Study of Nusantara Satu Satellite parameter evaluation for broadband application in Indonesia

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Abstract. This study aims to evaluate the performance of Satellite Nusantara Satu which has just been launched. Nusantara Satu Satellite is a broadband satellite that uses High Throughput Satellite (HTS) technology and uses Ku-band transponders to cover all regions in Indonesia. However, the use of Ku-band frequencies in Indonesia, which is located at a tropical region, must be evaluated because of the characteristics of the Ku-band frequency are very vulnerable to rain attenuation. In general, a broadband service requires link availability of 99.9% with a minimum speed of 100 Mbps. Our simulation results show that in the western part of Indonesia, to reach 100 Mbps with 99.9% link availability, the EIRP of the earth station VSAT is minimum at 79 dBW. In the central part of Indonesia, to reach speeds of 100 Mbps with 99.9% link availability, the EIRP of the earth station VSAT is minimum at 83 dBW. And in the eastern part of Indonesia, to reach speeds of 100 Mbps with 99.9% link availability, the EIRP of the earth station VSAT is minimum at 84 dBW.

1. Introduction
An industrial revolution 4.0 era requires high-speed data services. In order to improve internet quality and broaden the network, Indonesian government launched a satellite called Nusantara Satu Satellite on February 18th, 2019. Nusantara Satu Satellite was placed in a position above the equator at 146°E and moved simultaneously with the earth rotation. To cover all regions in Indonesia, Nusantara Satu Satellite has the capacity of 26 C-band transponders and 12 Extended C-band transponders, as well as 8 Ku-band spot beams with a total bandwidth capacity of 15 Gbps. The use of Ku-band frequencies on Nusantara Satu Satellite is to avoid terrestrial microwave systems interference that use more C-Band frequencies, and Ku-band frequencies also have greater bandwidth. Thus, the use of Ku-band frequencies can support high-speed services. Indonesia is a developing country that has a tropical climate. The implementation of Ku-band satellite in this country is a challenge because Ku-band has a frequency of 12 GHz for downlink and 14 GHz for uplink. The tropics have quite high rainfall, while satellite frequencies above 10 GHz are very vulnerable to rain. This causes greater attenuation to the Ku-Band frequency, increases signal quality in satellite communications, and decreases its availability link. In implementing satellite Ku-bands in the tropical area, a link budget with the right calculation is required.

Rain attenuation limits the communication distance from radio communication systems and also limits the use of higher frequencies, both in terrestrial microwave link communication systems and in satellite communication systems. In general, there are two approaches used in research on rain
attenuation, namely theoretical approaches and empirical approaches [1]. In the theoretical approach, the difference in random rainfall (including the shape of the raindrops, the diameter of the raindrops and the distribution of precipitation) causes electromagnetic waves to experience diffraction, absorption and multipath effects on their propagation. Theoretical approach uses a scattering volume model and a rain grain size distribution model to estimate and calculate the amount of rain attenuation. In the empirical approach, the relationship between rainfall and signal attenuation, the influence of climate regional differences and the efficiency of communication are collected statistically to create an empirical model.

In the tropics there have been many studies on attenuation due to raindrops. In Singapore [2,3] conducted several studies of rain attenuation on electromagnetic waves with empirical and theoretical models. Reference [4-7] had carried out several researches about empirical model from cumulative rainfall obtained by changing cumulative rainfall model from rain gauge and rain attenuation. Rainfall attenuation researches were also carried out on satellite links - earth stations on [4,8-11] in contribution to make a satellite channel model - earth station. International Telecommunication Union (ITU) through its other body, International Radio Consultative Committee (CCIR), built several earth stations to observe and analyze various propagation attenuation mechanisms in the atmosphere throughout the world. The rain zones in various parts of the earth have been mapped by the ITU and documented in [7]. The importance of this paper is Nusantara Satu Satellite just launched few months ago and it is important to simulate its performance to cover few places/cities in Indonesia for broadband communication. This paper describes the calculation of a one-way link budget from Jakarta - Medan, Jakarta - Banjarmasin and Jakarta - Jayapura with Ku-band HTS which is divided into 8 spot beams where Jakarta is located on beam 3, Medan on beam 1, Banjarmasin on beam 7 and Jayapura on Beam 8.

2. Theoretical foundations

2.1. Gain
Gain is how much output power compared to the input power of a system. If there is a strengthening in the system, then the output power will be greater than the input power.

\[ G_{\text{max}} = \left( \frac{4\pi}{\lambda^2} \right) A_{\text{eff}} \]  

(1)

where \( G_{\text{max}} \) is the maximum gain, \( \lambda \) is the wavelength (m), \( A_{\text{eff}} \) is the effective aperture of the antenna (m²) and \( \pi \) is 3.14. The wavelength value is obtained from \( \lambda = c/f \) where \( c \) is the speed of light (3.108 m / s) and \( f \) is the frequency used by the antenna. For an antenna with an aperture or a circular reflector, the formula is:

\[ A_{\text{eff}} = \eta \left( \frac{\pi D^2}{4} \right) \]  

(2)

where \( \eta \) is the efficiency of an antenna with a value of 60% to 75% and \( D \) is the antenna diameter (m).

Therefore, by combining (1) and (2), the gain in dBi unit is obtained as follows:

\[ G_{\text{max}} = 10 \log \left[ \eta \left( \frac{\pi D f}{c} \right)^2 \right] \text{dBi} \]  

(3)

2.2. Transmitted and received power
To calculate the transmit power and antenna receiving power, the antenna power value multiplied by the antenna gain will produce an antenna EIRP with the formula as follows [8]:

\[ EIRP = P_t G_t \text{(W)} \]  

(4)
where $P_t$ is antenna power (watts) and $G_t$ is antenna gain. Furthermore, a receiving antenna that has an effective area of $A_e$, will have the power of $P_r$ with the following formula:

$$P_r = P_t G_t \frac{A_e}{4\pi d^2}$$  \hspace{1cm} (5)

The above equation can also be stated as follows:

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2$$  \hspace{1cm} (6)

where $G_r$ is the strengthening of the receiving antenna, $\lambda$ is the wavelength used, and $(4\pi d/\lambda)^2$ is a quantity known as free space loss which can also be stated as follows:

$$L_{FSL} = 92.45 + 20 \log f + 20 \log d$$  \hspace{1cm} (7)

where $L_{FSL}$ is free space loss (dB), $f$ is the frequency (GHz) and $d$ is the distance between the satellite and the earth station (km).

2.3. Rain attenuation

The rain attenuation formula in general is [9]:

$$A(dB) = aR^b L(R)$$  \hspace{1cm} (8)

where $A$ is the attenuation value (dB), $a$ and $b$ are constants that depend on frequency, $R$ is rainfall (mm/h), $L(R)$ is the parameter of the path length which is the $R$ function.

2.4. Distance and elevation angle

With this data, the elevation angle of the antenna and the actual distance from the earth station to the satellite can be found in [10]:

$$E = \tan^{-1}\left(\frac{r - R_e \cos \phi \cos \theta_S - \theta_S}{R_e \sin \phi \cos \theta_S \cos \theta_S \sin \theta_S - \theta_S}\right) - \cos^{-1}\left(\cos \phi \cos \theta_S - \theta_S\right)$$  \hspace{1cm} (9)

where $E$ is the elevation angle (°), $r$ is the distance from the center of the earth to the satellite (42164.2 km), $R_e$ is the radius of the earth (6378,155 km), $\phi$ is the earth station latitude (°), $\theta_S$ is the satellite longitude (°) and $\theta_S$ is the longitude of the earth station (°). From the value of the elevation angle obtained, the distance between the earth station and the satellite can be calculated by the following formula:

$$d^2 = (R_e + H)^2 + R_e^2 - 2R_e(R_e + H)\sin\left[ E + \sin^{-1}\left(\frac{R_e \cos E}{R_e + H}\right)\right]$$  \hspace{1cm} (10)

where $H$ is the height of the geostationary satellite from the earth surface, which is about 36000 km.

3. Method and parameters

3.1. Satellite parameter

Nusantara Satu Satellite is a broadband satellite that uses High Throughput Satellite (HTS) technology and uses K-band transponders to cover all regions in Indonesia. There are eight beams to cover all of Indonesia region. Table 1 describes the parameters of the Nusantara Satu Satellite. EIRP and G/T value are vary depending on the beam of satellite.
Table 1. Satellite parameters.

| Parameters                  | Value | Unit   |
|-----------------------------|-------|--------|
| Satellite Location          | 146   | Degree East |
| **Beam 1-6 (Jakarta & Medan)** |       |        |
| EIRP                        | 59    | dBW    |
| Satellite G/T               | 11.8  | dB/K   |
| **Beam 7 (Jakarta & Banjarmasin)** |   |        |
| EIRP                        | 54    | dBW    |
| Satellite G/T               | 8     | dB/K   |
| **Beam 8 (Jayapura)**       |       |        |
| EIRP                        | 53    | dBW    |
| Satellite G/T               | 7     | dB/K   |

3.2. Rainfall rate measurements cities in Indonesia

Every place has rainfall rate. In the ITU-R P.837 recommendation [7], it is stated that Indonesia is in the rain zone type P with rainfall values for a percentage of time of more than 0.01% having less or equal rainfall intensity values with 100 mm/hour. The rainfall prediction model Crane [1] stated that Indonesia is in the H type rain area with rainfall values for a percentage of time more than 0.01% having a rainfall intensity value of less than or equal to 209.3 mm/hour [11].

Basically, ITU and Crane rain prediction model are a point rain rate, which means that the intensity of rainfall is measured at a certain point and the cumulative rainfall distribution calculation procedure for rain attenuation calculations can be done by using the point rainfall model. Differences in rainfall prediction models between ITU and Crane can occur due to differences in measurement data held including the place where measurements are made, length of measurement and age of the model.

Table 2 shows the rainfall rates in Jayapura, Jakarta, Medan and Banjarmasin are strong (R<sub>0.01</sub>). At high frequencies such as K<sub>u</sub>-band, satellite performance is affected by high rainfall levels [10].

Table 2. Rainfall rate.

| City           | Altitude | Latitude | Longitude | R<sub>0.01</sub> |
|----------------|----------|----------|-----------|-------------------|
| Jayapura       | 210      | -2.37    | 140.69    | 113.9             |
| Jakarta        | 5        | -6.15    | 106.8     | 120.4             |
| Medan          | 49       | 3.57     | 98.6      | 126.2             |
| Banjarmasin    | 0        | -5.27    | 105.1     | 123.3             |

4. Link budget calculation and simulation results

The following tables will shown the parameters in the K<sub>u</sub>-band beam of Nusantara Satu Satellite link and the results of the calculation of link budget K<sub>u</sub>-Band satellites for broadband applications with 99.9% link availability and 100 Mbps speed. Table 3, Table 4 and Table 5 show link budget calculation for Jakarta – Medan link, Jakarta – Banjarmasin link and Jakarta – Jayapura link, respectively.
Table 3. Link budget calculation for Jakarta – Medan satellite link.

| No  | Link Parameters Jakarta – Satellite – Medan |
|-----|--------------------------------------------|
|     | Uplink (Jakarta – Satellite)               |
| 1   | EIRP Station at Jakarta                     | 79  | dBW |
| 2   | Total Losses at Jakarta                    | 232.28 | dB |
|     | Satellite Parameter                        |
| 3   | Satellite Noise Figure (G/T)               | 11.8 | dB/K |
| 4   | C/N₀ uplink                                | 86.88425045 | dB |
| 5   | C/I uplink                                 | 15  | dB |
| 6   | E₀/N₀                                      | 5.980754507 | dB |
|     | Downlink (Satellite – Medan)               |
| 7   | Total Losses at Medan                      | 212.368861 | dB |
| 8   | Rx Noise Temperature                       | 61  | K   |
| 9   | Rx Antenna Noise Temperature               | 26  | K   |
| 10  | Feeder Noise Temperature                   | 290 | K   |
| 11  | Medan Station Antenna G/T                  | 22.33093212 | dB/K |
| 12  | C/N₀ downlink                              | 97.5620711 | dB |
| 13  | C/I downlink                               | 15  | dB |
| 14  | E₀/N₀ downlink                             | 11.87 | dB |
| 15  | C/N₀ total                                 | 86.52 | dB |
| 16  | E₀/N₀ total                                | 4.98 | dB |
| 17  | E₀/N₀ required                             | 4.7 | dB |
| 18  | Margin                                     | 0.28 | dB |

From the link budget calculation that shows in Table 3, to reach 100 Mbps with 99.9% link availability, the EIRP of the earth station VSAT at Jakarta is minimum at 79 dBW. The greatest attenuation is contributed by free space loss and rain attenuation. With the parameters described in Table 1 and Table 2, E₀/N₀ is obtained in the Earth station in Medan about 4.98 dB. The E₀/N₀ required setting is 4.7 dB, so the satellite channel link margin is 0.28 dB.

Table 4. Link budget calculation for Jakarta – Banjarmasin satellite link.

| No  | Link Parameters Jakarta – Satellite – Banjarmasin |
|-----|--------------------------------------------------|
|     | Uplink (Jakarta – Satellite)                     |
| 1   | EIRP Station at Jakarta                           | 83  | dBW |
| 2   | Total Losses at Jakarta                           | 32.23 | dB |
|     | Satellite Parameter                               |
| 3   | Satellite Noise Figure (G/T)                     | 8   | dB/K |
| 4   | C/N₀ uplink                                      | 87.27 | dBHz |
| 5   | C/I uplink                                       | 15  | dB |
| 6   | E₀/N₀                                           | 6.29 | dB |
|     | Downlink (Satellite – Banjarmasin)               |
| 7   | Total Losses at Banjarmasin                      | 212.07 | dB |
| 8   | Rx Noise Temperature                             | 61  | K   |
| 9   | Rx Antenna Noise Temperature                     | 26  | K   |
| 10  | Feeder Noise Temperature                         | 290 | K   |
| 11  | Banjarmasin Station Antenna G/T                  | 22.33 | dB/K |
| 12  | C/N₀ downlink                                    | 92.85 | dB |
| 13  | C/I downlink                                     | 15  | dB |
| 14  | E₀/N₀ downlink                                   | 10.03 | dB |
| 15  | C/N₀ total                                       | 86.21 | dB |
| 16  | E₀/N₀ total                                      | 4.76 | dB |
| 17  | E₀/N₀ required                                   | 4.7  | dB |
| 18  | Margin                                          | 0.06 | dB |

From the link budget calculation that shows in Table 4, to reach 100 Mbps with 99.9% link availability, the EIRP of the earth station VSAT at Jakarta is minimum at 83 dBW. Same with the other link, the greatest attenuation is contributed by free space loss and rain attenuation. With the parameters described
in Table 1 and Table 2, $E_b/N_0$ is obtained in the Earth station in Banjarmasin about 4.76 dB. The $E_b/N_0$ required setting is 4.7 dB, so the satellite channel link margin is 0.06 dB.

### Table 5. Link budget calculation for Jakarta – Jayapura satellite link.

| No. | Uplink (Jakarta – Satellite) | Link Parameters Jakarta – Satellite - Jayapura |
|-----|-----------------------------|-----------------------------------------------|
| 1   | EIRP Station at Jakarta     | 84 dBW                                        |
| 2   | Total Losses at Jakarta     | 231.48 dB                                     |
| 3   | Satellite Noise Figure (G/T)| 7 dB/K                                        |
| 4   | $C/N_0$ uplink              | 88.96 dBHz                                    |
| 5   | $C/I$ uplink                | 15 dB                                         |
| 6   | $E_b/N_0$                   | 7.58 dB                                       |
| 7   | Downlink (Satellite – Jayapura) | Total Losses at Jayapura 211.82 dB           |
| 8   | $C/N_0$ downlink            | 92.10 dB                                     |
| 9   | $C/I$ downlink              | 15 dB                                         |
| 10  | $E_b/N_0$ downlink          | 9.62 dB                                      |
| 11  | $C/N_0$ total              | 87.24 dB                                     |
| 12  | $E_b/N_0$ total            | 5.47 dB                                      |
| 13  | $E_b/N_0$ required         | 4.7 dB                                       |
| 14  | Margin                      | 0.77 dB                                      |

From the link budget calculation that shows in Table 5, to reach 100 Mbps with 99.9% link availability, the EIRP of the earth station VSAT at Jakarta is minimum at 84 dBW. Same with the other link, the greatest attenuation is contributed by free space loss and rain attenuation. With the parameters described in Table 1 and Table 2, $E_b/N_0$ is obtained in the Earth station in Jayapura is about 5.47 dB. The $E_b/N_0$ required setting is 4.7 dB, so the satellite channel link margin is 0.77 dB.

### 5. Conclusion

The link budget calculation on the K_s-Band satellite link for communication between Jakarta – Medan, Jakarta – Banjarmasin and Jakarta – Jayapura, is an appropriate link with speeds of 100 Mbps with 99.6% link availability. Besides of that, the magnitude of the transmission power at the earth station in Jakarta is highly different from the earth station in Medan, Banjarmasin and Jayapura. The EIRP of the earth station VSAT in the western part of Indonesia is minimum at 79 dBW. In the central part of Indonesia, the EIRP of the earth station VSAT is minimum at 83 dBW. And in the eastern part of Indonesia, the EIRP of the earth station VSAT is minimum at 84 dBW. However, in general, the simulation of the link budget calculation can be used to get an accurate results by putting the accurate parameters.

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