Journal of Physics: Conference Series

PAPER • OPEN ACCESS

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To cite this article: N Fadilah and R Pratama 2018 *J. Phys.: Conf. Ser.* **1130** 012036

IOP Conf. Series: Journal of Physics: Conf. Series **1130** (2018) 012036 doi:10.1088/1742-6596/1130/1/012036

Comparison of rain attenuation estimation in high frequency in Indonesia region for LAPAN communication satellite

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Abstract. Rain attenuation is one of the factors taken into consideration in the telecommunication system using frequencies above 10 GHz. As a tropical country, Indonesia has an annual average weather of high rainfall, causing the atmospheric conditions to contain a lot of water vapor. At frequencies above 10 GHz, the rain greatly affects the attenuation of the signal transmitted from/to telecommunication satellites. The objective of the research is to know the rain attenuation value estimation that used in link budget communication design to compensate the appropriate margin in LAPAN communication satellite. The study compared the rain attenuation estimation using ITU-R, Global Crane, and DAH modelling. The highest estimated rainfall value is found in Pare-pare using the Global Crane method. The result of the calculation with ITU-R model is the closest method for rain attenuation prediction in LAPAN communication satellite. The study recommends that the method to be used in the design of high frequency communication satellite operating in Indonesia is the ITU-R modelling.

1. Introduction

Increased demand for wireless communication services requires the use of wider frequency bandwidth. One of the services that need to be improved is communication via satellite, which to meet the bandwidth requirements, a higher frequency band is used. High-frequency usage on satellites is important because it can provide higher data rate communication. Rain attenuation estimation is important in the planning of satellite communication systems at a frequency band higher than 10 GHz, as it. Rain is a major cause that affects signal transmission [1]. Rain attenuation should be considered in the design of satellite communication to compensate the appropriate margin when performing link budget calculations. Designed communication satellites operate at frequencies of 20 GHz. Satellite communications that require high data rates, can satisfy the data rate requirement by using high frequency band such as Ku and Ka Band [2]. Frequency that higher than 10 GHz has impairment such as gaseous absorption, cloud attenuation, and rain attenuation on the troposphere. The main impairment is rain fade [3]. This paper describes the calculation of rain attenuation in several Indonesia regions to determine the requirement of LAPAN communication satellite. LAPAN communication satellite is one of the satellite that will be design by LAPAN. The main payload of this satellite provides internet communication. This communication will used Ka-band and Ku-band for communication link. Early rain attenuation predictions may use the model proposed by the International Telecommunication Union (ITU-R). This paper predicts the rain attenuation in Kototabang, Rancabungur, Pare-pare, and Biak where predicted as locations of satellite communication gateway.

2. Rain attenuation models

Figure 1 is an example of a communication satellite constellation that is used as assumption. To meet the design needs of such satellite communications, rain attenuation values are calculated in Kototabang, Rancabungur, Parepare, and Biak areas. Those area are LAPAN's satellite monitoring station and serves as a gateway to monitor designed communication satellites. The calculation of rain attenuation in the area is necessary to estimate the link margin required by the communication satellites. The calculation of rain attenuation value is done by using several methods to get the estimated rain attenuation value. The methods used are ITU-R, Crane, and DAH. The values obtained from the modeling are adjusted to the rainfall conditions in Indonesia to obtain the suitable value that meets the requirement of the satellite communication.

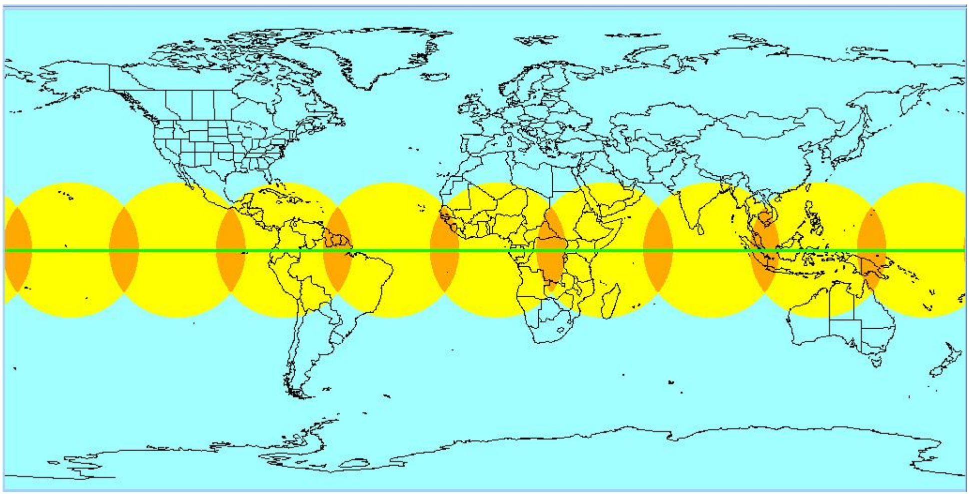

Figure 1. Concept of equatorial low earth satellite communication constellation.

At frequency higher than 10 GHz, rain attenuation becomes the main cause that decrease the quality of transmission signal. Extensive efforts have been undertaken to measure and model long-term rain attenuation statistics to aid communication system design. Measured data is necessarily restricted to a specific location and link parameters. ITU-R rain attenuation model is the widely accepted international method for the estimation of rain effect on the communication system. The ITU-R states that the modelling procedures estimate annual statistics of path attenuation at a given location for frequencies up to 55 GHz [4]. This paper predicts the rain attenuation value in several cities in Indonesia. The ITU-R rain attenuation model is as below [5][6][7][8]:

Step 1: define the rain height at the ground station of interest.

$$h_r = h_o + 0.36 \ (km) \tag{1}$$

h_o is the average annual 0^0 C isotherm height. h_r is the upper atmosphere altitude at which rain is in the transition state between rain and ice. The rain height is defined in km above sea level.

Step 2: calculate the slant-path length and horizontal projection.

$$L_s(\theta) = \frac{(h_R - h_s)}{\sin\theta} \ \ for \ \theta \geq 5° \tag{2}$$

$$L_s(\theta) = \frac{2(h_R - h_s)}{\left(\sin^2\theta + \frac{2(h_R - h_s)}{R_e}\right)^{1/2} + sin\ \theta}, \ for \ \theta < 5 \tag{3}$$

h_s is altitude ground receiver site from sea level (km), Θ is elevation angle, R_e is 8500 km (effective earth radius).

$$L_G = L_s \cos\theta \tag{4}$$

L_G is horizontal projection in km.

Step 3: Define the rain rate for 0.01% of an average year
Obtain the rainfall rate, $R._{0.01}$ exceeded for 0.01% of an average year for the ground station interest.

Step 4: calculate the specific attenuation
The specific attenuation is based on the equation below:

$$\gamma_R = k\, {R_{0.01}}^{\alpha} \tag{5}$$

γ_R is the specific attenuation in (dB/km). k and α are dependent variables, each of which are functions of frequency. The calculation can be found in [7].

Step 5: calculate the horizontal reduction factor

$$r_{0.01} = \frac{1}{1+0.78\sqrt{\frac{L_G\gamma_R}{f}}-0.38(1-e^{-2L_G})} \tag{6}$$

Step 6: calculate the vertical adjustment factor

$$v_{0.01} = \frac{1}{1+\sqrt{\sin\theta\left[31\left(1-e^{-(\theta/1+x)}\right)\sqrt{\frac{L_R\gamma_R}{f^2}}-0.45\right]}} \tag{7}$$

$$L_R = \frac{L_G\, r_{0.01}}{\cos\theta}, for\ \zeta > \theta \tag{8}$$

$$L_R = \frac{h_r - h_s}{\sin\theta}, for\ \zeta \le \theta \tag{9}$$

$$\zeta = tan^{-1}\ \frac{h_R h_s}{L_G r_{0.01}} \tag{10}$$

Step 7: determine the effective path length

$$L_E = L_R V_{0.01}\ km \tag{11}$$

Step 8: calculate the attenuation exceeded for 0.01% of an average year

$$A_{0.01} = \gamma_R L_e\ dB \tag{12}$$

The attenuation, $A_{p,}$ exceeded for other percentages, p, of an average year, in the range p=0.001 to 5 %, can be determine from

$$A_p = A_{0.01}\left(\frac{p}{0.01}\right)^{-[0.655+0.033\ln(p)-0.045\ln(A_{0.01})-\beta(1-p)\sin\theta]}\ \text{dB} \tag{13}$$

where

$$\beta = \begin{cases} 0 \quad ;\ if\ p\ \ge 1\%\ or\ |\varphi| \ge 36° \\ -0.005\ (|\varphi| - 36)\ ;\ if\ p < \ 1\%\ and\ |\varphi| < 36°\ and\ \theta \ge 25° \\ -0.005\ (|\varphi| - 36) + 1.8 - 4.25\sin\theta \quad ; otherwise \end{cases} \tag{14}$$

The crane developed model, usually referred as global crane attenuation model. This model was proposed by R.K Crane in 1980 [11]. Crane attenuation is an empirical model based on rain distribution, vertical rain extent, path length immersion in the rain, and frequency-dependent coefficient [12].

The Dissanayake-Allnut-Haidara (DAH) and ITU-R (2009) attenuation models are similar, except in terms of rain height parameter [8][12]. In the DAH model, the rain height is fixed to 5 km, whereas for ITU, rain height varies depending on the latitude and longitude of the measurement site [12][13].

3. Result and analysis

Estimation is done in Indonesia by taking a sample of Kototabang, Rancabungur, Pare-Pare, and Biak. These four regions are estimated as a place to be used as the communications satellite gateway. Kototabang is in West Sumatra, Rancabungur is in West Java, Pare-Pare is in South Sulawesi, and Biak is in Papua. The attenuation value obtained is taken into consideration in the preparation of the communication satellite link budget to get the link margin that is in accordance with the needs of the designed communication satellite. The information of the ground station can be seen in table 1.

Table 1. Ground station.

No	Ground Station	Latitude	Longitude	Altitude (m)
1	Kototabang	-0.204	100.320	854
2	Rancabungur	-6.531	106.702	145
3	Pare-Pare	-4.009	119.629	16
4	Biak	-1.174	136.100	47

3.1. The comparison of rainfall attenuation values with ITU-R, Crane, and DAH methods

In figure 1, it can be seen the difference of rain attenuation values generated using ITU-R, Global Crane, and DAH methods. At percentage of time 0.01%, 0.1%, and 1% the highest attenuation value is in the city of Pare-pare using the global crane method which is 79.279 dB, 35 dB, and 5.3 dB. Global cranes perform modeling based on rain distribution, ITU-R performs modeling with rain height variations depending on the latitude and longitude of the earth station while DAH performs modeling with a fixed rainfall height of 5 km. The value of rain attenuation can be seen in table 2.

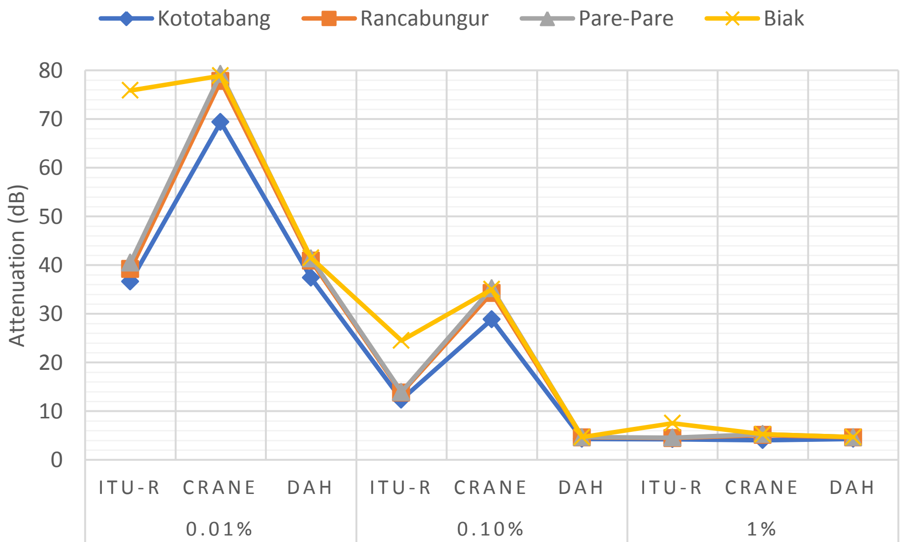

Figure 2. Variation of attenuation value using ITU-R, Crane, and DAH.

Table 2. Attenuation value using ITU-R, Crane, and DAH.

Percentage of time	0.01%			0.1%			1%		
Attenuation Value (dB)	ITU-R	CRANE	DAH	ITU-R	CRANE	DAH	ITU-R	CRANE	DAH
Kototabang	36.663	69.394	37.398	12.377	28.858	4.312	4.245	4.070	4.312
Rancabungur	39.194	77.824	40.917	13.781	34.280	4.631	4.476	5.113	4.631
Pare-Pare	40.542	79.279	41.380	13.952	35.274	4.672	4.597	5.314	4.672
Biak	75.892	78.932	41.526	24.526	35.035	4.685	7.557	5.266	4.685

Global Crane provides higher rainfall attenuation value than other models. DAH performs modeling with a fixed rainfall height of 5 km, because the rainfall value in Indonesia is different in each region and it is influenced by latitude and longitude, rain attenuation estimation is done using ITU-R modeling with combination of rainfall value at BMKG observation station. ITU-R modeling was chosen because it suits the satellite communication needs and the availability of power so that it can produce the expected margin.

3.2. Variation percentage of time using ITU-R model

In figure 3, there can be seen the difference of rain attenuation value for the different percentage of the time. The calculation uses four variations of the percentage of time of an average year, those are at 0.01%, 0.1 %, 1%, and 2%. The attenuation value is calculated in Kototabang, Rancabungur, Pare-pare, and Biak at a frequency of 20 GHz. The value percentage of time of an average year that is chosen for the calculation affects the attenuation value; the greater the percentage of the time, the lower the attenuation value. Figure 3 shows the rain attenuation value at the frequency of 20 GHz. In frequency of 20 GHz, attenuation value in Kototabang is 36.6 dB, 0.01 dB, 12.38 dB, 4.24 dB, 2.53 dB, Rancabungur is 39.19 dB, 13.78 dB, 4.47 dB, 2.66 dB, Pare-Pare is 40.54 dB, 13.95 dB, 4.59 dB, 2.73 dB, in Biak is 75.89 dB, 24.52 dB, 7.55 dB, 4.41 dB for percentage of time 0.01%, 0.1 %, 1%, and 2%. There can be concluded that the decreasing value of rain attenuation corresponds to the given percentage of time value. When the value of exceeded time increases, then the value of the rain attenuation becomes smaller. When calculating the rain attenuation value, choose the suitable percentage of time that match the needs of desired communication performance to provide the suitable link margin. For further estimation, this paper uses the value of rain attenuation at 1% percentage time because the value has been meeting the requirement of communications satellite performance that has been designed.

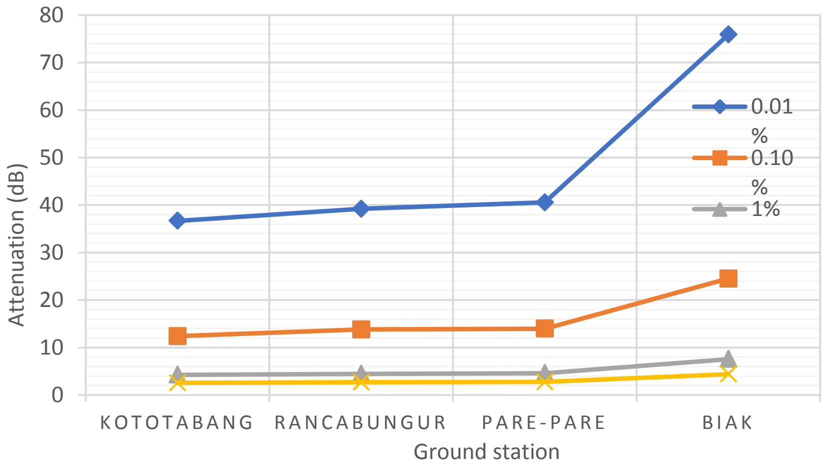

Figure 3. Variation of the percentage of time using ITU-R model.

3.3. Attenuation value based on amount rainfall from BMKG

Table 3. The amount of rainfall and the number of rainy days at BMKG observation station.

Year		**2013**		**2014**		**2015**	
No	Province	the amount of rainfall (mm)	the number of rainy day	the amount of rainfall (mm)	the number of rainy day	the amount of rainfall (mm)	the number of rainy day
1	Sumatera Barat	4627.4	232	2838.4	163	3548	185
2	Jawa Barat	2682	240	2388	226	2199.3	177
3	Sulawesi Selatan	3973	213	2739	190	3382	155
4	Papua	4033	251	2731	202	1265.9	168

Table 4. Rain distribution based on BMKG observation.

Rain rate	**BMKG Observation Station**			
	Sicincin	Kemayoran	Hasanudin	Fakfak
1mm/day	49.31%	30.13%	43.82%	50.68%
20mm/day	21.91%	8.76%	16.43%	15.89%
50mm/day	9.58%	2.73%	4.10%	4.79%
100mm/day	1.64%	0.54%	0.82%	1.09%
Not rainy	17.56%	57.84%	34.83%	27.55%

Table 5. Rain Attenuation Value using Rainfall BMKG

No	**GroundStation**	**Rain Attenuation Value (dB)**	
		BMKG Rainfall	ITU-R 1%
1	Kototabang	0.601	4.245
2	Rancabungur	0.425	4.475
3	Pare-Pare	0.701	4.597
4	Biak	0.473	7.557

Table 3 shows the value of several province in Indonesia rainfall in 2013-2015. Rainfall value in West Sumatera province is taken to represent rainfall of Kototabang area, West Java into Rancabungur area, South Sulawesi representing Pare-Pare area, and Papua representing Biak area.The value in the Table 5 is a comparison of rain attenuation values using rainfall data from BMKG observation stations obtained from the Central Statistics Agency and ITU-R. The Differences in rain attenuation values can be seen in the table 5. Based on table 5 can be seen the rain attenuation using BMKG rainfall data are in Kototabang 0.601 dB, Rancabungur 0.425 dB, Pare-pare 0.7012 dB, Biak 0.473 dB. Whereas by using rainfall parameter ITU-R rain attenuation value are in Kototabang 4.245 dB, Rancabungur 4.475 dB, Pare-pare 4.597 dB, Biak 0.473 dB. Differences in rainfall attenuation values are caused by differences in rainfall parameters. In the ITU-R method the value of rainfall distribution is considered the same for each Indonesian region. To obtain more accurate attenuation value data for certain regions in Indonesia can use rainfall data issued by BMKG. The attenuation values obtained using ITU-R can be used for initial design on link margin design.

4. Conclusion

According deviation value between BMKG rain data with three methods is used, the result of the calculation with ITU-R model is the closest. Based on the data generated as well, the authors concludes ITU-R model is the most suitable for use in Indonesia country. This method can be varied the value of latitude and height of the area. Also, this model can be implemented in many frequencies and elevation angles, also reduce the probability of error during calculation.

Acknowledgement

The authors would like to thank Wahyudi Hasbi, Nayla Najati, and Robertus Heru Triharjanto for their supervision and Satellite Technology Center, National Institute of Aeronautics and Space for supporting in this research.

References

[1] K.P.S Sudarshana and A.T.L.K. Samarasinghe 2011 *Rain Rate and Rain Attenuation Estimation for Ku Band Satellite Communications over Sri Lanka* International Conference on Industrial and Information Systems
[2] F. Moupfouma and L. Martin 1995 *Modeling of the Rainfall Rate Cumulative Distribution for the Design of Satellite and Terrestrial Communication Systems* Int. J. Sat. Communication vol. 13 pp 105-115
[3] M. R. Islam, M.A. Rahman, S. K. Eklas Hossain and M. S. Azad 2008 *Rainfade analysis on earth-space microwave link in a subtropical region* Dhaka Bangladesh 5th International Conference on Electrical and Computer Engineering (ICECE2008) pp 793-798
[4] Ippolito and Louis J 2008 Satellite Communication Systems Engineering: *Atmospheric Effects, Satellite Link Design, and System Performance*: John Wiley & Sons Inc
[5] International Telecommunication Union 1995 ITU-R Rec. P.618-8 *Propagation data and prediction methods required for the design of earth-space telecommunication system* Geneva Switzerland
[6] International Telecommunication Union 2003 ITU-R Rec. P.8347-4 *Characteristic of precipitation for propagation modelling* Geneva
[7] International Telecommunication Union 2005 ITU-R Rec.P.838-3 *Specific attenuation model for rain use in prediction methods* Geneva
[8] International Telecommunication Union 2001 ITU-R Rec. P.389-3 *Rain height model for prediction methods* Geneva
[9] J. S. Mandeep and J. E. Allnutt 2007 *Rain Attenuation Predictions at Ku-Band in South East Asia Countries* Progress in Electromagnetic Research vol 76 pp 65-74
[10] J. S. Ojo and M.O. Ajewole 2008 *Rain rate and rain attenuation prediction for satellite communication in ku and ka bands over Nigeria* Progress in Electromagnetics Research B vol 5 pp 207-223
[11] R.K. Crane, 'Prediction of attenuation by rain,' IEEE Trans. Comm., Vol. COM-28, No. 9, pp. 1717-1733, Sept. 1980.
[12] Dissanayake, J. Allnutt, F. Haidara, A prediction model that combines rain attenuation and other propagation impairment along earth-satellite paths, IEEE Transactions Antennas Propagation, vol. 45, pp. 1558-1564, 1997.
[13] Propagation data and prediction methods required for the design of Earth-space telecommunication systems, ITU-R P.618-10, 2009.