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Site Diversity Mitigation Technique for Satellite Services for Ku and Ka-band in Tropical Region

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Abstract: - The demand for satellite communication has increased which led to spectral congestion. Recently, the satellite services use Ku and Ka-band as additional spectrum for satellite communication services. Ku and Ka-band are categorized as high frequency range which is around 12 to 14 GHz and 20 to 30 GHz respectively. However, the higher frequency will affect the quality of services and lead to signal impairment. This is mainly caused by the atmosphere effect which is oxygen, liquid water, and precipitation. But among the list, rain causes most signal fading due to the scattering and depolarization. The aim of this research is to study the site diversity as mitigation techniques operating at Ku and Ka-band for enhancing the gain of the signal and calculating diversity gain. There are modelling of diversity gain that has been proposed by previous researchers namely Hodge, Panagopolous, ITU-R, X.Yeo and Semire models which were validated in different climate regions respectively. By using all previous modelling of diversity gain, it will also compare with the measured local diversity gain. Suitable modelling that can be used in this tropical region has been proposed by improving the mathematical model that will be suitable in the tropical regions. This is important for encouraging the finding of new theories for the future broadcasting systems to decrease the power loss during the rain fade.

Keywords: satellite, ku band, ka band, site diversity

1. **Introduction**

Satellite users usually utilize the frequency band that can support the power of the signal. The frequency that is suitable for communication is C band (4/6 GHz), Ku band (12/14 GHz) and Ka-band (20/30 GHz) which has a higher frequency. However, when the frequency crosses 10 GHz it will rise to signal fading due to phenomena likes fog, rain, hail and snow. Since we are in the tropical region, rain has become the major challenge due to the implementation of higher frequency [4]. Even though, Ku and Ka-band are better than other frequency bands for communication but still there are issues with its system reliability. The Ku and Ka-band are more susceptible to rain because of its higher frequency. These can be avoided by using a larger antenna or increasing the power satellite. The disadvantages of the Ku and Ka-band lead to an impact on communication services and it is supremely occurring at downlink process rather than uplink because of uplink, we can increase the satellite gain of the terrestrial station but at the space, we cannot increase its gain. To counteract the problem, fade mitigation techniques are being introduced [1]-[2]. Malaysia's first local satellite framework is called MEASAT (Malaysia East Asia Satellite) is operated by MEASAT satellite system Sendirian Berhad (MSS). MEASAT is the fundamental supplier of satellites to more than 150 nations crosswise over Asia, Middle East, Africa, Europe and Australia. MEASAT offers a wide scope of communication administrations including standard definition and top quality video playout, up-connecting, fiber and co-area administrations. The most noticeable satellite correspondence benefit in Malaysia is direct to home (DTH) administrations worked by ASTRO which manages 107 TV stations and ASTRO On-Demand. Direct to home is satellite programs that provide a smaller number of Ku band at the satellite operator. Fig. 1 illustrate the flow chart on high-definition television (HDTV) provided by MEASAT.

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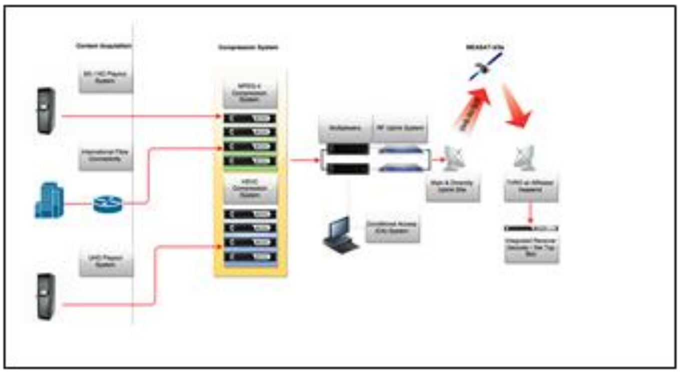

Fig. 1. Block Diagram of MEASAT HDTV

2. System Setup

The data collection for this research was provided by MEASAT. This research was done in two frequency bands, Ku and Ka-band. Location for both frequencies is also different. Ka-band data were measured from two ground stations located in Rawang and Cyberjaya, Malaysia. Whereas, Ku-band data were measured from two ground stations located in Cyberjaya and Bukit Jalil, Malaysia. For this research, the frequency used for Ka band is at 20.199 GHz. The distance between two ground station separation of Cyberjaya and Rawang was around 41.04 km. The base line angle and elevation angle were 68.770° and 99.040° respectively. On the other hand, the frequency of Ku-band is 12.201 GHz, using two different locations Cyberjaya and Bukit Jalil with site separation 14.18 km. The baseline angle and elevation angle were 77.50° and 245.050° respectively. The data was analyzed in the year 2015 to investigate how rain affects the degradation of the signal. The period of these collection of data is 11 months from January 2015 until November 2015. The data for December 2015 was not included due to maintenance activity. Collection of raw data was done by using two receivers at different locations, Rawang and Cyberjaya. The distance between them were around 41.04 km as shown in Fig. 2. Both antennas were using the same operating frequency which is Ka-band. Antenna size for both receivers were 8 meters. The result of the signal strength was measured in dBm unit. Fig. 3 and 4 show the system setup for Ku and Ka-band

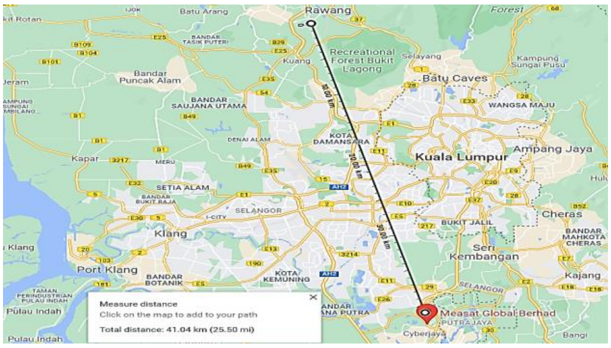

Fig. 2: Distance between Rawang and Cyberjaya on maps

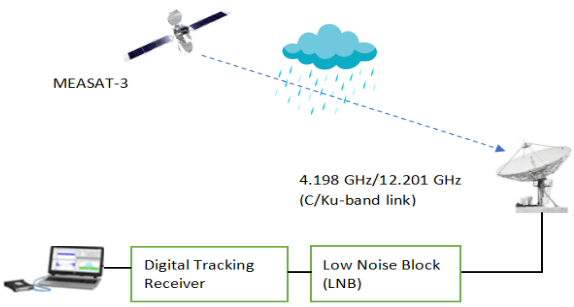

Fig.3. Overview of System Setup for the Ku-bands

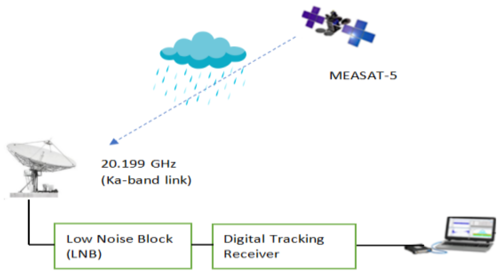

Fig. 4. Overview of System Setup for the Ka-band

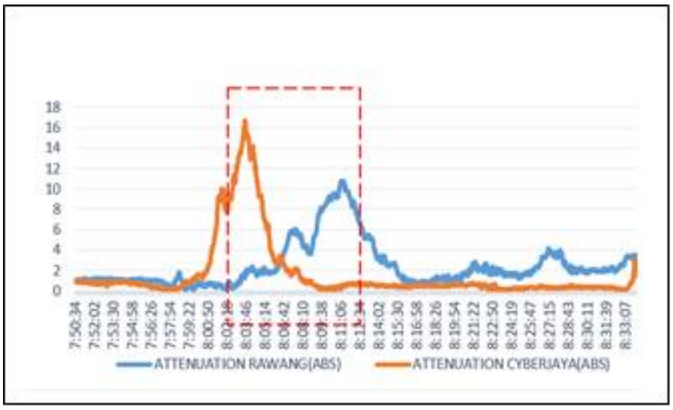

Fig. 5. Rain attenuation for Ka-band on 15th Jan 2015

The data was divided into two cases: rainy and no rains events. During clear sky (no rains), the average signal strength in Cyberjaya and Rawang is calculated to be -67 and -59 dBm respectively. From fig. 5, the signal strength can be evaluated. The graph shows that the attenuation level at both locations at the same period and from this information, we can evaluate the joint diversity. In the graph, it shows the drastic different in attenuation at the same period. Then, the same step was repeated for Ku-band.

3. Site Diversity Modelling

After analyzing the data, Hodge, ITU-R, Panagopolous, X.yeo and Semire diversity gain is compared to the measured MEASAT data in this research.

A. Hodge Site Diversity Model

Finding the diversity gain using Hodge [3] modelling is shown in Equation (1):

$$GD = G_d(d, A_S) \cdot G_f(f) \cdot G_\theta(\theta) \cdot G_\phi(\phi) \qquad (1)$$

Where;

d=distance of separation, in km;

AS=single terminal attenuation in dB;

f-frequency, in GHz;

θ=elevation angle, in degree;

ϕ = baseline orientation angle, in degrees.

Finding the gain function:

$Gd(d,AS)=a(1–e^{-bd})$ (2) where;

a=0.64AS-1.6(1–e-0.98AS) (3) $b=0.585(1–e^{-0.98AS})$

The frequency is 20.199.827 GHz from equation (4) we get:

$Gf(f)=1.64e^{-0.0025f}$ (4)

$G\theta(\theta)=0.00492\theta+8.34$ (5)

$G\phi(\phi)=0.00177\phi+0.887$ (6)

So, by using the equation (1), the value of Gain Diversity, GD can be obtained.

B. ITU-R Site Diversity

ITU-R site model [9] is based on improvement from the Hodge model and it is an empirically derived model [5]. Analyzing using the ITU-R model can be used as a prediction model to reduce the attenuation [4]. Step by step procedure for ITU-R diversity model explained in ITU-R Recommendations P.618-13. The switching process will occur when the site has the lowest attenuation during the fading period.

C. Panagapolous Site Diversity Gain Model

Panagopoulos diversity gain model is an improved model for a distance less than 15 km. But, more than 15 km still perform equally well. The calculation for diversity gain algorithm was shown below and as can be referred in [6]. This model still preserves the Hodge model but in this model the author did multiply gain of attenuation at a single site.

D. X.yeo Diversity Gain Model

Next, the X.yeo diversity gain model was being researched in the tropical regions. This research has been made in Singapore. Compared with the past diversity gain model, this model excludes the gain of frequency and baseline orientation. Thus, it only holds on site separation distance, elevation angle and wind direction. Diversity gain of X.yeo model was much simpler than Hodge model as shown below and can be referred to as in [8].

$$G_{SD}= (-0.78+0.88AS)(1-e^{-0.18d})(1+e^{-0.14e}) \quad (7)$$

E. Semire Gain Diversity Model

Semire diversity gain model firstly agrees with X.yeo model. But, in 2015, Semire proposed an algorithm of diversity gain that improvised the Hodge model. This model was an experiment at tropical region and can be referred in [7]. Calculation of diversity gain same as Hodge model but different of factor gain.

Site diversity is using the selection scheme (SC) to choose the lowest attenuation between the sites when both of site is having rain at the same period. Moreover, when one of the sites are clear sky, the satellite will transmit the signal to the earth station. Analyzing the data of signal strength can be made using the model of radio communication likes ITU-R site diversity gain, ITU-R improvement of gain diversity and Hodge site diversity model. From the analyzing data, we can get the diversity gain and the improvement factor of single site and joint site

RESULTS AND CONCLUSION

F. Cumulative Distribution Function for Joint Diversity

System performance of site diversity can be achieved by creating Annual CDF of single site and join site diversity. Fig. 6 shows the annual CDFs graph for single site and joint site diversity. From the graph, there are two single terminals involved to compare with joint terminal. Joint terminal is when both sites are raining at the same time. When two sites are involved, fade margin required for each site is reduced. Single site operation of Cyberjaya required a fade margin 18 dB as to maintain the availability of 99.9%. But when the join diversity is implemented, the fade margin is reduced to 0 dB and the availability can be increased up to 99.99%. It can be concluded that the implementation of diversity technique will increase the percentage of signal availability and reduce the fade margin required.

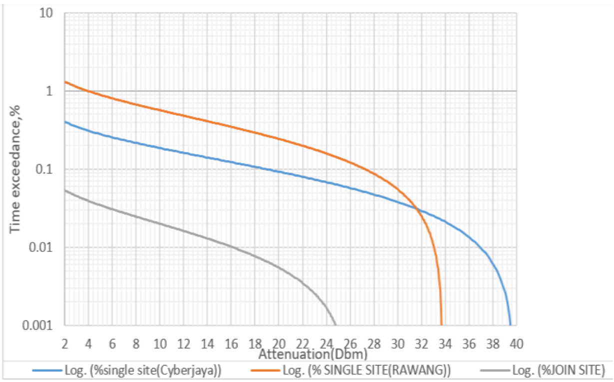

Fig.6: Annually CDFs of single site and join site diversity

Table 1 and 2 illustrate the fade margin for both frequency, Ku and Ka-band. From both tables 1 and 2, its show that the fade margin for joint site is smaller than single site. So, it is clearly shown that, by implement the site diversity we can reduced the number of fade margin required to increase availability of the signal.

TABLE 1: FADE MARGIN FOR SINGLE SITE VS JOINT SITE FOR KA-BAND.

Link availability	Fade margin for single site (dB)	Fade margin for joint site (dB)
99.9%	18 dB	0 dB
99.99%	33 dB	16 dB
99.999%	33.9 dB	25 dB

TABLE 2: FADE MARGIN FOR SINGLE SITE VS JOINT SITE FOR KU-BAND.

Link availability	Fade margin for single site (dB)	Fade margin for joint site (dB)
99.99%	17 dB	0 dB
100.00%	37.5 dB	15.5 dB
100.00%	37.9 dB	17 dB

G. Comparison with Other Modelling of Site Diversity

Analyzing the data by using the Hodge, ITU-R, Panagopolous, X.yeo, and Semire diversity gain model can improve the diversity gain. Relationship between the distance between two site and diversity gain was model in Hodge site diversity gain model. Next, it is being improvised by Panagopolous by adding attenuation at single site gain. ITU-R model maintained the equation of Hodge model but is different in terms of single gain. X.yeo model was implemented in tropical region, Singapore. The researcher conclude that the diversity gain excludes the frequency gain and baseline orientation as compared with Hodge model. Further research has been made in tropical region in southeast Asia which is Semire model. This model preserved the equation of Hodge model but its only suit with low elevation angle and distance less than 10km. Furthermore, all models were calculated by using the formula given in the literature [3],[6],[7],[8] illustrates the parameter used to predict the diversity gain model. Site Separation from 1 to 45 km was involved. Single of attenuation was 18 dB at 99.9% availability. The graph of Hodge, ITU-R, Panagopolous, X.yeo and Semire diversity gain model can be observed in fig. 7. All models were slightly increased in terms of diversity gain and maintained constant after certain distance except for Panagopolous model. ITU-R model produced slightly higher gain than all models. As site separation between Cyberjaya and Rawang was 41.04 km the improved diversity gain by using Hodge,ITU-R, Panagopolous, X.yeo and Semire model was 12, 20, 14, 15 and 13 dB respectively. Based on annually cumulative distributive graph for Ku-band, as in fig. 8, Diversity gain for availability at 99.9% is 18 dB which is nearest to ITU-R model. To sum up, ITU-R model is much more suitable for ka-band frequency with distance of 41.04 km in the tropical region.

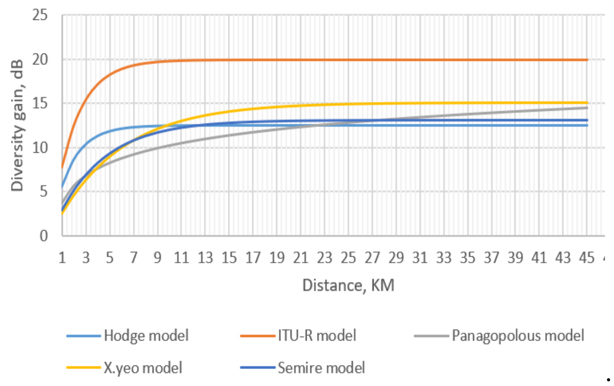

Fig. 7: Diversity gain vs distance for each modelling for Ka-band

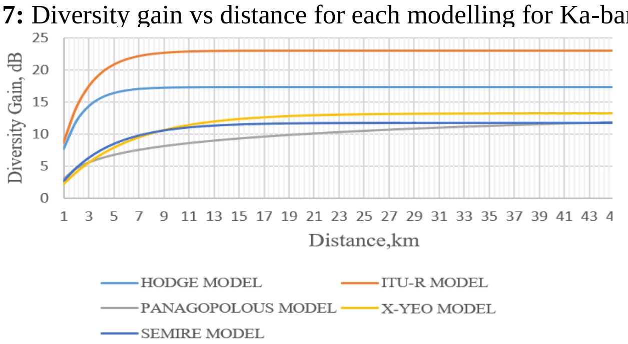

Fig. 8: Diversity gain vs distance for each modelling for Ku-band

Performance for site diversity can be measured using diversity gain, GD. Site Diversity Gain is the different between Single Site Attenuation, *As* and Joint Site Attenuation, *Aj* with same percentage exceedance. Both are presented in decibels(dB). After some analysis, we found out that the equation ITU-R is the most suitable and having the nearest values to improve the model that suit the condition in tropical region especially Malaysia. The general equation for diversity gain is the same as suggested by ITU-R model as discuss in ITU-R Recommendations P.618-13. Table 3 shows the difference of the equation and the proposed model achived from the research.

TABLE 3: PROPOSED MODEL FOR TROPICAL REGION COMPARED TO ITU-R MODEL

Items	ITU (2009)	Proposed (2023)
Diversity Gain, G_D	$=G_d(d,AS)G_f(f)G\theta(\theta)G\phi(\phi)$	$= Gd\ (d, AS)Gf\ (f\ )G\theta\ (\theta)G\phi\ (\phi)$

Gain contribute by site diversity, $G_d(d, AS)$	$a(1 – e^{-bd})$ Where; $a= 0.78\ AS - 1.94(1−e^{-0.11AS}$ $b = 0.59(1− e^{-0.1AS})$	$a (1 – e\text{-}bd)$ *Where;* $a = 0.76AS - 1.889\ (1–e^{-0.122AS})$ $b = 0.59(1 – e^{-0.988AS})$
Gain contribute by frequency gain, $G_f(f)$	$=e^{-0.025f}$	$=e^{-0.005f}$
Gain contribute by elevation angle, $G\theta(\theta)$	$= 1+0.006\theta$	$0.00598\theta+0.988$
Gain contribute by orientation, $G\phi(\phi)$	$1+0.002\phi$	$0.002\phi+0.988$

CONCLUSION

The frequencies that were used in this research are 20.199 GHz and 12.201 GHz. Basically, this technique is the most popular technique that was used in any broadcasting services to maintain their quality of services. This technique was used only at terrestrial station because of complexity when it is implemented at the space station. Even though high number of costs to build up new terrestrial station is needed as compared with other techniques, site diversity technique will increase the availability of the signal, especially in our tropical region which produce higher number of rainy events. From measurement of Ku-band, diversity gain for availability 99.9% was around 18 dB and improvement of site diversity increase to availability of 99.99%. Next, further analysis was made using Hodge, ITU-R, Panagopolous, X.yeo and Semire diversity gain model to calculate the diversity gain. From the study, ITU-R model showed higher diversity gain than the other modelling. It is also found that, after 11 km and above, the diversity maintained constant for both models except for Panagopolous model. Also, the results shows that the higher the distance between single site terminal the higher the availability of the signal. In addition, diversity gain was also being compared with other modelling and it can be concluded that the nearest diversity gain was ITU-R model with a difference of only at 2dB.

Next, measurement for Ku-band also has been made. From the measurement, It can be concluded that the improvement of site diversity increases to availability of 99.999%. The diversity gain for availability at 99.99% was around 16 dB. Next, the Diversity gain is compared with other modelling, the result was the same with Ka-band, where is after 11 km and above, the diversity gain maintained constant except for Panagopolous model. The diversity gain of Ku-band was almost similar with Hodge model with a different only 1 dB. Afterall, the study proposed a model that suitable for tropical region site diversity measurement after considering the condition in the region.

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