Analysis of rain fade mitigation using site diversity on earth-to-satellite microwave links at Ku-band

6 Author(s)

Rafiqul, I.M. ; Kulliyyah of Eng., Int. Islamic Univ. Malaysia, Kuala Lumpur, Malaysia ; Muhammad, N. ; Singh, M. ; Lwas, A.K.
more authors

Rn is the major challenge to design reliable earth to satellite microwave link at higher frequencies in tropical regions. Site diversity is one of the techniques used to mitigate this problem. Hodge Site Diversity Gain Model, ITU-R Site Diversity Gain Model and ITU-R Diversity Improvement Factor Model are analyzed based on rainfall data measured in Malaysia and four locations in Kuala Lumpur and MEASAT3A as reference satellite. In analysis, it is found that significant improvement in availability can be achieved through the site separations of 6 to 37 Km in site diversity technique.

Published in:
Engineering and Technology (BICET 2014), 5th Brunei International Conference on

Date of Conference:
1-3 Nov. 2014

Page(s):
1 - 5

Conference Location :
Bandar Seri Begawan

Print ISBN:
978-1-84919-991-9

DOI:
10.1049/cp.2014.1104

INSPEC Accession Number:
14810197

Publisher:
IET

Analysis of Rain Fade Mitigation Using Site Diversity on Earth-to-Satellite Microwave links at Ku-Band

Islam Md. Rafiqul*, Norhafizah Muhammad †, Mandeep Singh‡, Ali K. Lwas*, Robiatul Adawiyah*, Ayunie Ismail*

**Kulliyyah of Engineering, International Islamic University Malaysia*
Jalan Gombak, 53100 Kuala Lumpur, Malaysia, E-mail: rafiq@iium.edu.my

† Dept. Electrical and Electronic Engineering, Faculty of Engineering, Institut Teknologi Brunei,
Brunei Darussalam, Email:norhafizah.muhammad@itb.edu.bn

‡ Faculty of Engineering, University Kebangsaan Malaysia

Keywords: Rain Fade Mitigation, Site Diversity, Microwave Link.

Abstract

Rn is the major challenge to design reliable earth to satellite microwave link at higher frequencies in tropical regions. Site diversity is one of the techniques used to mitigate this problem. Hodge Site Diversity Gain Model, ITU-R Site Diversity Gain Model and ITU-R Diversity Improvement Factor Model are analyzed based on rainfall data measured in Malaysia and four locations in Kuala Lumpur and MEASAT3A as reference satellite. In analysis, it is found that significant improvement in availability can be achieved through the site separations of 6 to 37 Km in site diversity technique.

1 Introduction

Rain is the major challenge to design reliable earth to satellite microwave link at higher frequencies in tropical regions. By giving sufficient power margins on the uplink and the downlink segments, these systems can be planned to run at a suitable performance level. This can be proficient straightforwardly by rising the size of the antenna and the RF transmit power, or both. In tropical area particularly in Malaysia, rain attenuation is the major restraint for implementing earth-to-satellite microwave system at Ku-Band. The most important factors in earth-to-satellite link design are the high rainfall rate, which leads to outage link availability and quality of service. Thus, it is important to reduce rain fade margin to maintain the reliability of the system. This paper aims to analyze site diversity technique to mitigate the rain fade in Malaysia.

To develop generally link performance by having benefit on inhomogeneous nature of rain, site diversity is one of the techniques used. In principle, two sites located in different places will not simultaneously undergo equal rain attenuation. So, by monitoring whichever signal is the less attenuated, overall system throughout is improved. When the experiments in present day are being conducted using three or more ground stations, the models typically focus on a two site configuration.

This paper discusses about the attenuation using the rain fall rate measured at Malaysia. Hodge Site Diversity Gain, ITU-R Site Diversity Gain and ITU-R Diversity Improvement Factor are analyzed. Four locations namely, IIUM Gombak campus, IIUM Petaling Jaya campus, International Institute of Islamic Thought and Civilization (ISTAC) campus and Universiti Kebangsaan Malaysia UKM Bangi campus are used as the reference earth stations and MEASAT3A as reference satellite in this paper.

2 Site Diversity

Site diversity is a useful rain attenuation mitigation method, mostly in the humid region with high rain fall rate. As the result of dissimilar factors such as site separation distance, frequency, elevation angle, polarization angle, baseline orientation and wind direction are taken into account. A site diverse satellite system consists of two or more spatially separated ground stations. Less correlated propagation paths between the earth stations and the satellite are provided by the different sites. The idea of site diversity is based on the fact that in short term, large signal fades can affect one satellite link, but have less affect on another spatially separated satellite link. The consequence of rain attenuation can be condensed or eliminated. The ground station with the higher received signal power at any instant in time is always chosen so as to considerably reduce the effect of rain attenuation [2]. Fig. 1 represents a simple site diversity systems.

3 Diversity Gain and Diversity Improvement

The effect of site diversity on system performance can be quantitatively defined by taking the attenuation statistics associated with a single terminal and with diversity terminals, for the same rain conditions into account.. The diversity gain, GD(p), is the difference between the attenuation value of one workstation with multiple workstations, at the same percentage of time, p, i.e.,

$$G_D(p) = A_S(p) - A_J(p) \qquad (1)$$

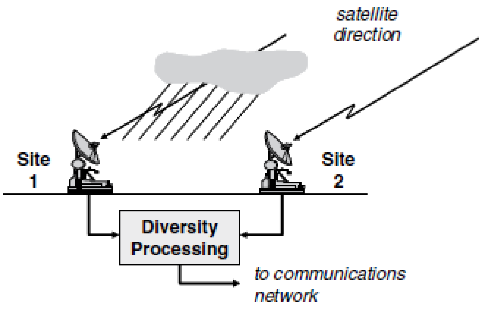

Figure 1: Site Diversity Concept [1]

where A_S (p) and A_J (p) are the single site and joint attenuation values at the probability p respectively. The Fig. 2 represents the diversity gain explanation [1-2].

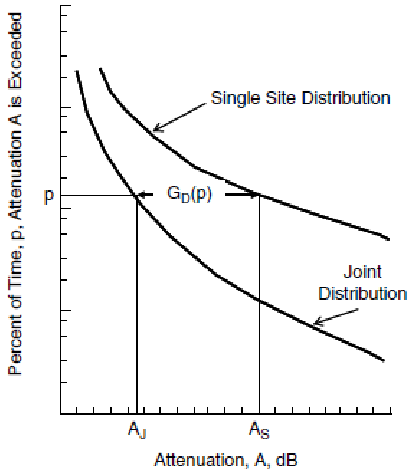

Figure 2: Definition of Diversity Gain [1].

Diversity performance can also be quantified in terms of outage times by the diversity improvement. Diversity improvement is defined as follow;

$$I_D(A) = p_s(a = A) / p_J(a = A) \qquad (2)$$

where I_D (A) is the diversity improvement at the attenuation level A dB, p_S (a = A) is the percent of time associated with the single terminal distribution, at the attenuation level A, and p_J(a = A) is the percent of time associated with the joint terminal distribution, at the value of attenuation level A. Diversity improvement factors over 100 are not abnormal, particularly in areas of severe thunderstorm occurrence [1-2].

3.1 Hodge Site Diversity Gain Model

The original Hodge model considers only the relationship between diversity gain and site separation. This model was based on a limited database: 15.3 GHz measurements in Columbus, Ohio, and 16 GHz measurements in Holmdel, New Jersey. It includes site separations from 3 to 34 km [3]. The improved diversity gain model, used an expanded database of 34 sets of measurements, and included the dependence of diversity gain on frequency, elevation angle, and baseline orientation, as well as site separation. Hodge assumed the empirical relationship for diversity gain, GD, can be split into components dependent on each of the system variables, i.e.,

$$G_D = G_d(d, AS) \cdot G_f(f) \cdot G_\theta(\theta) \cdot G_\Phi(\Phi) \qquad (3)$$

where d = site separation, in km; A_S = single terminal attenuation, in dB; f = frequency, in GHz;
θ = elevation angle, in degrees; and Φ = baseline orientation angle, in degrees. The gain functions were empirically determined as [3-4]

$$G_d(d, A_S) = a(1 - e^{-b\,d}) \qquad (4)$$

with

$$a = 0.64\,AS - 1.6(1 - e^{-0.11\,As})$$
$$b = 0.585(1 - e^{-0.98\,AS}) \qquad (5)$$

and

$$G_f(f) = 1.64 e^{\square 0.025 f} \qquad (6)$$

$$G_\square(\square) = 0.00492 \pm 0.834 \qquad (7)$$

$$G_\square(\square) = 0.00177 \pm 0.887 \qquad (8)$$

The model had an r.m.s. error of 0.73 dB when compared with the original data sets, covering frequencies from 11.6 to 35 GHz, site separations from 1.7 to 46.9 km, and elevation angles from 11 to 55°. ITU-R extends and improves the Hodge model and the model is adopted in Recommendation P.618. Both diversity gain and diversity improvement models are provided by the ITU-R [3-4].

3.2 ITU-R site diversity gain model

The ITU-R site diversity gain model [5] is an empirically derived model that is based on the revised Hodge model. The input parameters required are as follows:

d: separation distance, in km

A_S: single-site attenuation, in dB

f: operating frequency, in GHz

θ: elevation angle, in degrees

Φ: baseline orientation angle, in degrees

The overall improvement in system performance in terms of diversity gain, G_D, in dB is predicted by the model. The step-by-step method for the ITU-R site diversity gain model is given below [5]:

Step 1: The gain contributed by the site separation distance, d, is calculated from

$$G_d(d, A_s) = a\left(1 - e^{-bd}\right) \quad (9)$$

where

$$a = 0.78A_s - 1.94\left(1 - e^{-0.11A_s}\right) \quad (10)$$

and $$b = 0.59\left(1 - e^{-0.1A_s}\right) \quad (11)$$

Step 2: The gain contribution from the operating frequency, f, is calculated from

$$G_f(f) = e^{-0.025f} \quad (12)$$

Step 3: The gain contribution from the elevation angle, θ, from is calculated

$$G_\theta(\theta) = 1 + 0.006\theta \quad (13)$$

Step 4: The gain contribution from the baseline orientation angle, Φ, is calculated from

$$G_\Phi(\Phi) = 1 + 0.002\Phi \quad (14)$$

Step 5: The total diversity gain is calculated as the product of the individual component contributions,

$$G_D = G_d(d, A_S) \cdot G_f(f) \cdot G_\theta(\theta) \cdot G_\Phi(\Phi) \text{ dB} \quad (15)$$

where the result is expressed in dB.

3.2 ITU-R diversity improvement factor

The ITU-R also gives a procedure to calculate the diversity improvement factor, a complementary parameter to diversity gain [5-8]. Rather than calculating a dB level of gain, the diversity improvement, I, is measured as a ratio of the single site exceed time percentage to the two-site exceed time percentage. Diversity improvement is a function of the exceed time and the site separation only [1,5]. The input parameters necessary for the calculation of I are as follows:

d: site separation distance, in km
p_1: single-site time percentage for a single site attenuation of $A(p_1)$
p_2: diversity time percentage for the single site time percentage p_1

The step-by-step procedure for the ITU diversity improvement factor model follows.

Step 1: Determine the empirical coefficient
Calculate the empirical coefficient, β^2

$$\beta^2 = d^{1.33} \times 10^{-4} \quad (16)$$

Step 2: Determine the diversity improvement factor
Calculate the diversity improvement factor, I

$$I = p_1 / p_2 = 1/(1 + \beta^2) \cdot (1 + (100 \cdot \beta^2/p1))$$
$$\approx 1 + 100 \cdot \beta^2/p1 \quad (17)$$

4 Locations of Proposed Sites

Fig. 3 shows the four locations that are considered as the proposed sites analysis, IIUM Gombak, IIUM Petaling Jaya, ISTAC campus and UKM Bangi.

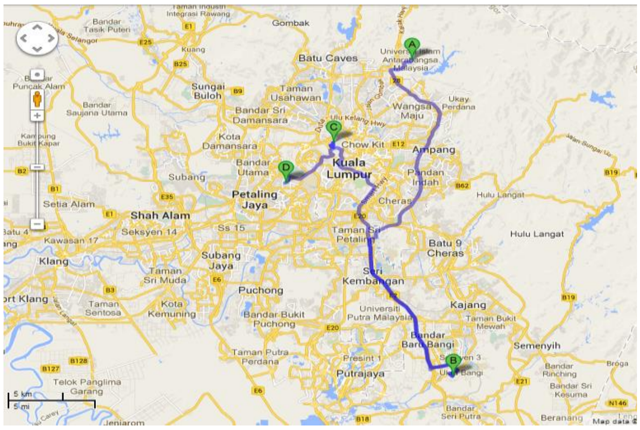

Figure 3. Location of IIUM Gombak(A), UKM Bangi(B), ISTAC campus(C),and IIUM Petaling Jaya (D)

The distance between IIUM Gombak-IIUM Petaling Jaya, Gombak-ISTAC, Gombak- UKM, ISTAC- Petaling Jaya, ISTAC-UKM and Petaling Jaya- UKM are calculated using great-circle distance between two points. R is earth's radius (mean radius = 6371km). The coordinates of IIUM Gombak : 3.2528N, 101.7372E, Petaling Jaya : 3.1192N, 101.6387E, ISTAC : 3.1661N, 101.6739E and UKM Bangi : 2.91972°N 101.78139° E. The distances are shown in Table 1.

Table 1: Distances between two sites

Location	Distance, km
IIUM Gombak - UKM	37.36
ISTAC – UKM	29.88
CFS Petaling Jaya - UKM	27.26
IIUM Gombak-CFS PJ	18.45
IIUM Gombak –ISTAC	11.93
ISTAC – CFS Petaling Jaya	6.517

5 Results and Analysis

Comparison between Hodge and ITU-R Model

The Hodge and ITU-R site diversity gain models are evaluated based on MEASAT3 satellite and IIUM Gombak campus and shown in Fig. 4. It can be observed that the Hodge Site Diversity model gives higher gain compared to ITU-R Site Diversity model. As the site separations are more than 10km, the ITU-R model gives slightly higher gain than Hodge model. The gains obtained by Hodge model are higher than ITU-R model until the site separation is about to 10km. At 20km, the site diversity gain for ITU-R model is 7.916dB which is slightly higher than Hodge model where the gain is 9.611dB and the gain is constant for 30km and above. The site diversity gain using ITU-R model for six different distances are given in Table 2 which shows that site separation from 6 km to 37 km varies the gain less than 1 dB.

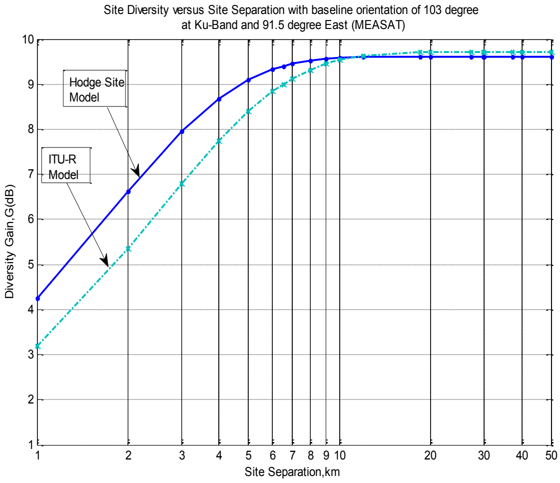

Figure 4: Site Diversity versus Site Separation with Baseline Orientation of 103 degree at Ku-Band and 91.5 degree East (MEASAT3A).

Table 2: Analysis of Site Diversity Model Based on Four Sites

Sites	Site separations, km	ITU-R Site Diversity Gain, dB
CFS PJ- ISTAC	6.5	9.00
Gombak-ISTAC	11.9	9.64
Gombak-CFS PJ	18.5	9.72
CFS PJ-UKM	27.3	9.72
ISTAC-UKM	29.9	9.719
Gombak-UKM	37.4	9.719

Diversity Improvement Factor

The diversity improvement is measured as a ratio of the single site exceedance time percentage to the two-site exceedance time percentage. In the graph of percentage time with two site diversity, Gombak- PJ has the lowest percentage of time. For 0.002 percentage of time which availability is 99.998% for a single site, Gombak-PJ shows 8.29e-006 which gives 99.99999171% availability compared to other two which are 1.473e-005 and 3.257e-005 percentage of time and their availability are 99.99998527% and 99.9999675% respectively. As a conclusion, this shows that the diversity site improves the system availability and the higher the site separation the better the link availability which is clearly better than single site availability. This can be concluded that the diversity improvement factor is also increasing when the site separation increases.

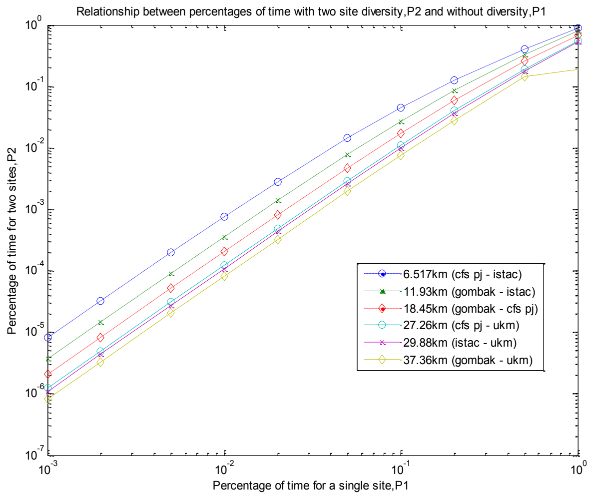

Figure 5: Percentage of Time with Two Site Diversity,P2 and without diversity, P1.

From the Fig. 6, it is obvious that 0.001% has the highest diversity improvement factor compared to the other percentage and 1% has the lowest diversity improvement factor. As the site separation is increasing, the diversity improvement for all percentage are also increasing.

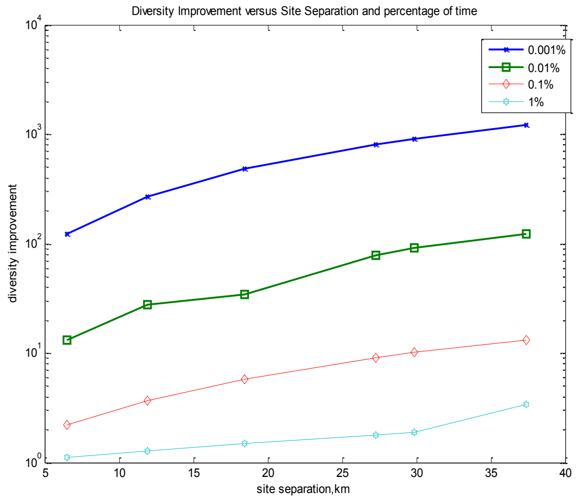

Figure 6. Diversity Improvement Factor versus Site Separation with different Percentage of Time

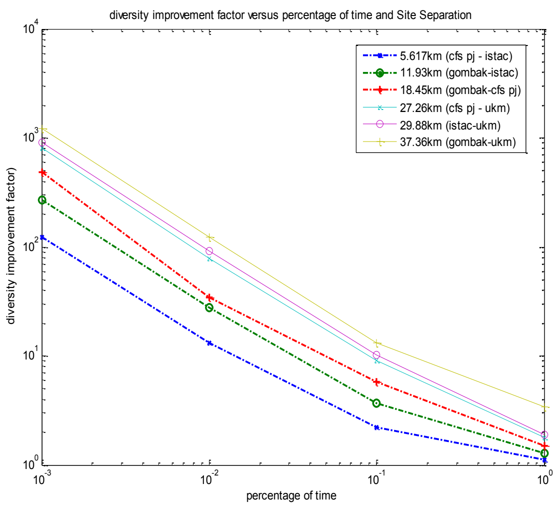

Figure 7. Diversity Improvement Factor versus Percentage of Time and Site Separation

From the graph above we can say that the site separation with the distance of 37.36km (Gombak-UKM) has the highest diversity improvement factor compared to the other site separations and the site separation of 5.617km (CFS-PJ-ISTAC) has the lowest diversity improvement factor. From Fig. 7, Gombak-UKM, ISTAC-UKM and CFS PJ – UKM have the highest site diversity gain at percentage of time of 0.005% or availability 99.995% which has 15.1864dB and the lowest diversity gain is 1.2280dB at percentage of time of 0.5% or availability of 99.5%. As conclusion, that when the site separation is small, the site diversity gain obtained is also small and vice versa until it achieved the limitation of site separation then the site diversity gain become constant.

5 Conclusions

Rain is considered as the major challenge in designing a reliable earth to satellite microwave link at higher frequencies in the tropical regions. Site diversity technique was analyzed using four locations in Malaysia namely, IIUM Gombak campus, IIUM Petaling Jaya campus, International Institute of Islamic Thought and Civilization (ISTAC) campus and Universiti Kebangsaan Malaysia UKM Bangi campus. In this analysis, the four locations were considered as the reference earth stations and MEASAT3A as reference satellite. The rainfall data measured in Malaysia was used for this analysis. It is found that site diversity improvement is almost constant after the site separation is 6 Km and higher and 1 dB improvement observed by increasing the separation distance from 6 Km to 37 Km. It is also found that the site diversity improves the system availability and also the higher the site separation the better the link availability which is clearly better than a single site availability.

References

[1] Louis J. Ippolito, Jr. “Satellite Communications Systems Engineering - Atmospheric Effects, Satellite Link Design and System Performance”, *John Wiley & Sons Ltd* (2008).

[2] Yeo, J. X., Lee, Y. H., & Ong, J. T. “Performance of Site Diversity Investigated Through RADAR Derived Results”, *IEEE Transactions on Antennas and Propagation*, 59(10), 3890–3898 (2011).

[3] D.B. Hodge, ‘An empirical relationship for path diversity gain,’ *IEEE Trans. on Antennas and Propagation*, Vol. 24, No. 3, pp. 250–251, (1976).

[4] D.B. Hodge, “An improved model for diversity gain on earth space propagation paths”, *Radio Science*, Vol. 17, No. 6, pp. 1393–1399, (1982).

[5] ITU-R Rec. P.618-10, ‘Propagation data and prediction methods required for the design of earth-space telecommunication systems,’ International Telecommunications Union, Geneva, 2009.

[6] ITU-R Rec. P.837-6, ‘Characteristics of precipitation for propagation modelling,’ International Telecommunications Union, Geneva, 2012.

[7] ITU-R Rec. P.838-3, ‘Specific attenuation model for rain for use in prediction methods,’ International Telecommunications Union, Geneva, 2005.

[8] ITU-R Rec. P.839-3, ‘Rain height model for prediction methods,’ International Telecommunications Union, Geneva, 2001.

[9] Chethana Nagaraja and Ifiok E. Otung, “Statistical Prediction of Site Diversity Gain on Earth-Space Paths Based on Radar Measurements in the UK”, *IEEE Transactions On Antennas And Propagation*, Vol. 60, No. 1, January (2012).