THE DESIGN OF G2-SAT OPERATION SCENARIO FOR DATA ACQUISITION AND TRANSMISSION

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ABSTRACT

G2-SAT mission concept is designed according to its payload requirements. G2-SAT will carry four channels imager as its payload, to support food security program. Results from orbit analysis are combined with payload specification data, ground station accesses and by implementing mission constraints to create the mission concept. This paper will present the design of operation scenario that can be applied on INASAT-1 as a part of mission concept. Operation scenarios will define how data is acquired and transmitted from the satellite to ground stations so that its mission can be fulfilled.

Keywords: *G2-SAT, Mission concept, Mission design*

ABSTRAK

Konsep misi satelit LAPAN generasi II (G2-SAT) dirancang berdasarkan muatan yang akan dibawa oleh G2-SAT yaitu sistem *imager* dengan empat kanal sebagai alat untuk menghasilkan citra yang dapat dimanfaatkan untuk program ketahanan pangan. Perancangan konsep ini dilakukan dengan menggabungkan hasil analisa orbit, data spesifikasi muatan yang telah diolah, akses satelit ke stasiun bumi serta dengan menerapkan batasan-batasan misi. Paper ini membahas tentang perancangan skenario operasi yang dapat diterapkan pada G2-SAT sebagai bagian dari sebuah konsep misi. Skenario operasi menjelaskan bagaimana data/citra di ambil oleh satelit dan dikirimkan dari satelit ke stasiun bumi sehingga tujuan misi yang direncanakan dapat dicapai.

Kata kunci: *C2-SAT, Mission concept, Mission design*

1 INTRODUCTION

Satellite is a system consists of several subsystems, the satellite bus and payload. Those subsystems; structure, power, communication, onboard data handling, attitude and orbit determination and control and thermal control are interdependent to each other creating a satellite bus. The duty of satellite bus is supporting the payload while the payload does the mission.

The process of designing a satellite begins with designing a mission concept to answer mission requirements and constraints. In the mission concept, the relations between subsystems are defined. Mission concept also consists of the operation scenario, which describe how the satellite will operate during its mission.

In the mission concept of operation, it is defined how the satellite communicate with the ground station, how the payload do its mission, how the mission is control, etc. For a satellite with an imager as its payload, like G2-SAT, it is defined in the mission concept, how the imaging system captures an image and how the data is delivered.

Mission concept design is influenced by a satellite orbit, as well as its ground stations location and the imager specifications. It is necessary to conduct through analysis of satellite orbit, its access to ground stations and image-data parameters to design a concept of operation.

• This research aims to design some operation scenarios as a part of mission concept for G2-SAT. The operation scenario will describe the scanning process (capturing images) and sending images to ground stations as a part of mission concept. Those scenarios will be created based on analysis result of orbital parameters and ground tracks, ground station access and image (data) related parameters.

2 METHODOLOGY

Following successful launch of LAPAN-TUBSAT, LAPAN is initiating a new satellite program in 2005. The satellite, which is a remote sensing satellite, has a mission to support national food security program which become one of priorities of Indonesian government.

In order to support food security program, the satellite should be able to estimate crop planting and harvesting area, identify crop growth stage, identify vegetation type, identify crop condition and estimate land' productivity. G2-SAT is a satellite concept proposed to fulfill the mission.

To perform those functions (estimating crop area, growth stage, etc), the satellite must satisfy certain requirements. As stated in the mission definition document (Mission Analysis and Design Team, 2006), the mission requires that G2-SAT imager capable of providing images with 10 to 30 m spatial resolution, able to capture images of the whole area of Indonesia in one month and have four channels in RGB and NIR bands. It is also required that images are taken under constant illumination condition for analysis purpose.

An imager that has four channels in red, green, blue and near infrared frequency is chosen based on the mission requirements above. It has been analyzed that the imager is capable to provide an approximately 22 m spatial resolution and 221 km swath width in nadir pointing orientation (Payload Analysis and Study Team, 2007). The imager consists of two linier CCD, each contains of 3 lines but only four will be used. Each CCD consists of 10200 pixels with scan rate of 411 Hz. This payload system also has its own memory unit to stored images (Sun Space, 2007).

G2-SAT orbit is also selected regarding to its mission requirements and constraints too. G2-SAT will be orbited in low altitude (Low Earth Orbit) with Sun Synchronous Polar Orbit (SSPO) as orbit type. SSPO is necessary to get a constant illumination condition during scanning process due to its constant local time of ascending/ descending node (Wertz, James R. and Larson, Wiley J., 1999).

Piggyback launch strategy as a mission constraints are also taken into consideration in designing G2-SAT orbit. This strategy is a common solution for a small satellite program to reduce the overall cost of the program. But as a consequence, the mission designer has no freedom to choose the satellite orbit as desired. It means orbital parameters (altitude and inclination) will follow the main payload of the launcher.

In G2-SAT case, it has been analyzed that the most suitable launcher is Long March 4B which scheduled to launch satellites to 778 km altitude in 2011 (G2-SAT Launch System Team, 2007).

Having the orbital altitude decided, other orbital parameters are now can be obtained using Keplerian orbit equations. Keplerian orbit are often used to describe the motion of a body orbiting a central body. In Keplerian orbits, only two bodies are taken into considerations.

Keplerian orbital equations are known as 2-body equation of motion. Effect of third body, for example gravity of sun or moon in the case of earth orbiting satellite is ignored. Earth gravity is assumed to be the only force acting on it. Figure 2-1 shows the definition of parameters in 2-body equation of motion (Wertz, James R. and Larson, Wiley J., 1999).

In Figure 2-1, orbital orientations are defined regarding to inertial frame (X, Y, Z). This frame is assumed fix in space. Ascending node is the node where the orbit cross equator in ascend/descend motion. Inclination can be defined as the tilting angle of the orbit from earth pole.

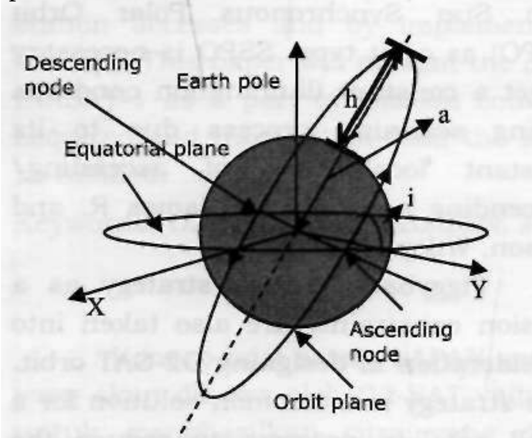

Figure 2-1: Definition of Keplerian orbital parameters

Keplerian orbital equations to calculate orbital parameters for circular SSPO orbit analysis are:

Semi major axis (a) in km

$$a=h+R_{\oplus} \tag{2-1}$$

Eccentricity (for circular orbit) (e)

$$e\cong 0 \tag{2-2}$$

Orbital Velocity (V) in km/s

$$V=\left(\frac{\mu_{\oplus}}{r}\right)^{1/2} \tag{2-3}$$

SSPO inclination (i) in deg

$$i=\cos^{-1}\left(\dot{\Omega}_{J2}/-1.5nJ2(R_{\oplus}/a)^2(1-e^2)^{-2}\right) \tag{2-4}$$

Orbital period (P) in sec

$$P=2\pi\left(\frac{a^3}{\mu_{\oplus}}\right)^{1/2} \tag{2-5}$$

Mean motion (n) in rev/day

$$n=\frac{24\times 60}{P} \tag{2-6}$$

Ground velocity (Vg) in km/s

$$V_g=\frac{2\pi R_{\oplus}}{P} \tag{2-7}$$

ju_9 is geocentric gravitational constant

After estimating orbital parameters, the payload data parameters can be obtained from the following equations.

Scanned lines in the service area

Lines=Access durationxLine_rate (2-8)

Scanned pixels in the service area

Pixel=LinesxPixel_per_lines (2-9)

Scan time in sec

Ts=LenglhxVg (2-10)

Data size in bits

Data _ sue=PixelxQuantization (2-11)

Equations 2-8 to 2-11 are parameters needed for analytical purpose to create the operation scenario. *Lines* in equation 2-8 refers to total scanned line in one pass when the satellite is inside the service area. *Pixel* in equation 2-9 refers to total pixel of the image taken in one pass. Scan time in equation 2-10 is the time needed to scan the service area. Line rate, quantization and pixel rate are parameters provided from the imager specification.

The complete step in designing G2-SAT mission concept is shown in Figure 2-2.

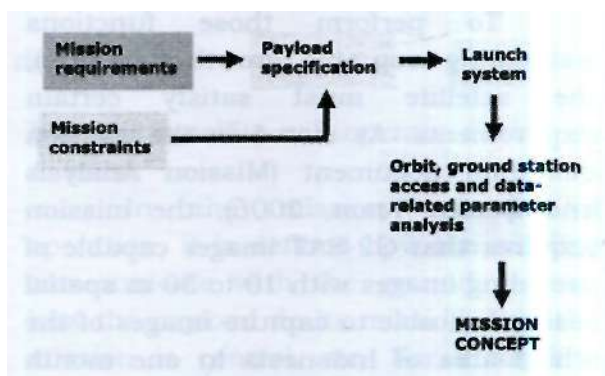

Figure 2-2: Steps in designing G2-SAT mission concept

As shown in Figure 2-2, the design of mission concept is started by defining mission requirements and constraints then followed by establishing payload specifications. In G2-SAT case, the first three processes had been done previously while the fourth and the fifth step are conducted in this research.

The purpose of doing orbit analysis is to predict the ground track of G2-SAT orbit and estimate orbital parameters. Orbital parameters are determined using Keplerian orbit equations. By predicting the ground track via simulation, mission designer can predict the performance of the satellite and propose some operation scenario.

After conducting orbit analysis, the next analysis as can be seen in Figure 2-2 is access analysis between satellite and ground station. Access duration is obtained as a simulation result using STK software.

Once the access analysis is done, the payload data parameters: data rates, number of pixels, number of scenes per orbit, etc can be estimated using equation 2-8 to 2-11.

The final step of designing mission concept is defining a strategy, when and how G2-SAT will do its missions. Several assumptions need to be taken in order to conduct the analysis.

2.1 Service Area

Service area is defined as a region where the satellite does its mission. In G2-SAT case, the mission consists of two main tasks: capturing images and sending those images to ground stations. Service area of G2-SAT is assumed limited to Indonesian boundary which lies from 6° North Latitude to 11° South Latitude and 95° to 141° East Longitude.

This assumption is considered valid since the mission itself does not required to provide the data for other countries. The definition of G2-SAT service area within Indonesian boundary is shown in Figure 2-3. On Figure 2-3, G2-SAT service area is described by the yellow box which means that G2-SAT will operate only inside this box. The green line is the track where G2-SAT will scan or capture images.

Figure 2-3: Definition of G2-SAT service area

2.2 Ground Stations

After conducting orbit analysis, the next step in designing mission concept is investigating the coverage of ground stations. Three ground stations, all located in Indonesia, are assumed to be utilized to communicate with G2-SAT. One ground station which located in Biak is utilized for Telemetry, Tracking and Control (TTC), hence to control the satellite. Another one, located in Pare-Pare is utilized for downloading data. While the last one, located in Rumpin can be utilized for both TTC and data.

Location of each ground stations are Biak; 1,15° S, 136.05° E, Altitude: 100m, Rumpin; 6.2168° S, 106.3261° E, Altitude 100 m, Pare-pare; 4.0083° S 119.618° E, Altitude 100m. TTC ground stations operated in S-band frequency while data ground stations operated in X-bands frequency. Elevation angle of all ground stations are assume to be 5°.

3 RESULT AND ANALYSIS

3.1 Orbit Analysis

Orbital parameters of G2-SAT are presented in Table 3-1. These parameters are calculated using equation 2-1 - 2-6 for 778 km orbital altitude, which is the expected altitude given by G2-SAT launcher.

Table 3-1: ORBITAL PARAMETERS OF G2-SAT AT 778 KM ALTITUDE

Parameter	**Value**
Altitude, h	778 km
semi major axis, a	7156.14 km
orbital period, P	100.41 minutes
Mean motion, n	14.34 revs/day
satellite velocity, v	7.463 km/s
inclination, i	98.51 deg
eccentricity, e	0

From Table 3-1, G2-SAT orbital period at 778 km altitude is expected to be 100.41 minutes. It means G2-SAT will need 100.41 minutes to complete one revolution around the earth. Orbit revolutions per day are expected to be 14.34 revolutions per day. It means G2-SAT circling around the earth 14.34 times a day. The (SSPO) inclination is 98.51 deg means G2-SAT orbit tilted 8.51 deg from earth poles. G2-SAT eccentricity is 0 which is expected to be an approximate value since it is assumed that the orbit is circular and only earth gravity is taken into account (Keplerian orbit).

Parameters in Table 3-1 are used to do the simulation of the ground track of G2-SAT orbit. In Figure 3.1, the simulation result using software STK 8.0 is presented. The simulation result is G2-SAT's predicted ground track which is propagated for two days. Keplerian orbit in this simulation is corrected by selecting J2 propagator to represent the effect of earth oblateness.

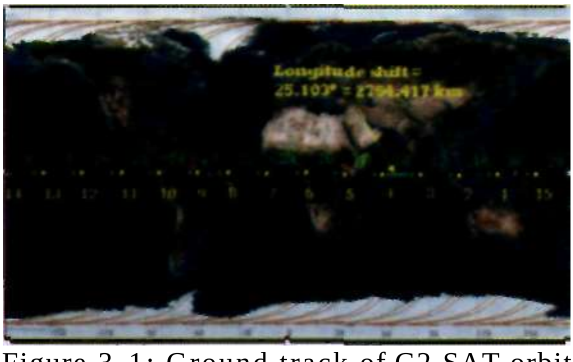

Figure 3-1: Ground track of G2-SAT orbit for two days propagation

The simulation result in Figure 3-1 is showing G2-SAT ground track in descending paths only. The brown lines are the ground tracks of G2-SAT orbit. Simulation results of ascending paths do not shown here because it is almost similar to the descending paths; differ only in the direction which is opposite to one another. Four brown lines cross Indonesia every two days in Figure 3-1. It means G2-SAT pass Indonesia two times a day for descending path and the same happen to ascending path. Total pass a day is four times.

It can be seen in Figure 3-1, G2-SAT ground track drifting westward. This phenomenon occurs as a result of earth rotation from west to east. Longitude shift between two neighboring orbits is 25.103° or about 2794.417 km at equator. The ground track of G2-SAT orbits on day one is represented by the yellow numbers while green numbers represent the ground track on day 2.

Since the imager field of view is 221 km as required by the mission, there will be a lot of gaps in the images. Other simulations were done by adding propagation days to check how many days needed so that images of Indonesia are taken without gaps. Figure 3-2 shows ground tracks of G2-SAT orbits for 13-days propagation.

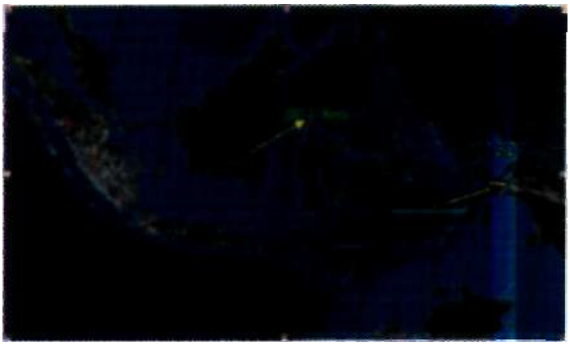

Figure 3-2: Ground tracks of G2-SAT orbits for 13-days propagation

It is shown in Figure 3-2 that after 13 days propagation, the distance of two orbits decreased to 607 km. Another interesting result from Figure 3-2 is that after 13 days, the ground track repeating the path of day 1 with a slight drift.

More simulation was done by adding more propagation days to see in how many days will the distance between orbits is close to 221 km. The result is presented in Figure 3-3 which shows ground track simulation for 30 days propagation.

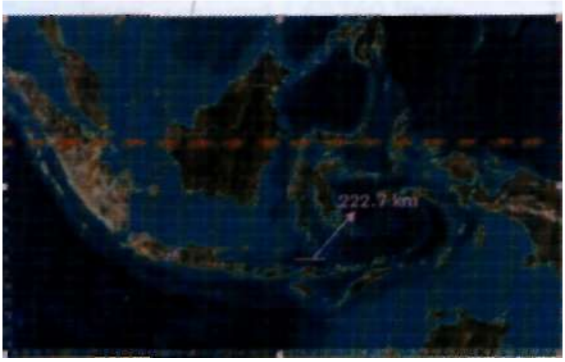

Figure 3-3: One month propagation of G2-SAT orbits

Figure 3-3 shows that for one month orbit propagation, the maximum distance between two neighbors' orbits is approximately 222.7 km. This value is closed to payload swath width parameter required at this altitude which is 221 km. By assuming that G2-SAT is nadir pointing when capturing images, full coverage of Indonesia without any gap will be achieved in one month.

3.2 Ground Station Access Analysis

Figure 3-4 shows coverage of all G2-Sat ground stations. As mention before in chapter 2.2, TTC ground stations are located in Biak and Rumpin. It means only from these two ground stations G2-SAT will be able to controlled, downlink telemetry and commanded. Data ground stations, utilized for downloading image data are located in Pare-Pare and Rumpin. Only from these two ground stations, image data will be downlinked from G2-SAT.

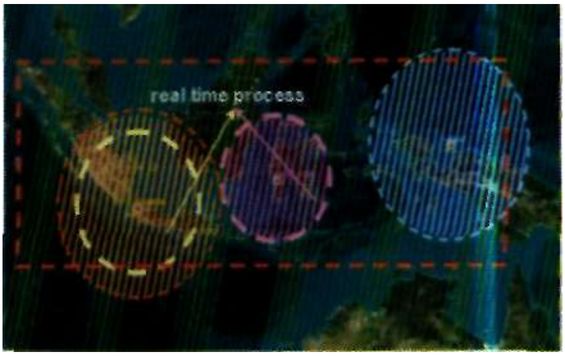

Figure 3-4: Coverage of G2-SAT ground stations

Figure 3-4 show the region where G2-SAT can communicate with the ground stations which represented by four dashed circles. The blue circle is the region where G2-SAT can communicate with Biak (TTC) ground stations. The pink circle represents the region where G2-SAT can down link image data to Pare-Pare ground station.

Two orange circles with different size represent the region where G2-SAT can communicate with Rumpin ground station. Down linked data can only be done in the smaller region while telemetry and control can be done in the bigger region. The real time process can be done in the smaller region since only in this area, images can be down linked.

Maximum access duration which defines how long a satellite can communicate with ground station is estimated using reports from STK simulations. For G2-SAT, maximum access duration is divided into two categories: access duration to TTC ground stations and access duration to data ground station. STK reports for access summary from G2-SAT to Rumpin (TTC ground station) are presented in Table 3-2.

Table 3-2: ACCESS REPORT FOR S-BAND

16 «ir 200714:55:11

16 Mr 2007 11:55:11

&te'ilite-G2SAT-Sefsor-SJ*id-To-facni:y-RWK-Sensor-TTC_aitf2: Access SMHry Seport

S_Band-To-TTC_ant2

	Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)
	1	1 Jul 2011 15:17:28.485	1 Jul 2011 15:20:31.757	183.272
	2	2 Jul 2011 14:44:58.358	2 Jul 2011 14:48:48.306	229.948
	3	4 Jul 2011 02:49:29.328	4 Jul 2011 02:53:37.556	248.228
	4	4 Jul 2011 15:20:20.556	4 Jul 2011 15:23:01.242	160.686
	5	5 Jul 2011 14:47:35.457	5 Jul 2011 14:51:33.128	237.671
	6	7 Jul 2011 02:52:10.838	7 Jul 2011 02:56:17.788	246.951
	7	7 Jul 2011 15:23:16.286	7 Jul 2011 15:25:27.033	130.746
	8	8 Jul 2011 02:21:27.345	8 Jul 2011 02:22:48.979	81.625
	9	8 Jul 2011 14:50:13.642	8 Jul 2011 14:54:16.838	243.196
	10	10 Jul 2011 02:54:53.540	10 Jul 2011 02:58:57.058	243.518
	11	10 Jul 2011 15:26:18.338	10 Jul 2011 15:27:45.455	86.117
	12	11 Jul 2011 02:23:44.829	11 Jul 2011 02:25:52.955	128.126
Global Statistics				
Min Duration	8	8 Jul 2011 02:21:27.345	8 Jul 2011 02:22:48.979	81.625
Max Duration	3	4 Jul 2011 02:49:29.328	4 Jul 2011 02:53:37.556	248.228
Mean Duration				184.999
Total Duration				2219.986

As can be seen in Table 3-2, maximum access duration from G2-SAT to TTC ground station is approximately 248 second or 4.13 minutes. During this time, G2-SAT can be control by command from ground station and be able to downlink the telemetry data.

STK reports for access summary from G2-SAT to Rumpin (X-Band Ground Station) are presented in Table 3-3.

Table 3-3: ACCESS REPORT FOR X-BAND

MSN

Sitellite-e23AT-Sensor-XJuid-To-Fjcility-J!imit-Sensor-SJWTA2: Kces Swary Report

X_Band-To-GS_DATA2

	Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)
	1	2 Jul 2011 14:45:44.070	2 Jul 2011 14:48:02.616	138.546
	2	4 Jul 2011 02:50:09.792	4 Jul 2011 02:52:57.085	167.293
	3	5 Jul 2011 14:48:18.762	5 Jul 2011 14:50:49.842	151.080
	4	7 Jul 2011 02:52:51.749	7 Jul 2011 02:55:36.969	165.220
	5	8 Jul 2011 14:50:55.412	8 Jul 2011 14:53:35.083	159.671
	6	10 Jul 2011 02:55:35.207	10 Jul 2011 02:58:15.375	160.167
Global Statistics				
Min Duration	1	2 Jul 2011 14:45:44.070	2 Jul 2011 14:48:02.616	138.546
Max Duration	2	4 Jul 2011 02:50:09.792	4 Jul 2011 02:52:57.085	167.293
Mean Duration				156.996
Total Duration				941.977

From Table 3-3, it can be seen that maximum access duration from G2-SAT to TTC ground station is approximately 167.3 second or 2.8 minutes which is relatively short. It means this is maximum duration for G2-SAT to downlink images to ground stations. It is become important to optimize this duration for data downlink by designing the good scenario.

3.3 Image-Data Parameters Analysis

Image-data parameters of G2-SAT are presented in Table 3-4. Parameter values are estimated values calculated using equation 2-7 - 2-11 except for number of pixels, line rate and quantization which are obtained from imager specifications.

Table 3-4: IMAGE-DATA PARAMETERS OF G2-SAT AT 778 KM ALTITUDE

Parameter	Value
Pixel	10200
Line rate	411 Hz
Quantization	8 bits/Pixel
Ground velocity	6.653 km/s
Total scan length in the service area	1907.083 km
Total scan lines in the service area	117809 lines
Total number of pixel in **the service** area	1201.65 **Mpix**
Total scan time	4.78 minutes
Total data size in the service area	9.613 Gb

Parameters in Table 3-4 describe the image data taken inside the service area. From the results in Table 3-4, when G2-SAT passes the service area, it scans 117809 lines which is divided into four channels. Data sized for the whole service area that needs to be sent to ground is 9.613 GBits.

It mentioned before that realtime process can only be done in a certain region around data ground station, so image-data parameters in this area should also be estimated. These parameters are presented in Table 3-5. Assumption taken when calculating parameters in Table 3-5 is that data rate for downlinking the data is 50 Mbps.

Table 3-5: IMAGE-DATA PARAMETERS OF G2-SAT DURING ACCESS TO GROUND STATION

Parameter	Value
Maximum access duration	167 s
Total lines scanned during access	*68760 lines*
Number of lines to be sent realtime	17190 lines
Number of pixel to be sent realtime	175.338765 MPix
Data size to be sent realtime	1402.71012 Mb
Data size to be stored (remaining data)	8210.507544 Mb
Time needed to sent the remaining data	164.2 s

It is shown in Table 3-5 that during access to ground stations which is about 2.8 minutes, G2-SAT collects 9612 Mbits data. 1402.710 Mbits can be sent realtime, while the remaining 8210.5 Mbits data has to be stored in the memory units. The time needed to send the stored data is 164.2 sec. Because the maximum access duration is 167 sec, all data in the memory unit will be transfer completely in one pass.

3.4 Mission Concept

All information gather from orbit, ground station access and image-data parameters analysis are combined to create scenarios for G2-SAT to do its mission, hence taking and sending images. G2-SAT pass Indonesia four times a day, two pass at day time and two pass at night. The image should be taken at daytime pass, since the imager is optical imager that needs sunlight.

Based on the analysis, there are two operation scenarios which are possible to be implemented on G2-SAT; the stored and forward operation and semi real-time operation. Store and forward scenario is illustrated in Figure 3-5a and 3-5b while Semi realtime scenario is illustrated in Figure 3-6a and 3-6b.

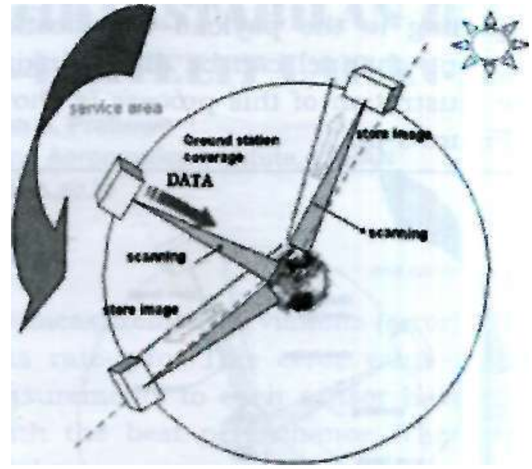

Figure 3-5a: Semi realtime scenario during daytime

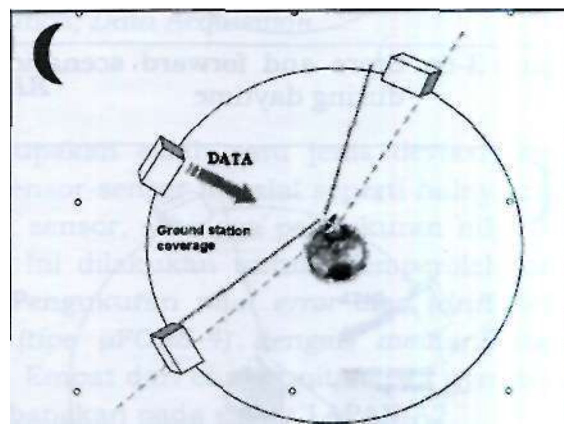

Figure 3-5b: Semi real time concept of operation during night time

On store and forward scenario, G2-SAT will scan (take images) the earth when it enters the service area during daytime. In Figure 3-6a, the service area is inside the brown border. When G2-SAT reach ground station coverage, one channel will be down linked. The remaining data will be stored in the memory units inside the payload system. Data communication system will be off during this process. When G2-SAT passes its ground stations other at night (right side), stored data in the memory unit will be down linked.

Semi real-time scenario means the real-time process where image is taken and immediately sent to ground only happen at some part of the service area. Outside the service area, data will be stored. The scanning process itself happens when G2-SAT passes service area as in store and forward scenario.

Regarding to the payload specification, only one channel can be direct linking. The illustration of this process is shown in Figure 3-6b.

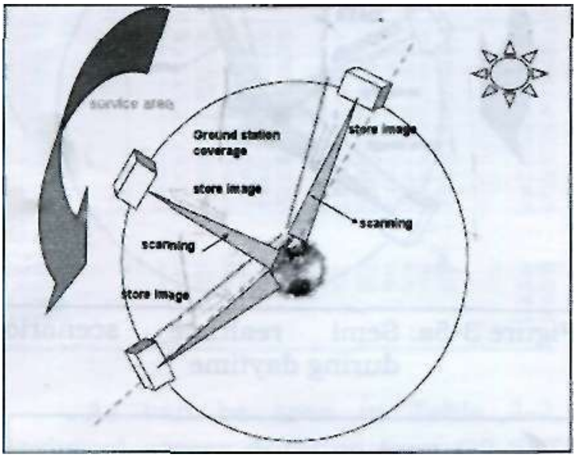

Figure 3-6a: Store and forward scenario during daytime

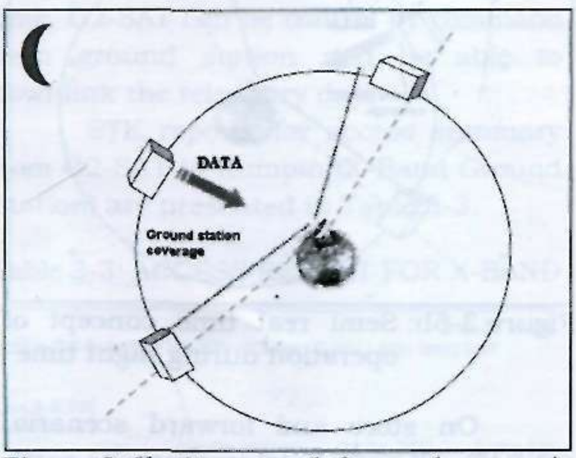

Figure 3-6b: Store and forward scenario during night time

4 CONCLUSION

Two scenarios had been designed as a part of G2-SAT mission concept; semi realtime operation and store and forward operation. These scenarios are resulted from detail analyses of G2-SAT orbit; ground stations access and image-data parameters. Both scenarios are possible to be implemented on LAPAN's satellite program. Although each concept will drive a different result on the satellite configuration, it should give a big advantage if the concept implemented at LAPAN's satellite program.

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