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Interfade Duration Statistics at Ku-band for Satellite Earth Links System in Equatorial Malaysia: Modeling Distribution

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Abstract

Fade dynamics is one of more important parameters when implementing Fade Mitigation Techniques (FMTs) to counteract an excessive attenuation that affect satellite communication systems operating above 10 GHz. The statistics of probable duration between two rain fade namely interfade duration enables system operator to estimate how long the system will need to recover before the next outage and assist in designing the FMTs. In this paper, interfade duration statistics have been derived from one year of slant path attenuation measurements data collected in Equatorial Johor Bahru at 12.2 GHz with elevation angle of 75.61^o. The result had shown the dependency of number of events with attenuation thresholds. Empirical interfade duration statistics are also obtained and suitable model distribution are proposed.

Keywords: *Interfade duration, rain attenuation, Ku-band, satellite communication, equatorial*

1. Introduction

It is well known that satellite communication systems operating at high frequencies are severely impaired by atmospheric phenomenant and rain attenuation has become the most causes that degrading the transmitted signal [1, 2]. This even much more critical in tropical or equatorial region as this area exibit higher rainfall rate than in temperate region. In order to make satellite systems operations feasible at frequencies above 10 Gz, aropriate Fade Mitigation Techniques (FMTs) are needed and this requires the characterization of fade dynamics, such as fade duration, interfade duration and fade slope [3, 4]. Amongs all, interfade duration has been poorly studied in the past.

The interfade duration is generally defined as time interval between two fade events at the same thresholds that enables system providers to predict the duration of which satellite system has the oortunity to recover from the previous impairments [5]. The knowledge from interfade duration statistics is essential in alications such as diversity switching and resources allocation and also can provide much precaution for the system to maintain service availability [6]. Many studies on interfade duration have been focused on temperate area [7-9], which such result might not truly represent the statistics in equatorial region as they portray different climatic characteristics. An analysis from the measurement campaign carried out in Ottawa, the system is declared as unavailable after a fade event of at least 10 s has occur, whereas after 10 s of interfade event the system was declared available again. As for complementary cumulative distribution function (CCDF) of interfade duration, they found that the distribution is decreased with attenuation threshold, while the median interfades increases [9]. In addition, to the best knowledge of the authors, there is no widely used model to predict interfade events yet although there is some proposal from ITU-R study group. As a consequence, the crucial statistics of interfade events particularly in equatorial zone remains as an interesting topic of investigation. Recently, an attempt of estimating interfade duration using Stratiform-Convective Synthetic Storm Technique (SC-SST) prediction model in equatorial region [10] has been carried out but

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need further inspection on the comparison with measured result especially for higher frequency band.

Thus, based on one year of slant path propagation experiment carried out in Johor Bahru, Malaysia, an intensive interfade duration statistics is produced. The paper is organized as follows: Section 2 presents the experimental propagation campaign and data processing. Section 3 which is divided into two parts discusses statistical properties of the interfade duration and modelling of the interfade distribution based on classification component of interfade behavior.

2. Experimental Measurement and Data Processing

The experimental measurement campaign is located at Universiti Teknologi Malaysia (UTM) Johor Bahru, Malaysia consisting of one direct broadcast receiving antenna with diameter 90 cm pointed towards Malaysia East Asia Satellite-3 (MEASAT-3) broadcast satellite at an elevation angle of 75.61°. The Ku-band downlink frequency, 12.2 GHz is monitored and recorded using spectrum analyser and data logger. The experimental setup is illustrated as in Figure 1. The receiver is installed on the roof top to avoid blockage of the first Fresnel ellipsoid [11]. An automatic weather station is also located at a meteorological station, which is equied with various sensors and tiing bucket rain gauge. The meteorological station is placed near the reciving system to obtain simultaneous measurements and observations. It was installed in an open space and the surrounding area was clear from any obstacles in order to avoid measurement biases due to blockages.

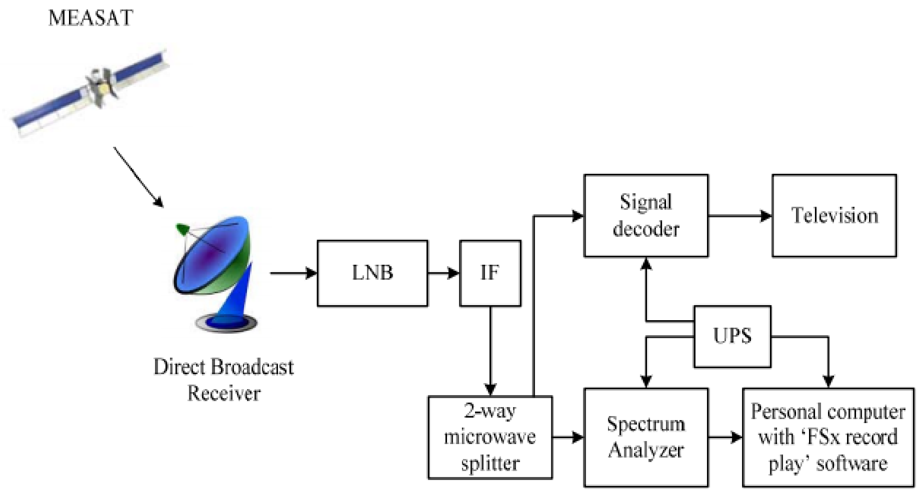


Figure 1. Block diagram of satellite receiving system.

The raw data recorded by the receiving system was sampled at a rate of 1 Hz which enables the analysis of fade dynamics. One year of experimental data from February 2013 to January 2014 were processed and filtered using fifth-order Butterworth high-pass filter with a cut-off frequency of 0.02 Hz [11] to remove the fast components of the signal cause by scintillations and rain-induced fade effects. These two effects must be separated as much as possible prior to computing rain attenuation and fade dynamic analysis. The time series of rain attenuation is calculated with respect to clear-sky reference level which is identified from the observation of the rain rate time series concurrently gathered from the co-located rain gauge at meteorological station. The availability of the receiver during the operation year was very high with 99.27% ratio of recorded-to-total time.

3. Results and Analysis

3.1. Characterisation of Interfade Duration

Interfade duration statistics can be described by many distributions. Following an aroach similar to ITU-R P.1623-1[12], the probability of interfade duration time, *d* exceeds *D*, given that the attenuation, *a* is equal or less than *A* can be given by:

$$P(d > D|a \leq A) = \frac{P(d>D \cap a \leq A)}{P(a \leq A)} \quad (1)$$

In this paper, distribution of the number of interfade events exceeding certain duration for the same attenuation thresholds, together with probability of occurences of interfade events are presented. The total number of interfade events for each attenuation thresholds is first been calculated as presented in Figure 2. The result clearly shows that as the attenuation increases the number of events decreases and the distributions seems to follow a power law. Table 1 present the average number of interfade events per year and it aears evident the dependancies of number of interfade events with attenuation thresholds. In the same figure, it aears a maximum duration is increased with attenuation thresholds. The maximum duration for higher attenuation can up to 2-3 days that might occur in very low number of events per year. On the other hand, a short duration is observed at low attenuation threshold indicates a very fast response is needed to recover from the link outage.

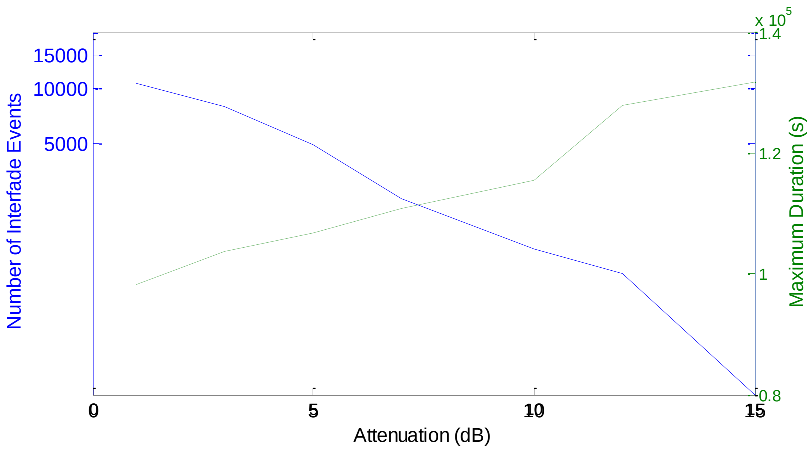


Figure 2. Number of interfade events and the maximum duration observed as a function of the attenuation

Table 1. Average Number of Interfade Events per Year

Attenuation Threshold (dB)	Average Number of Interfade Events
1	10,404
3	926
5	495
10	147

Figure 3 shows the number of interfade events at different attenuation thresholds. Eventough depending on the attenuation thresholds, the total interfade duration does not increase as the attenuation increases. All the curves seem converges at the same crossing point, at around 100000 s duration, same as found in [13]. As expected, the larger number of interfade events is associated to the lower durations. This indicates a very short gap is taken between two fades to occur. As the duration time increased, the number of interfade events is reduced. In fact, the longer period of interfade events (greater than a day) is hardly depends on the attenuation. Particularly, these interfade periods aear during driest months (June or July every year) in the southwest monsoon season for equatorial Malaysia with a minimum montly rainfall of less than 100 mm [9]. Their duration can be up to several days with total no rain and low clouds.

Probability of occurences of interfade events distribution is obtained by dividing the normalised number of interfade events with total number of events at every threshold, as represented in Figure 4. The behaviour can well be described in three different phenomenant. Independently on the attenuation tresholds, there is a constant slope at short duration in between 30-50 s of duration normally cause by the rapid fluctuation of signal transmits or small scale effects that due to the atmospheric turbulence [14]. After that, it turns clear that the distribution slope decreased rapidly which depends on the attenuation thresholds. This component might be influenced by the rain cell structure orientation (correlated to both wind speed and direction) and their both horizontal and vertical extension. Another increase of the slope distribution in the final part may be due to the influenced by climate factors. Refering to different characteristics at each component, a careful time thresholds are determine to distinguish interfade duration behaviour for later development of model distribution.

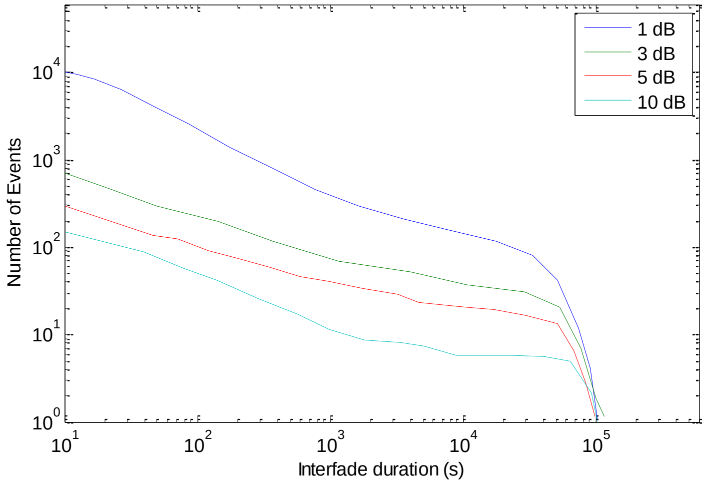


Figure 3. Number of interfade events exceeding certain duration at different attenuation thresholds

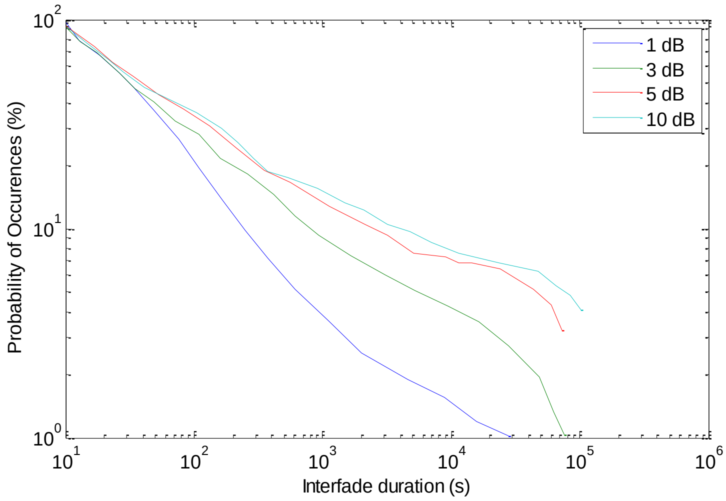


Figure 4. Probability occurences of interfade events exceeding certain duration at different attenuation thresholds

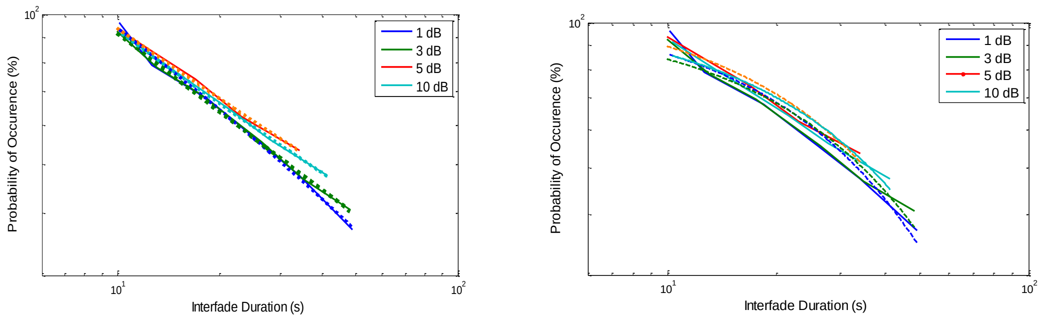
3.2. Modeling of Interfade Duration

Up to this moment, there is no widely used model has been developed to predict interfade duration on slant paths. Altough there is some proposals within the ITU-R study group to use triple lognormal model in the prediction. However, comprehensive testing of this model with measured data is still pending. Nevertheless, many experimental results agree that combination of power-law and lognormal distribution function is suitable for modeling interfade duration statistics [15, 16]. But most of the studies have concentrated on temperate area. Very recent, there is an attempt to model the interfade by separately classified four component of the distribution based on physical phenomenant and medium structure [17]. Each component been separated using time-based classification. The results found that for short duration can be well model by power law distribution, follows by double-exponential and lognormal distribution. Using the same method, the interfade events have been separated into short and long duration to test the ability of these model distributions to fit the measured data in equatorial region.

a. Short duration

Considering a time thresholds less than 50 s for short duration, CCDF of interfade duration for every threshold is plotted as represented by Figure 5. It is clearly seen that the distribution is hardly depends on the attenuation. The distribution is fitted by power-law, lognormal and exponential model and the goodness of fit, R^2 for each distribution model are tabulated as displayed in Table 2. Power-law function given according to (2) seems gave the best result in modelling the short duration of interfade. This is well agreed by most of others experimental studies [5], [15-17].

$$P(d > D|a \leq A) = \alpha d^{\beta} \tag{2}$$



(a) (b)

Figure 5. CCDF of interfade duration for short duration at different attenuation thresolds (a) with power-law fit (b) with exponent-fit

Table 2. The Performance R^2 of Interfade Duration Distribution Model for Short Duration

Model	Attenuation (dB)			
	1	3	5	10
Power-law	0.9947	0.9977	0.9976	0.9998
Exponential	0.9585	0.9505	0.9538	0.9502
Lognormal	0.9365	0.9392	0.9413	0.9355

b. Long duration

Longer duration of interfade duration as depicted in Figure 6 has strongly increased with attenuation thresholds. This component has previously been modelled using cascaded exponential model with formulation given by

$$P(d > D|a \leq A) = \sum_{i=1}^{N} \alpha_i e^{-\beta_i t} \tag{3}$$

Where the decay constant $1/\beta_i$ is in seconds and is called as characteristic durations. In this study, double exponential function (N=2) is fitted accordingly to the measured distribution as it has been proven in previous study that term two cascaded exponent function can successfully model the interfade duration statistics for long duration [17].

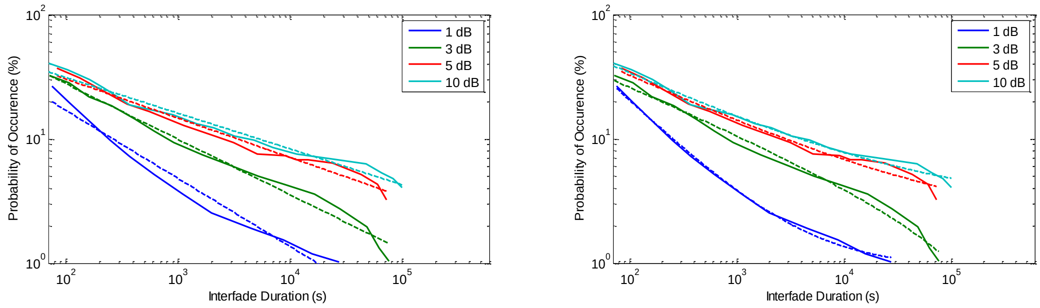


Figure 6. CCDF of interfade duration for long duration at different attenuation thresolds (a) with power-law fit (b) with exponent-fit

Ordinates of distribution for long interfade duration used a probability scale (inverse of cumulative Gaussian distribution) and measured statistics seem represented in a straigth line which actually can be modelled by lognormal function. Performances inspection of the distribution results indicated that the most suitable models are lognormal and double-exponential distribution model.

Table 3. The Performance R^2 of Interfade Duration Distribution Model for Long Duration

Model	Attenuation (dB)			
	1	3	5	10
Power-law	0.9702	0.9732	0.9768	0.9704
Cascaded Exponential (N=2)	0.991	0.9887	0.9841	0.9817
Lognormal	0.9848	0.9812	0.9858	0.9878

This result may be important as it points the way towards a possible modelling tool, which a distribution statistics can be obtained for a given attenuation thresolds by knowing a specific distribution. However, longer period of datasets are needed in order to confirm the distribution behavior as it contributes to the more stability of time series data.

4. Conclusion

This paper investigated interfade duration statistics in equatorial Malaysia region for one year of propagation campaign. Intensive analysis shows that interfades are strongly dependent on attenuation thresholds. The ability of power-law, exponential and lognormal cumulative distribution functions to fit the interfade duration data was evaluated in order to find the best prediction model. Short duration interfade can be well represented by power-law distribution, while longer events follow log-normal distributions. Such results provide crucial information for system providers regarding the criteria in designing adaptive FMTs towards the improvement of outage probability.

Acknowledgements

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References

[1] AD Panagopoulos, P Arapoglou, PG Cottis. Satellite Communications at Ku, Ka and V-bands : propagation impairments and mitigation techniques. *IEEE Communications Survey & Tutorials*. 2004; 6(3): 2-14.

[2] IF El-Shami, J Din. Seasonal and Diurnal Variation on Tropospheric Scintillation at Ku-Band in Tropical Climate. *International Journal of Electrical and Computer Engineering (IJECE)*. 2016; 6(4): 1710-1716.

[3] SL Jong, MD Amico, J Din, HY Lam. Analysis of fade dynamic at ku-band in Malaysia. *International Journal of Antennas and Propagation*. 2014.

[4] Yussuff Abayomi IO, Nor Hisham Khamis. Rain Attenuation Modelling and Mitigation in The Tropics, *International Journal of Electrical and Computer Engineering (IJECE)*. 2012; 2(6): 748-757.

[5] F Jorge, C Riva, A Rocha. Characterization of interfade duration for satellite communication systems design and optimization in temperate climate. *Radio Sci*. 2016; 51.

[6] Working Document toward a Revision of Recommendation ITU-R P.1623 including New Inter-Fade Interval Prediction Method. International Telecommunication Union, Recommendation ITU-R P.1623-1. 2004.

[7] C Amaya, T Nguyen. *Fade and Interfade duration on earth-space links in temperate and tropical location*. International Union of Radio Science-URSI Proceeding GA06, URSI, New Delhi, India. 2005.

[8] QW Pan, JE Allnut. 12 GHz fade duration and interval in the tropics. *IEEE Trans. Antenna. Propag*. 2004; 52(3): 693-701.

[9] P Garcia Del Pino, JM Riera, A Benarroch. Dynamic characteristics of fading on a 50 GHz slant path. EuCAP European Conference on Antennas and Propagation. 2006: 1-6.

[10] MM Yunus, J Din, HY Lam, SL Jong. Estimation of Interfade Duration for Ku- and Ka-Band Satellite Communication System in Equatorial Malaysia. URSI Asia Pacific Radio Science Conference, Korea. 2016: 1967-1970.

[11] SL Jong. Rain fade dynamics characteristics for Ku-band satellite communication systems in Malaysia, PhD. Thesis, Fac. Of Electrical Eng., Universiti Teknologi Malaysia. 2015.

[12] Prediction method of fade dynamics on earth-space paths, International Telecommunication Union, Recommendation ITU-R P.1623-1, Switzerland, 2003.

[13] P Garcia Del Pino, JM Riera, A Benarroch. Fade and Interfade duration statistics on an earth-space link at 50 GHz, *IET Microw. Antennas Propag*. 2011; 5: 790-794.

[14] MM Yunus, J Din, HY Lam, SL Jong. Analysis of Inter-fade Intervals at Ku-Band in Heavy Rain Region. 2015 IEEE International RF and Microwave Conference (RFM), Kuching, Sarawak. 2015; 281-284.

[15] LE Braten, C Amaya, DV Roger. *Fade and inter-fade duration at Ka-band on satellite-Earth links: Modelling and system implications*. AIAA International Communications Satellite Systems Conference, France. 2001.

[16] HW Arnold, DC Cox, HH Hoffman. Fade Duration and Interfade Interval Statistics Measured on a 19-GHz Earth-Space Path *IEEE Trans. Commun.* Com-30. 1982; 1: 265–269.

[17] F Jorge, C Riva, A Rocha. *Interfade and Inter-Event Interval: a Time-Based Classification and Modelling.* EuCAP European Conference on Antennas and Propagation. 2016.