International Journal of Scientific & Engineering Research, Volume 4, Issue 7, July-2013 367
ISSN 2229-5518

IMPROVEMENTS OF SIGNAL GAIN FOR MEASAT-2 AND MEASAT-3 USING ORBITAL DIVERSITY UNDER RAIN ATTENUATION: A SIMULATION APPROACH

Harlisya Harun, Halid Agil, Ruhaida Abdul Rashid

Abstract—The effect of rain attenuation becomes significant for satellites operating at 10 GHz and above. This has become a matter of concern, especially in tropical regions where relatively heavy rainfall occurs throughout the year. Orbital diversity (OD) is seen to be a viable method to mitigate rain attenuation. It employs multiple satellites transmitting identical signal streams toward a mutual ground station. Although OD has been studied with great interest in regions such as Europe, there is little information of OD research in tropical regions, particularly in Malaysia. Therefore, this paper proposed an analytical approach towards the study of OD in Malaysian climate using MEASAT satellites. The performance of OD is dependent upon the operating frequency and the satellite's elevation angle. From the simulation, the rain attenuation increases exponentially with the increasing frequency. Therefore, the signal gain decreases in inverse exponential manner. The simulation also shows that MEASAT-3, having an elevation angle of 77.695°, experiences higher signal attenuation than MEASAT-2 (elevation angle 34.324°). Using signal combination, an OD signal experiences signal boost of up to 2.3 times the individual signal gain. With this significant finding, the OD is proposed to mitigate rain attenuation in Malaysia.

Index Terms—Maximal Ratio Combining, Orbital Diversity, Rain Attenuation, Signal Strength.

---

1 Introduction

Rain attenuation is the main contributor towards signal degradation for satellite systems, and the effect of rain attenuation is significant for systems operating at 10 GHz and above [1]. Malaysia experiences heavy rainfall which causes significant attenuation effects toward satellite systems operating at 10 GHz and above, particularly MEASAT satellite system resulting to the instability of signal strength. The problem is clearly demonstrated by the reception problem of Astro that utilizes Ku-band [2] during heavy rain.

Orbital diversity (OD) is seen as a viable method to mitigate rain attenuation effects. It is considered to be adaptive in nature [2]. To achieve this, multiple transmitting satellites are required, and they are spatially separated so that independent slant paths can be created. When rainfall occurs, the OD system selects the least attenuated slant path and adopts a re-route strategy [3].

The concept of OD is still relatively new in Malaysia. As far as the research is concerned, although OD has been a subject of interest among industries and academics for more than 20 years [4], there are relatively sparse experiments or measurements that have been performed to know its performance in the South East Asian region, especially in Malaysia. Thus, this research serves to propose OD as well as to provide a better understanding of its importance as fade mitigation technique (FMT) in Malaysian climate

This research utilizes MATLAB simulation to predict the performance of OD under rain attenuation. The simulation has taken into account two transmitting satellites toward a mutual ground station, as discussed in [3] to [6]. The transmitting satellites are MEASAT-2 and MEASAT-3, while the selected ground station is MEASAT Satellite Control Centre (MSCC) situated in PulauLangkawi, Kedah.

- *Harlisya Harun is a senior lecturer in Aerospace Engineering Department in University Putra Malaysia (UPM), Malaysia. E-mail: harlisya@eng.upm.edu.my*
- *Halid Agil has earned a master degree in Aerospace Engineering from Aerospace Engineering Department in University Putra Malaysia (UPM), Malaysia. E-mail: fatamorgana_2121@yahoo.com*
- *Ruhaida Abdul Rashid is a lecturer in Avionics Department in UniKL MIAT, Malaysia. E-mail: ruhaida@gmail.com*

2 ORBITAL DIVERSITY (OD)

OD refers to the usage of two or more appropriately separated satellites to provide two or more separate converging paths to a common ground terminal. By utilizing the link with the lowest path attenuation, diversity gain is achieved. The main advantage of OD is that the satellites involved can be used in a resource-sharing scheme, meaning that they can be used with many ground sites.

With the advent of satellite television, there is a need for higher performance of satellite signal strength. But, the quality of the satellite TV signal reception can be affected by adverse weather. Heavy rains for example can attenuate signal enough to result in noticeable degradation of image quality. For radio systems which operate above 10 GHz, excess attenuation due to rainfall and losses due to atmospheric gases are significant. The impairment caused by rain increases with frequency and varies with regional locations [7].

The poor performance of the satellite TV signal reception is due to reliable communication which depends on the strength of a single signal path [8]. This can be mitigated by using OD. Independent signal paths have a low probability of experienc-

ISSN 2229-5518

ing deep fades simultaneously [9]. With diversity, the same data will be sent over independent fading paths. These independent paths are combined so that the fading of the resultant signal is reduced.

Consider a system with two antennas at either the transmitter or receiver that experience independent fading, as shown in Fig. 1. Both antennas will not experience deep fades at the same time if the antennas are spaced sufficiently far apart. With selection combining, the antenna with the strongest signal will be selected and thus, a much better signal can be obtained compared to one antenna.

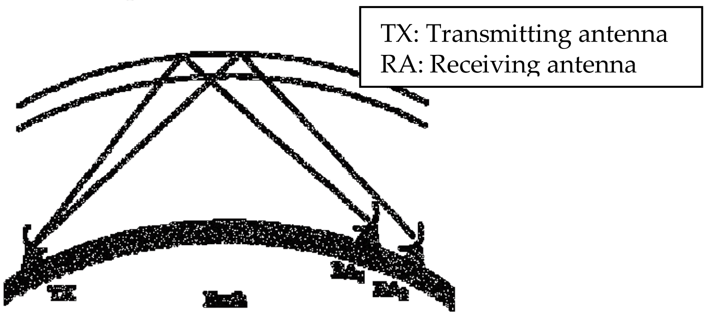

Fig. 1. Illustration of diversity reception using two receiving antennas [10].

High rainfall rate in Malaysia degrade the performance of MEASAT satellite systems. Thus, the rain attenuation model is needed to improve the performance of the MEASAT satellite system. In this research, the ITU-R model [11] has been used to analyze the performance of the MEASAT satellite system with OD.

3 SIMULATION MODEL

The configuration of the OD simulation model is illustrated as in Fig. 2. The OD model takes the 2:1 configuration; that is two transmitting satellites to one receiving earth station. Earlier works utilizing 2:1 configuration has been performed in [3-6]. The main reason to use only two transmitting satellites is to simplify the analysis of rain attenuation statistics over a limited amount of time.

It is clearly shown in Fig. 2 that there are two resulting earth-space paths, D_1 and D_2, which connect MSCC with MEASAT-2 and MEASAT-3, respectively. Elevation angle (θ) is the angle of the earth-space path with respect to the earth's horizon. The angular position of MEASAT-2 relative to MEASAT-3 is called the separation angle (φ).

Fig. 3 shows the schematic details of an earth-space path derived from ITU-R recommendation (2009). The earth-space path (D) propagates through two regions in the atmosphere: frozen precipitation region (A) and liquid precipitation region (C). The rain height (h_R, in km) is the transition height in the atmosphere at which beyond it the freezing phenomenon would occur. The rain height is region specific. The height position of the earth station (h_S, in km) is measured above mean sea level. The slant path (L_S, in km) exists along D from h_S up to h_R. The horizontal projection (L_G, in km) is the projection of L_S on the earth's horizon. Both L_S and L_G are dependent on θ.

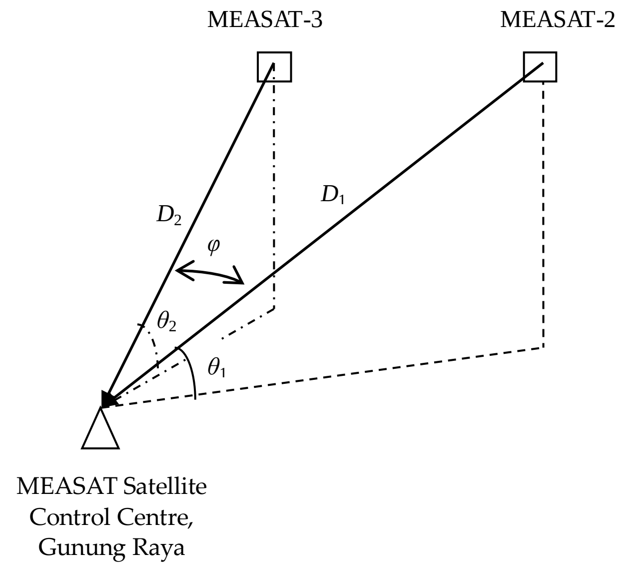

Fig. 2. OD simulation model configuration.

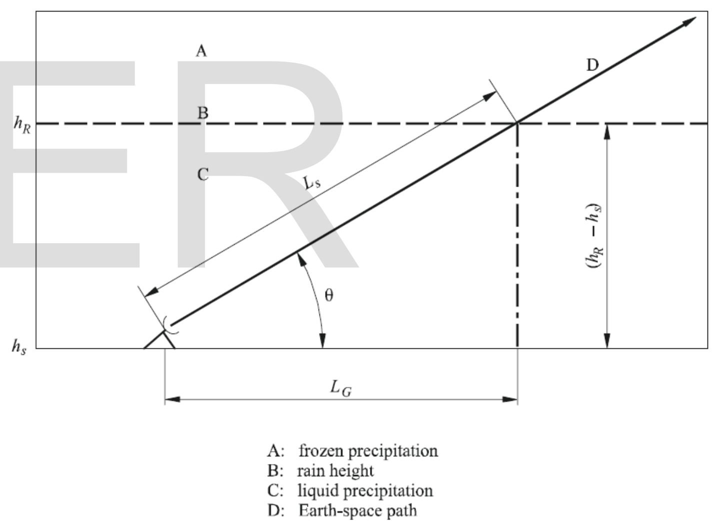

Fig. 3. Schematic representation of an earth-space path [11].

The ITU-R model has been chosen for this simulation process. The relevant parameters are based on the ITU-R recommendation (2007) [12]. The ITU-R model is based on the probability of rainfall rate in the percentage of time. It provides the rain attenuation at 0.01 percent of the time rain rate is exceeded, as follows:

$$A_{0.01} = kR_{0.01}^{\alpha} dr_{0.01} \quad (1)$$

where $R_{0.01}$ and $r_{0.01}$ are the rain rate and reduction factor at 0.01 percent of the time respectively. The latter is expressed as:

$$r_{0.01} = 1/\left(1 + d/d_0\right) \quad (2)$$

and

$$d_0 \begin{cases} 35e^{-0.015R}, R_{0.01} < 100mm/hr \\ 35e^{-1.5R}, R_{0.01} < 100mm/hr \end{cases} \quad (3)$$

$A_{0.01}$ is chosen to represent the requirements of obtaining near continuous transmission (99.99 percent of signal availability). The procedures to obtain $A_{0.01}$ are based on ITU-R Recommendation (2007) [12] prediction of attenuation statistics for an average year.

Maximal Ratio Combining (MRC) has been used to join the received signals from both MEASAT-2 and MEASAT-3. The joint signals will indicate the signal strength of the OD scheme compared with the individual signals. Orbital diversity gain, G_{OD}, is defined as the difference between the attenuation exceeded on a single link and the attenuation jointly exceeded on the total links involved in the orbital diversity scheme [13].

$$SNR_i = SNR_{cs,i} - A_{0.01,i} \qquad i = 1,\ 2\ \ (dB) \quad (4)$$

where

SNR_i: signal-to-noise ratio for satellite i.
$SNR_{cs,i}$: signal-to-noise ratio transmitted during clear sky conditions for satellite i.
$A_{0.01,i}$: attenuation exceeded for 0.01% of an average year for satellite i.

To obtain the joint signals for both satellites, SNR_1 and SNR_2 are combined using MRC. MRC receives individual signals from all involved channels, and combines them in linear scale to obtain the total gain:

$$SNR_{MRC} = SNR_1 + SNR_2 \quad (5)$$

where

SNR_{MRC}: total signal gain.
SNR_1: signal gain for MEASAT-2.
SNR_2: signal gain for MEASAT-3.

Equation (5) is expressed in dB as:

$$SNR_{MRC} = 10\log\left(10^{SNR_1/10} + 10^{SNR_2/10}\right)\ dB \quad (6)$$

An extension to Equation (6) has been proposed by Crane [15], by taking into account the description of the vertical variation of rainfall structure and combines it with Equation (5) to yield:

$$SNR_{MRC} = 10\log\left(10^{\frac{SNR_{cs,1} - A_1' / \cos\phi_1}{10}} + 10^{\frac{SNR_{cs,2} - A_2' / \cos\phi_2}{10}}\right) \quad (7)$$

where

SNR_{MRC}: total signal gain.
$SNR_{cs,1,2}$: signal-to-noise ratio transmitted during clear sky conditions for MEASAT-2 and MEASAT-3, respectively.

$A'_{1,2}$: attenuation of projected earth-space links for MEASAT-2 and MEASAT-3, respectively.

The joint signal gain is therefore used to compare with the individual signal gains for both MEASAT-2 and MEASAT-3. The difference between these gains is known as the diversity gain. The diversity gain is the figure of merit of this research. An orbital diversity gain (ODG) is defined as the difference between the attenuation exceeded on a single link and attenuation jointly exceeded on both links in an OD scheme for a fixed percentage of time [13]. It is obtained from:

$$G_{OD_i} = A_i - A_D, \quad i = 1,2\ \ dB \quad (8)$$

where

G_{ODi}: orbital diversity gain for link i.
A_i: attenuation exceeded on link i.
A_D: attenuation threshold jointly exceeded for fixed percentage of time.

As attenuation reduces signal strength, Equation (8) can be expressed in terms of transmitted signal gain. Equations (4) and (7) are combined into Equation (8) to obtain:

$$G_{OD_i} = SNR_{MRC} - SNR_i, \quad i = 1,2\ \ dB \quad (9)$$

where

GOD_i: orbital diversity gain for link i.
SNR_{MRC}: total signal gain.
SNR_i: signal gain for link.

To analyze the potential of the OD in improving the performance of satellite communication, a series of simulation is performed using MATLAB (as can be found in Section 4). It aims to highlight the impact of OD from the aspect of rain attenuation exceeded at 0.01 percent and signal strength as compared to the frequency.

4 IMPLEMENTATION OF THE SIMULATION

The simulation is performed in MATLAB programming language. It is written and saved into three different script files: Script 1 for rain attenuation simulation, Script 2 for joint attenuation simulation and Script 3 for diversity gain simulation.

Script 1 includes the identified input parameters into a series of calculations based on the ITU-R recommendation (2009) [11]. The parameters are sorted into three groups. Each group represents the satellites' parameters, the ground station's parameters and climate specified parameters. The required parameters for the rain attenuation simulation can be found in Table 1.

TABLE 1
Input parameters for Script 1 rain attenuation simulation

ELEMENT	VALUE
SATELLITE PARAMETERS	
a. Operating frequency	10 GHz – 20 GHz, 1 GHz step
b. Elevation angle	34.324° (MEASAT-2) 77.695° (MEASAT-3)
GROUND STATION PARAMETERS	
a. Latitude	6.367° N
b. Altitude above mean sea level	0.881 km
c. Polarization tilt angle with respect to the horizon	0°
d. Effective earth radius	8500 km
e. Climate specific parameters	
i. Average annual 0° Celcius isotherm height	4.5 km
ii. Rain rate for 0.01% of an average year	120 mm/h

Script 1 simulation is designed to calculate and simulate the attenuation exceeded for 0.01 percent of an average year, $A_{0.01}$, for both MEASAT-2 and MEASAT-3 links. Thus, equations (1) until (3) were included in Script 1 simulation. The results are displayed in MATLAB Command Window as numerical figures. These numbers are then used to create a graph using MATLAB plot functions.

Script 2 includes the numerical results in Script 1 and converts them into signal gain. The signal gains are then combined using MRC to obtain the total signal gain. MRC is used in this research due to its relatively low selective complexity and it is one of the common methods to be used when combining diversified signals alongside selection combining. Sakarellos et al. [14] states that MRC performance is influenced by the satellite angular separation and climate conditions of the region in which the user's ground segment is located. Equations (4) until (7) were included in Script 2 simulation.

Equations (8) and (9) can be found in Script 3 simulations to obtain the diversity gain, in which the signals from both MEASAT-2 and MEASAT-3 were combined together. The joint signals will indicate the signal strength of the orbital diversity (OD) scheme compared with the individual signals.

5 PERFORMANCE OF OD

Rain attenuation level depicts the severity of rain fade on a particular frequency of a signal. As such, lower attenuation level is preferred over higher ones. Fig. 4 shows the rain attenuation exceeded at 0.01 percent for an average year for both MEASAT-2 and MEASAT-3. It is also shown from Fig. 4 that the level of rain attenuation is severe for tropical regions such as in Malaysia, with the minimum average is slightly above 20 dB for MEASAT-2 and 60 dB for MEASAT-3 at 10 GHz. As the operating frequency increases, the rain attenuation gain increases exponentially. The level of rain attenuation is also dependent upon elevation angle such that for MEASAT-2 (θ = 34.324°) experiences lower rain attenuation than MEASAT-3 (θ = 77.695°). Hence, higher elevation angle results to a higher rate of attenuation per frequency.

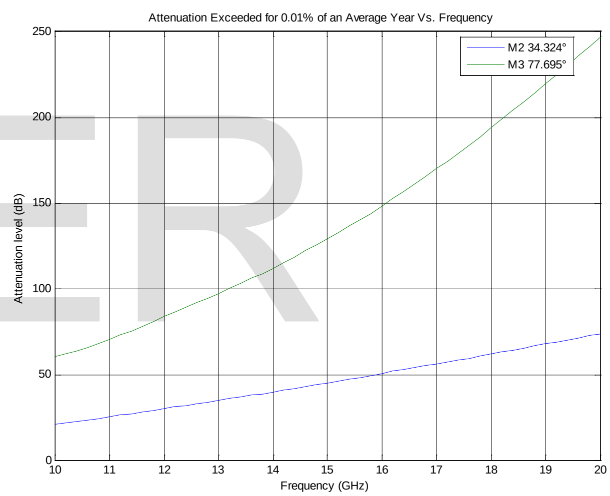

Fig. 4. Graphical representations for rain attenuation simulation results.

Using exponential regression, an estimation of the curves for both $A_{0.01,M2}$ and $A_{0.01,M3}$ can be determined. The curves follow a general exponential pattern:

$$y = me^{nx} + c \quad (10)$$ (10)

where

m and n: numerical constants.
c: intersection point along y axis when $x = 0$.

The calculated exponential regressions for $A_{0.011,M2}$ and $A_{0.01,M3}$ are given below:

$$A_{0.01,M2} = 7.2759e^{0.1183f} + 12.3096 \quad (11)$$

$$A_{0.01,M3} = 715.8774e^{0.1384f} + 42.0784 \quad (12)$$

International Journal of Scientific & Engineering Research, Volume 4, Issue 7, July-2013 371
ISSN 2229-5518

where

$A_{0.01,M2}$: attenuation exceeded for 0.01 percent of an average year for MEASAT-2.
$A_{0.01,M3}$: attenuation exceeded for 0.01 percent of an average year for MEASAT-3.
f: operating frequency.

From the simulation data, it is discovered that the residual sum of squares (RSS) i.e. error becomes more apparent when the elevation angle is increased. Thus, the estimation can be more erroneous for MEASAT-3 with the total RSS of 83.7642 dB^2 as opposed to MEASAT-2 with only 44.4139 dB^2. Fig. 5 and 6 show the error between the calculated $A_{0.01}$ and the actual $A_{0.01}$ for MEASAT-2 and MEASAT-3, respectively.

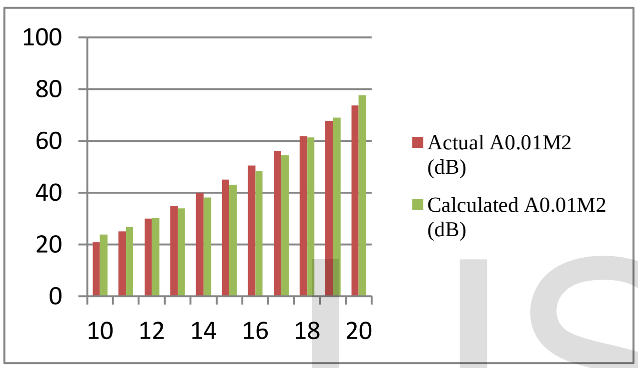

Fig. 5. Error (RSS) in $A_{0.01}$ for MEASAT-2.

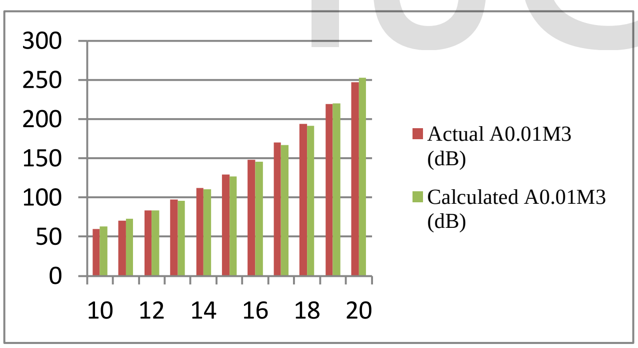

Fig. 6. Error (RSS) in $A_{0.01}$ for MEASAT-3.

To conclude, the level of rain attenuation is severe for tropical regions such as in Malaysia, with the minimum average is slightly above 20 dB for MEASAT-2 and 60 dB for MEASAT-3 at 10 GHz. As the operating frequency increases, the rain attenuation gain increases exponentially. Fig. 4 also shows that the level of rain attenuation is also dependent upon elevation angle, θ. MEASAT-2 (θ = 34.324°) experiences lower rain attenuation than MEASAT-3 (θ = 77.695°). In effect, higher elevation angle results to a higher rate of attenuation per frequency.

A simulation model has been constructed to join the expected received signals from both MEASAT-2 and MEASAT-3. The joint signals will indicate the signal strength of the OD scheme compared with the individual signals. From Fig. 7, a significant improvement in signal strength can be noticed when the signals are jointly received. Comparing the joint signal with the individual signals, the decrement is nearly linear in pattern for the joint signal, while the strength for both the individual signals decrease in exponential pattern.

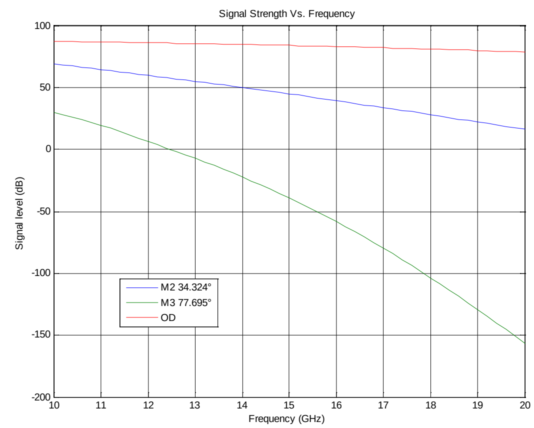

Fig. 7. Signal strength comparison between MEASAT-2, MEASAT-3 and combined (OD) signals.

Looking at the lower end of the frequency range, at 10 GHz, the values of MEASAT-2, MEASAT-3, and the combined signal strengths are 69.083 dB, 29.847 dB and 87.563 dB, respectively. The diversity gain for the OD system at 10 GHz is therefore around 1.3 to 2.3 times higher than the signal strength for MEASAT-2 and MEASAT-3, respectively. This is shown in Fig. 8. The value of the diversity gain varies with operating frequency.

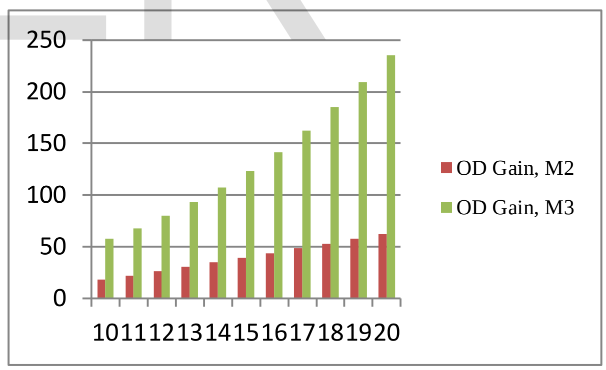

Fig. 8. Advantage of OD signal strength over the individual signals.

Using exponential regression, an estimation of the SNR_{OD} curve can be determined. It follows the exponential pattern given in Equation (10). The calculated exponential regression formula for SNR_{OD} is given as:

$$SNR_{OD} = 97.7390e^{-0.0103f} - 0.5758 \quad (13)$$

where

SNR_{OD}: OD gain.
f: operating frequency.
The OD simulation shows that the signal strength of the diver-

sity (joint) system is higher than the individual signal strengths. It is important to have an increased signal gain within the same bandwidth to ensure that the signal is more robust, and therefore the quality of service could be maintained.

6 Conclusion

Rain attenuation remains to be a problem since the introduction of the satellite television. Many research papers have been published in recent years, and this research area is still in a growing stage, particularly in Malaysia. This paper presents the detail study of the orbital diversity on MEASAT system to mitigate the rain attenuation problem.

OD is seen as one of the promising methods in which the effects of rain attenuation can be mitigated. The simulations of OD system based on MEASAT satellites under rain attenuation effects show that the minimum limit of signal strength can be significantly increase of up to 2.3 times the strength of individual satellites at 10 GHz. The simulations also show that the performance of an OD system is dependent upon the transmitting frequency, the elevation angle and the separation angle.

Possible studies in the future can be conducted to further exploring the possibilities of implementing OD in Malaysia. For example, the performance of the OD system is not limited for signal strength, but also by measuring the outage probability. Several factors other than rain attenuation such as gaseous, cloud and fog attenuation should also be considered in assessing the OD performance. Utilizing multiple satellites with intersatellite links could also increase the efficiency of an OD system.

References

[1] L.J. Ippolito, *Satellite Communications Systems Engineering: Atmospheric Effects, Satellite Link Design and System Performance*. John Wiley & Sons Ltd UK, 2008.

[2] A. Yagasena and S.I.S. Hassan, “Worst-month rain attenuation statistics for satellite-Earth link design at Ku-band in Malaysia,” *IEEE-TENCON 2000*, Kuala Lumpur, vol. I, pp. 122-126, 2000.

[3] A.D. Panagopoulos, P.M. Arapoglou and P.G. Cottis, “Site Versus Orbital diversity: Performance Comparison Based on Propagation Characteristics at the Ku Band and Above,” *IEEE Antennas and Wireless Propagation Letters*, vol. 3, pp. 26-29, 2004.

[4] E. Matricciani, “Orbital Diversity in Resource-Shared Satellite Communication Systems above 10 GHz,” *IEEE Journal on Selected Areas in Communications*, vol. 5, no. 4, pp. 714-723, 1987.

[5] C. Capsoni, E. Matricciani and M. Mauri, “SIRIO-OTS 12 GHz Orbital Diversity Experiment at Fucino,” *IEEE Transactions on Antennas and Propagation*, vol.**38**, no. 6, pp. 777-782, 1990.

[6] E. Matricciani and M. Mauri, “Italsat-Olympus 20-GHz Orbital Diversity Experiment at Spino d'Adda,” *IEEE Transactions on Antennas and Propagation*, vol. 43, no. 1, pp. 105-108, 1995.

[7] F. Fedi, “Prediction of attenuation due to rainfall on terrestrial links,” *Radio Science, vol.* 16, no. 5, pp. 731-743, 1981.

[8] D. Tse and P. Viswanath, *Fundamentals of Wireless Communication*. United Kingdom, Cambridge University Press, 2005.

[9] A. Goldsmith, *Wireless Communications*. Cambridge, University Press, USA, 2005.

[10] J.G. Proakis and M. Salehi, *Communication Systems Engineering*, 2nd edn. Upper Saddle River, New Jersey, Prentice-Hall, Inc, 2002.

[11] ITU-R Recommendation P.311-13, Acquisition, presentation and analysis of data in studies of tropospheric propagation. International Telecommunication Union, 2009.

[12] ITU-R Recommendation P.682-2, Propagation data required for the design of Earth-space aeronautical mobile telecommunication systems. International Telecommunication Union, 2007.

[13] A.D. Panagopoulos and J.D. Kanellopoulos, “A Simple Model for Orbital Diversity Gain on Earth-Space Propagation Paths,” *IEEE Transactions on Antennas and Propagation*, vol. 51, no. 6, pp. 1403-1405 2003.

[14] V.K. Sakarellos, D. Skraparlis, A.D. Panagopoulos and J.D. Kanellopoulos, “Performance of MRC Satellite Diversity Receivers over Correlated Lognormal and Gamma Fading Channels”, *10th International Workshop on Signal Processing for Space Communications*, 2008.

[15] R.K. Crane, *Propagation Handbook for Wireless Communication System*. CRC Press, Boca Raton, Fla., 2003.