INTER-SATELLITE LINK ASSESSMENT FOR THAICHOTE EOS SATELLITE COMMUNICATION ENCHANCEMENT

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KEY WORDS: Data Relay Satellite (DRS), Remote sensing satellite communication, LEO-GEO satellite link

ABSTRACT: Since 1970, satellite based remote sensing has progressively been an important platform for Earth monitoring activities. From past to present, it is obvious that EOS satellite technology has developed at a very fast pace. Although the resolution and the performances of the payload have been continuously improve, current communication link capability is one of the bottleneck that limits this advancement. This is due to the fact that there is a limitation in transferring images, telemetry and telecommand between the satellite and ground station. This limitation either caused by the insufficient satellite pass duration or the data bandwidth capability.

Based on GISTDA experiences in satellite operations, THAICHOTE has also faced these problems, especially, during the malfunction of the ground station antenna, or in the case that the satellite needs to increase the frequency of connections for reconfiguration procedure. One of the solutions for these problems that is currently implemented is to use additional ground stations, however another novel approach, which is to use the geostationary data relay satellite (DRS) might be also possible in the near future. This paper shows the feasibility analysis to link THAICHOTE remote sensing satellite via four approaches which are; the actual operation setup, LEO-GEO connection, link via the network of ground stations and LEO-GEO-Ground network. A comparison between each approach is made in the conclusion and the perspectives to cooperate among the nations in Asia region is discussed.

1. INTRODUCTION:

Obviously, the space-borne remote sensing technology has emerged in a very fast pace, especially in this decade. This might due to many factors, for example, the rapid advancement in the sensor technology, the cost reduction for space application materials as a result of the booming space industries, or the miniaturization of the satellites that reduce the launch budget and makes space-borne remote sensing mission more accessible, etc. Indeed, it is undeniable that during these days, human can collect more data from space than we are able to process.

More remote sensing satellites are placed into the orbit. With the new techniques to fabricate new sensors, the satellite imagery contains much higher spatial and spectral resolution. SAR (Synthetic Aperture Radar) imagery has become a common practice in most GIS applications, the use of hyperspectral imagery is also emerging. From these reasons, the trend of the data generated from space tends to be increasing exponentially. However, this data will not be usable if it could not transfer back to ground station. Hence, aside of the development of new space payload, the improvement in communication link, to get the capability to transfer all of the data has to be brought into consideration alongside.

In addition of the data bottleneck problem, for remote sensing satellite operation, it is necessary to also have the redundancy for the ground station. This back up is necessary in order to make sure that the new acquisition commands are always able to be uplinked to the satellite. In addition, for satellite maintenance and configuration purpose, more ground terminal to increase the satellite connection passes and connection duration can help to speed up the procedure and bring the satellite back to operation faster. This paper demonstrates the feasibility to increase the satellite connection visibility duration. In the next section, the use of geostationary (GEO) data relay satellite is introduced. Then, in section 3, the method to simulate satellite connection visibility duration is shown, four approaches to communicate with the satellites are presented. Conclusion and the possible future perspectives to improve the remote sensing satellite communication are shown and discussed in the last section.

2. DATA RELAY SATELLITE

Data Relay Satellite is a communication satellite that is generally placed in the geostationary orbit to serve as a space-borne communication relay or tracking station for other spacecrafts. Started in 1983, NASA has deployed the first Tracking Data Relay Satellite System (TDRS) in the orbit. Up until now, more than ten TDRS satellites were launched. TDRS satellites provide various types of services and expand the space networks, for example, providing space links for the international space station and other LEO satellites or being a space-borne communication platform for deep space exploration, etc. (Brandel, D. L., Watson, W. A., & Weinberg, A.,1990).

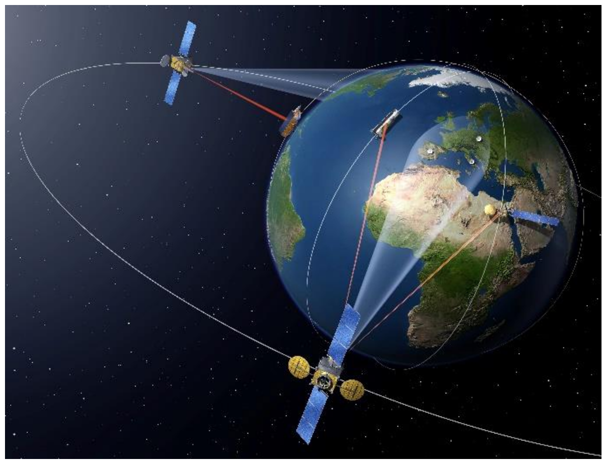


Figure 1: European Data Relay System (courtesy: ESA)

Recently, ESA also planned a GEO communication a satellite data relay constellation, namely, European Data Relay System (EDRS) as shown in figure 1. The EDRS will serve in a very near future as the data relay platform for constellation of remote sensing satellites and UAVs. On the other side, JAXA also has data relay system, so called Data Relay Test Satellite (DRTS) which is currently used as the links for Advanced Land Observing Satellite (ALOS) and International Space Station (ISS). JAXA has proven that DRTS is very useful especially for Synthetic Aperture Radar (SAR) technology because the SAR imagery contains tremendous amount of data. For example, in the case of DRTS-ALOS link (Fujiwara, Y., Sudo, Y., Nagano, H., & Kanamori, Y. ,2003) both satellites are connected in Ka-band which can be reached up to 240 Mbps data rate.

From all of the benefits and the proven experiences of the deployed data relay satellites as stated above, it is obvious that this space-borne communication platform will be the future of the remote sensing satellites communication, especially when the payload technology has evolved rapidly in both spatial resolution, spectral resolution and the wide range of new sensors that will result in much bigger amount of data per day.

3. REMOTE SENSING SATELLITE COMMUNICATION FEASIBILITY ANALYSIS

The advantage of the increased connection is not only for increasing imagery downlink data quantity. It is also increase the possibility to modify or add the acquisition command on the satellite in near real time for the case that the telecommand, telemetry and data link connection are all available during the visibility period. Therefore, for this communication feasibility study, we focus mainly on the possible connection duration of the satellite.

The feasibility simulation is set based on the operation of THAICHOTE satellite, where the acquired images are needed to be transfer to the ground station located in Chonburi, Thailand, in order to be processed and utilized. Also, the telemetry and telecommand are needed to be downlinked and uplinked from the same station. In this study, a tool, called Inter-Satellite Assessment Tool (Inter-SAT), is developed and implemented in order to determine the feasibility of the satellite communication in term of the link visibility duration.

At first, the satellite orbit information is input as a set of TLE (Two Line Elements) data which is a set of orbital parameters. Then, SGP4 (Simplified Perturbations Models) is used in order to propagate the TLE into the satellite positions in the True Equator Mean Equinox (TEME) reference frame corresponding to each step of time. The details of the propagation algorithms is shown in (Felix, Ronald, 1980). Then, the position in TEME frame is converted to the Earth Center Earth Fix (ECEF) reference frame through the Pseudo Earth Fix (PEF) frame, according to equations 1 and 2, where GMST or Greenwich Mean Sidereal Time, is the angle between the mean vernal equinox and the Greenwich Meridian.

The coefficient polar motion is also taken into account on the frame conversion. The coefficient polar motion is represented by x_p, y_p. Consequently, X, Y, Z in ECEF frame can be used to refer the positon of the satellite ground track on Earth for display and further analysis.

$$\begin{bmatrix} X_{PEF} \\ Y_{PEF} \\ Z_{PEF} \end{bmatrix} = \begin{bmatrix} \cos(GMST) & \sin(GMST) & 0 \\ -\sin(GMST) & \cos(GMST) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_{TEME} \\ Y_{TEME} \\ Z_{TEME} \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} X_{ECEF} \\ Y_{ECEF} \\ Z_{ECEF} \end{bmatrix} = \begin{bmatrix} \cos(x_p) & 0 & -\sin(x_p) \\ \cos(x_p)\sin(y_p) & \cos(y_p) & \sin(y_p)\cos(x_p) \\ \sin(x_p)\cos(y_p) & -\sin(x_p) & \cos(y_p)\cos(x_p) \end{bmatrix} \begin{bmatrix} X_{PEF} \\ Y_{PEF} \\ Z_{PEF} \end{bmatrix} \tag{2}$$

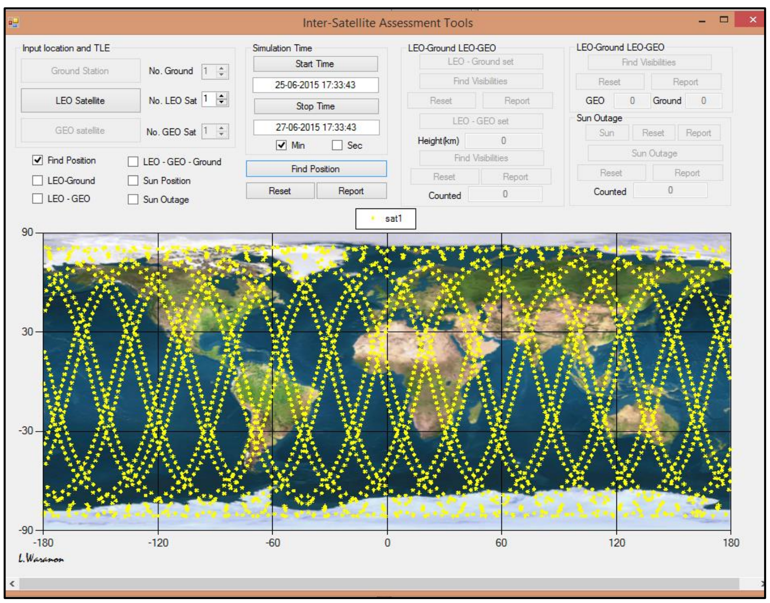


Figure 2 the Inter-SAT that is developed in this study

Figure 2 shows the interface and the result of orbit propagation from Inter-SAT. The orbit is propagated from THAICHOTE TLE for the duration between 25-06-2015 17:30:00 UTC to 27-06-2015 17:30:00 UTC. The result, which is the satellite position X, Y, Z is then compared with the actual THAICHOTE position, obtained from GPS telemetry, for the corresponding date and time, the difference between the propagated value and the actual value is plotted and shown in figure 3. Some small differences on X, Y and Z can be found, these might due to TLE uncertainties on the propagation or the measurements, however the error is very small and would not affect the feasibility analysis for the communication link, which is the purpose of this study.

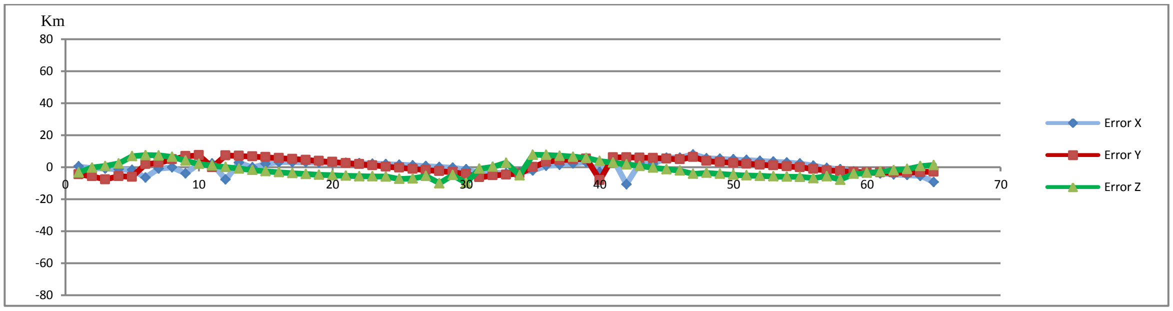


Figure 3: comparison of propagate and actual satellite position from GPS telemetry

3.1 LEO SATELLITE - GROUND STATION VISIBILITY

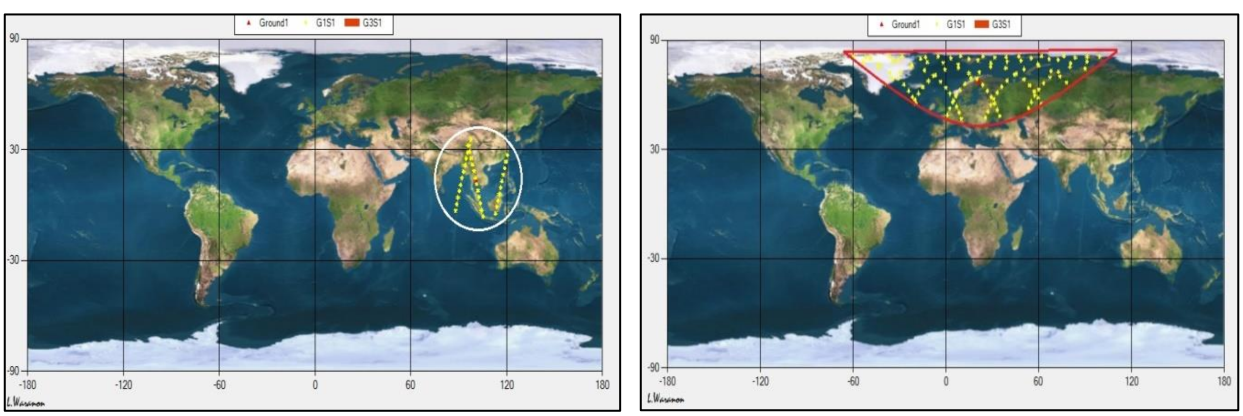
This section shows the satellite passes visibility for connecting THAICHOTE with ground stations based on GISTDA on current operation. Two ground stations are used, which are GISTDA Siracha ground station, located in Chonburi, Thailand and the polar SSC ground station, Kiruna Sweden.

After, the satellite position is determined based on the method mentioned in the previous section. The link duration can be obtained by considering the ground station antenna elevation angle. The ground station is considered to start acquiring signal from the satellite at 5 degrees antenna elevation angle and loss of signal at 5 degrees elevation correspondingly. Azimuth and elevation angle of the ground antenna can be found by using the position of ground station and satellite by equation 3 and 4.

$$\begin{bmatrix} e \\ n \\ u \end{bmatrix} = \begin{bmatrix} cos(-90) & -sin(-90) & 0 \\ sin(-90) & cos(-90) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} cos(90-\varphi) & 0 & -sin(90-\varphi) \\ 0 & 1 & 0 \\ sin(90-\varphi) & 0 & cos(90-\varphi) \end{bmatrix} \begin{bmatrix} cos(-\lambda) & -sin(-\lambda) & 0 \\ sin(-\lambda) & cos(-\lambda) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_s - x_G \\ y_s - y_G \\ z_s - z_G \end{bmatrix} \quad (3)$$

$$\begin{aligned} &\text{Azimuth} = 90 - \tan^{-1}(n/e) \quad ; e>0 \\ &\text{Azimuth} = 270 - \tan^{-1}(n/e) \quad ; e<0 \\ &\text{Elevation} = \tan^{-1}(u/\sqrt{e^2 + n^2}) \end{aligned} \quad (4)$$

Where x_s, y_s, z_s are position of satellite and x_G, y_G, z_G are position of ground station. Latitude and longitude are represented by φ and λ respectively. As a result, THAICHOTE passes over GISTDA ground station and Kiruna station for one day period is shown in figure 4a and 4b respectively. Evidently, since THAICHOTE is in sun-synchronous, polar orbit, the satellite passes Kiruna station much more frequent and passes GISTDA ground station only three to four passes daily. From the simulation for 25-06-2015, THAICHOTE visibility duration for GISTDA ground station is 34 minutes and 111 minutes for SSC Kiruna ground station.



(a) *(b)*

Figure 4: (a) THAICHOTE – GISTDA ground station (13.2021 latitude 100.929 longitude) (b) visibility of THAICHOTE – SSC Ground 67.53 latitude 21.04 longitude As of 25-26 Jun 2015

3.2 LEO - GEO VISIBILITY

This section demonstrates the feasibility to connect THAICHOTE with geostationary data relay satellite. The assumption is made that THAICOM-5, a telecommunication satellite which located at 0N, 78.5E, equipped with an S-band module to link with THAICHOTE and works as a data relay satellite over South East Asia region. It is also assumed that THAICHOTE is equipped with antenna pointing module in order to track THAICOM-5 during their visibility.

To determine the visibility duration, the acquisition of signal (AOS) and loss of signal (LOS) time is decided regarding the maximum line of sight distance , d_{max}, as shown in figure 6. This maximum distance is considered as a direct LEO-GEO line of sight which is higher than 90 km above the Earth surface in order to avoid the effect of Earth troposphere. In this scenario, two satellite is considered to be able to link with each other when $d < d_{max}$, where d_{max} can be calculated according to equation 5 and 6.

- Kepler's Third Law

$$a^3 = \frac{GM_e}{n^2} \tag{5}$$

$$d_{max} = \sqrt{a^2 - (R_E + 90)^2} + \sqrt{h_{LEO}^2 - (R_E + 90)^2} \tag{6}$$

a = semi-major axis of eclipse (km)
GMe = the earth's geocentric gravitational constant 398600.5 km^3/s^2
n = Mean motion (rad/s)
h_{LEO} = Altitude LEO satellite from center of the Earth (Km)
R_E = Radius of the Earth (6378.135 Km)
d_{max} = Maximum distance between LEO and GEO

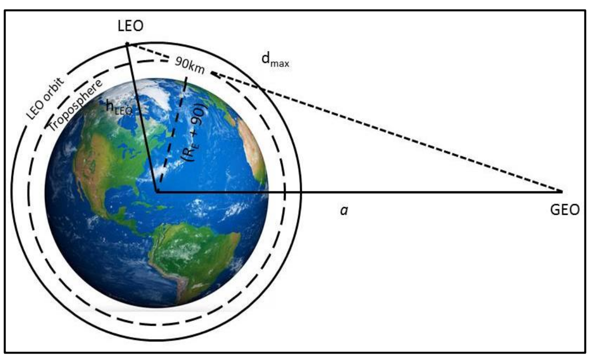


Figure 5 finding d_{max} process

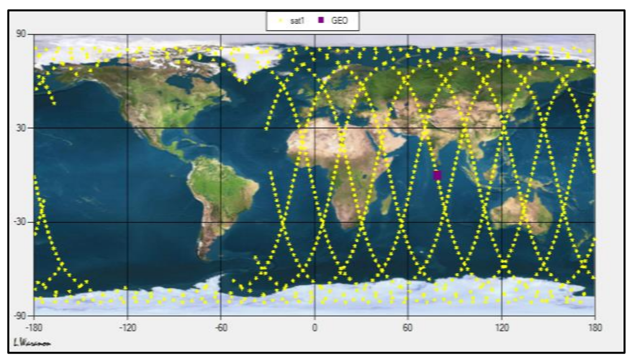


Figure 6 visibility of THAICHOTE (LEO) – THAICOM5 (GEO) on 25-26 Jun 2015 17:33:43

The result from the simulation in Inter-SAT shows that the LEO-GEO visibility can be up to 1011 minutes per day. Satellite ground track during the connection period is shown in figure 6. The long duration of the link is due to the very high altitude and large field of view of the communication platform. The feasibility of using other GEO communication relay satellite is also analyzed and shown in figure 7. Obviously, by implementing GEO data relay satellite, it is possible for the ground station to have the direct downlink in near real time. Besides, in the case of the agile remote sensing satellite, or multi-mode payloads, if the relay satellite also equipped with telemetry and telecommand channel, this real time connection possibility also enable the operators to modify or put additional plan onto the satellite at any time according to the needs of the image users. Especially during the disaster, for instance.

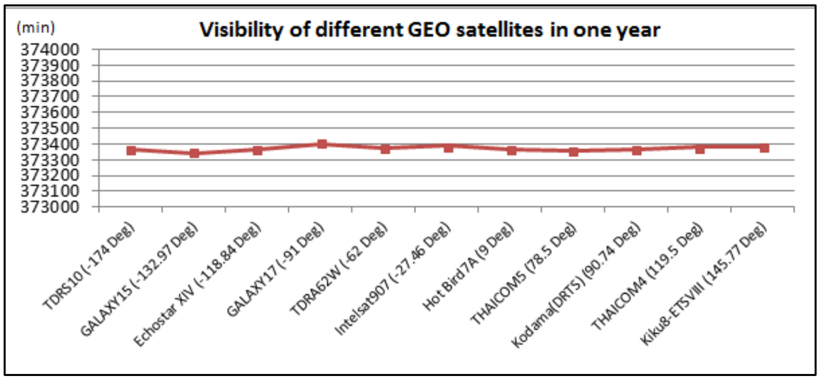


Figure 7 Link duration per year for THAICHOTE and GEO satellite at various position.

3.3 GROUND STATION NETWORK

The alternate solution to increase the link duration is by sharing satellite ground station facilities among the remote sensing satellite operators. This could be an establishment of the ground stations network to increase the communication capacity up twice the capability of a single station. This section demonstrate an assumed scenario that three operators in the South East Asia, which are VNSC (Vietnam), LAPAN (Indonesia) and GISTDA (Thailand) are sharing their ground facilities together, where the satellites resource that need to be connected and used as an input orbit information are VNREDSAT, LAPAN-TUBSAT and THAICHOTE, respectively. Additionally, we assumed that every facilities and the satellites utilize X-band frequency for data downlink and the frequency can be switched by each station to support the connecting satellite.

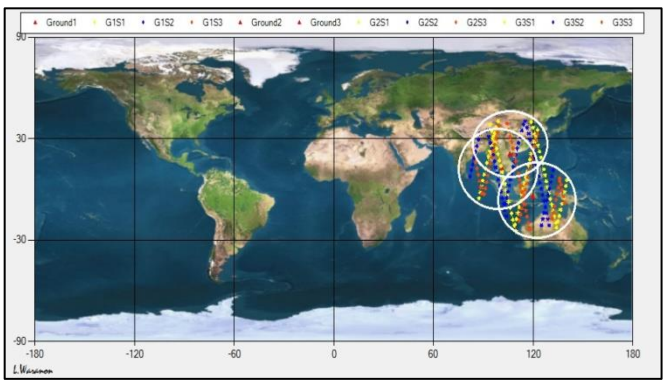


Figure 8 Visibility for 3 ground stations and 3 satellites.
Yellow, blue and red dotted lines represent THAICHOTE, VNREDSAT and LAPAN respectively.

Table 1 Summary increasing visibility time in one day

Satellite	Increased pass duration (min)	New Passes
THAICHOTE	42	2
VNREDSAT	31	1
LAPAN	32	2

The priority to link each satellite with the ground station is set according to the visibility of satellite of the host ground station. In other words, if THAICHOTE and LAPAN-TUBSAT has a link visibility with GISTDA ground station at the same period of time, THAICHOTE will have the priority, however if these two satellites has a visibility with LAPAN at the same period, LAPAN-TUBSAT will get the link priority. The link visibility consideration is set to be at 5 degrees elevation which is the same as in 3.1.

The result from the analysis, put in schedule, is shown in figure 12. In addition, table 1 shows the benefits of sharing and the use of network ground station as we can see the increase in number of passes per day and the increase of daily connection duration for data link.

3.4 LEO - GEO - GROUND

In the previous sections, three communication schemes, which are using single station or with polar station, using GEO data relay satellite and using the sharing network of ground stations are considered. In this section, the combination of using both GEO data relay satellite (3.2) and sharing ground stations antennas (3.3) is simulated and analyzed.

The assumption of the ground-satellite connection priority is set to be the same as in section 3.3 where the satellite of the host station will have the highest priority. For GEO-LEO link, the management of the connection priority can be set in respect with the GEO satellite share. The proposed link decision flowchart is shown in figure 9. Figure 10 shows the ground track when the satellites are in connection based on the simulation result.

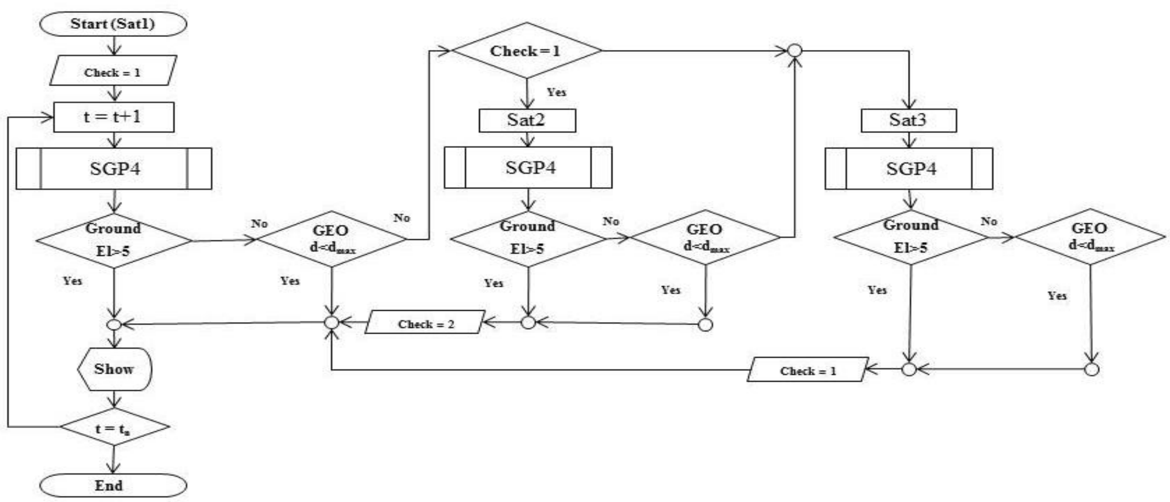


Figure 9 Proposed multi satellites communication with a GEO data relay satellite

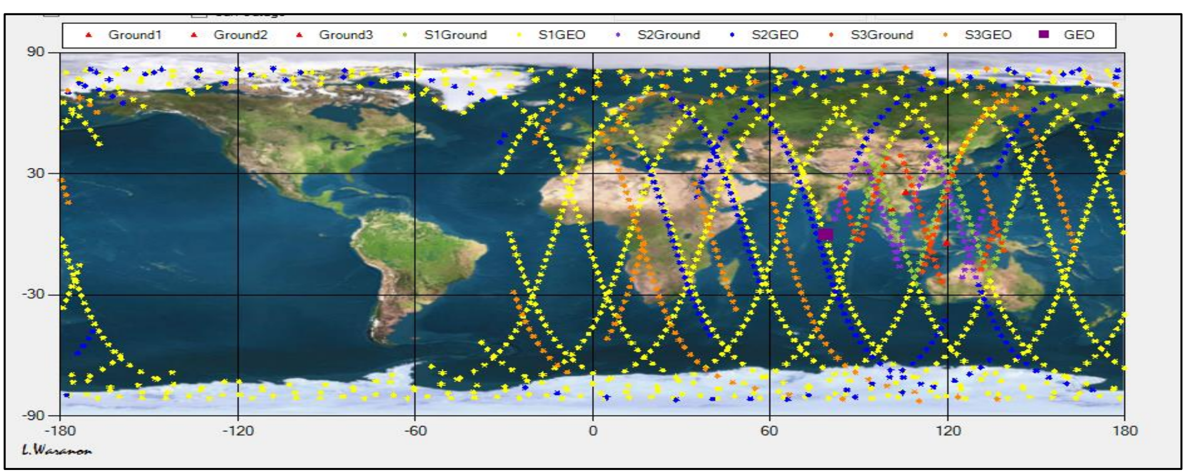


Figure 10 Result visibilities of 3 satellites and 3 ground stations,
Yellow, blue and red dotted lines represent THAICHOTE, VNREDSAT and LAPAN respectively.

According to the proposed criteria, the connection schedule with ground and GEO satellite for each corresponding remote sensing satellite is shown in figure 11. This example is made for the period of 16 to 17 August 2015. The result shows that from this communication approach, the link duration of the first priority satellite can be arrived up to 1,008 minutes (77 for ground and 931 for GEO data relay satellite), and up to 301 and 260 minutes for other two satellites respectively. To be noticed that in the actual case, the duration might be decreased for some amount due to the duration that needs to be used for switching connection.

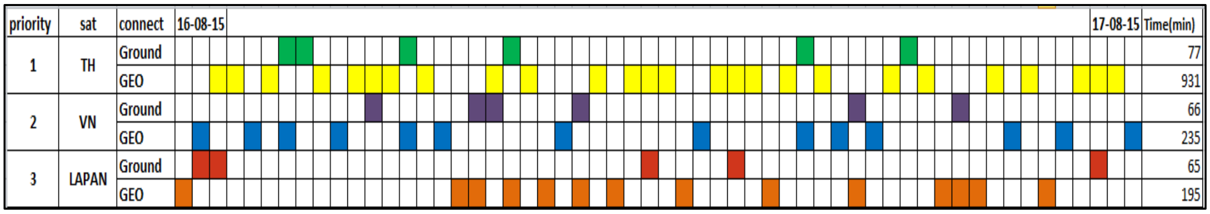


Figure 11 Schedule visibilities for 3 satellites and 3 ground stations within one day

4. CONCLUSION AND PERSPECTIVES

In order to deal with the remote sensing satellite data communication bottleneck, four connection approaches are proposed in this paper. The first approach is a baseline, which demonstrates the current setup for THAICHOTE communication link by using a ground station in Thailand and SSC polar station services. The second approach is by looking forward to the possibility to implement GEO data relay satellite as a communication relay. The simulation result shows that using the GEO communication relay satellite will increase greatly the communication duration and makes the near real time connection feasible. However, GEO relay satellite requires very high amount of budget to start up, sharing, leasing a platform, or international collaboration should bring into consideration.

Another approach that is presented is to share the ground station among the satellite operators in the region. An example of the time slot management for ground station is proposed. The network ground station scheme based mainly on the agreement to collaborate. Thus, the cost is very low. However, by sharing the ground station, the pass duration can increase up to twice the duration of using single station (from 35 minutes to 77 minutes for the case of THAICHOTE). The last approach that is proposed in this paper is to combine the usage of GEO data relay satellite and the network of ground station together. Collaborating among the satellite operators can help a lot in sharing the relay satellite budget and enable the use of their facilities and resources at full potential. The comparison of each presented approach is summarized in Table 2. Moreover, the possible daily connection duration and transferable data amount is shown in figure 12.

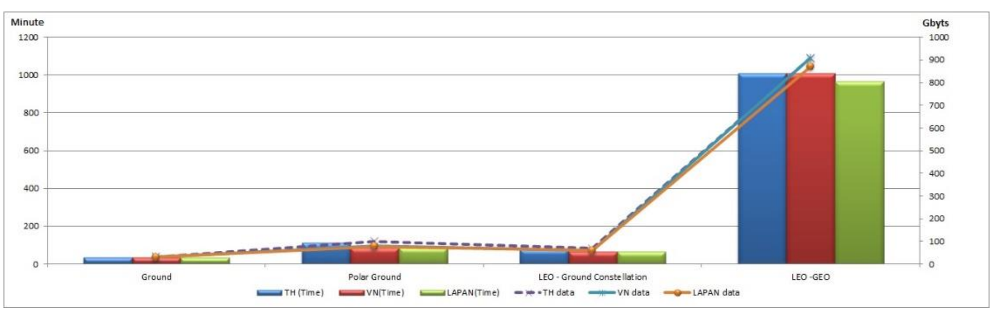


Figure 12 Daily connection duration and transferable data amount

In addition of the advantages that more downlink data is possible with longer pass duration, another important benefits of the long and full time remote sensing satellite communication is to enables the satellite operators to modify or add acquisition queue to the satellite in any time. For example, as the South East Asia region is located in the tropical zone, cloud coverage has always been an important obstacle to get clear image from satellite. The ability to modify the acquisition queue in near real time will make it possible to change the acquisition area to the clear zone and increase the success rate of the mission. Besides, for satellite maintenance or reconfiguration purpose, the full time link duration can immensely speed up the process and ensure that the satellite is always in operable state.

Table 2 Comparison chart for each connection approach for THAICHOTE

	Single Ground Station (GISTDA)	**Polar Ground Station**	**Ground Station Network**	**GEO Data Relay Satellite**	**GEO DRS and Ground Station**
Visibility duration (av. Per day)	35 min	111 min	77 min	1011 min	931 min (1st Priority)
Bit Rate (X-band)	120 Mbps	120 Mbps	120 Mbps	120 Mbps	120 Mbps
Cost	High, if setting up new antenna facility	high (per time)	Low (sharing facilities)	low (leasing)	low (cooperate investment)
Maximum connection gap	≈ 10 Hours	≈ 8 Hours	≈ 9 Hours	≈ 1 Hour	≈ 1 Hour
Image size	43,312 km^2	138,600 km^2	95,287 km^2	> 1 million km^2	> 1 million km^2

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