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Tropospheric scintillation prediction models for a high elevation angle based on measured data from a tropical region

Nadirah Binti Abdul Rahim [a,*], Md. Rafiqul Islam [a], J.S. Mandeep [b,1], Hassan Dao [a], Saad Osman Bashir [a]

[a] *Electrical and Computer Engineering Department, Kulliyyah of Engineering, International Islamic University Malaysia (IIUM), Kuala Lumpur, Malaysia*
[b] *Department of Electrical, Electronic & Systems Engineering, Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia, 43600 Bangi, Malaysia*

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ABSTRACT

The recent rapid evolution of new satellite services, including VSAT for internet access, LAN interconnection and multimedia applications, has triggered an increasing demand for bandwidth usage by satellite communications. However, these systems are susceptible to propagation effects that become significant as the frequency increases. Scintillation is the rapid signal fluctuation of the amplitude and phase of a radio wave, which is significant in tropical climates. This paper presents the analysis of the tropospheric scintillation data for satellite to Earth links at the Ku-band. Twelve months of data (January–December 2011) were collected and analyzed to evaluate the effect of tropospheric scintillation. Statistics were then further analyzed to inspect the seasonal, worst-month, diurnal and rain-induced scintillation effects. By employing the measured scintillation data, a modification of the Karasawa model for scintillation fades and enhancements is proposed based on data measured in Malaysia.

1. Introduction

Tropospheric scintillation is one of several signal impairment factors that affects satellite links at frequencies above 10 GHz, especially in the case of Earth–space paths (Ippolito Jr., 2008). This effect causes random scintillation fades and enhancements of the received signals, especially at low elevation angles (Mandeep, 2009; Mandeep and Ng, 2010; Mandeep et al., 2010). When designing satellite communication systems, the signal degradation due to these scintillations must be accurately identified and measured (Mandeep et al., 2011). Rapid fluctuations are often observed on a satellite link during clear-sky conditions as well as in the presence of rain (Otung et al., 1998). These rapid fluctuations occur due to scattering by tropospheric inhomogeneity, which is known as tropospheric scintillation (Otung et al., 1998). Tropospheric scintillation is the rapid fluctuation of the signal amplitude and phase due to the inconsistencies in the temperature, humidity and pressure that cause small-scale variations in the refractive index.

Tropospheric scintillations are a problem in satellite communication systems, especially for low-fade margin, high-frequency systems (Ippolito Jr., 2008). Many tropospheric scintillation studies have been performed to assess cases of high frequencies and low elevation angles. However, very few studies have been performed for systems with high frequencies and high elevation angles. Hence, a model must be developed to overcome this issue. The remainder of this paper is organized as follows: Section 2 elaborates on the scintillation measurement; Section 3 explains the modification of the Karasawa model; and conclusions and recommendations are presented in Section 4.

2. Scintillation measurement

The Ku-band signal was transmitted at 10.982 GHz from MEASAT 3 at longitude 91.5° East and latitude 0.02° South. This signal has a vertical polarization with QPSK modulation that provides more than 100 channels for Malaysian direct broadcast satellite (DBS) pay television service (Astro) (Dao et al., 2011). A 2.4 m dish antenna was fixed on the rooftop of the International Islamic University Malaysia Engineering Building. The dish antenna elevation angle was positioned at 77.5°.

The dish antenna with Low Noise Block (LNB) and a 0.5 dB noise level was used to receive the satellite signal data from MEASAT 3. The satellite signals were down-converted to an Intermediate Frequency (IF) signal as an L-band frequency using Local Oscillator (LO) 975 MHz (Dao et al., 2011). The digital receiver was then used to record the IF satellite signals. A spectrum analyzer was used to

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[*] Corresponding author. Tel.: +60 361964572.
E-mail addresses: aira3@yahoo.com (N.B. Abdul Rahim), rafiq@iium.edu.my (Md.R. Islam), mandeep@eng.ukm.my (J.S. Mandeep), sun.spu@gmail.com (H. Dao), saadbashir@iium.edu.my (S.O. Bashir).
[1] Tel.: +60 38921 6448.

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receive the subsequent IF, which set to a post-detection bandwidth (video bandwidth) of 10 Hz. The spectrum analyzer was also used to observe the carrier signals and omit any unwanted signals. The output signals from the spectrum analyzer were logged and saved in a database using LABVIEW software with a sampling time interval of 0.1 s (Dao et al., 2011). The data-logging system functions 24 h per day on a continuous basis, with the exception of periods for system calibration, equipment failure or the unavailability of TV satellite signal transmission. A 0.2 mm tipping bucket rain gauge was placed near the dish antenna to measure the amount of liquid precipitation at a 10 s intervals. The experimental data obtained regarding the scintillation were captured from January 2011 to December 2011 over a 12-month period (Rahim et al., 2012).

2.1. *Scintillation fades and enhancements*

Scintillations consist of fades, which refer to negative signal levels, and enhancements, which refer to positive signal levels. Scintillation fades normally affect the “simple earth station step tracking systems or uplink power control (UPPC) systems”, which rely on the length of time constant used in the particular system. Scintillation enhancements on a satellite uplink cause an increase in the intermodulation noise in a satellite transponder consumed by a multicarrier, which causes system failure.

3. Modification of the Karasawa model to fit the measured scintillation data

In the past, many prediction models that were developed by researchers throughout the world were based on both theoretical and experimental data. Most of these models considered satellite link specifications, such as the beacon frequency and elevation angle, as well as meteorological parameters, such as the ground temperature and humidity (Akhondi and Ghorbani, 2005).

The majority of these models, e.g., P.618-10 Recommendation ITU-R (2009), Otung (1996)), Ortgies (1993), and Van de Kamp et al. (1999), were developed using climate databases of the authors′ respective countries. These models mainly originated from European countries. It is well known that the climates in European countries vary significantly from that of Malaysia. European countries have four seasons consisting of summer, winter, autumn and spring, and the weather pattern is typically cold and dry. In contrast, Malaysia is hot and humid and receives abundant rainfall. Hence, due to the differences in the temperature and humidity throughout the year, the aforementioned models may not be suitable for predicting scintillations in Malaysia. Therefore, the Karasawa model was chosen to be modified and compared against the Malaysian tropical climate. The Karasawa model was developed based on experimental data collected from Yamaguchi, Japan, over a 1-year period. Those data are similar to the 1-year used in this present study. In addition, the Karasawa model used a frequency range of 7–14 GHz, which is similar to the measured data for which the frequency is 10.982 GHz. The only drawback of this model is that the elevation angle was between 4° and 30°, the elevation angle used in this present work was 77.5°. Therefore, certain modifications were required regarding the elevation angle parameter. According to Karasawa et al. (1988),

$$\sigma_{pre} = 0.0228\,(0.15 + 5.2\,x\,10^{-3} N_{wet}) f^{0.45} \sqrt{G(D_c)} / \sin^{1.3}\varepsilon \text{ dB} \tag{1}$$

where:

σ_{pre} = the predicted signal standard deviation or “scintillation intensity”
f = frequency in GHz
ε = apparent elevation angle
$G(D_c)$ = an antenna averaging
D_c = effective antenna diameter given by

$$D_c = D\sqrt{\eta} \tag{2}$$

D = geometrical antenna diameter
η = antenna aperture efficiency

In this prediction model, Karasawa et al. (1988) claimed that the antenna averaging function also depends on the elevation angle, and the height of the turbulence is 2000 m.

If $\varepsilon < 5°$, $\sin\varepsilon$ in (1) should be replaced by $(\sin\varepsilon + \sqrt{\sin^2\varepsilon + 2h/R_e})/2$where:

h = height of the turbulence
R_e = effective Earth radius = 8.5×10^6 m (Karasawa et al., 1988).

The following equation is the wet term of the refractivity at ground level:

$$N_{wet} = \frac{22790\text{U}e^{19.7t}}{(t+273)^2} \text{ (ppm)} \tag{3}$$

where:

N_{wet} = relative humidity in percentage due to water vapor in the atmosphere
t = temperature in degrees centigrade

In addition, the percentage time factor of scintillation fades and enhancements is as follows:

$$n(p-) = -0.061(\log p)^3 + 0.072(\log p)^2 - 1.71(\log p) + 3.0, \quad \text{for } 0.01 < p \le 50 \tag{4}$$

$$n(p+) = -0.0597(\log(100-p))^3 - 0.0835(\log(100-p))^2 - 1.258(\log(100-p)) + 2.672, \quad \text{for } 50 < p \le 99.99 \tag{5}$$

Eqs. (6) and (7) are used compute the cumulative distribution of scintillation fades and enhancements, respectively:

$$X(p) = n(p-) \times \sigma_{pre} \tag{6}$$

$$X(p) = n(p+) \times \sigma_{pre} \tag{7}$$

3.1. *Climate information*

Malaysia is well known for its hot and humid climate and abundant rainfall. Accordingly, the average annual temperature and humidity in Malaysia are 28.5 °C and 81%, respectively. Fig. 1 presents the temperature and humidity from January 2011 to December 2011. This information is essential for adapting the climate component of the Karasawa model. The N_{wet} and σ_{ref} values calculated on a monthly basis are presented in Table 1.

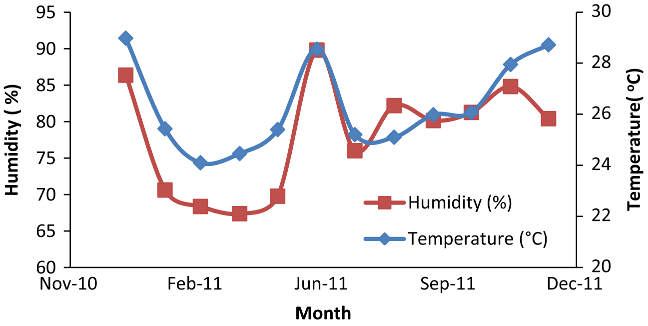

Fig. 1. Temperature and humidity from January 2011 till December 2011.