# A Case Study in User Capacity Planning for Low Earth Orbit Communication Satellite

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***Abstract*—Nowadays, Indonesia as archipelago country is focusing on strengthening their competitive advantage in boosting the capability and development of satellite technology especially in providing communication link for rural area in Indonesia. Currently, low earth orbit satellites constellation is the best choice to complement terrestrial networks, and one of the most important process of the communication satellite design is user capacity planning. In the proposed design, user capacity planning became a determining factor whether the satellite is feasible to be implemented. With benchmarking to TELESAT Low Earth Orbit (LEO), this paper aims to calculate and analyze user capacity in proposed low earth orbit communication satellite design using throughput calculation. The result of this communication satellite planning can provide services up to 74,746 user uplinks and 9,753 user downlinks. This paper also explores power variations of the power transmission which able to confirms the feasibility of the proposed design, where the user capacity in the lowest power scenario is 25,299 user uplinks and 6,705 user downlinks.**

***Keywords—capacity planning, throughput, communication satellite, low earth orbit***

## I. Introduction

Indonesia as one of the largest archipelago country in the world has many rural areas. Therefore, to build terrestrial networks will need enormous cost. Satellite is the most powerful complementary of terrestrial networks especially in rural area. Furthermore, in the last decade, the development of communication satellite can provide a capability which is par to terrestrial networks by using a LEO (Low Earth Orbit) constellation satellites. LEO satellite has shorter delay and low propagation loss compared to MEO and GEO satellites [1]. Along with Ku-Ka band which provides benefits of having a larger bandwidth, LEO satellites are capable in delivering high speed data transfer [2]. Another merit of LEO constellation satellites is its micro size, hence the lowest possible cost can be achieved.

However, these advantages came with many challenges that need to be solved. First, routing problem of LEO satellites constellation which is usually composed of tens satellites is more complicated than that of GEO and MEO satellite network [1]. Thus, it affect handover mechanism that must be well designed, where advanced procedure handover required because the LEO satellites constellation move at very fast speed [5]. Second, the rain attenuation has a very severe impact on the quality of satellite links [3] because LEO satellite system will be operated at higher frequency.

Therefore, the design of the satellite becomes a very crucial factor to get the most performance for the money spent. In [4], there are four important steps to design satellite which divided into several sub-steps. The process starts from define objectives, characterize the mission, evaluate the mission, and define requirements. All of the process determine how well the performance and how much the cost obtained. User capacity planning is one of the process that will define whether the cost is worthed, and becomes the basis in calculating satellite revenue potential. With the comparison to the amount of capital that needs to be invested, user capacity planning became a determining factor whether the satellite is feasible to be implemented.

The proposed communication satellite is a constellation of 9 satellites in low earth orbit. While it is still in design phase, the optimization of the design is widely open, and one of them is concerning user capacity planning. This paper aims to calculate and analyze user capacity for proposed design of communication satellite. The calculation conducted in this paper is limited to satellite throughput from link budget calculation benchmarked to the TELESAT LEO satellite's parameter. Conducting both calcuation of user capacity on TELESAT LEO satellites and the proposed design, the result is then compared to evaluate whether the proposed design is feasible to be developed.

With exploration in power limit or link budget, this paper also conducted calculation in link budget with power variation which results in deviation of the number of user. The evaluation of this exploration will be used to understand the limitation of power variation in the proposed design.

## II. Proposed Design

This section will examine the requirements of the proposed design of communication satellite. These requirements are defined following the satellite purpose as the complementary of terrestrial network in rural areas. The requirements of the proposed design of the communication satellite is divided into two subsections, satellite requirements and user requirements.

### A. Satellite Requirements

The proposed design of communication satellite is following some initial requirements which manage limitations and purposes of the satellite. The communication satellite is a microsatellite which arranged to orbit in low earth orbit (LEO) with altitude 1200 km, and have 9 satellites in 1 orbital plane.

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Because the purpose of the satellite is to serve the Indonesian region which is all around the equator, the orbit inclination of 0 to 2 degrees is established. By determining the inclination, the proposed design is expected to be optimal for serving all regions in Indonesia, especially in remote areas. The proposed frequency is set to 20.15 GHz for downlink, and 20 GHz for Uplink, with 7 spot-beams appointed for each downlink and uplink.

Other satellite that would be very similar to this proposed design is TELESAT LEO which uses 2 sets of orbits with 9 satellites on each orbital plane. TELESAT LEO also operate at altitude of 1248 km which is similar with the proposed design. There are slight differences on frequencies of TELESAT LEO, which sets to 17.8 - 20.2 GHz for the downlink and 27.5 – 30 GHz for the uplink. Other dissimilarity is on the number of spot-beams, where the TELESAT LEO produce 16 spot-beams for each uplink and downlink.

### B. User Requirements

User requirements are determined based on the needs in Indonesia. The communication satellite is also intended to serve the business sector in rural areas, especially the tourism industry, including hotels, restaurants and all other businesses related to the industry. The reason for this choice is because the tourism industry has become the second largest foreign exchange, and widely available in rural areas.


Graph 1 Number of hotel and restaurant growth

Based on data from Central Bureau of Statistics (BPS) [14, 15], the number of hotels throughout Indonesia in 2010-2016 had a growth trend of 11% per year, while the number of medium to upper class restaurants in 2007-2011 had a growth trend of 17%. As presented in graph 1, it is estimated that the number of hotels and restaurants in Indonesia in 2020 is around 3626 hotels and 12245 restaurants.

## III. User Capacity Planning

User capacity planning is one part of the process in satellite design which has an important role to give prediction of the number of users. Using this information, revenue potential of satellite can be calculated and will be compared to the cost of production and deployment satellite.

### A. Link Budget

Link budget is a way to calculate all parameters in signal transmission from transmitter to receiver through transmission media. There are many parameters calculated in link budget starting from transmit power, gain, loss, attenuation, noise, receiver gain [6], etc. The parameter needed to calculate user capacity planning is throughput. Nevertheless, to get the value of throughput, other parameters must be calculated accurately. Some important reviews of these parameters are as follows.

*1) Effective Isotropic Radiated Power (EIRP):* a combination of transmitter power and antenna gain which transmitted uniformly in all directions. Mathematically, EIRP can be formulated as [11]

$$[EIRP] = [P_{hpa}] - [tfl] + [G_{es}] \quad (1)$$

where $[P_{hpa}]$ refers to transmitted power, $[tfl]$ refers to transmitter to antenna line loss and $[G_{es}]$ refers to antenna gain.

*2) Figure of merit (G/T ratio):* a parameter in link budget which is used to specify system performance. The formula of G/T ratio can be expressed as [12]

$$[G/T] = [G] - [T_s] \ (in \frac{dB}{K}) \quad (2)$$

where $[G]$ refers to antenna gain of the satellite or ground station and $[T_s]$ refers to system noise temperature.

*3) Carrier to noise density ratio:* the ratio of carrier power to noise density [12]

$$[C/N_o] = [EIRP] - [fsl] + \left[\frac{G}{T}\right] + Boltzman\ constant \quad (3)$$

where $[fsl]$ refers to free space loss and Boltzman constant refers to 228.6 (dB).

*4) Energy per bit to noise density :* the ratio of carrier power to noise density [13]

$$[E_b/N_o] = [C/N_o] - [R_b] \quad (4)$$

where $[R_b]$ refers to bit rate (dB).

Sample of clear sky uplink and downlink budget for TELESAT LEO have been provided in Table 1 which is derived from TELESAT exhibit [7]. Hereby as a reference, the proposed communication satellite uplink and downlink budget is calculated. This can be done because as stated in the previous chapter, the proposed design has many similarities in some specifications. Link budget for the proposed design have been provided in Table 2.

Table 1 : TELESAT LEO link budget

| Parameter | Uplink | Downlink |
|---|---|---|
| **Effective Isotropic Radius Power (EIRP) (dBW)** | 47.3 | 17.5 |
| **Free Space Loss (Path Loss) (dB):** | -188.922 | -185.169 |
| **D (Km)** | 2341 | 2341 |
| **F (GHz)** | 28.5 | 18.5 |
| **λ (m)** | 0.010526 | 0.016216 |
| **Atmospheric Loss (dB)** | -0.3 | -0.2 |
| **G/T (dB/K)** [a] | 7.205811 | 20.48 |
| **Boltzman Constant (dB)** | -228.599 | -228.599 |
| **Bandwidth (dB)** | 70 | 70 |
| **Bit Rate (dB)** | 77.78151 | 75.2304 |
| **FEC Rate (dB)** | 0.8 | 0.833 |
| **C/No (dBHz)** | 93.88266 | 81.21031 |
| **Eb/No (dB)** | 16.10114 | 5.979905 |
| **C/N (dB)** | 23.88266 | 11.21031 |
| **C/I ASI from GSO (dB)** | 20.2 | 29.9 |
| **C/I Xpol (dB)** | 25 | 25 |
| **C/I IM (dB)** | 25 | 20 |
| **C/N+I (dB)** | 16.9974 | 10.46417 |
| **Required C/N+I (dB)** | 15.9 | 9.3 |
| **Eb/No+I (dB)** | 13.93456 | 5.74239 |
| **Required Eb/N0+I (dB)** | 13.03491 | 5.103533 |
| **Implementation Margin** | 0 | 0 |
| **Link Margin (Eb/No+I)** | 0.899652 | 0.638857 |
| **Link Margin (C/N+I)** | 1.097397 | 1.164167 |
| [a] G/T satellite for uplink and G/T ground station for downlink. | | |

Table 2 : Proposed communication satellite link budget

| Parameter | Uplink | Downlink |
|---|---|---|
| **Effective Isotropic Radius Power (EIRP) (dBW)** | 47.3 | 17.5 |
| **Free Space Loss (Path Loss) (dB):** | -186.354 | -186.419 |
| **D (Km)** | 2482 | 2482 |
| **F (GHz)** | 20 | 20.15 |
| **λ (m)** | 0.015 | 0.014888 |
| **Atmospheric Loss (dB)** | -0.3 | -0.2 |
| **G/T (dB/K)** [a] | -12.5942 | 15 |
| **Boltzman Constant (dB)** | -228.599 | -228.599 |
| **Bandwidth (dB)** | 70 | 70 |
| **Bit Rate (dB)** | 72.10853 | 69.82445 |
| **FEC Rate (dB)** | 0.8 | 0.833 |
| **C/No (dBHz)** | 76.65095 | 74.48023 |
| **Eb/No (dB)** | 4.542413 | 4.655785 |
| **C/N (dB)** | 6.650946 | 4.480235 |
| **C/I ASI from GSO (dB)** | 20.2 | 29.9 |
| **C/I Xpol (dB)** | 25 | 25 |
| **C/I IM (dB)** | 25 | 20 |
| **C/N+I (dB)** | 6.343263 | 4.310741 |
| **Required C/N+I (dB)** | 4.811573 | 3.17572 |
| **Eb/No+I (dB)** | 4.350504 | 4.47944 |
| **Required Eb/N0+I (dB)** | 3.3 | 3.3 |
| **Implementation Margin** | 0 | 0 |
| **Link Margin (Eb/No+I)** | 1.050504 | 1.17944 |
| **Link Margin (C/N+I)** | 1.53169 | 1.135022 |
| [a] G/T satellite for uplink and G/T ground station for downlink. | | |

## B. *Planning by throughput*

Planning by throughput aims to determine the number of users that can be served by satellites based on the throughput supported by satellites. In this method, the throughput value will be the basis for calculating the total users. The satellite throughput will be compared to the required throughput for one user called single user throughput.

Planning by throughput calculation is approached by calculation in LTE system, because the expected service from satellite similar to service provided by LTE. Furthermore, the objective of this satellite planning is become the complementary network for LTE system in rural area.

To maintain the quality of satellite services, it is necessary to estimate throughput value that must be provided by a network. Throughput per session is a minimum throughput that must be provided to maintain the quality of service (Kbit). The throughput per session is calculated based on the following equation [8, 9]

$$\frac{Throughput}{Session} = Bearer\ Rate\ \times PPP\ Session\ Time\ \times PPP\ Session\ Duty\ Ratio \times \left[\frac{1}{1-BLER}\right] \quad (5)$$

where *Bearer Rate* (Kbps) refers to data rate that the service application layer should provide, *PPP Session Time* (seconds) refers to average duration of each service, *PPP Session Duty Ratio* refers to ratio of data sent per session, and *BLER* refers to block error rate allowed in every session. The calculation of throughput per session provided in table 3 and table 4.

Table 3 : Uplink throughput per session [8]

| Traffic Parameter | Uplink | | | | UL Throughput/ Session (Kb) |
|---|---|---|---|---|---|
| | Bearer Rate (Kbps) | PPP Session Time (s) | PPP Session Duty Ratio | BLER (%) | |
| **VoIP** | 26.90 | 80 | 0.40 | 1% | 869 |
| **Video Phone** | 62.53 | 70 | 1.00 | 1% | 4,421 |
| **Video Conference** | 62.53 | 1,800 | 1.00 | 1% | 113,691 |
| **Real Time Gaming** | 31.26 | 1,800 | 0.20 | 1% | 11,367 |
| **Streaming Media** | 31.26 | 3,600 | 0.05 | 1% | 5,684 |
| **IMS Signalling** | 15.63 | 7 | 0.20 | 1% | 22 |
| **Web Browsing** | 62.53 | 1,800 | 0.05 | 1% | 5,685 |
| **File Transfer** | 140.69 | 600 | 1.00 | 1% | 85,267 |
| **Email** | 140.69 | 50 | 1.00 | 1% | 7,106 |
| **P2P File Sharing** | 250.11 | 1,200 | 1.00 | 1% | 303,164 |

Table 4 : Downlink throughput per session [8]

| Traffic Parameter | Uplink | | | | UL Throughput/ Session (Kb) |
|---|---|---|---|---|---|
| | Bearer Rate (Kbps) | PPP Session Time (s) | PPP Session Duty Ratio | BLER (%) | |
| VoIP | 26.90 | 80 | 0.40 | 1% | 869 |
| Video Phone | 62.53 | 70 | 1.00 | 1% | 4,421 |
| Video Conference | 62.53 | 1,800 | 1.00 | 1% | 113,691 |
| Real Time Gaming | 125.06 | 1,800 | 0.40 | 1% | 90,953 |
| Streaming Media | 250.11 | 3,600 | 0.95 | 1% | 864,016 |
| IMS Signalling | 15.63 | 7 | 0.20 | 1% | 22 |
| Web Browsing | 250.11 | 1,800 | 0.05 | 1% | 22,737 |
| File Transfer | 750.34 | 600 | 1.00 | 1% | 454,752 |
| Email | 750.34 | 50 | 1.00 | 1% | 37,896 |
| P2P File Sharing | 750.34 | 1,200 | 1.00 | 1% | 909,503 |

Each user in the network has a range of throughput values as a result of services accessed during peak hours. So the calculation of single user throughput (SUT) [8, 9] is obtained from the equation as follows

$$SUT = \frac{\sum\left[\left(\frac{Throughput}{Session}\right) x\ BHSA\ x\ Penetration\ Rate\ x\ (1 + Peak\ Average\ Ratio)\right]}{3600} \quad (6)$$

where *Traffic Penetration Ratio* refers to proportion of the possibility of a service used by users in a region, *BHSA* refers to busy hour service attempt for one user, *Peak to Average Ratio* refers to the highest percentage assumption of overload on a network or added value added on the calculation to anticipate in case of traffic spikes.

From the data in table 5 and table 6, the calculation of single user throughput is provided in table 7.

Table 5 : Traffic model parameter [8]

| User Behaviour | Dense Urban | | Urban | | Sub Urban | | Rural Area | |
|---|---|---|---|---|---|---|---|---|
| | Traffic Penetration Ratio | BHSA | Traffic Penetration Ratio | BHSA | Traffic Penetration Ratio | BHSA | Traffic Penetration Ratio | BHSA |
| VoIP | 100% | 1.4 | 100% | 1.3 | 50% | 1 | 50% | 0.9 |
| Video Phone | 20% | 0.2 | 20% | 0.16 | 10% | 0.1 | 5% | 0.05 |
| Video Conference | 20% | 0.2 | 15% | 0.15 | 10% | 0.1 | 5% | 0.05 |
| Real Time Gaming | 30% | 0.2 | 20% | 0.2 | 10% | 0.1 | 5% | 0.1 |
| Streaming Media | 15% | 0.2 | 15% | 0.15 | 5% | 0.1 | 5% | 0.1 |
| IMS Signalling | 40% | 5 | 20% | 4 | 25% | 3 | 20% | 3 |
| Web Browsing | 100% | 0.6 | 100% | 0.4 | 40% | 0.3 | 30% | 0.2 |
| File Transfer | 20% | 0.3 | 20% | 0.2 | 20% | 0.2 | 10% | 0.2 |
| Email | 10% | 0.4 | 10% | 0.3 | 10% | 0.2 | 5% | 0.1 |
| P2P File Sharing | 20% | 0.2 | 20% | 0.3 | 20% | 0.2 | 5% | 0.1 |

Table 5 : Peak to average ratio [8]

| Dense Urban | Urban | Sub Urban | Rural Area |
|---|---|---|---|
| 40% | 20% | 10% | 0% |

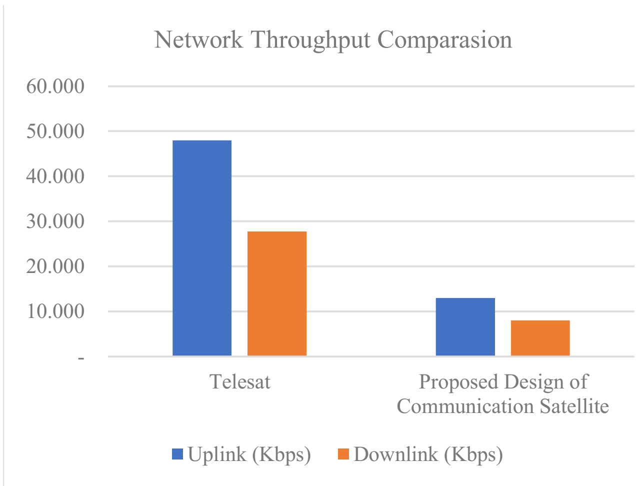
Table 6 : Single user throughput [8]

| Traffic Parameter | Dense Urban | | Urban | | Sub Urban | | Rural Area | |
|---|---|---|---|---|---|---|---|---|
| | UL | DL | UL | DL | UL | DL | UL | DL |
| VoIP | 1,704 | 1,704 | 1,356 | 1,356 | 478 | 478 | 391 | 391 |
| Video Phone | 248 | 248 | 170 | 170 | 49 | 49 | 11 | 11 |
| Video Conference | 6,367 | 6,367 | 3,070 | 3,070 | 1,251 | 1,251 | 284 | 284 |
| Real Time Gaming | 955 | 7,640 | 546 | 4,366 | 125 | 1,000 | 57 | 455 |
| Streaming Media | 239 | 36,289 | 153 | 23,328 | 31 | 4,752 | 28 | 4,320 |
| IMS Signalling | 62 | 62 | 21 | 21 | 18 | 18 | 13 | 13 |
| Web Browsing | 4,775 | 19,099 | 2,729 | 10,914 | 750 | 3,001 | 341 | 1,364 |
| File Transfer | 7,162 | 38,199 | 4,093 | 21,828 | 3,752 | 20,009 | 1,705 | 9,095 |
| Email | 398 | 2,122 | 256 | 1,364 | 156 | 834 | 36 | 189 |
| P2P File Sharing | 16,977 | 50,932 | 21,828 | 65,484 | 13,339 | 40,018 | 1,516 | 4,548 |
| SUT (Kbps) | **10.80** | **45.18** | **9.51** | **36.64** | **5.54** | **19.84** | **1.22** | **5.74** |

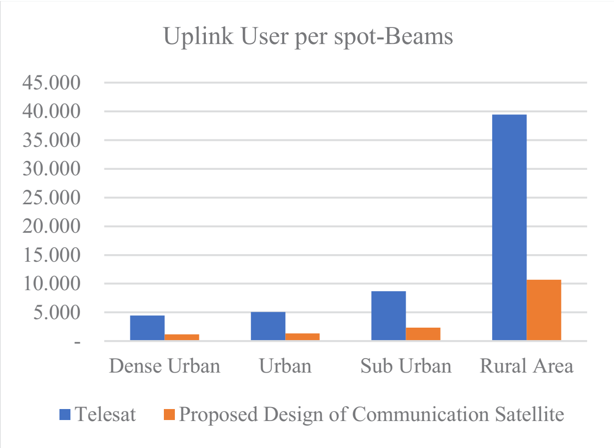
## IV. Results and Analysis

### A. User Capacity

Network throughput has been calculated using the link budget data in previous section. The comparison results of TELESAT LEO and the proposed communication satellite is demonstrated in graph 1. The graph 1 shows that there are significant gaps between TELESAT LEO and the proposed design, where in the uplink, proposed communication satellite perceiving throughput 27% of throughput of TELESAT LEO, and in the downlink the number increase to 28%.

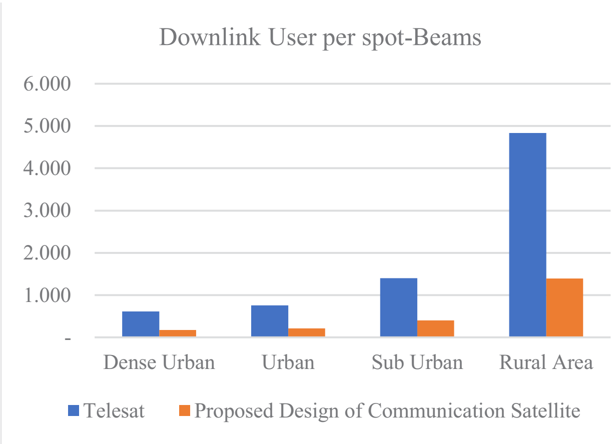



Graph 2 Network throughput comparison




Graph 3 Uplink users' comparison

Those throughput gaps, affecting the number of users that can be served. For better affirmation, graph 2 and graph 3 presents users comparasion for TELESAT LEO and proposed communication satellite in uplink and downlink respectively.




Graph 4 Downlink users' comparison.

In addition, graph 2 and 3 also show the difference in the number of users capable of being served by region. It demonstrates that at lower population density, more users can be served. Because the goal of satellite is to complement terrestrial network, then sub urban is the most suitable region as the reference. Therefore, this paper used rural area to calculate the total user.

Table 7 : Total user that can be served

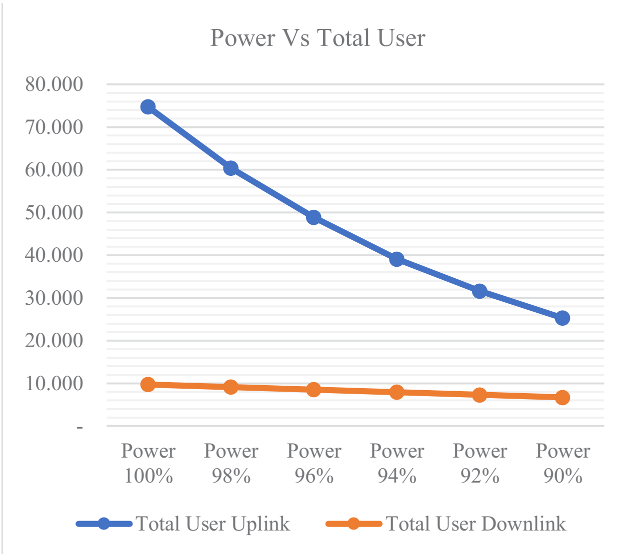
| Satellite | Uplink users | Downlink users |
|---|---|---|
| **TELESAT LEO** | 630,826 | 77,401 |
| **Proposed Design of Communication Satellite** | 74,746 | 9,753 |

Total user can be calculated by multiplying number of users in uplink and downlink to number of satellites spot-beams. The number of spot-beams that used by TELESAT LEO for uplink and downlink is 16 spot-beams, while the proposed communication satellite uses only 7 spot-beams. The total user that can be served by satellites are presented in table 7, and it demonstrate the impact of spot-beams number to the total user, where the total user of proposed communication satellite is around 11% to 12% of total user of TELESAT LEO. The throughput generated by proposed communication satellite also affects the number of users capable of being serviced. It is caused by several factors starting from frequency, altitude, G/T satellite and ground station, and modulation. From [10], there are some strategies to improve throughput capacity which is using frequency re-use strategies, optimized frequency plans in multi spot-beams architectures, and improving system EIRP.

From the calculation, the total downlink user can be used to represents the total user that can be served by the proposed design. With comparison to the total user for tourism industry in 2020 from the previous chapter, the total user that can be served by the proposed design satellite is up to 61%. Based on data from Indonesian Internet Service Provider Association (APJII) [16] in 2013, the demand of satellite services for hotels and restaurants is around 4.6% and 2.9% respectively. Assuming in 2020 the demand is increasing up to 2%, it can be concluded that the proposed satellite design is giving a good number of user capacity as the complementary to the terrestrial networks.

### *B. Power Variation*

Another important work is to explore power variations to total user capacity in the satellite transmission. The calculation is conducted for transmission power varies from 100% to 90%. This calculation is performed to see how the variation power transmission affecting the number of users. Graph 5 demonstrates that the decrease in power impact the total uplink users (25,299 users) more than the total downlink users (6,705 users) where the proposed satellite design is able to serve up to 42% of the total user. Hence, the proposed design is still able to serve the needs even in the lowest power scenario.




Graph 5 Effect of power variation to user capacity

## V. Conclusion

The objective of this work was to calculate and analyze user capacity for proposed design of communication satellite. From the calculation, the total users that can be served by proposed communications satellite is lower than TELESAT LEO where the total user of proposed communication satellite is only 11% to 12% of the total user of TELESAT LEO. Aside from the difference in number of satellite spot-beams, one of the factor for this significant gap is the throughput from link budget calculation of proposed communication satellite that is relatively lower. It is because of the difference in distance, frequency, G/T, and modulation used in both satellites. However, according to the purpose of the proposed design which is to compliment the terrestrial network, the proposed design has a good capability in the term of user capacity which is up to 61% of total needs in Indonesia. With the exploration in power variations up to 90% of the power transmission, the proposed design has the user capacity up to 42% of the total needs, and confirms the feasibility of the proposed design to be implemented.

In further research, it is best to improve some parameters which able to raise the value of throughput such as frequency re-use, modulation method, type of antenna, etc. As the biggest factor for determining the number of user, the satellite spot-beams number can be increased, thus the design of communication satellite will be able to give a better capabilities in terms of user capacity.

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