Performance analysis of LAPAN-A3 data acquisition using X-band receiver at Rancabungur ground station

P R Hakim and S Utama

Satellite Technology Center, National Institute of Aeronautics and Space (LAPAN)
patriarachmanhakim@lapan.go.id

Abstract. As an experimental remote sensing microsatellite, LAPAN-A3/IPB satellite mission produces at least 10 GB payload data daily, mainly comes from multispectral imager payload with the addition of digital matrix imager, Automatic Identification System (AIS) and scientific earth magnetometer. To improve the satellite data reception capability, LAPAN had already installed dual X-band and S-band receiver on Rancabungur ground station. This research aims to analyze the performance of LAPAN-A3 payload data reception by using X-band receiver from Rancabungur ground station. The assessment consists of determining daily payload data transmission capability and realtime multispectral image acquisition performance, as well as distortion occurs on the received data caused by signal interferences. Based on the first four months of the X-band receiver operation, it is found that the receiver has similar data reception performance compare to the X-band receiver on Kongsberg ground station currently leased for LAPAN-A3 operation, i.e. receiving about 7 GB payload data in high elevation satellite pass. The X-band receiver could also receive realtime multispectral image acquisition when the satellite passes western part of Indonesia in the morning, producing up to 10 GB of multispectral image in single satellite pass. However, the data reception performance often degraded by signal interferences from ground station neighborhood, both quantitative and qualitatively. Based on these performances, a better LAPAN-A3 satellite mission planning can be developed and systematic interferences detection can be done based on the received data. This allows LAPAN-A3 satellite to produce more payload data with better quality.

1. Introduction

LAPAN-A3/IPB satellite has several payloads to fulfill its earth surveillance and remote sensing missions. Three of the payload are optical payloads which are pushbroom multispectral imager, digital matrix camera and microbolometer, where the other two payloads are Automatic Identification System (AIS) to detect ships and scientific magnetometer to measure earth magnetic field [1][2]. Due to high multispectral imager data rate, LAPAN-A3 satellite uses X-band transmitter which has 105 Mbps transmission rate to transmit the payload data to ground station receiver [3][4]. From beginning of its launch, LAPAN-A3 payload data was downloaded by using X-band receiver of third party Kongsberg ground station. Since the payload data transmission is limited only once a day, LAPAN-A3 mission operation is also limited to only able to produce about 7 GB of payload data, mostly comes from 6 GB of multispectral image, 500 MB of digital matrix image, and another 500 MB of combined AIS and magnetometer data. To improve the payload data reception capability, LAPAN had installed dual X-band and S-band receiver on Rancabungur ground station on late of 2017. The addition of the receiver will obviously improve the quantity of daily payload data that can be produced by any of LAPAN
satellites, but most importantly it also builds national sovereignty in terms of national satellite data reception, reducing the needs of satellite image from foreign country and also keeping important data to be safe from unauthorized adversaries.

With the addition of X-band receiver on Rancabungur ground station, LAPAN-A3 payload data can be downloaded up to four times a day in Indonesia, allowing reduction the use of Kongsberg ground station to receive the payload data, thus saving significant annual fee for renting the receiver. The new installed X-band receiver also allows realtime operation mode of LAPAN-A3 multispectral image acquisition of west Indonesia region, which was not possible previously [5][6]. This research aims to analyze the performance of LAPAN-A3 payload data reception from Rancabungur ground station by using the new installed X-band receiver, based on several abovementioned aspects. First aspect to be investigated is the daily capability of the receiver to receive LAPAN-A3 payload data, considering number of satellite passes each day and also the satellite transmission rate, with Kongsberg receiver daily capability will be used as a benchmark to measure the receiver performance. Second aspect to be investigated in this research is performance of realtime multispectral image acquisition mode, where both quantity and quality of the images captured under realtime operation mode are compared to the images captured under default operation mode. In addition of daily data reception and realtime mode capability analysis, this research also discusses about potential signal interferences which could affect both quality and quantity of the received LAPAN-A3 payload data, since Rancabungur ground station located in considerably not far away from city center thus has many possible interference sources around the ground station.

Based on the analyzed X-band receiver performance, this research also aims to provide further LAPAN-A3 satellite mission enhancements, including optimized mission planning and detection of signal interference based on the received payload data. The proposed mission planning based on the fact that by knowing characteristics of X-band data reception on Rancabungur ground station, many payload acquisitions can be planned, efficient data memory storing can be achieved and much more payload data can be downloaded. Meanwhile, daily systematic interference detection can be conducted by calculating the percentage of the valid time counter on the received data, and then plotting the result on earth spatial coordinate by using satellite orbit model [7][8]. Last but not least, this research will discuss about potential benefit of having several X-band receivers within Indonesia region, to support LAPAN-A3 satellite payload data downloading in particular, as well as LAPAN-A2 or any LAPAN satellites in the future in general.

2. Methodology

This research investigates the quality of LAPAN-A3 payload data reception by X-band receiver on Rancabungur ground station, inspired by analysis done to LAPAN-A3 data reception on existing receiver on Parepare ground station [9]. In general the payload data transmission by LAPAN-A3 satellite can be divided into two different modes, i.e. recorded payload data transmission in the night and realtime multispectral imager acquisition in the morning. This research starts by evaluating the size of LAPAN-A3 payload data that can be downloaded by using Rancabungur ground station for each single satellite pass in recorded transmission mode. Based on experiences on payload data reception from Kongsberg ground station, averaged of 7 GB payload data can be downloaded from high elevation satellite pass. The figure will be used as benchmark for performance evaluation of X-band receiver on Rancabungur ground station when receiving LAPAN-A3 payload data. The capability of the X-band receiver to receive multispectral imager data in realtime acquisition transmission mode is also evaluated, however there is no benchmark for this evaluation since LAPAN-A3 satellite has not been activated realtime acquisition mode prior to Rancabungur X-band receiver installment. Several analysis have been done about LAPAN-A3 realtime acquisition prior to this X-band receiver installment, but both researches based on simulation and predicted characteristics [5][10][11].

After evaluating LAPAN-A3 payload data reception on Rancabungur ground station in terms of the quantity of received payload data in both transmission modes, this research also briefly evaluates the quality of the received data. This research assumes that the satellite always transmit valid payload data, which has been validated from many received data from Kongsberg ground station. Any error on
LAPAN-A3 payload data received from Rancabungur ground station is assumed exclusively comes from imperfection of ground station reception, which could be caused mostly by signal interference sources from ground station neighborhood. Figure 1 shows general flowchart of this research, which essentially evaluates both quantity and quality of LAPAN-A3 payload data reception from X-band receiver on Rancabungur ground station under both transmission modes.

Figure 1. General flowchart used in this research.

Apart of evaluating the performance of LAPAN-A3 data reception on Rancabungur ground station, this research also develops some methods to improve LAPAN-A3 satellite performance in general. First improvement is satellite mission planning enhancement based on known characteristics of data reception on Rancabungur ground station. Given precise information about data reception and satellite passes, it is possible to plan highly efficient mission planning and on-board data storing which in turn avoiding unnecessary redundant transmitted data. Second improvement proposed in this research is possible systematic detection of signal interference which only solely based on received data without the need of actual laborious interference measurement. The proposed method works based on quality of the received payload data, measured by percentage of valid codeword received during predetermined sampling time interval. This quality metric is then plotted with respect to actual transmitted time, where with SGP-4 orbit model can be further transformed into earth spatial information of latitude and longitude [8]. Given a quality metric value of the received data and its corresponding latitude and longitude, as well as location of the ground station, the quality metric of data reception by X-band receiver can be trivially calculated by using simple trigonometric function. Figure 2 shows general flowchart of the proposed systematic signal interference detection in this research, based solely on the received payload data.

Figure 2. Flowchart of the proposed systematic signal interference.

3. LAPAN-A3 data reception performance
Three aspects that will be discussed are the daily downloaded capacity of the Rancabungur X-band receiver to receive LAPAN-A3 payload data, the performance of realtime transmission mode, and the effect of signal interferences on the received LAPAN-A3 transmitted data. The analysis is done based
on actual LAPAN-A3 payload data which have been received since beginning of X-band receiver installment on Rancabungur ground station.

3.1. Daily download capability

Since January 2018, Rancabungur ground station has been receiving LAPAN-A3 satellite payload data regularly both for recorded and realtime transmission mode. However, the size of downloaded data varies significantly from one transmission to the other, depends on the transmission mode type and duration of satellite contact time to ground station. Figure 3 shows the size of downloaded payload data received since January up to April 2018 for recorded transmission mode. It can be seen that the size varies significantly with maximum downloaded data size around 7 GB data. Note that in many occasions it is possible for the satellite to transmit the data twice a day in the night for recorded mode, although one of the transmission could only transmit small size of data due to very short satellite contact time duration.

![Received Data Size Timeline](image)

**Figure 3.** Size of downloaded LAPAN-A3 data from Rancabungur ground station.

While figure 3 shows informative timeline for LAPAN-A3 downloaded data from Rancabungur ground station, it is unclear about the size uncertainty between one transmission to the other. Figure 4 shows relationship between the size of downloaded data to the satellite contact time duration, or in more convenient way, to the maximum elevation angle of the particular satellite pass. It can be seen clearly that for the passes with maximum elevation angle of about 60 degree or more (equivalent to less than 30 degree zenith angle), the X-band receiver is able to receive around 7 GB data, same as the downloaded data size received from Kongsberg ground station. It can also be seen that the passes with lower maximum elevation angle produces slightly lower received data, and the size of received data suffers significantly when the maximum elevation angle drops below 30 degree. Furthermore, figure 4 also shows that satellite passes on the right and the left side of the ground station produces different characteristics, where satellite passes on the west of Rancabungur ground station produces slightly better performance. Based on several brief inspections, it is found that this happens due to presence of signal interference and will be discussed on the latter section.
3.2. Realtime transmission capability

Realtime acquisition mode of multispectral image is one of important feature of LAPAN-A3 satellite. In this transmission mode, the satellite keep transmitting imager data without the need of on-board memory to store the data, thus the satellite could transmit the observed imager data indefinitely as long as the satellite power permits. Therefore, while multispectral imager observation in recorded mode could only produce about 4 GB maximum for each acquisition, in realtime acquisition mode it is possible to produce up to 10 GB downloaded image data for just only one satellite pass. This 10 GB data is produced from about 5 minutes observation, equivalent to more than 2000 kilometer along track coverage, more or less the distance from the northeast to the southwest part of Indonesia. However, the image produced are compressed version of original image, thus has lower image quality although the quality degradation is not significant. LAPAN-A3 multispectral imager data could be transmitted realtime by using two mode of compression, which are lossless and lossy mode. In lossless mode of realtime transmission, the image data to be transmitted is compressed by using Differential Pulse Code Modulation (DPCM) and Huffman encoding [10]. Meanwhile in lossy mode realtime transmission, the imager data is compressed by using Fast-Fourier Transform (FFT) and Huffman encoding [11]. Image produced in lossless mode has better quality with reduced swath-width, while image produced in lossy mode has degraded image quality due to compression process.

Figure 5 shows 109 images of LAPAN-A3 multispectral imager captured by using X-band receiver on Rancabungur ground station for the first four months of its operation. It can be seen that the satellite could observe all western part of Indonesia region, from Sabang in the west up to Kupang in the east, as well as majority area of south-east Asia country such as Singapore, Malaysia, Brunei, Thailand, Myanmar, Cambodia, Vietnam, Philippines and even small part of north-western of Australia. Note that in most cases, the realtime acquisition mode only executed for less than 5 minutes, since the Rancabungur ground station located on the southern part of Indonesia, and the realtime acquisition mode mainly planned to capture Indonesia area, not to capture more southern part of the ground station which is literally vast of Indian ocean and some west-northern parts of Australia. The rest of satellite pass is usually used for transmitting the recorded payload data. From figure 5, it can be seen that in some occasions the received satellite data are corrupted or even cannot be received completely, which are caused by signal interference same as problem exists on the transmission of recorded payload data earlier.
3.3. Data corruption due to signal interferences

Figure 5 shows that the reception of LAPAN-A3 payload data from Rancabungur ground station has been distorted in some cases. Some of the images are heavily distorted by the interference, and in few cases the interference could produce total failure of data reception. As already mentioned earlier, the distortion might be caused by the presence of signal interference which comes from X-band interference source on surrounding of the ground station. Interference sources that cause the X-band receiver fails to receive appropriate payload data should be eliminated so that complete and undistorted data can be downloaded from Rancabungur ground station. Rigorous signal interference scanning measurement could be conducted regularly to find these interference sources, but it needs laborious effort and time consuming. Another simpler approach is needed to regularly find these interference sources. Therefore, this research proposes easier method to find interference sources based on solely on the received data, it can be the received payload data from recorded transmission mode or the received multispectral image data from realtime acquisition mode.

4. LAPAN-A3 satellite mission enhancement

Based on several analysis that have been done, several aspects can be discussed to improve the quality of overall LAPAN-A3 satellite operation in general. First and foremost, possibility of interference sources detection based on the received data will be investigated to replace or at least to complement rigorous interference scanning measurements. Some improvement related to satellite mission planning will also be discussed, which focuses on how to produce the most unique downloaded payload data as possible from Rancabungur ground station. Last but not least, potential addition of X-band receiver on
east Indonesia region will also be investigated, opening the possibility that LAPAN-A3 satellite could produce vast and realtime image of entire Indonesia archipelago regularly.

4.1. Systematic interference detection

The basic concept of the proposed method is to analyze the quality of the received data. However, to directly analyze image quality is not an easy task, therefore the analysis will be conducted based on metadata embedded to the downloaded payload data. LAPAN-A3 satellite implements international data format for its data transmission which is recommended by Consultative Committee for Space Data System (CCSDS) [12]. Based on these standards, the transmitted payload data will have several metadata embedded on each data packet, which are in most cases have some pattern or even fixed values. One important metadata on payload data is a time counter, which indicates incremental time of each data packet relative to the start of on-board computer powered up. In this research, these data packet time counter is used to identify the quality of the received signal. The received signal is said to be good if the received time counter has nominal incremental pattern, while signal interference might be present if the received time counter has no appropriate incremental pattern due to the value has been distorted by the noise.

Once positions of the distorted data packet time counter have been determined, then absolute time of the corrupted data packet can also be calculated. This absolute time can be processed to produce earth location where the satellite transmitted signal is interferenced, in terms of latitude and longitude coordinates. Furthermore, the position of latitude and longitude can be transformed into azimuth and elevation angle with respect to particular ground station, in this case Rancabungur ground station. Figure 6 shows plots of systematic interference detection based on the received payload data of recorded transmission mode during April 2018.

![Figure 6. Systematic interference detection based on the received data.](image)

Green plot indicates that the data were received perfectly, while red plot indicates that the data were not received perfectly, either can be caused by interference or by low elevation angle. From figure 6, it can be said that repeated source of interference occurs on azimuth 120 degree and 300 degree, with elevation up to 15 degree. Example on figure 6 shows that the proposed method able to
periodically monitor the location of signal interference which degrade the quality of the received LAPAN-A3 payload data on both recorded and realtime mode of transmission. With current setup of twice recorded payload transmission a day and twice realtime, it is possible to provide appropriate weekly artificial interference scanning measurement of entire Rancabungur ground station coverage. This continuous detection of possible X-band signal interference could be used as references to conduct further coordination with Ministry of Communication and Information Technology to eliminate the interference sources exist around Rancabungur ground station.

4.2. Optimal mission planning
In most of operational satellite mission operation, the ultimate goal is to produce as many as payload data with highest quality. LAPAN-A3 satellite is no different, where main payload instruments such as multispectral imager and AIS are needed to produce the data regularly with high quality and quantity. However, daily capability of LAPAN-A3 satellite to transmit payload data is limited to once a day before X-band receiver installment in Rancabungur ground station. With an addition of Rancabungur ground station, LAPAN-A3 could transmit payload data up to three times a day, or equivalent to total of 20 GB recorded payload data. To further optimize of the satellite mission operation, all of these 20 GB data must be guaranteed comes from several different and unique payload data. Any redundant data received can be considered a failure of satellite mission operation.

With information about characteristics of payload data reception on Rancabungur ground station such as the possible of received data size and location of latest interference source, precise timing of the satellite to transmit the payload data to particular ground station can be planned effectively. With this careful mission scheduling, LAPAN-A3 has been producing about 15 GB unique payload data daily, which mostly consists of around 12 GB of multispectral imager data. Table 1 shows an average data size planned for each month for each satellite payload instrument data, with comparison to data size produced before the installment of X-band receiver on Rancabungur ground station.

| No  | LAPAN-A3 Payload Mission          | Mission Planning in 1 Month (30 days) | 2017     | 2018     |
|-----|----------------------------------|--------------------------------------|----------|----------|
|     |                                  | Data | Size (GB) | Data | Size (GB) |
| 1   | Multispectral imager (recorded)  | 60 images | 165 | 60 images | 165 |
| 2   | Multispectral imager (realtime)  | - | - | 30 images | 240 |
| 3   | Multispectral imager (worldwide) | - | - | 15 images | 52.5 |
| 4   | Digital camera                   | 30 images | 36 | 75 images | 90 |
| 5   | Scientific magnetometer          | 60 hours | 6 | 60 hours | 6 |
| 6   | Automatic Identification System  | 30 days | 6 | 30 days | 6 |
| 7   | Thermal imager                   | 4 videos | 2 | 4 videos | 2 |
|     | TOTAL                            | 215 GB data | 561.5 GB data | 215 GB data | 561.5 GB data |

It can be said that the addition of X-band receiver on Rancabungur ground station has effectively increased the quantity of the received unique payload data of LAPAN-A3 satellite, for about at least twice or even three times bigger compare to only using Kongsberg ground station. However as direct consequences, there are much more unique data that need to be processed and distributed to the end users. Most significant additional effort needed is to process the received realtime acquisition data of multispectral imager, where in most cases the received image data needs up to 10 hours of processing time. This realtime image data processing should be improved in the future, and the ultimate goal would be to implement realtime quicklook decoder by using Field Programmable Gate Array (FPGA), so that the received image data can be viewed directly exactly the same time as the satellite capture the image, of course with some acceptable degraded image quality.
4.3. Addition of X-band receiver on eastern Indonesia

Figure 5 above shows that LAPAN-A3 multispectral imager realtime acquisition has great potential in providing vast Indonesia archipelago coverage in relatively short time duration. However, the X-band receiver on Rancabungur ground station still unable to support realtime image acquisition for eastern Indonesia region. Based on the first four months of realtime mode operation, it can be concluded that X-band receiver on Rancabungur could produce realtime image acquisition from Subang in the west to Kupang in the East. It can also be said that entire area of Sumatera, Kalimantan, Java, Nusa Tenggara and Sulawesi can be supported for realtime multispectral imager acquisition. That leaves only Maluku islands and Papua region that cannot be supported by X-band receiver on Rancabungur ground station for realtime acquisition. Therefore to provide ultimate image coverage for Indonesia region, at least one additional X-band receiver should be installed in eastern part of Indonesia.

There are two possible locations in which this additional X-band receiver could be installed, Parepare on South Sulawesi and Biak on West Papua, since LAPAN has already established operational ground station in these two places for more than two decades. The addition of an additional X-band receiver on either Parepare or Biak ground station will surely be supported, both in terms of operator experiences and ground station maintenance. Figure 7 show potential realtime image coverage produced by using two X-band receivers on Rancabungur ground station in the west and Parepare and Biak ground station in the east.

![Figure 7. Potential LAPAN-A3 realtime coverage by using two X-band receivers in Indonesia.](image)

With two X-band receivers on Rancabungur and either Parepare or Biak ground station, it can be shown that multispectral imager of LAPAN-A3 satellite could produce observation images which cover for whole of Indonesia region completely once every 21 days, directly related to revisit time of the imager itself [13]. The vast majority of sea area within Indonesia will also be covered regularly, which is not possible without the presence of X-band receiver in Indonesia since the number of payload data transmission is limited once a day and realtime mode of acquisition is not possible. Several interesting objects around the world could also be observed more often than before, allowing more researches can be conducted continuously. In overall, with two X-band receivers in Indonesia, LAPAN-A3 satellite could produce up to 40 GB payload data a day which is significant improvement from current satellite operation.

5. Conclusions and Future Works

To improve satellite data reception capability of LAPAN satellites, LAPAN has installed dual X-band and S-band receiver on Rancabungur ground station, which was effectively operated since the beginning of 2018. The X-band receiver has been successfully received LAPAN-A3 data since the beginning of its operation, with performance similar to currently leased X-band receiver at Kongsberg ground station, i.e. average of 7 GB of data can be downloaded from each single high elevation satellite pass. The presence of X-band receiver in Rancabungur also allows LAPAN-A3 multispectral imager to produce realtime image acquisition when the satellite passes western part of Indonesia,
producing up to 10 GB decompressed image data. The ability to download payload data up to four times a day from Rancabungur ground station has also significantly increased LAPAN-A3 overall payload data generation, increasing from only 200 GB into about 600 GB a month, almost three times bigger than previous. Addition of another X-band receiver in eastern part of Indonesia could further improve LAPAN-A3 payload data generation, where 40 GB data could be produced daily, and guarantees that any area in Indonesia can be observed at least once every 21 days.

However, LAPAN-A3 payload data reception on Rancabungur ground station is suffered from X-band signal interference from ground station neighborhood, which causes significant distortion on the received data. Algorithm for systematic detection of signal interference based on solely the received band signal interference from ground station neighborhood guarantees improvements that are bigger than previous.

Addition of another X-band receiver also has been developed, and has successfully found several suspects of interference source around the ground station, which can be followed with actual signal interference scanning measurement before reporting to Ministry of Communication and Information Technology to take further action.

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