Journal of Information Systems Engineering and Management
2025, 10(7s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Rain Attenuation Investigation for Ka band Satellite Transmission in Tropical Region

Khairunnisa Aziding1, Insyirah Balqis Hasan2, Khairayu Badron3, Atikah Balqis Basri4*
1 Student, ECE Department, Kulliyyah of Engineering, International Islamic University Malaysia, Gombak, Malaysia
2 Student, ECE Department, Kulliyyah of Engineering, International Islamic University Malaysia, Gombak, Malaysia
3 Assoc. Prof., ECE Department, Kulliyyah of Engineering, International Islamic University Malaysia, Gombak, Malaysia
4 Asst. Prof., Information Systems Department, Kulliyyah of ICT, International Islamic University Malaysia, Gombak, Malaysia
Email : 1nisazidin@gmail.com, 2insyirahbb@gmail.com, 3khairayu@iium.edu.my, 4atikahbalqis@iium.edu.my,
Orchid ID Number : 1https://orcid.org/0000-0003-2758-3528,2https://orcid.org/0009-0002-8435-8351 3https://orcid.org/0000-0003-0123-8603, 4https://orcid.org/0000-0003-0262-3298
Corresponding Author* : Atikah Balqis Basri

ARTICLE INFO

Received: 09 Oct 2024

Revised: 10 Dec 2024

Accepted: 24 Dec 2024

ABSTRACT

Growing demands in satellite communication are driving a shift towards higher frequency bands, as lower bands become oversaturated. It is crucial to explore higher frequency bands beyond 10 GHz in order to satisfy the rapidly increasing demand for dependable and high-capacity satellite communication. But to explore into higher frequency bands, a problem has been encountered where there is a significant deterioration of Ka-Band signal quality caused by continuous heavy rainfall in the tropical regions. Rain attenuation caused a great loss in signal compared to other attenuation. The objective of this study is to determine the fade margin estimation for the measured data. This research compares and analyses a set of data from 2022 measured in Cyberjaya. This study also conducted a comparison of rain attenuation estimation utilizing ITU-R model. Fade margin estimation at 99.9% availability obtained from this research is 20 dB at Ka-band frequency.

Keywords: Rain attenuation, Ka-band, Fade Margin, Satellite Link..

INTRODUCTION

Satellite communication is crucial for global connectivity, and enables the transmission of information, speech, and multimedia over long distances. The increasing demand for faster and more reliable communication has led to the use of higher frequency bands like the Ka-band (26–40 GHz). However, deploying Ka-band satellite communication faces challenges, particularly rain attenuation. Rain particles in the atmosphere absorb, scatter,

and disperse the signal, reducing signal strength and leading to deteriorated signal quality, increased data transmission errors, or even total signal loss in severe cases [1]. This impacts the overall reliability of satellite communication systems, affecting applications such as data transmission, broadcasting, and communications.

Rain and other attenuations are more likely to cause interference in the higher frequency band such as Ka-band, which can affect how efficiently a satellite communication system operates. Rain attenuation occurs when rain scatters and absorbs electromagnetic signals from satellites, weakening the signals and reducing received power at ground stations. It is the dominant form of signal loss compared to other types of attenuation [2]. Factors influencing attenuation include the amount and height of rain, signal frequency, and the distance between the transmitter and receiver. Higher frequencies are more susceptible to rain attenuation due to easier absorption and scattering by raindrops. As satellite communication shifts from the C- band to higher frequencies like the Ku-band and Ka-band, rain becomes a significant factor in signal loss, especially above 10 GHz. This necessitates flexible strategies to ensure reliable and continuous satellite communication.

This research also compares the observed measurement with rain attenuation model prediction such as ITU-R. The ITU-R model, was developed to determine the long-term statistics of the slant-path rain attenuation at specific locations. It is also the most common method employed for computing rain attenuation on satellite communication systems [3]. This new model can be easily estimated to adjust for regional prediction models as it offers a framework for calculating how rain affects signal propagation at different frequencies and with different rainfall situations [4].

The Ka-band is the part of the electromagnetic spectrum that belongs to the microwave sector, more precisely, the frequency range of around 26 to 40 gigahertz (GHz) [1]. Ka band is part of the millimeter-wave (mmWave) frequency range, which is higher than the frequencies used by cellular networks and Wi-Fi. Large-scale data transmission over short distances is made possible by the Ka-band's higher frequency, which makes it ideal for high-speed communications applications including video streaming, broadband internet access, and data-intensive satellite communications [5],[6]. Compared with lower frequency bands, the Ka-band requires smaller antennas due to its higher frequency, which is useful in situations where there are weight and space restrictions [7]. Due to that, Ka-band is suitable for VSAT because of the small antenna size. The Ka-band's characteristics make it particularly suitable for current high-speed data transfers, and an increasing number of satellite communication applications are using it. Despite the high performance, Ka-band are more sensitive to atmospheric attenuation, especially in heavy rain conditions, which can impact the reliability of communication links in regions with frequent adverse weather [8],[9],[10].

DATA COLLECTION

Data collections used in the study were Ka-band beacon signals throughout the year of 2022 transmitted from the MEASAT-5 satellites. MEASAT-5 was successfully launched into orbit from the Guiana Space Center in French Guiana, South America, at 5:50 am Malaysian time or 6:50 pm local time on June 22. MEASAT-5 has approximately 18 years of lifespan located 91.5°E in the Earth's orbit and has primary coverage of Asia, Australia, Africa, and Southern Europe. Figure 1 shows the footprints and specifications of MEASAT-5 for Ka-Band [11]. The footprints show the portion of the Earth observable by the satellite. As the accuracy of viewing diminishes towards the edges of the footprint, overlapping satellite footprints ensure coverage for these regions. The specification for Ka-Band is the highest compared to C-Band and Ku-Band.

Figure 1 MEASAT-5 Ka-Band Footprints and Specifications [5]

Another set of data was collected by the Drainage and Irrigation Department (DID) which contains information of rainfall rate throughout the year of 2022. Rainfall rate is a method of measuring rainfall intensity that involves calculating how much rain would fall in a certain amount of time if the intensity of the rainfall remained constant during that time. Figure 2 shows the type of rain gauge used by the DID.

Figure 2 Tipping Bucket Used by DID

To generate the attenuation time-series graph, the data was plotted using Microsoft Excel tools. Next, attenuation on rainy days was chosen to calculate Probability Distribution Function (PDF) with rainfall data. Next, monthly and annual Cumulative Distribution Function (CDF) can be generated from PDF. From the CDF graphs of Attenuation Time Exceedance was generated. The rain attenuation of the Ka-band time-series graphs were generated and correlated with the rates of recent rainfall. On rainy days, a thorough analysis of the Ka-band attenuation data was performed. Lastly, from the graph the fade margin of the measured data can be determined and compared with other available models.

RESULTS AND ANALYSIS

Rain attenuation data from MEASAT Teleport & Broadcast Center (MTBC), collected at two-second intervals over 24 hours each day from January to December 2022, was statistically analyzed. The results, presented in graphs and tables, compare and contrast with other studies. The section highlights the relationship between rainfall intensity and rain attenuation in Malaysia, using the Cumulative Distribution Function (CDF) to analyze time exceedances monthly and annually, determining availability, fade margin, and more. The measured fade margin is compared with other tropical region studies to assess the Ka-Band's performance and the impact of weather conditions on signals in Malaysia during 2022. Figure 3 shows the signal attenuated during the time stated due to rain events.

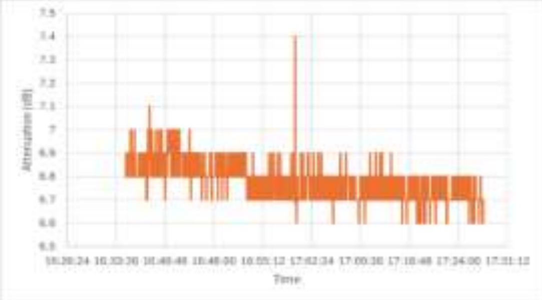

Figure 3 Attenuation Time Series Graph during raining on 21 December 2022 (16:30 – 17:30)

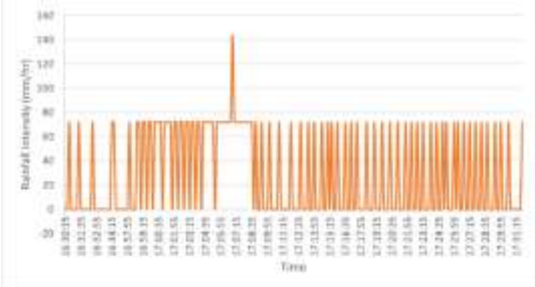

Figure 4 Rainfall Intensity Graph on 21 December 2022 (16:30 – 17:30)

Figures 3 and 4 display the time series of rainfall intensity and rain attenuation over approximately one hour from 4:30 PM to 5:30 PM on December 21, 2022. The graphs show peaks representing the highest values of rain attenuation and rainfall intensity, which align with each other. This observation demonstrates a direct correlation between increasing rainfall intensity and higher attenuation.

Figure 5 Attenuation Time Series Graph during raining on 21 December 2022 (08:00 – 08:30)

Figure 6 Attenuation Time Series Graph during raining on 21 December 2022 (entire day)

Figure 5 shows a time series graph of rain attenuation during heavy rainfall on December 21, 2022, from approximately 8:00 AM to 8:30 AM. This pattern is consistent with Figure 6, which presents rain attenuation for the entire day, with the lowest value observed at 7 dB before escalating to the peak during the rainfall. Figure 6 also presents the rain attenuation time series for December 21, 2022. Without rain, the signal at the MEASAT database experienced minimal attenuation. The highest peak, 33 dB, occurred at 8:08 AM, illustrating how higher frequencies are more susceptible to rain, which increases attenuation.

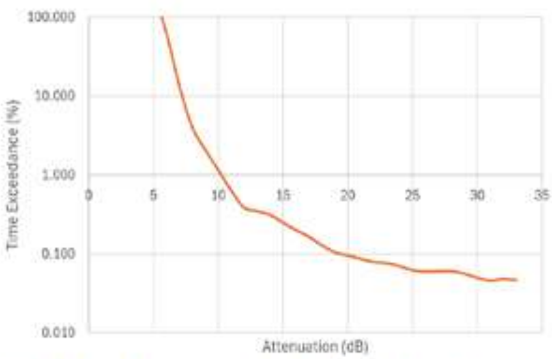

Figure 7 Annual CDF of Rain Attenuation for Ka Band in 2022

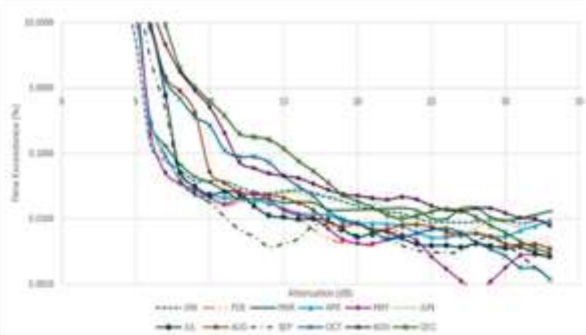

Figure 8 Measured Monthly CDF of Rain Attenuation for Year 2022

Figure 7 displayed the annual CDF of rain attenuation for Ka Band in the year 2022. The total rain-induced attenuation over one year, at time exceedance of 0.1 was 20 dB.

Figure 8 shows the monthly measured rain attenuation of the Ka Band for 2022, derived from monthly CDFs. The lowest time exceedance, below 0.001%, occurs in May, likely due to fewer rainy days. The rain attenuation varies throughout the year across different time exceedance levels.

COMPARISON WITH ITU-R RAIN ATTENUATION MODEL

The ITU-R model, which was developed to determine the long-term statistics of the slant-path rain attenuation at specific locations at frequencies up to 55 GHz, is the method most commonly employed for computing rain attenuation on satellite communication systems [3]. ITU-R offers a framework for calculating how rain affects signal propagation at different frequencies and with different rainfall situations [12],[13]. This model can be easily modified to adjust for regional prediction models.

Table 1 Comparison of ITU-R model and measured Rain Attenuation value at Cyberjaya in 2022

Time Exceedance (%)	ITU-R	Measured Attenuation (dB)
0.001	61.59	55
0.003	56.97	51
0.005	53.43	48
0.008	49.57	44
0.03	36.89	33
0.05	31.72	29
0.08	27.00	22
0.1	24.79	20
0.3	14.40	14
0.5	9.97	12
1	4.57	10

Table 1 compares calculated rain attenuation from the ITU-R model with measured attenuation in 2022. The highest ITU-R prediction at 0.001% time exceedance is 61.59 dB, while the measured peak is 55 dB, showing discrepancies between predicted and actual values.

Figure 9 illustrates that both ITU-R and measured attenuations decrease as time exceedance increases, with ITU-R predictions generally higher at lower exceedance percentages. This indicates that the ITU-R model tends to overestimate attenuation for rare, intense rain events.

The ITU-R prediction model for tropical regions must be carefully crafted using tropical climate data. This is essential for accurately predicting rain attenuation in areas that experience frequent heavy rainfall and various types of rainfall year-round.

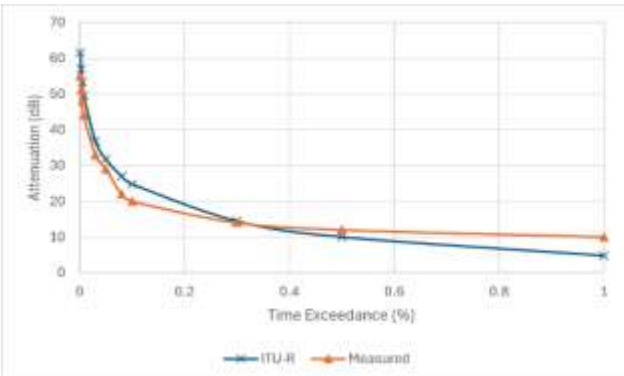

Figure 9 Comparison of ITU-R model and measured Rain Attenuation value at Cyberjaya in 2022

CONCLUSION

In conclusion, this research investigates the propagation effects on Ka-Band satellite links, particularly focusing on how atmospheric conditions like rain attenuation impact signal quality. Rain attenuation is the most significant factor, causing substantial disruption to satellite signals, especially in tropical regions with heavy, persistent rainfall. This issue is critical for the satellite industry as it complicates maintaining reliable internet access and television broadcasting in such areas. The study aimed to analyze rain attenuation data from the MEASAT-5 Ka-Band satellite link, compare this data with existing rain attenuation models, and identify the fade margin for Ka-

Band satellite data at 99.9% availability.

ACKNOWLEDGEMENT

This research is sponsored by FRGS/1/2023/TK08/UIAM/03/2 and the data is generously provided by the MEASAT Satellite System Sdn Bhd and Drainage and Irrigation Department (DID) Malaysia. The authors would like to thank all the sponsors and the relevant agency that contribute to the study and research.

REFERENCES

[1] K. S. Choi, J. H. Kim, D.-S. Ahn, N. H. Jeong, and J. K. Pack, "Trends in rain attenuation model in satellite system," International Conference on Advanced Communication Technology, pp. 1530–1533, Apr. 2011.

[2] L. J. Ippolito, Satellite Communications Systems Engineering: Atmospheric effects, satellite link design and system performance (Wireless communications and mobile computing). 2008.

[3] P. Panchal and R. Joshi, "Performance Analysis and Simulation of Rain Attenuation Models at 12–40 GHz Band for an Earth Space Path over Indian Cities," Procedia Computer Science, vol. 79, pp. 801–808, Jan. 2016.

[4] M. Behjati, J. S. Mandeep, M. Ismail, and R. Nordin, "Investigation of accuracy of rain-rate and rain-attenuation prediction models in satellite communications based on meteorological skills," MAUSAM, vol. 68, no. 4, pp. 621–632, Oct. 2017.

[5] G. Maral and M. Bousquet, Satellite Communications Systems. John Wiley & Sons, 2011.

[6] T. Pratt and J. E. Allnutt, Satellite Communications, Third Edition. John Wiley & Sons, 2019.

[7] P. M. Kalaivaanan, A. Sali, R. S. A. R. Abdullah, S. Yaakob, M. J. Singh, and A. M. Al-Saegh, "Evaluation of Ka-Band rain attenuation for satellite communication in tropical regions through a measurement of multiple antenna sizes," IEEE Access, vol. 8, pp. 18007–18018, Jan. 2020.

[8] J. X. Yeo, Y. H. Lee, and J. T. Ong, "Rain attenuation Prediction Model for satellite communications in tropical regions," IEEE Transactions on Antennas and Propagation, vol. 62, no. 11, pp. 5775–5781, Sep. 2014.

[9] N. A. Rahim, H. N. A. Mulop, and K. Badron, "Study of tropospheric scintillation effects in Ku-band frequency for satellite communication system," International Journal of Electrical and Computer Engineering (IJECE), vol. 10, no. 3, p. 3136, Mar. 2020.

[10] N. Fadilah and R. Pratama, "Comparison of rain attenuation estimation in high frequency in Indonesia region for LAPAN communication satellite," Journal of Physics Conference Series, vol. 1130, p. 012036, Nov. 2018.

[11] MEASAT, "Satellite Details," *MEASAT*, Jun. 12, 2019.

[12] ITU-R, "Propagation data and prediction methods required for the de sign of earth-space telecommunication systems," Recommendation ITU-R P.618-12, 2015.

[13] ITU-R, "Propagation data and prediction methods required for the design of Earth-space telecommunication systems," Recommendation ITU-RP.618-14, 2023.