J. Electrical Systems 20-4s (2024): 1790-1797

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Fade Duration Analysis on a Ka-Band Link Operating in the Tropical Region

Journal of Electrical Systems

Abstract: - Communication systems are rapidly shifting towards higher frequencies due to congestion experienced at lower frequencies and the growing demand for higher data transmission rates within the network. However, it has been observed that as frequency increases, the susceptibility of the system to weather-related factors, particularly adverse weather conditions like rain, becomes more pronounced. This has raised significant concerns regarding the dependability of satellite communication links. This research investigates the dynamic characteristics of signal degradation caused by atmospheric effects, specifically focusing on the impact of rain fade. The study involves an analysis of fading duration using a year's worth of data extracted from Measat-5, operating at a beacon frequency of 20.199 GHz and positioned at an elevation angle of 68.8°. Such data is useful when developing a fade mitigation technique (FMT) that mitigates the disruptive effects caused by heavy rainfall, ultimately leading to an enhancement in both signal quality and overall signal availability.

Keywords: Fade dynamics, fade duration, Ka-Band, satellite

I. INTRODUCTION

The deployment of satellites for communication has grown significantly over the past few decades to meet the rising demand in providing coverage to rural and remote areas. Satellite communications are well-placed for broadcasting and network connection to audiences over a large geographic area. The television broadcast is unquestionably a primary satellite service; however, the rising amount of data network traffic is contributing to the requirement for higher capacity and lower latency communications networks. Due to this, satellite communication system providers are now shifting to the higher frequency bands to meet higher data rates and bandwidth demands [1].

The interest is also now focused on the utilization of higher bands, as the C-band is already congested, and the Ku-band is fast filling up. The next move by the satellite operator is to utilize the Ka-band (27–40 GHz) and Q/V-band (40–75 GHz). However, at such a high frequency, the atmospheric and rain attenuation can potentially cause signal degradation on Earth space along the propagation path, which leads to a reduction in the quality and availability of satellite communication service. The propagation of a radio frequency signal between an earth station and a satellite must pass through the atmosphere in the presence of gases, water vapor, oxygen, clouds, rainfall, thunderstorms whilst raining, and fog, which contributes to the signal impairment [2].

According to the Malaysian Meteorological Department, Malaysian climate is characterized by a uniform temperature, high humidity, and heavy rainfall as Malaysia is located just north of the equator and the climate is equatorial [3]. There are two main seasons of the climate year in Malaysia which are the northeast monsoon (early November to March) which is a wet season that brings downpours and rough seas to the exposed coasts of southwest Sarawak and northeast Sabah. This season sometimes causes flooding, affecting the east coast of Peninsular Malaysia and the northeast coast of Borneo. While the southwest monsoon (May or early June to September) causes the entire country except Sabah to experience relatively dry weather and encounter minimal monthly rainfall.

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When a satellite signal encounters rain, the droplets may partially absorb, disperse, or diffract the signal. The signal strength may suffer as a result, which may cause data reception issues. The likelihood that a signal will be impacted by rain increases with frequency because as the wavelength gets smaller, the signal is more sensitive to being scattered and absorbed by tiny raindrops [4]. In order to provide not just a dependable service but also systems that can cater to the fading during rain events while saving energy, further in-depth research must be conducted. This is significant because the majority of earlier studies did not concentrate on the tropical region. Hence, the significance of this study is to provide an analysis on the fade duration, where the objective is to help in designing reliable satellite communications systems and help to minimize power usage. A good satellite communication system will boost living standards and offers chances for growth, learning, and connection.

II. DATA MEASUREMENT

The analysis process has been conducted using the data extracted from Measat-5, which is owned and managed by the Malaysian satellite company, MEASAT Satellite Systems Sdn. Bhd. It was launched on a Russian Proton-M rocket on 12th June 2006. The satellite has 36 Ku-band transponders and 4 Ka-band transponders and it covers Southeast Asia, India, and Africa. Its function is to provide services for direct-to-home television broadcasts, VSAT networks, and telecommunications services. It is located in a geostationary orbit (GEO) at a longitude of 119.5° East [5]. The received data was extracted from 1st January 2021 to 31 December 2021 at the ground station located in Cyberjaya. The parameters of the systems link are as follows in Table I:

Table I: Parameters of Measat-5 communication link

Satellite	**Measat-5**
Ground Station Location	2°56'08.1"N 101°39'30.1"E
Satellite Position	119.5° E
Antenna Diameter	8.1m
Azimuth Angle	99°
Elevation Angle	68.8°
Beacon Frequency	20.199 GHz

The satellite data received from Measat is first coordinated with the rainfall data from the Department of Irrigation and Drainage (DID). The evaluation is essential for defining a signal strength level during clear skies using the averaging technique [5]. Then, the clear sky value is used as a threshold reference for the analysis of the rain attenuation. The measured signal strength during rain events is deducted from the clear sky value to get the attenuation value due to rain in decibels (dB). Fig. 1, presented here, provides a comprehensive representation of the dataset acquired from DID encompassing meteorological information. This extensive dataset encompasses the precise and intricate measurements of rainfall rates at strategically located nearby stations, notably Putrajaya and Puchong, illustrated in visually distinctive shades of blue and yellow, effectively conveying the varying degrees of precipitation at these locales. Additionally, within this dataset, one can discern the vital aspect of signal attenuation, which was extracted from the Measat-5 satellite's extensive data archives, specifically focusing on the date of 29 August 2021, during the time interval spanning from the early hours of 3 a.m. to 7 a.m. in Malaysian Time.

The time-series plots labeled as Fig.1 show that there is a strong relationship between the amount of attenuation fading and the intensity of the rainfall on 29 August 2021. In other words, the more rain that falls, the more attenuation fading that is observed. This is because the raindrops in the atmosphere absorb some of the signal and disperse it, weakening it and leading to signal degradation. The interaction between electromagnetic waves with atmospheric water droplets occurs in rain attenuation. These droplets weaken or spread the signal by absorbing it and scattering it [4].

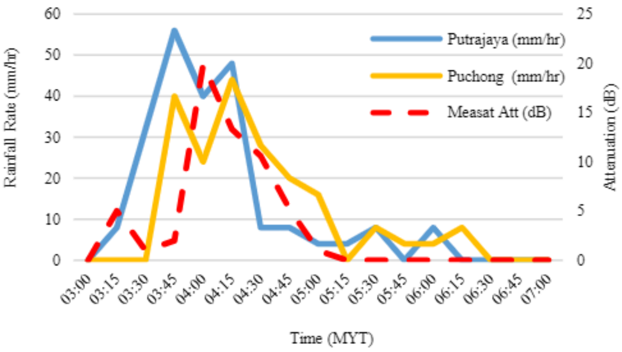

Fig 1: Comparison of rainfall rate and attenuation level

III. FADE DURATION STATISTICS

A. Characteristics of Fade Duration

Fade dynamics refers to the variation in signal strength that occurs due to atmospheric conditions like rain, clouds, and other forms of precipitation. The fluctuations are usually referred to as fades, and they influence the quality and reliability of the satellite-to-earth communication link. Fig 2 illustrates the features of fade dynamics characteristics which include fade duration, fade slope, and inter-fade duration statistic at particular attenuation values. In this paper, we will be focusing on fade duration analysis.

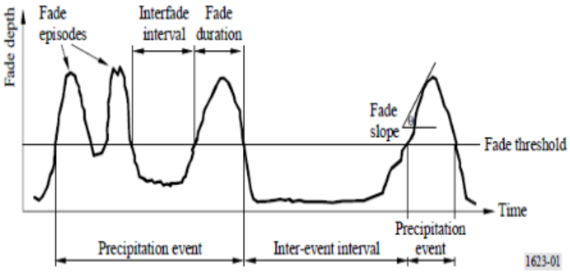

Fig 2: Features of fade events [6]

Fade duration refers to the amount of time that a signal strength is reduced due to atmospheric conditions [6]. The severity of the atmospheric conditions and the signal frequency can determine the signal fading and the duration of the fade. Fade duration plays an important role in satellite communication design as it can influence the quality of the link service. The longer the fade durations, the higher the signal disruption that may lead to performance degradation or even signal loss [7].

Taken from ITU-R Rec. P. 1623-1, the parameters used to characterize the fade dynamics in this paper are considered the standard parameters in this calculation. ITU-R P.1623 [6] proposed a prediction model for the fade duration that takes the influences of clouds, rain, gases, and scintillation into account. This prediction model implemented a log-normal distribution function and a power-law function for long- and short-term fade duration respectively. The input parameters needed for the model are as below:

f: frequency from10 to 50 GHz

φ: elevation angle from 5° to 60°

A: attenuation threshold in dB

where the probability of occurrence of the fade durations for d longer than D at attenuation a is greater than A is;

For $1 \leq D \leq D_t$

$$P\ (d > D|a > A) = D^{-\gamma} \qquad (1)$$

For $D > D_t$

$$P\ (d > D|a > A) = D^{-\gamma} . \frac{Q\ (\frac{\ln(D)-\ln(D2)}{\sigma})}{Q\ (\frac{\ln(Dt)-\ln(D2)}{\sigma})} \qquad (2)$$

These functions are obtained after considering the standard deviation σ and the exponent γ of the power-law distribution. The model has been verified for the frequency range of 1 to 50 GHz and elevation angle between 6° to 60°. Given that the threshold A is exceeded, this probability can be calculated from the ratio of $N\ (d > D|a > A)$, or the number of fades of duration longer than D, to the total number of fades observed $N_{tot}\,(A)$.

B. Monthly Data

In 2021, the month of December recorded the highest number of rain events and the highest fade duration for the year as represented in Fig 3. The low rainfall events in January and February may be related to the Northeast monsoon season as Cyberjaya is located in the western part of Malaysia, which is protected from the Northeast monsoon by the mountain ranges. As a result, this region experiences less rainfall during this time of year, which can be considered the dry season [8].

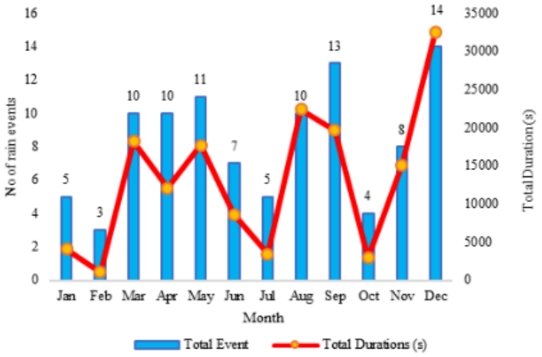

Fig 3: Monthly rain events

C. Hourly Rain Event

As demonstrated in Fig 4, the highest rain event in 2021 occurred in the evening, from 12 p.m. to 6 p.m., with a probability of greater than 50%. This can be related to [9], which states that the southern part of Selangor experiences frequent thunderstorms and heavy rain in the late afternoon during the wet season. This happens because as the ground warms up, it creates atmospheric convection currents that push moist air near the ground upwards to colder air at higher altitudes. This often results in rapid cloud formation near noon, and the weather is likely to rain in the afternoon and evening.

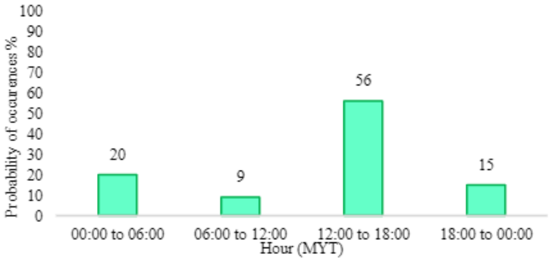

Fig 4: Rain event based 6 hours timeframe

IV. ANALYSIS OF FADE DURATIONS

A. Total number of the fade events

Fig 5 illustrates the total number of fade events $N_{tot}(A)$ measured between January 2021 and December 2021 against the attenuation threshold. It is evident that as the attenuation increases, the occurrence of fades decreases. This effect is particularly pronounced for attenuation levels exceeding 27dB, where there were fewer than 100 events in the year 2021.

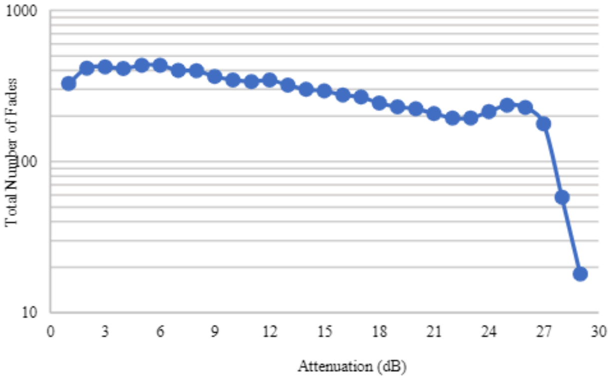

Fig 5: Total Number of Fades

B. Total number of fades of duration

Fig 6 shows the number of fades exceeding a given duration. The distributions maintain a consistent shape across various attenuation thresholds, exhibiting a nearly parallel alignment. This implies that the trend observed in Fig2 can be projected to apply to different durations through predictive analysis. It can be seen that the duration of the fade events for the attenuation of 1 dB to 28 dB is not more than 1000s and attenuation of 28 dB has the least fade events for fade duration less than 10s.

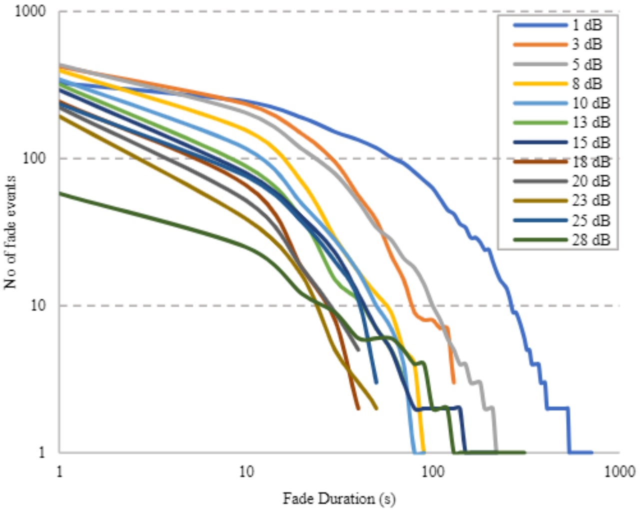

Fig 6: Total number of fades of duration exceeding threshold

C. Probability of occurrence

The probability of occurrence of fades that last longer than a certain duration $P\ (d > D|a > A)$, can be estimated by dividing the number of fades $N\ (d > D|a > A)$, by the total number of fades observed $N_{tot}(A)$ given that the threshold A is exceeded. The equation for this is shown below:

$$P(d > D|a > A) = \frac{N\,(d>D|a>A)}{N_{tot}\,(A)} \qquad (3)$$

The experimental results are presented in Fig 7 The percentage of occurrences with 1dB attenuation is the highest across all durations, while the percentage of occurrences with 28dB attenuation is higher for rainfall events lasting longer than 100 seconds. Furthermore, there is a probability exceeding 20% that rainfall will extend beyond 10 seconds, for all attenuation greater than 1dB.

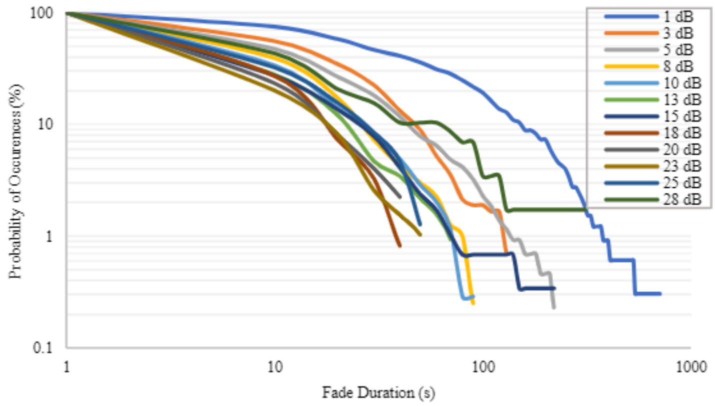

Fig 7: Occurrence probability of fade duration

This holds significant importance due to the fact that the ITU-T G.821 [10] guideline articulates the notion of "unavailable time." This concept pertains to the timeframe during which a link disruption endures for more than 10 consecutive seconds. Understanding and tracking this aspect is essential for assessing the reliability and performance of communication links, particularly in scenarios where extended disruptions can have notable impacts on network operations and user experience.

D. Average Fade Duration

The average duration of a specific fade level can be determined by dividing the total time the threshold *A*, $T_{tot}\,(A)$ by the number of events that occurred at that particular fade level, $N_{tot}\,(A)$ [11]. As for the average interval for hours, it refers to an average time gap or duration between events or occurrences, measured in hours for the year 2021. The equations are expressed below.

$$Average_{duration} = \frac{T_{tot}\,(A)}{N_{tot}\,(A)}\ (s) \qquad (4)$$

$$Average_{interval} = \frac{365}{N_{tot}\,(A)}\ 24\ (hr) \qquad (5)$$

Table II Annual average duration and interval

Fade (dB)	**Total No. of Events**	**Total Duration (s)**	**Average Duration (s)**	**Average Interval (Hour)**
1	328	20418	62.25	26.707

3	423	8712	20.596	20.709
5	434	8241	18.988	20.184
8	398	5080	12.764	22.01
10	347	4027	11.605	25.245
13	320	3266	10.206	27.375
15	293	3313	11.307	29.898
18	244	2380	9.754	35.902
20	223	1890	8.475	39.283
23	194	1610	8.299	45.155
25	236	2686	11.381	37.119
28	58	1416	24.414	151.034

Table II shows the calculated average duration (s) and average interval based on (4) and (5). The extended duration of 1 dB fades during rainy conditions can be attributed to the gradual attenuation caused by rain. Unlike abrupt signal fluctuations, rain causes a slow and continuous decrease in signal strength as rain intensity increases, and conversely, signal strength gradually recovers as the rain intensity decreases. This gradual change is a contributing factor to the extended duration of 1 dB fades in such conditions.

CONCLUSION

This research explores the challenges faced by modern communication systems as they shift to higher frequencies to meet the demand for faster data transmission. While higher frequencies offer benefits, they also make systems more vulnerable to adverse weather conditions like rain. This study focuses on the impact of rain fade on satellite communication links, using data from Measat-5 at 20.199 GHz with an elevation angle of 68.8°.

The findings indicate that the rainiest month and the timing of rain events were identified. Importantly, the result shows that heavy rain or high signal attenuation tends to occur over periods. The signal strength is influenced by the size of raindrops and the intensity of rainfall. Consequently, the number of fade events exceeding the 1 dB threshold is higher compared to events at other threshold levels when considering the duration of signal fading.

This research, based on a year's worth of data analysis, seeks to enhance comprehension of the dynamic aspects of signal degradation due to rain. Moreover, it necessitates a detailed examination of the ITU-R recommendation for the development of an appropriate model tailored to tropical regions, specifically Malaysia. The overarching objective is to formulate a fade mitigation technique (FMT) capable of improving signal quality and availability in instances of heavy rainfall.

ACKNOWLEDGEMENT

This work was supported by the Fundamental Research Grant Scheme (FRGS) Research Project FRGS/1/2021/TK0/UIAM/02/21.

REFERENCES

[1] M. M. Yunus, J. Din, S. L. Jong, and H. Y. Lam, "Slant Path Ka-Band rain attenuation statistics in equatorial Malaysia obtained using stratiform convective-synthetic storm technique," 2018. [Online]. Available: www.sciencepubco.com/index.php/IJET

[2] M. E. Sanyaolu, O. F. Dairo, A. A. Willoughby, and L. B. Kolawole, "ESTIMATION OF RAIN FADE DURATIONS ON COMMUNICATION LINKS AT Ka BAND IN EQUATORIAL AND TROPICAL REGIONS," 2020.

[3] "Malaysia's Climate - Official Website of Malaysian Meteorological Department." https://www.met.gov.my/en/pendidikan/iklim-malaysia/ (accessed Sep. 16, 2023).

[4] S. Shrestha and D. Y. Choi, "Study of rain attenuation in Ka band for satellite communication in South Korea," J Atmos Sol Terr Phys, vol. 148, pp. 53–63, Oct. 2016, doi: 10.1016/j.jastp.2016.08.008.

[5] N. H. S. Suhaimi, K. Badron, A. F. Ismail, Y. A. Ahmad, M. R. M. Yassin, and M. H. Rahmat, “DETERMINATION OF FADE MARGIN FOR KA BAND OPERATING IN EQUATORIAL REGION,” 2018, doi: 10.4314/jfas.v10i2s.19.

[6] ITU-R-P.1623-1, “Prediction method of fade dynamics on Earth-space paths.,” Geneva: International Telecommunications Union., 2005.

[7] Maitra, A. De, and A. Adhikari, “Rain and rain-induced degradations of satellite links over a tropical location,” IEEE Trans Antennas Propag, vol. 67, no. 8, pp. 5507–5518, Aug. 2019, doi: 10.1109/TAP.2019.2911376.

[8] J. Suhaila and A. A. Jemain, “A comparison of the rainfall patterns between stations on the East and the West coasts of Peninsular Malaysia using the smoothing model of rainfall amounts,” Meteorological Applications, vol. 16, no. 3, pp. 391–401, 2009, doi: 10.1002/met.137.

[9] M. Hashim et al., “A preliminary analysis of solar irradiance measurements at TNB solar research centre for optimal orientation of fixed solar panels installed in Selangor Malaysia,” in IOP Conference Series: Earth and Environmental Science, Institute of Physics Publishing, 2013. doi: 10.1088/1755-1315/16/1/012001.

[10] “ITU-T Error performance of an international digital connection operating at a bit rate below the primary rate and forming part of an Integrated Services Digital Network,” 2002.

[11] Institute of Electrical and Electronics Engineers., [4th International Conference on Computer and Communication Engineering] : [Kuala Lumpur, July 3-5, 2012, ICCCE 2012]. IEEE, 2012.