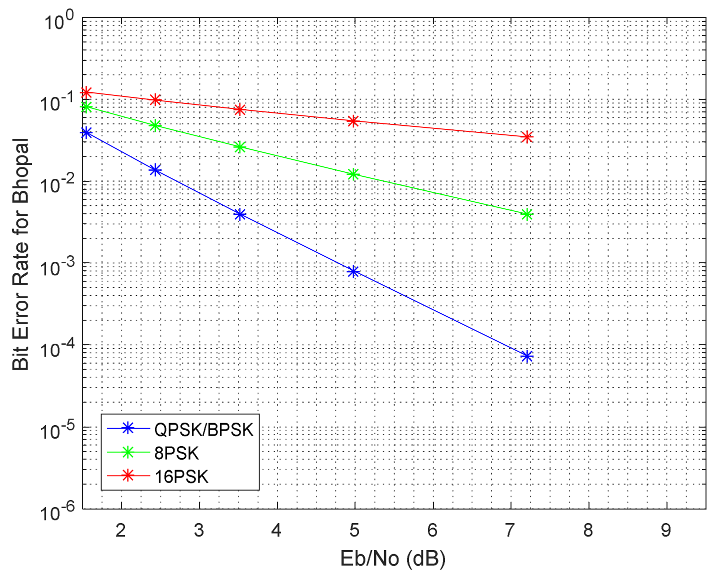

Figure 4: E_b/N_0 vs BER curve for JJAS months for Bhopal

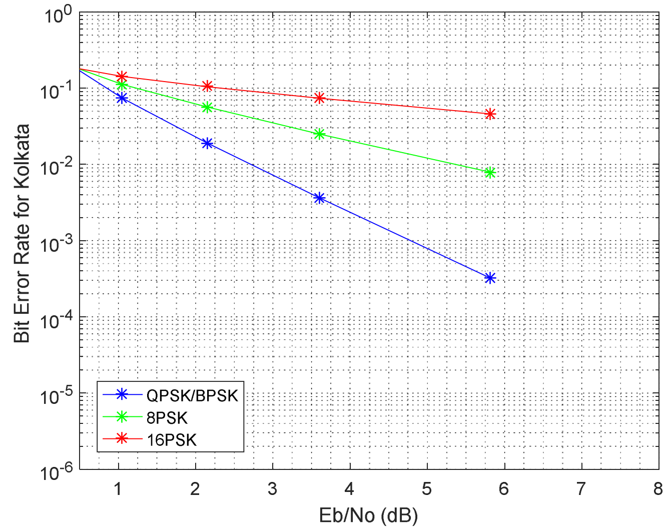

Figure 5: E_b/N_0 vs BER curve for JJAS months for Kolkata

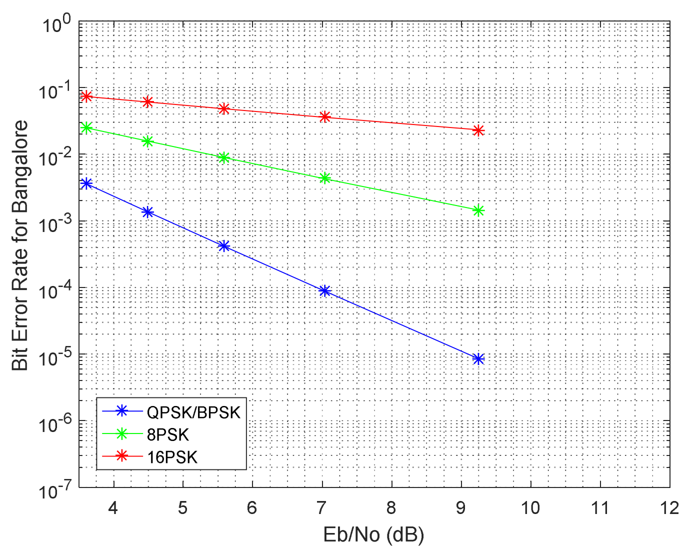

Figure 6: E_b/N_0 vs BER curve for JJAS months for Bengaluru

Figure 7 shows the BER comparison for QPSK/BPSK modulation for different regions of India for Ka-band downlink frequency of 20.2 GHz. As is visible from figure the highest BER is for the city of Kolkata and hence in East India, while the lowest BER is obtained for the city of New Delhi (North India). Central India (Bhopal) is having mid values of BER.

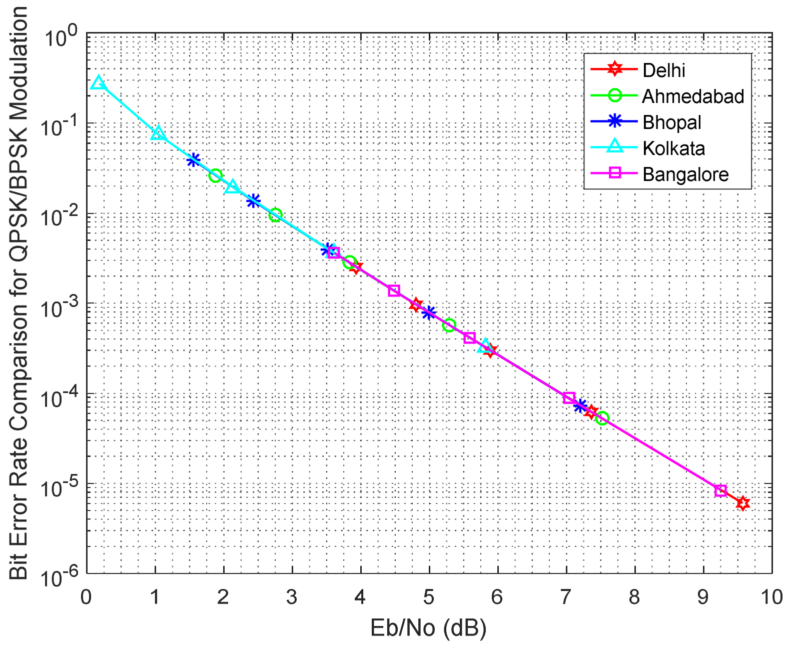

Figure 7: BER comparison for QPSK/BPSK modulation for different regions of India

Figure 8 shows the BER comparison for 8-PSK modulation scheme. As can be observed, again Kolkata is having highest value of BER and New-Delhi is having lowest value of BER. The reason for this is during monsoon heavy rainfall, clouds and fog is present for East India and lowest atmospheric disturbances occurs for North India causing high BER for East India and low BER for North India.

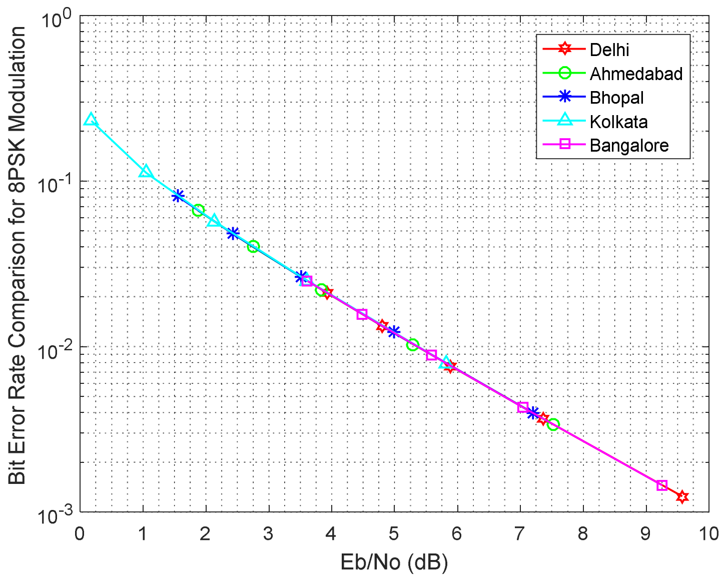

Figure 8: BER comparison for 8-PSK modulation for different regions of India

Figure 9 shows the comparison for 16-PSK digital modulation scheme for different cities of India. As is obvious, Kolkata (East India) is having highest BER and New-Delhi(North India) is having lowest BER for 16-PSK modulation scheme.

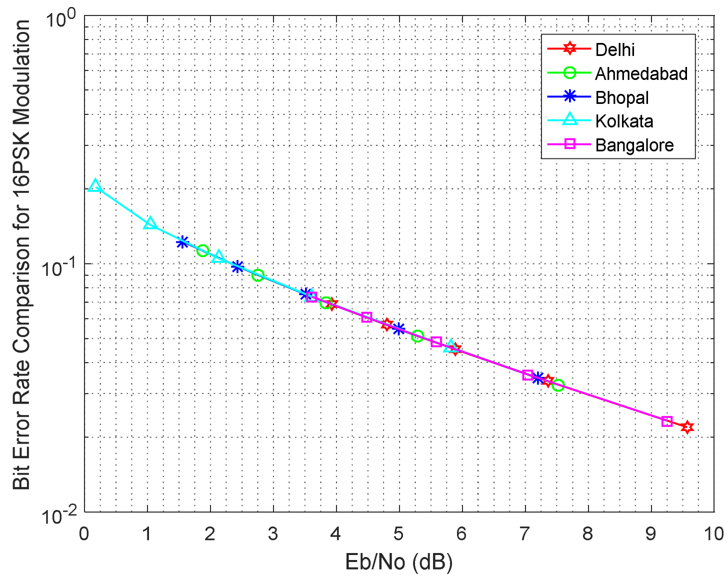

Figure 9: BER comparison for 16-PSK modulation for different regions of India

Table 3 shows the BER values obtained for different regions/cities of India for different modulation scheme for 99.99% link availability or 0.01% exceedance values. As can be observed and highlighted, North India (New-Delhi) is having highest E_b/N_0 and conversely lowest BER for a particular bit rate of 30 Mbps, whereas East-India (Kolkata) is having lowest E_b/N_0 or highest BER for same bit rate of 30 Mbps. After North India (lowest BER) comes the region of South India (Bengaluru), West India (Ahmedabad), Central India (Bhopal) and East India (Kolkata) in increasing order in the terms of BER.

Location	**City**	**Bit Rate**	**Eb/No (dB)**	**BER (QPSK/BPSK)**	**BER (8PSK)**	**BER (16PSK)**
North India	New Delhi	30Mbps	**9.57**	**6.0734e-06**	0.0012446	0.021955
		50Mbps	7.3516	6.292e-05	0.0036784	0.033655
		70Mbps	5.8903	0.00029927	0.0076352	0.045126
		90Mbps	4.7988	0.00097413	0.013343	0.056687
		110Mbps	3.9273	0.0025345	0.021073	0.068541
West India	Ahmedabad	30Mbps	7.5176	5.276e-05	0.0033886	0.032574

		50Mbps	5.2992	0.00056596	0.010314	0.051
		70Mbps	3.8379	0.0027984	0.022101	0.069924
		90Mbps	2.7464	0.0095472	0.040105	0.090119
		110Mbps	1.8749	0.026406	0.066435	0.11248
Central	Bhopal	30Mbps	7.1974	7.4103e-05	0.0039699	0.034694
		50Mbps	4.979	0.0008008	0.012157	0.054556
		70Mbps	3.5177	0.0039958	0.026244	0.075176
		90Mbps	2.4262	0.013803	0.048088	0.097516
		110Mbps	1.5547	0.03892	0.080827	0.12286
East India	Kolkata	30Mbps	**5.8222**	**0.00032197**	0.0079026	0.04576
		50Mbps	3.6038	0.00363	0.025054	0.073716
		70Mbps	2.1425	0.019226	0.056682	0.10482
		90Mbps	1.051	0.073551	0.11218	0.1429
		110Mbps	0.1795	0.27452	0.23041	0.20379
South India	Bangalore	30Mbps	9.257	8.4327e-06	0.0014481	0.023294
		50Mbps	7.0386	8.7734e-05	0.0042955	0.035803
		70Mbps	5.5773	0.00041913	0.0089489	0.048132
		90Mbps	4.4858	0.001371	0.015702	0.060631
		110Mbps	3.6143	0.0035875	0.024912	0.073539

Table 3: BER for 0.01% exceedance value or 99.99% link availability for Ka-band satellite communication for different regions of India under atmospheric disturbances

The reason of highest BER for Kolkata is the heavy rainfall, fog, clouds and other gases in the season of monsoon (June, July, August and September). Hence it can be concluded that the mean atmospheric disturbances like rain, cloud and gases are highest for East India and lowest for North India during the season of monsoon. Consequently, the Bit Error Rate (BER) is highest for East India and lowest for North India. These results are helpful for designing of different fade mitigation techniques for different regions of India for Ka-band satellite communication.

Acknowledgment

The authors are sincerely thankful to SAC-ISRO, Ahmedabad for their help in this study and IMD (Indian Meteorological Department) which is the source of required data. Our special thanks to our research advisors Dr. Subhash Chandra Bera (Scientist, Space Application Centre (ISRO), Ahmedabad) and Dr. Kiran R. Parmar (Adjunct Professor, Adani institute of Infrastructure Engineering, Ahmedabad) for their invaluable guidance for this research work.

References:

1. J. Mandeep and Y. Ng, "Satellite Beacon Experiment for Studying Atmospheric Dynamics," Journal of Infrared, Millimeter and Terahertz Waves, vol. 31, pp. 988-994, 2010.
2. A. D. Panagopoulos, P. D. M. Arapoglou, and P. G. Cottis, "Satellite communications at KU, KA, and V bands: Propagation impairments and mitigation techniques," Communications Surveys & Tutorials, IEEE, vol. 6, pp. 2-14, 2004.
3. T. V. Omotosho and C. O. Oluwafemi, "Impairment of radio wave signal by rainfall on fixed satellite service on earth–space path at 37 stations in Nigeria," Journal of Atmospheric and Solar-Terrestrial Physics, vol. 71, pp. 830-840, 2009.
4. M. Zubair, Z. Haider, S. A. Khan, and J. Nasir, "Atmospheric influences on satellite communications," Przeglad Elektrotechniczny, vol. 87, pp. 261-264, 2011.
5. ⟨www.mathworks.com⟩, The Mathworks ®, Inc.
6. Dennis Roddy, Satellite communications, McGraw-Hill Publication, Fourth edition-2006, page 352.
7. Dennis Roddy, Satellite communications, McGraw-Hill Publication, Fourth edition-2006, page 353.
8. NORTHEAST MONSOON, http://www.imdchennai.gov.in/northeast_monsoon.htm.
9. Bangalore facts | Temperature | Rainfall, https://www.karnataka.com/bangalore/facts/
10. Area Weighted Monthly, Seasonal And Annual Rainfall (in mm) For 36 Meteorological Subdivisions | Open Government Data (OGD) Platform India, https://data.gov.in/resources/area-weighted-monthly-seasonal-and-annual-rainfall-mm-36-meteorological-subdivisions
11. Kothyari, U.C. & Garde, R.J. (1992) Rainfall Intensity-Duration-Frequency Formula for India. Journal of Hydraulic Engineering, ASCE, 118, 323-336, http://dx.doi.org/10.1061/(ASCE)0733-9429(1992)118:2(323).
12. P. Series, “Characteristics of precipitation for propagation modelling”, Recomm. ITU-R P 837-6, 2013.
13. P. Series, “Propagation data and prediction methods required for the design of Earth-space telecommunication systems”, Recomm. ITU-R P 618-8, vol. 10, 2009.
14. Alpesh H. Dafda and Dr. Kishor G. Maradia, International Journal of Research in Engineering, IT and Social Sciences, ISSN 2250-0588, Impact Factor: 6.452, Volume 08 Issue 08, August 2018, Page 335-339.
15. Dennis Roddy, Satellite communications, McGraw-Hill Publication, Fourth edition-2006, page 305.
16. Dennis Roddy, Satellite communications, McGraw-Hill Publication, Fourth edition-2006, page 375.
17. Bit error rate for 16PSK modulation using Gray mapping, http://www.dsplog.com/2008/05/18/bit-error-rate-for-16psk-modulation-using-gray-mapping/

AUTHORS PROFILE:

Alpesh H. Dafda completed his B.E.(Electronics) from B.V.M. Engineering college, Sardar Patel University and M.E.(Communication Systems Engineering) from L. D. College of Engineering, Gujarat Technological University. He has more than 15 years of teaching experience. He has written books on Basic Electronics, Audio Video Systems and Material Science. He is working as Asst. Prof. in Electronics and Communication Engineering department at Vishwakarma Government Engineering College, Chandkheda, Ahmedabad. He is pursuing his Ph.D in Satellite Communication from Gujarat Technological University. Mr. Dafda is a life member of I.E.T.E., India.

Email: sadafda@gmail.com

Dr. Kishor G. Maradia is currently working as Prof. & Head of EC Department(GEC-Class-I) at Government Engineering Collage, Sector 28, Gandhinagar. He joined as GES class – II as a lecturer in EC at L. D. College of Engineering, Ahmedabad in 1996. He received B.E. (EC) from Bhavnagar University in 1992 and received ME (EC) (Communication System Engineering) from Gujarat University in 2003. He is awarded his Ph.D in Wireless Communication from M.S University of Baroda in 2011. He has served as a Lecturer and Sr. Lecturer in E.C. at L. D. College of Engineering Ahmedabad for 14 years. He is having 22 years of teaching and 2 years Industrial experience. He was ex. Engineer with Gujarat Ambuja cements Ltd. He is Ex. Dean of Faculty of Engineering, Hem. North Gujarat University. He guided many PG and PhD students under him. He has published 30 research papers in to his credit at various national, international conferences and Journals.

He is associated with IETE since almost last 15 years and worked as EC member of IETE Ahmedabad Centre during in 2008 to 2010, as the Vice-chairman from 2012 to 2014 and as the Chairman from 2014 to 2016.

Email: kgmaradia@yahoo.com