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Boulanger

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Excess Attenuation Statistics of Earth-Space Propagation Experiments at Ka-Band over Tropical Locations: Shillong and Hassan, India

Arijit De, Arijit.de@onera.fr

Jean-Pascal Monvoisin, Jean-Pascal.Monvoisin@onera.fr

Valentin Le Mire, Valentin.Le_Mire@onera.fr

Laurent Castanet, laurent.castanet@onera.fr

ONERA/DEMR, Université de Toulouse, F-31055 Toulouse, France,

Xavier Boulanger, Xavier.Boulanger@cnes.fr

CNES, DTN/TPI/TCP, F-31401 Toulouse, France

Abstract

Contributions to the GSAT 14 Ka-band propagation campaign, designed and carried out by ISRO, has been conducted by ONERA in Shillong (25.6750°N, 91.9136°E), and CNES in Hassan, India since 2015. Two beacon Earth stations operating at 20.2 GHz, and 30.5 GHz, a profiling radiometer, and a rain gauge are available at the experiment site. Two beacon receivers at 20.2 GHz and 30.5 GHz measure the received signal strength with a 10-Hz sampling rate. In the present paper, rain rate and copolar attenuation data have been analysed. Details of the instruments and methodology of the data analysis have been described. A case study in terms of time series variation of rain rate, and copolar attenuation has been shown. The complementary cumulative distribution function (CCDF) of rain rate and copolar attenuation for the total study period has been calculated and compared with ITU-R model. A high year to year variability has been observed. The experimental CCDF shows good matches with Rec. ITU-R P.618-13 above 0.1 % of time exceedance over Shillong. The comparison of 30.5 GHz copolar attenuation data with ITU-R frequency scaling model shows a good match. Difference has been observed between experimental data and ITU-R model over Hassan.

1. Introduction

Earth-space satellite signals always suffer from propagation impairments; mainly due to rain attenuation above 10 GHz. Failure in Earth-space satellite communication signal link would affect many services like TV decoders and internet browsing etc. The major challenge of radio engineers is to model the severe signal degradation at a low latitude tropical location where heavy precipitation systems disturb satellite communication strongly compared to temperate locations. Already Ka-band satellite communication systems are in use like Yahsat in the Middle East [1], Ka-Sat in Europe [2]. Q/V band satellite communication systems are already in picture [3] to achieve higher bandwidths in order of Tbit/s. At higher frequencies above 10 GHz, the tropospheric propagation impairments, namely, attenuation, and depolarization are severe due to rain [4, 5-6]. Earth-Space tropospheric propagation experiments above 10 GHz have already been carried out all over the world [7-17]. The experimental results are very much helpful for propagation channel modeling for high frequency satellite communication systems. For various Fade Mitigation Techniques (FMT), the knowledge of statistical distribution of rain attenuation is required. However, the performance of existing statistical propagation models may vary from location to location due to their semi-empirical nature. Hence, to compensate for the effects of the Earth's atmosphere at Ka and Q/V bands, the performances of statistical models need to be verified over the region of interest and the best models with the lowest error margin should be recommended for use. Propagation experiments are sparse over tropical locations, where heavy precipitation (convective, stratiform and mixed) usually occurs every year and propagation effects are much more severe than in temperate locations [18]. India is a unique country with great diversity of geographic features and climates. For the development of future Ka-band Satellite Communication Systems over India, it is then very important to test and verify different existing statistical rainfall distributions and Ka-band attenuation prediction models over the Indian region. However, tropospheric propagation experiment data over India is very sparse. In order to achieve Very High Throughput Satellite (VHTS) communication systems over Tropical locations, like the Indian subcontinent, a propagation experiment at Ka-band has been carried out since 2015. User links have currently been planned at Ka-band over India, and in near future Q/V

band will be used for high-speed (1Tbs) satellite communication. In the present paper, rain attenuation characteristics have been studied over two tropical locations, Shillong and Hassan, India. The data analysis has been done over Shillong for the period 2016-2021, whereas over Hassan for the period 2015-2019.

2. Data and Methodology

The GSAT-14 satellite is located at 74°E of longitude on the geostationary orbit (elevation- 53.9559° , and azimuth- 216.7525°).

The ONERA experiment site at Shillong ($25^{\circ}6750'\text{N}$, $91^{\circ}9136'\text{E}$, elevation of 53.95°), India, is located 1038 m above mean sea level and experiences substantial rainfall throughout the year; two separate single frequency single polarization beacon receivers have been deployed at 20.2 and 30.5 GHz. The 20.2 GHz receiver consists of a 0.9 m focussed dish antenna, and a low noise block converter (LNBC), which down-converts the signal at 1.95 GHz. The 30.5 GHz beacon receiver is composed of a 0.9 m focussed dish antenna, and a LNBC, which down-converts the signal at 1.2 GHz. The sampling rate of the signal is 10 Hz, with horizontal polarization. The EMS BRNO tipping bucket rain gauge has been used for the rain rate measurement.



Fig. 1 ONERA beacon receivers

The CNES experiment site at Hassan ($13^{\circ}070'\text{N}$, $76^{\circ}097'\text{E}$) is located at 988 m above mean sea level with an elevation of 74.44° . It is equipped with a dual frequency dual polarization beacon receiver with an outdoor unit consisting of a 1.2 m parabolic antenna, a dual frequency feed, a RF box including the LNBC, antenna motors, rain sensor, and a GPS antenna. The indoor unit encompasses a 19" rack including power supply and conversion, signal acquisition and processing unit, antenna motors command/control unit, MMI computer and a dry air compressor.



Fig. 2 CNES dual frequency beacon receiver

The raw beacon data has been post-processed to eliminate various system effects. The data post-processing followed the NASA Earth Observation and Science Data Information System Processing Levels and developed a data processing tool for propagation data in collaboration with various European labs. The various level of data involved in this processing tool are, (i) level 0: Measured Instrumental Data (MID), (ii) level 1: Raw Propagation Data (RPD), (iii) level 2: Intermediate Propagation Data (IPD), (iv) level 3: Validated Time Series (VTS), and (v) Analyzed Experimental Statistics (AES). The data post-processing technique developed by ONERA has already been described in detail in [19].

3. Results

The propagation data has been analysed for both stations and the results are presented in Section 3.1 and 3.2 for the stations Shillong and Hassan respectively. The availability of the data, the best year CCDF statistics, monthly statistics for the best availability year, the annual to worst month comparison with experimental data have been discussed. Frequency scaling analysis and comparisons between Rec. ITU-R P.618 and measured experimental data are provided in Section 3.3.

3.1 Shillong Results:

At Ka-band, rain attenuation is the major factor causing degradations of the radio signal in Earth-space paths. A case study of rain rate, and rain attenuation has been shown in Figure 3. Fig. 3(a) and (b) shows measured rain rate, and measured rain attenuation respectively for an event on 1st October, 2021. The availability of rain attenuation at 20.2 GHz and 30.5 GHz over Shillong is shown in table 1 and table 2 respectively. The overall availability for this period is 63 % and 60 % at 20.2 GHz and 30.5 GHz respectively. The best availability of rain rate and excess attenuation data of the study period over Shillong is April-December, 2019, and December 2018-November 2019 respectively. The availability of excess attenuation at 20.2 GHz and 30.5 GHz is 82% and 72% respectively over this period. The CCDF of rain rate and rain attenuation at 20.2 GHz and 30.5 GHz for the best period has been computed and is shown in Fig.4. The experimental CCDFs of excess attenuation have been compared with Recommendation ITU-R P.618-13 [20] and the results of 20.2 GHz and 30.5 GHz are presented in Fig. 4 (b) and 4 (c) respectively. For 20.2 GHz, the ITU-R model over-estimates experimental CCDF. For 30.5 GHz, the experimental CCDF shows good matches with the ITU-R model. However, the ITU-R model estimates at above 1% of time exceedance. The availability of different months with more than 80% has been depicted in Fig. 5. Highest CCDF has been observed for the months of July and August. The major rainfall over Shillong occurs in these two months due to the Indian summer monsoon (ISM). The experimental worst month statistics have been compared with Rec. ITU-R P.841-5 annual to worst month conversion model [21] and shown in Fig. 6. The results show a difference between the experimental data and Rec. ITU-R P.841-5.

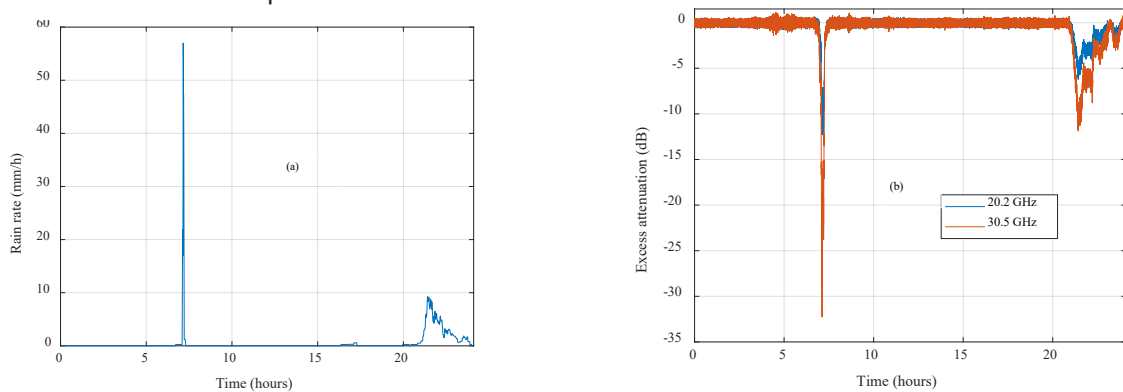


Fig. 3 (a) Rain rate, and (b) Rain attenuation for an event on 1 October, 2021.

Table 1: Availability matrix of 20.2 GHz excess attenuation data over Shillong

	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2016	-	-	87.25	72.96	47.70	11.35	12.41	82.95	96.66	96.74	70.26	99.98
2017	100.00	100.00	100.00	31.03	100.00	75.02	2.22	0.04	0.86	8.22	19.35	0.00

2018	0.00	0.00	35.96	39.55	94.54	72.52	26.02	59.52	89.60	63.10	33.94	75.82
2019	97.20	46.33	93.10	73.02	89.28	92.29	88.85	99.52	91.24	90.92	48.16	1.46
2020	29.88	86.71	90.50	40.24	99.96	37.37	0.00	0.00	0.00	0.00	0.00	0.00
2021	0.00	0.00	75.95	11.62	66.10	99.16	76.11	47.11	81.92	99.58	60.96	0.00

Table 2: Availability matrix of 30.5 GHz excess attenuation data over Shillong

	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2016	-	-	85.13	67.88	53.09	13.50	9.07	55.98	1.03	37.72	55.74	0.00
2017	0.00	39.34	49.30	30.28	59.85	27.93	53.66	63.12	43.72	33.85	53.55	0.00
2018	0.00	0.00	54.84	68.83	99.94	73.52	58.63	17.14	35.04	90.58	35.83	69.27
2019	38.85	98.96	97.14	98.47	81.58	64.36	91.83	80.62	70.16	27.53	43.18	29.30
2020	19.98	96.94	94.42	78.10	81.15	0.00	13.44	79.06	0.01	0.00	0.00	0.00
2021	0.00	0.00	95.94	87.37	83.97	63.88	92.25	31.21	76.80	97.99	78.89	70.06

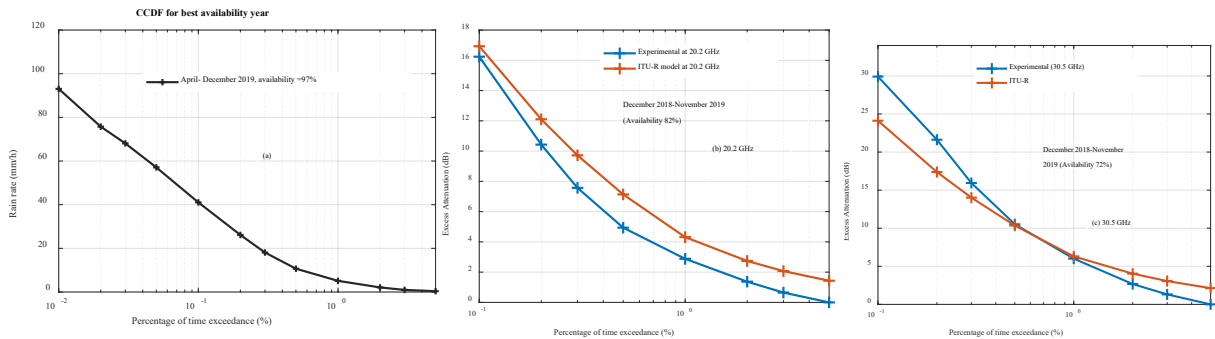


Fig. 4. CCDF of (a) rain rate, (b) excess attenuation at 20.2 GHz, and (c) excess attenuation at 30.5 GHz for best availability year.

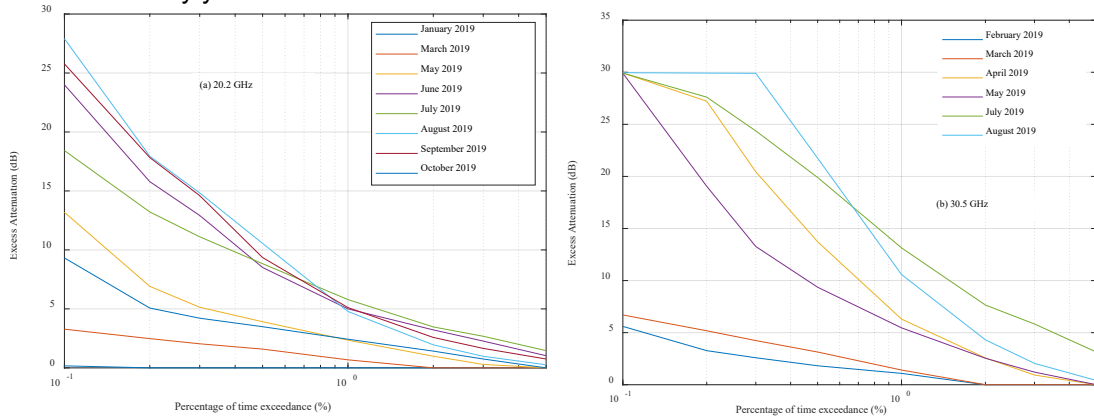


Fig. 5. Month wise CCDF over Shillong for (a) 20.2 GHz, and (b) 30.5 GHz with availability > 80%.

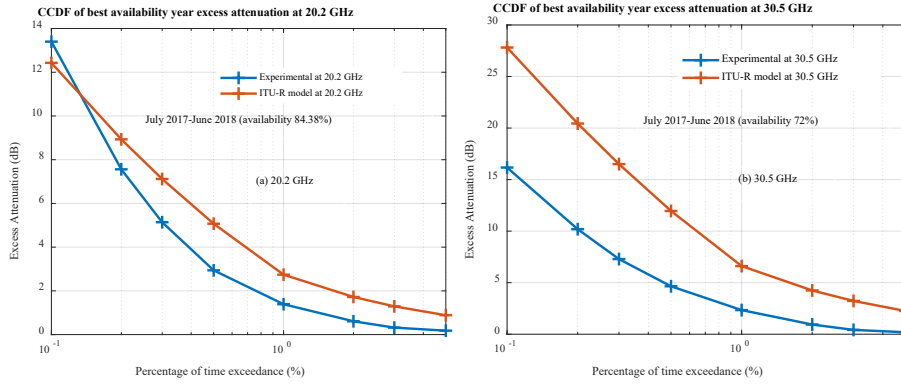


Fig. 7. Comparison of excess attenuation w.r.t to ITU-R prediction method over the experimental period in Hassan from GSAT 14 satellite at (a) 20.2 GHz, and (b) 30.5 GHz for best period.

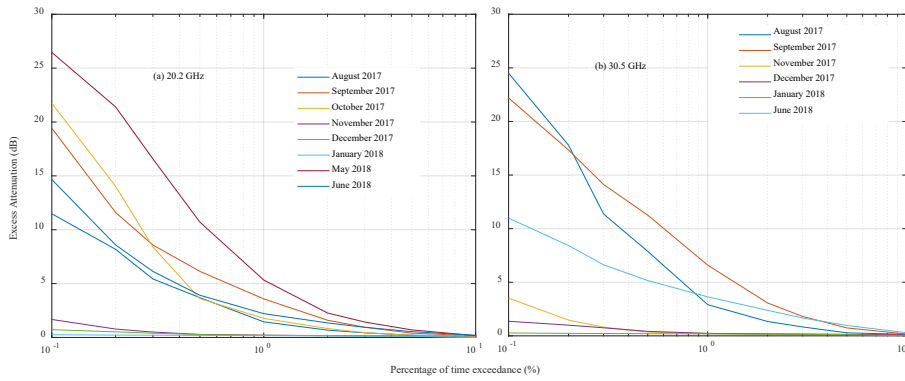


Fig. 8. Month wise CCDF over Hassan for (a) 20.2 GHz, and (b) 30.5 GHz with availability > 80%.

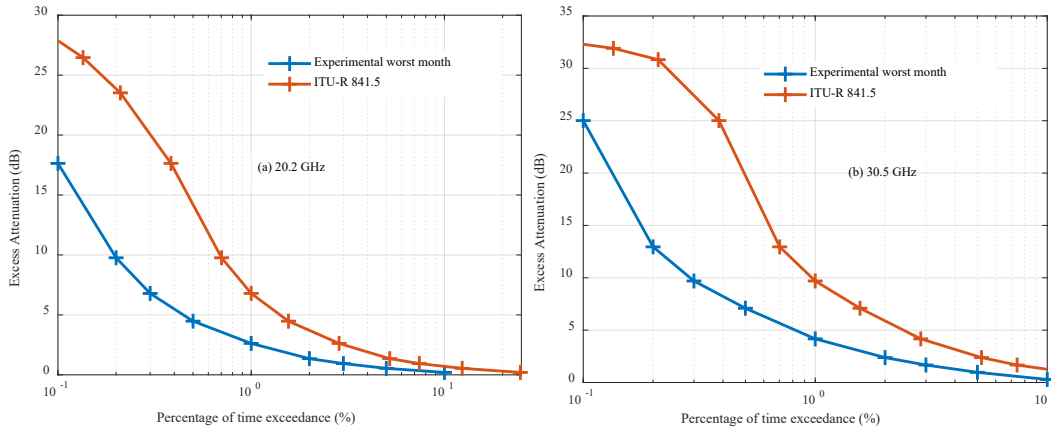


Fig. 9. Worst month statistics and comparison with ITU-R P.841-5.

3.3 Validation of ITU-R frequency scaling model:

In this section, the ITU-R frequency scaling model of Recommendation ITU-R P.618-13) [20] has been compared with experimental data at 30.5 GHz frequency over Shillong and Hassan. If rain attenuation data are available at one frequency, attenuation at a higher frequency can be estimated using the ITU-R frequency scaling model as follows:

$$A_2 = A_1 \left(\frac{\varphi_2}{\varphi_1} \right)^{1-H(\varphi_1, \varphi_2, A_1)} \quad (2a)$$

Where, $\varphi(f) = \frac{f^2}{1+10^{-4}f^2}$ (2b)

$H(\varphi_1, \varphi_2, A_1) = 1.12 \times 10^{-3} (\varphi_2/\varphi_1)^{0.5} (\varphi_1 A_1)^{0.55}$ (2c)

The 30.5 GHz attenuation statistics has been calculated from the 20.2 GHz experimental attenuation data over Shillong and Hassan using Recommendation ITU-R P.618-13. The experimental attenuation at 30.5 GHz has been compared with the predicted frequency scaling attenuation at 30.5 GHz over Shillong and Hassan. The experimental results show strong differences with the ITU-R model over Shillong and Hassan that could be explained by the relatively low measurement availability at both locations.

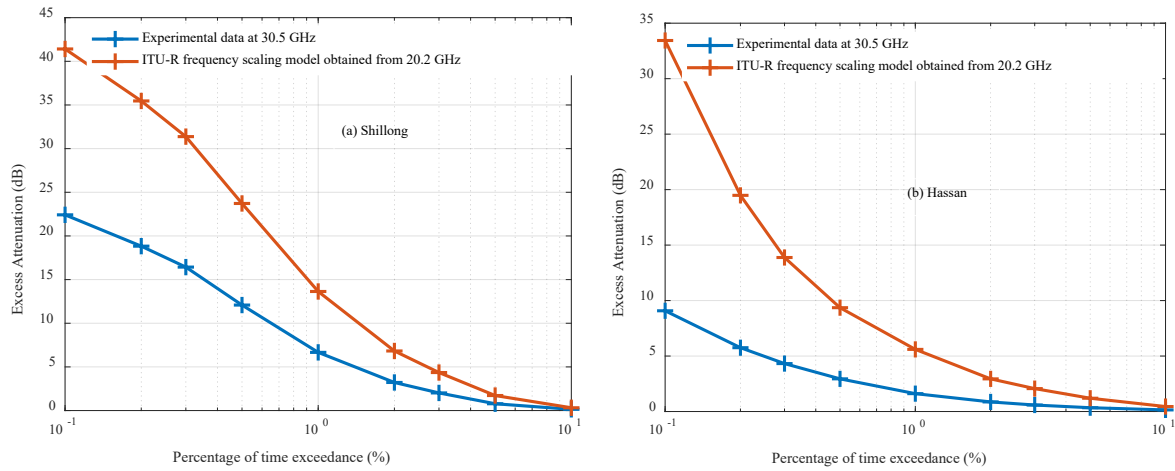


Fig. 10. Validation of ITU-R frequency scaling model in (a) Shillong, (b) Hassan.

4. Conclusion

In the present paper, the authors have investigated the experimental results of Ka-band excess attenuation at 20.2 GHz, and 30.5 GHz over two tropical locations, namely Shillong and Hassan in India. The performance of ITU-R propagation models with the experimental data has also been compared. The CCDF of best availability year has been shown for both locations. The monthly statistics with more than 80% availability has been observed too. The major signal degradation has been observed in July and August over Shillong, and in May and monsoon period over Hassan. The comparison of experimental excess attenuation CCDF, annual to worst month statistics, and frequency scaling with ITU-R model shows differences for both locations and both frequencies. More experimental data is required over other Indian locations to validate ITU-R propagation model for upcoming Ka-band satellite communication. In the absence of experimental data, numerical weather prediction (NWP) models may be helpful for propagation channel modelling at Ka and higher frequency bands.

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