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Designing a constellation for AIS mission based on data acquisition of LAPAN-A2 and LAPAN-A3 satellites

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Abstract

Indonesia requires a maritime surveillance system that's capable to monitor its extensive waters territorial. One of the maritime standard navigation systems named AIS (Automatic Identification System), which is based on GPS and VHF digital communication, have enabled the ship monitoring in a real-time. By placing AIS receiver on the satellite, its coverage will be larger compared to the one usually placed on the seashore by maritime authority. Orbiting the AIS receiver prompted appearing the limitation of Time Division Multiple Access (TDMA) technology so the probability of ship detection would decrease drastically due to a huge number of heard ship signal simultaneously. This paper describes the design of satellite constellation for Indonesian maritime surveillance based on the result of the AIS data acquisition by LAPAN-A2 and LAPAN-A3 satellites that operate in both equatorial and polar orbit.

Keywords*: AIS, LAPAN-A2, LAPAN-A3, satellites constellation*

1. Introduction

Indonesia is the largest archipelago country in the world. Its water area covers Indonesia territorial around 5.8 million km^2 or 75% of the entire area which is very broad, but the monitoring capacity is really limited so various illegal activity cases occurring in Indonesia. Located in Southeast Asia, Indonesia is one of the strategic countries of global fisheries production. Food and Agriculture Organization in 2016 mentioned that seventeen percent of global fish production is contributed from fishing industries in six countries, namely Indonesia, Vietnam, Myanmar, Thailand, Philippines and Malaysia. However, Southeast Asia is one of the vulnerable regions with large Exclusive Economic Zones (EEZ) which suffer from Illegal, Unreported and Unregulated (IUU) fishing [1].

Annual illegal and unreported marine fishing generates US$15.5 billion to $36.4 billion in illicit profits of that, the majority is generated off the coasts of developing countries. This estimate is conservative as it does not include unregulated fishing as well as any IUU fishing in inland fishing areas. It has major environmental, societal, and security impacts in developing countries, particularly in areas where the local economy and the local diet depend on fishing. Firms that participate in IUU fishing have been linked to other crimes such as the smuggling of migrants and the trafficking of drugs and persons [2].

The threat of IUU fishing was triggered by the condition of the global fisheries sector, where several countries experienced a decline in fish stocks, a reduction in fishing fleets due to restrictions on grant fishing licenses while the demand for fishery products increased. On the other hand, the ability to supervise marine and fisheries resources in Indonesia is inadequate. IUU Fishing is also a part of transnational crime which does not only cover fisheries, but also involves slavery, human trafficking, smuggling of animals, drugs and others. IUU Fishing threatens not only for marine and fisheries resources, but also endanger widely in the marine environment and human activities. IUU fishing has driven overfishing worldwide and takes in significant impacts on fishing capacity, depleting fish stocks, and destroying the marine environment worldwide. The large number of illegal fishing vessels arrested by the Indonesian government indicated that many illegal fishing vessels operated in Indonesian waters. Table 1 presents illegal fishing trends in Indonesia, as defined by arrested at sea.

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Table 1. Illegal Fishing Arrests based on Countries of Origin [1]

No	Country by origin	Year (Unit) 2010	2011	2012	2013	2014	2015	2016	2017	Total
1.	Indonesia	24	30	42	24	27	42	23	52	264
2.	Malaysia	22	11	5	14		5	26	19	102
3.	Vietnam	115	42	40	17	9	36	83	90	432
4.	Thailand	7	3	8	4	7	6	1		36
5.	China	7						1		8
6.	Hong Kong		1							1
7.	Taiwan		6							6
8.	Philippines	8	13	17	9		6	29	6	88
9.	East Timor								1	1
	Total	183	106	112	68	43	95	163	168	938

The United Nations Office on Drugs and Crime (UNODC) study in 2011 identified a number of vulnerabilities of the fishing industry to transnational organized crime and other forms of criminal activity. One of the main vulnerabilities identified is a general lack of governance and rule of law in the fishing industry, in particular there is 1) a lack of at-sea surveillance of vessel movements and transshipments; 2) a lack of transparency of the identity of the beneficial ownership of fishing vessels and a lack of international records of fishing vessels identity and history; 3) a lack of ability or willingness of some flag States to enforce their criminal law jurisdiction; and 4) a lack of international endorsement of existing international regulation of the safety of fishing vessels and working conditions of fishers at sea to bring these instruments into force and ensure compliance in port in the same manner as Port State Control of merchant vessels. Quota restrictions and declining fish stocks in many regions of the world have led to destitute fishers and fishing communities are deprived of their livelihoods and of an important food source. The socioeconomic conditions generated by overfishing may make fishers and fishing communities vulnerable to recruitment into criminal activities [3].

Ship monitoring can be carried out directly by extracting information from radar, imaging systems, ships broadcasting transponders as well as indirectly by detection of changes in the environment surround the ship [4, 5]. In Indonesia, maritime monitoring is conducted by the Ministry of Transportation that mainly uses the recording of the Vessel Traffic Information System (VTIS). Monitoring international ship routes in the trio of Indonesian Archipelagic Sea Lanes (IASL) are still taken out manually using beach radio facilities, visual observations and several coastal surveillance radar. Lombok Strait and Sunda Strait which are designated as IASL I and II has a significant traffic density of ships which serves national and international traffic lane. Established in the Automatic Identification System (AIS) data, there were 53,068 vessel voyages made through the area of Sunda Strait in 2016 [6]. This translates to around 145 ships per day. Summarized from 2014 to 2016, in average 29,841 unique voyages were made trough Lombok Strait annually [7]. Often times, many vessels have escaped from the monitoring of the authorities and threaten the safety and security over Indonesian waters. Meanwhile, the temporal resolution of ship patrols carrying radar and AIS data receivers is very low compared to the territorial waters that must be managed.

In the fishing industry, the Indonesian Ministry of Marine Affairs and Fisheries since 2003 has conducted surveillance using the Fisheries Ship Monitoring System or which is often referred to as the Vessel Monitoring System (VMS) by installing transmitters on fishing vessels measuring over 30 GT. In addition to knowing the movements of fishing vessels, VMS also ensures fishing vessel compliance with the applicable provisions. VMS describes the specific application of monitoring commercial fishing boats which is meant primarily for fisheries management, but the authority using it may utilize the information for other roles. VMS already provides a means of collecting more complete fishing position data to understand the footprint (extent and intensity) of fishing activity that shielded from public view. Despite the importance of these data, the temporal resolution of VMS is relatively low. Interpolation of VMS data is typically used to fill in the gaps between successive VMS points to produce a continuous track. On the other hand, there has been a recent increase in interest in the potential for using publicly available automatic identification system (AIS) vessel tracking data to investigate fishing activity. AIS data are openly available to the public, at high resolution, whereas VMS data are costly and subject to strict confidentiality regulations. Thus, the function of satellite-based AIS is an alternative source of information with which to understand patterns in fishing activity to overcome the gap in the VMS data [8, 9].

The universal shipborne AIS, as outlined by the International Maritime Organization (IMO) in the International Convention for the Safety of Life at Sea (SOLAS), is a shipborne transponder broadcasting ship, voyage, and safety-related reports. As a short distance tracking system employed by ships, AIS is used by ship traffic control systems or better known as Vessel Traffic Services (VTS) [10]. The AIS transponder will automatically transmit information such as position, speed, and navigation status at the same interval through the VHF transmitter mounted on the transponder. This information comes from navigation sensors owned by ships such as GPS receivers and gyrocompass or rate of turn indicators. Other info such as the name of the ship and the VHF call sign are programmed during installation of equipment and transmitted continuously with other data. The signal will be received by AIS transponders installed on other ships or on shore stations such as the VTS system. Information in the form of a unique identity, position, road status and speed can be displayed to assist ship crews and allow maritime authorities to track and monitor ship movements.

When satellites are utilized to detect AIS signatures, the term spaceborne/ satellite-based AIS is used. The development of a spaceborne AIS system has been carried out by several countries. Originating in 2007 where the US military experimental satellite TACSAT-2 tried to detect AIS signals in orbit, but the AIS signal was cut off due to co-channel interference when receiving signals from thousands of ships simultaneously. But presently there are commercial satellite providers, each of which designs and develops spaceborne AIS transceivers along with data processing supporting devices. Several big companies such as Orbcomm, Com Dev, SpaceQuest and Kongsberg Seatex have become the pacemaker of spaceborne AIS provider that successfully demonstrated the ability to acquire AIS data from space. SpaceQuest has successfully acquired AIS data globally via the AprizeSat 3 and 4 satellites in 2009. Orbcomm has developed satellite-based services to monitor various devices equipped with AIS transmitters in collaboration with the US Coast Guard [11]. Meanwhile Kongsberg Seatex in collaboration with the Norwegian Defense Research Institute (FFI) develops AIS receivers as AISSat-1 satellite payloads that launched in 2010. The AISSat payload was made simultaneously and similar to NORAIS (Norwegian AIS) which was tested by European Space Agency on the Station's Columbus laboratory of the International Space Station (ISS) in a program called COLAIS (Columbus AIS) [12].

Even though satellite-based AIS have been utilized in the maritime surveillance, it faces two challenges with respect to the signal decoding: 1) the AIS signal is weaker than on the surface of the Earth due to the increased range or distance; and 2) several signals may be received simultaneously because of a large coverage area that are not mutually organized with respect to the use of time slots. The first challenge is simply solved using a more sensitive receiver in space than on the shipborne equipment. The second challenge is dependent on the number of messages transmitted from within the entire field of view. The co-channel interference resulting from transmissions from densely trafficked waters is a greater challenge to decoding of messages than the weak signals [13], and there are several ways to solve this problem:
- decoding at lower difference in signal strength between the strongest and the interfering signal (referred to as desired-to-undesired signal ratio).
- utilization of a dedicated transmission method for a long-range AIS broadcast message from a ship to satellite.
- directional antennas that give a narrower field of view.

The possibility to apply a narrow field of view of a directional antenna underlies this study, which seeks satellites constellation for the AIS mission, including the number and type of its orbit, as well as the number of satellites within their antenna coverage.

2. Research Method

In the maritime monitoring using AIS, a simple link-calculations show that the signals can be detected in low Earth orbit. However, the AIS sensor in space will cover a very large area or horizon of the Earth beyond the designation of the AIS system at first. The system uses the concept of a frame that is 1 minute long and divided into 2250 time slots, so the two frequencies give 4500 slots per min. The slot length is 26.7 ms or 256 bits at 9.6 kbit/s as illustrated in Figure 1. The message entry is synchronized to the coordinated universal time (UTC). The distance delay bits (12 bits) prevent problems with overlapping messages due to different signal path lengths up to a range of 374 km. This is useful also for the space-based application. Access is managed using Self-Organized Time Division Multiple Access (SOTDMA) as the basic access scheme for scheduled repetitive transmissions from an autonomous station. In a very large footprint, thus receiving AIS signals from thousands of ships, would violate the SOTDMA limitations, and give major interference problems for the satellite [14]. Hence the large number of vessels in the viewing area will cause interference problems so that AIS messages from some ships may not be able to detect as shown in Figure 2.

To anticipate saturation in vessel detection due to the number of vessels that exceed the capacity of the standard AIS system, the AIS system intended for space monitoring must be modified both on the software and on the on-board processing. Many attempts have been constituted to discover techniques for avoiding message collisions on satellite-based AIS. Various papers have been published different methods to anticipate collisions of AIS messages known as "advanced demodulation". Some of these methods include a remodulation algorithm combined with a special demodulator, so that it can demodulate AIS signals with very low Carrier-to-Interferer (C/I) levels [15-17].

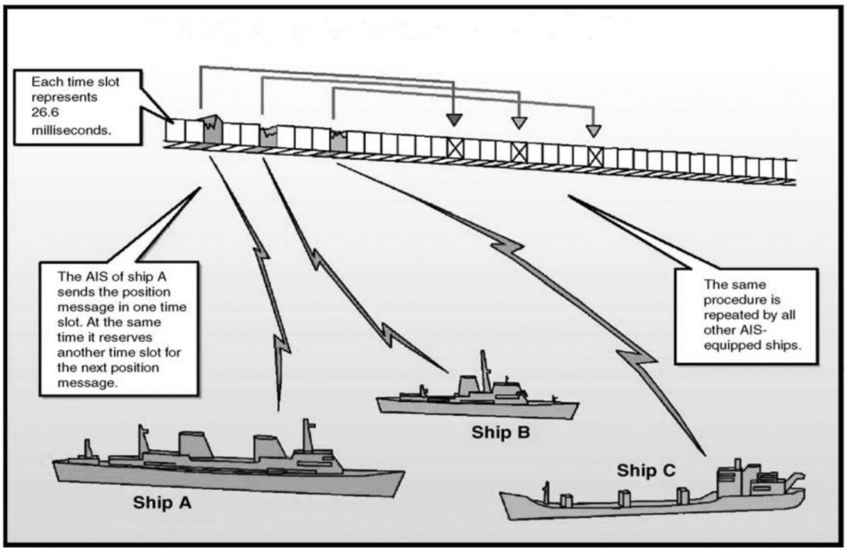

Figure 1. Time division multiple access (TDMA) access schemes [10]

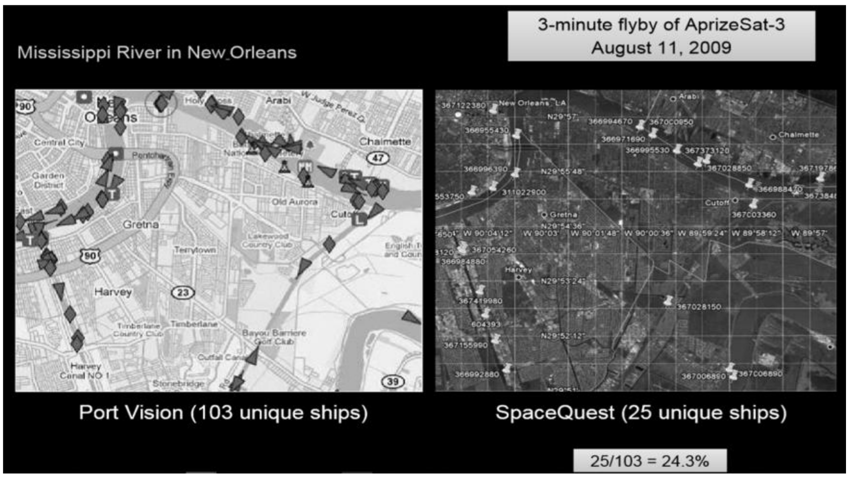

Figure 2. Comparison between spaceborne AIS and base-station AIS [18]

The advanced demodulation method can be efficient if two or three messages come together. But in areas with high ship density, such as the Malacca Strait generally more than two or three messages come together. Hence, in practice in the field in general the probability of detection is not significantly better. AISSat receiver introduces a new strategy that is to find the optimum performance between sensitivity, Carrier-to-Interferer (C/I) and Carrier-to-Noise (C/N). Figure 3 shows the simulation of ship detection probability, by satellite-based AIS carried out from 1000 km altitude. Nevertheless, with thousands of ships carrying AIS in Singaporean waters the ship detection probability would decrease drastically. According to the AIS data from Vessel Traffic Service (VTS) Singapore that monitored in four months, there was in total 17.026 distinct ships, signified by distinct MMSI [19]. Therefore, some part of Indonesian territory where is close to Singapore, the ship detection probability drops towards zero. The solution to this problem could be the constellation of satellites that use a more directional AIS antenna, limiting the field of view and thereby decreasing the number of ships simultaneously visible to the AIS sensor. The directional AIS antenna could be combined with an omnidirectional AIS antenna for increased coverage over areas where the ship density is low.

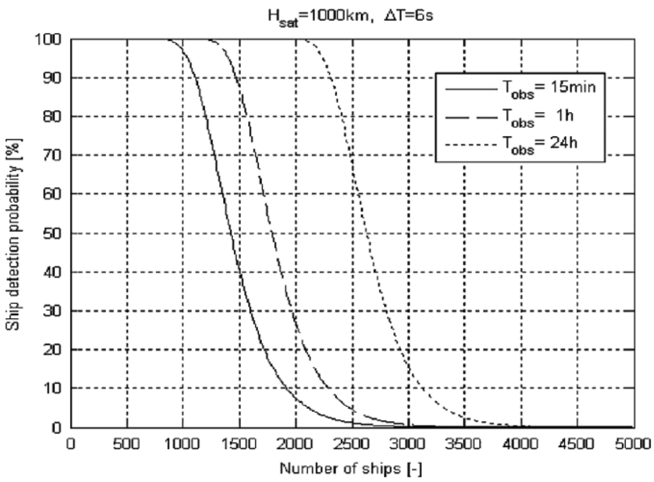

Figure 3. Ship detection probability as a function of number of ships for different observation times within ship reporting interval of 6 seconds [17]

One might tend to think that a higher orbital altitude would be advantageous for detection performance, because it raises wider coverage, which in turn leads to longer contact times. Even so, this will also cause an increase in the number of ships in the field of view, which consequently results in a higher number of message collisions. Thus, the height must be chosen by striking a careful equilibrium between the increase in performance that results from a larger coverage area and decreased performance due to more message collisions. Previous studies conducted by European Space Agency (ESA), by considering the number of detectable vessels related to the collision rate of the AIS signal, a constellation of 6 to 8 satellites within an orbit about 600 km altitude would satisfy the requirement of 3 hrs updating interval [20].

To initiate a maritime surveillance mission, Indonesia has flown two satellites (operated by LAPAN) as a pacer for the constellation of satellites carrying AIS, named LAPAN-A2 and LAPAN-A3 that have been established in 2015 and 2016 respectively [21-26]. LAPAN-A2 satellite operates in low inclination (near equatorial) orbit within 650 km altitude while LAPAN-A3 satellite carries out an AIS mission from sun-synchronous polar orbit (SSPO) within 515 km altitude. The low and near equatorial orbit inclinations allow satellites to pass through Indonesian territory 14 times per day while polar orbit gives advantage for global coverage. The typical ground track of LAPAN-A2 and LAPAN-A3 is depicted in Figure 4. Both satellites employ Kongsberg Seatex's AIS receiver that is similar to the AISSat and NORAIS receivers. Those AIS receivers implemented a software defined radio that supports in-orbit upgrade of the algorithm for higher performance. While the AISSat and NORAIS receiver have had algorithm upgrades since their original development in 2008, even more advanced algorithms have been developed since then [27-29]. The enhanced algorithms should improve the tracking capability of the next generation space-based AIS system significantly beyond the capability presented in this paper.

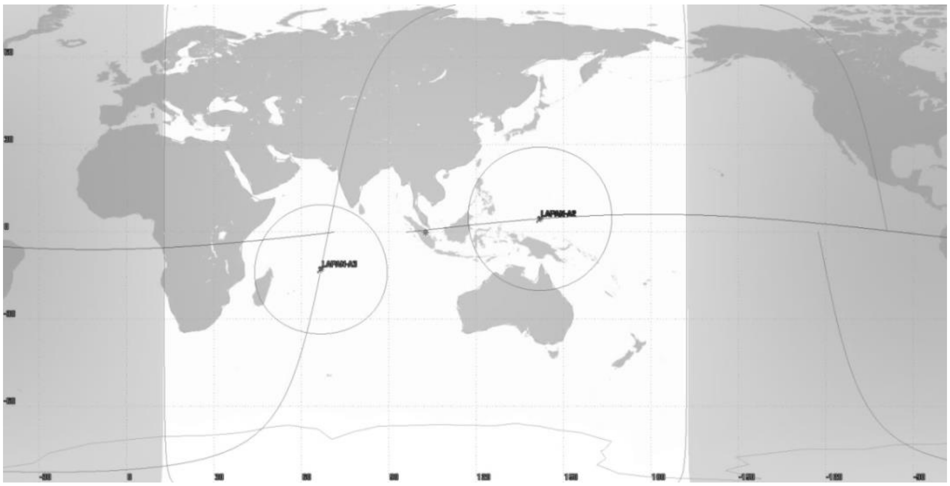

Figure 4. The orbit of LAPAN-A2 and LAPAN-A3 satellites

Established along the data acquired by satellite-based AIS receiver of LAPAN-A2 and LAPAN-A3, a study has been conducted to design a constellation of satellites carrying AIS for Indonesian maritime surveillance. Indonesia's geographical position where is stretching along the equator between two oceans and two continents has become a unique problem that is not found in any region. Its position also implicates a very heavy sea traffic over Indonesian’s water. Accordingly, the constellation design that implemented in Indonesia should consider the aforementioned problem. The data obtained from LAPAN satellites are very valuable information for determining the orbit, the suitable antenna coverage, and the minimum number of satellites should be deployed to meet the requirements. The satellite orbit, then simulated using the Systems Tool Kit (STK) version 11 software for better visualization.

3. Results and Analysis

In a month of AIS statistical data, every minutes LAPAN-A2 satellite collected 460 messages on average and 2270 at maximum while LAPAN-A3 satellite obtained 175 on average and 790 at maximum. Figure 5 depicts the typical plot of the AIS messages location on the world map which are acquired by LAPAN satellites in a month. This plot gives an information about ships distribution around the world, ship routes as well as their density. At a glance, the density of ships in the equatorial region (within -30° to +30° latitude) is higher than in the polar regions. On average, LAPAN-A2 collect more AIS data than LAPAN-A3, and even more than doubled per day. The general statistic of the AIS acquisition of LAPAN satellites is depicted in Table 2.

Even though the messages (ship’s location) could be easily plotted on the map, there is no transparency from which position of the satellite these messages have been heard. So, another plot containing the satellite positions together with the number of receiving messages should be made for better understanding. Since the orbital rotation only allows LAPAN-A2 circulates around equatorial region, it will not give representative situation of AIS message traffic around the globe. Thus, LAPAN-A3 is used for messages density mapping. Typical AIS signal density from about 500 km altitude of SSPO by LAPAN-A3 satellite is presented in Figure 6. It indicates that the probability detection became saturated (drop to zero) when the satellite passed above Malacca Strait/Singapore to South China Sea, Europe and US region.

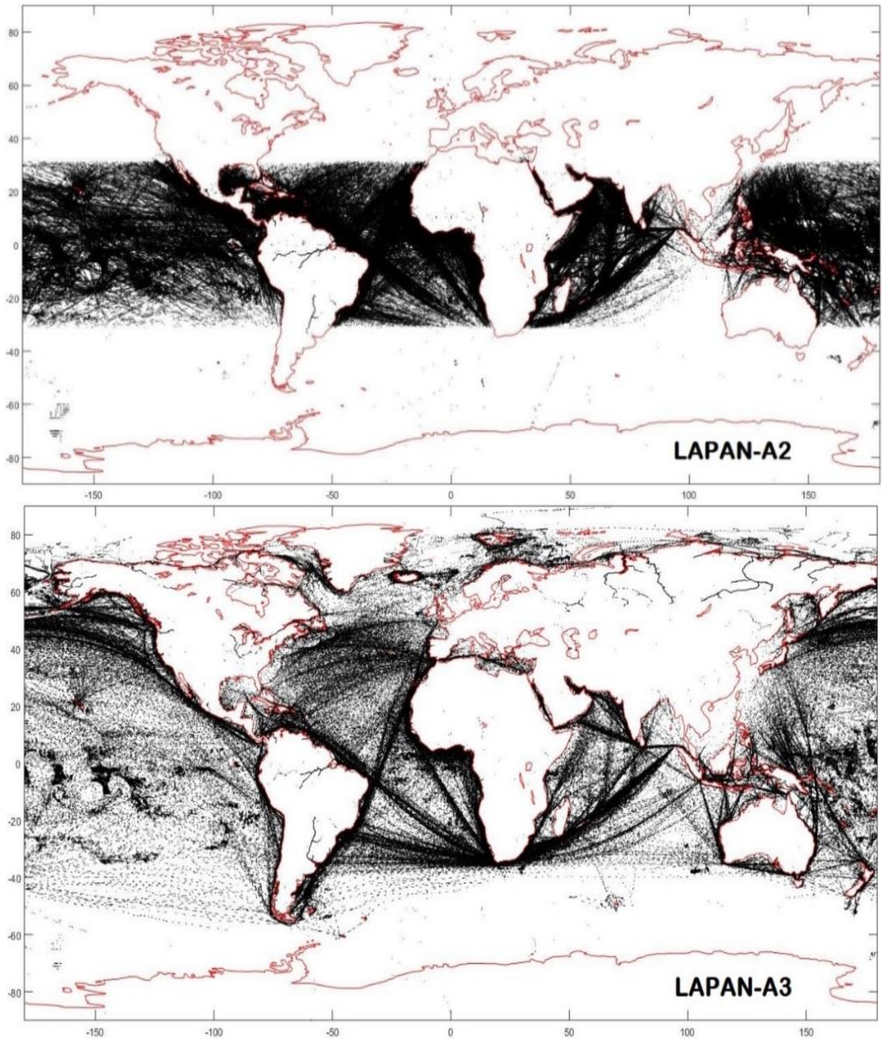

Figure 5. Typical plot of AIS acquisition in a month by LAPAN satellites

Table 2. General Statistic of AIS on LAPAN Satellites in a Semester

Parameter	Value	
Average of LAPAN-A2 distinct ships detection per day	16511	± 5%
Average of LAPAN-A2 total messages per day	446458	± 9%
Average of LAPAN-A3 distinct ships detection per day	18627	± 5%
Average of LAPAN-A3 total messages per day	187088	± 11%
Comparison between LAPAN-A2 & LAPAN-A3:		
Distinct ships detection per day (LAPAN-A2: LAPAN-A3)	4	: 5
Total message detection per day (LAPAN-A2: LAPAN-A3)	12	: 5

In case when an experiment involving satellite-based and terrestrial-based AIS simultaneously is needed, particularly in comparison, validation, calibration and so on, the mapping of signal density would provide information on where the experimental activities can be carried out. For instance, to compare the distinct ship detection between satellite-based and terrestrial-based AIS in Indonesia can only be conducted in eastern Indonesia. The number of distinct ships in the AIS data can be found by counting the number of distinct MMSI numbers across all message types. To perform such that experiment, a terrestrial AIS station was established in Kupang, eastern Indonesia. This location is determined either it is on an international ship route it is quite far from the Malacca Strait/Singapore, so the probability of detection would be adequate. Table 3 gives an information about all of distinct ship detected by Kupang Terrestrial Station compare to the satellite detection.

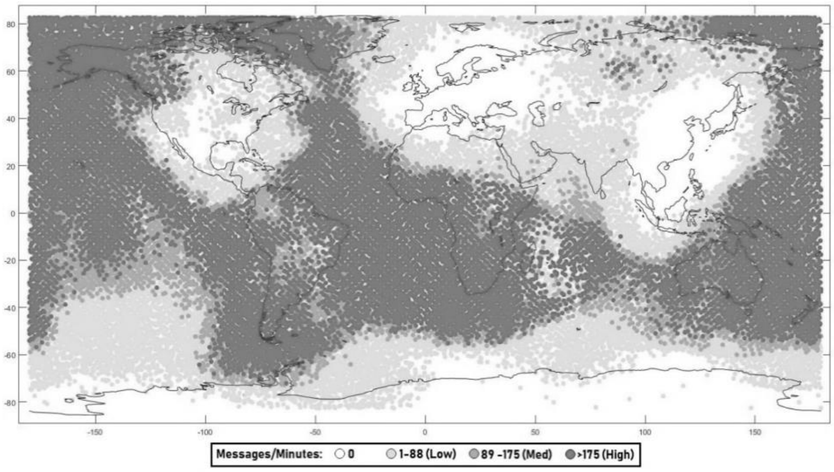

Figure 6. AIS signal density from 500 km altitude of SSPO

Table 3. Distinct Ship Detection by LAPAN Satellites and Kupang Terrestrial Station

Date: 7 August 2018			Date: 8 August 2018		
LAPAN-A2	LAPAN-A3	Terrestrial Station	LAPAN-A2	LAPAN-A3	Terrestrial Station
525001120	219483000	219483000	210246000	525006037	210246000
525006037	503002000	374216000	432919000	525100417	235009760
563053800	525005009	503002000	525100417	525105003	241276000
563771000	525006037	525001120	525105003	525200077	308579000
563860000		525005009	525200077		432919000
636015641		525006037			477139700
		525016204			477351900
		525022177			525001090
		525119033			525006037
		563053800			525025056
		563771000			525100417
		563860000			525101060
		636015641			525105003
		636016460			525200077
					563053800
					636016460

According a research by [19], there are 85,108 distinct ships around the world that's collected by satellite-based AIS. By using the trendline of LAPAN-A3 AIS detection statistic as shown in Figure 7, it will need 300 days to attain all of distinct ships. On the other hand, in that respect is no opportunity for LAPAN-A2 to detect all of distinct ship due to equatorial limitation orbit. However, after 300 days, the number of distinct ship detection by LAPAN-A2 (latitude between -30° to +30°) is approximately 84%. It remains only 16% of different ships are distributed outside equatorial coverage. Comparing the capability of LAPAN satellites AIS detection in a single day from Table 2 to the total of distinct ships from previous study led to percentage about 19.4% of LAPAN-A2 and 21.9% of LAPAN-A3. Meanwhile, the comparison with the terrestrial station as shown in Table 3, the detection probability of AIS data is 31.3-42.9% of LAPAN-A2 and 25-28.6% LAPAN-A3.

Based on the AIS data acquired by LAPAN satellites and the comparison test using terrestrial station, the study could conduct the constellation design for real-time AIS acquisition to support maritime surveillance over Indonesia. Since the dispersion of the ships is concentrated in the equatorial region, most of the satellites in the constellation should be put in the equatorial orbit preferably within 1200 km to cover a region within -30° to +30° latitude. The low earth orbit equatorial satellite has become a favorable option and gives the additional advantage for multipurpose mission for developing countries like Indonesia that spread along the equator line [30].

It has been demonstrated that higher orbit gives more AIS data. But the rise of the orbit altitude would expand the satellite field of view, hence, the AIS have to use a directional antenna to narrow its coverage. One option for a LEO satellite with an enhanced antenna design, providing a narrower beam to reduce the incoming AIS load is by using a high gain helix antenna. To this aim, the satellite AIS mission could consider as reference the DLR AISat-1 nanosatellite weighing 13 kg, which is equipped with a 4.2 m long high gain helix antenna [31]. The other interesting option to implement directional antenna for AIS mission is by developing a deployable Yagi antenna that has been proved in the orbit operation by NorSat-2 as shown in Figure 8 [32].

Within 1200 km altitude, a constellation requires 8 satellites in a plane of equatorial orbit to perform near real-time observation, so at least every 15 min the regional monitoring data would be renewed. Deploy additional three sun-synchronous orbit planes in the same altitude, consisting one satellite in each orbit, will improve a constellation with global ship monitoring that updated in every 110 minutes. The proposed AIS-based satellite constellation for Indonesia is depicted in Figure 9.

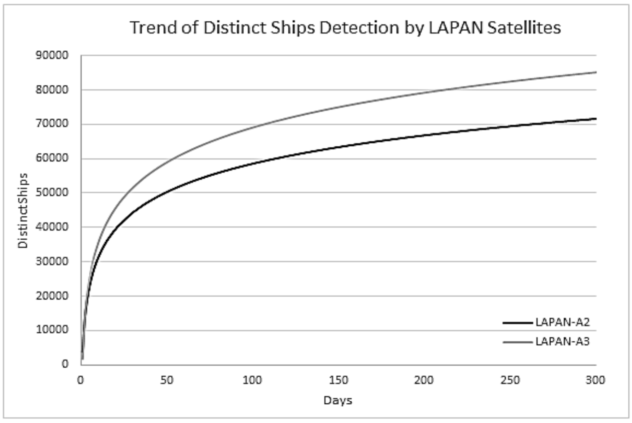

Figure 7. Trend of distinct ships detection by LAPAN satellites in 300 days

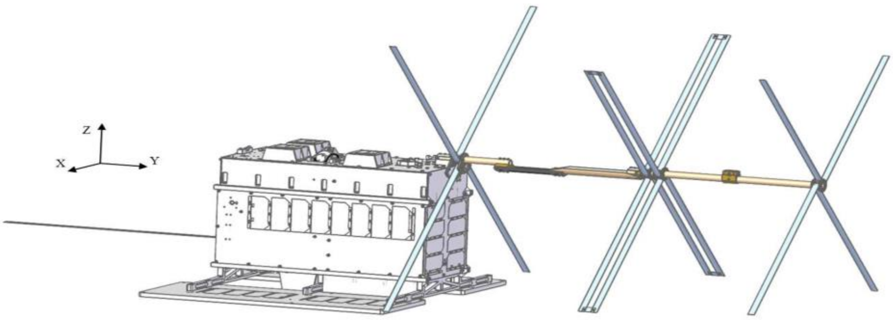

Figure 8. Norsat-2 configuration with deployed Yagi antenna [32]

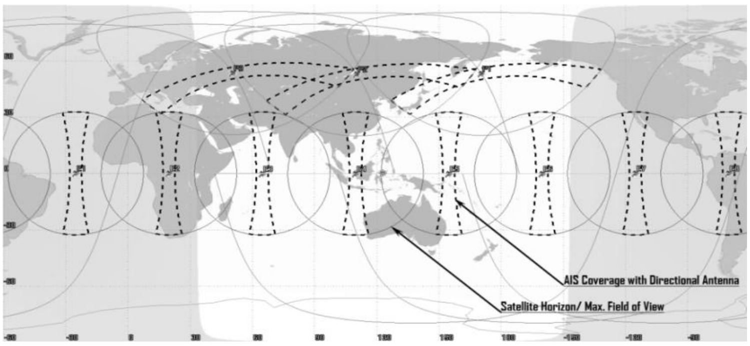

Figure 9. Proposed constellation for real-time AIS-based surveillance

4. Conclusion

Based on AIS data acquired from LAPAN satellites, there is a possibility for Indonesian authority to monitor its extensive waters territorial using satellite-based AIS. The statistical data show that the satellite in the equatorial with higher orbit gives a higher probability of ship detection. To perform adequate maritime surveillance, a constellation is needed with the narrowing the coverage of AIS receiver to increase the probability of detection. The eight satellites in an equatorial orbit will meet minimum requirement for near real-time AIS monitoring in Indonesia and the other equatorial region, but three additional satellites in sun synchronous polar orbit would make a better global maritime awareness.

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References

[1] Suwarsono DA. The Role of Community-Based Surveillance (POKMASWAS) in Combating Illegal Fishing in Indonesia. Master Thesis. Flinders University, School of Environment Humanities, Arts and Social Science Colleges. 2018.
[2] May C. Transnational Crime and the Developing World. Global Financial Integrity. March 2017.
[3] UNODC. Transnational Organized Crime in The Fishing Industry, focus on: Trafficking in Persons Smuggling of Migrants Illicit Drugs Trafficking. Vienna: United Nations Office on Drugs and Crime (UNODC). 2011.
[4] Sutikno, Wibawa HA, Sasongko PS. Detection of Ship using Image Processing and Neural Network. *TELKOMNIKA Telecommunication Computing Electronics and Control.* 2018; 16(1): 259-264.
[5] Arifin AS, Wahyuni DK, Suryanegara M, Asvial M. Ship Speed Estimation using Wireless Sensor Networks: Three and Five Sensors Formulation. *TELKOMNIKA Telecommunication Computing Electronics and Control*. 2018; 16(4): 1527-1534.
[6] IMO. Routeing Measures and Mandatory Ship Reporting Systems: Information on Routeing Measures and Mandatory Ship Reporting Systems in Sunda Strait, Indonesia. NCSR 5/INF.24 15 December 2017. International Maritime Organization (IMO), Sub-Committee on Navigation, Communications and Search and Rescue. 2017.
[7] IMO. Routeing Measures and Mandatory Ship Reporting Systems: Information on Routing Measures and Mandatory Ship Reporting Systems in Lombok Strait, Indonesia. NCSR 5/INF.23 15 December 2017. International Maritime Organization (IMO), Sub-Committee on Navigation, Communications and Search and Rescue. 2017.
[8] Shepperson JL, Hintzen NT, Szostek CL, Bell E, Murray LG, Kaiser MJ. A Comparison of VMS and AIS Data: The Effect of Data Coverage and Vessel Position Recording Frequency on Estimates Of fishing Footprints. *ICES Journal of Marine Science*. 2018; 75(3): 988-998.
[9] Longépé N, Hajduch G, Ardianto R, Joux Rd, Nhunfat B, Marzuki MI, et al. Completing Fishing Monitoring with Spaceborne Vessel Detection System (VDS) And Automatic Identification System (AIS) To Assess Illegal Fishing in Indonesia. *Marine Pollution Bulletin*. 2018: 33-39.
[10] Eriksen T, Høye G, Narheim B, Meland BJ. Maritime Traffic Monitoring Using a Space-Based AIS Receiver. *Acta Astronautica*. 2006; 58: 537–549.
[11] Trong TV, Quoc TD, Van TD, Quang HP, Nguyen H. Constellation of Small Quick-Launched and Self-Deorbiting Nanosatellites with AIS Receivers for Global Ship Traffic Monitoring. In 2nd Nano-Satellite Symposium. 2011.
[12] Skauen AN. Quantifying the Tracking Capability of Space-Based AIS Systems. *Advances in Space Research*. 2016; 57(2): 527-542.
[13] Eriksen T, Skauen AN, Narheim B, Helleren Ø, Olsen Ø, Olsen RB. *Tracking Ship Traffic with Space-Based AIS: Experience Gained in First Months of Operations*. In 2010 International Waterside Security Conference (WSS 2010). 2010; 1-8.
[14] Wahl T, Høye GK, Lyngvi A, Narheim BT. New Possible Roles of Small Satellites in *Maritime Surveillance. Acta Astronautica*. 2005; 59: 273–277.

[15] Cervera MA, Ginesi A. *Satellite-based AIS System Study*. In 26th International Communications Satellite Systems Conference (ICSSC), American Institute of Aeronautics and Astronautics. 2008.

[16] Hennepe Ft, Rinaldo R, Ginesi A, Tobehn C, Wieser M, Olsen Ø, et al. *Space-Based Detection of AIS Signals, Results of a Feasibility Study into an Operational Space-Based AIS System*. In 5th Advanced Satellite Multimedia Systems Conference and the 11th Signal Processing for Space Communications Workshop - IEEE; 2010

[17] Høye GK, Eriksen T, Meland BJ, Narheim BT. Space-based AIS for Global Maritime Traffic Monitoring. *Acta Astronautica*. 2008; 62: 240–245.

[18] Lorenzini D, Kanawati M. SpaceQuest, TEXAS (Technical eXchange on AIS via Satellite) III Presentation. 2009

[19] Smestad BB. A Study of Satellite AIS Data and the Global Ship Traffic Through the Singapore Strait. Master Thesis. Trondheim - Norway: Norwegian University of Science and Technology, Department of Marine Technology; 2015.

[20] Cervera MA, Ginesi A. *On the Performance Analysis of a Satellite-based AIS System.* In 10th International Workshop on Signal Processing for Space Communications, IEEE; 2008

[21] Hardhienata S, Triharjanto RH, Mukhayadi M. LAPAN-A2: Indonesian Near-Equatorial Surveillance Satellite. APRSAF-18 (Asia-Pacific Regional Space Agency Forum). 2011.

[22] Triharjanto RH. *Development of Micro-satellite Technology at the Indonesian National Institute of Aeronautics and Space (LAPAN).* The 17th CEReS (Center for Environmental Remote Sensing) International Symposium, Chiba University. Chiba, Japan. 2012.

[23] Fitrianingsih E. *Indonesian Capacity Building in Space Technology*. Proceedings of the UN/Japan Workshop and The 4th Nanosatellite Symposium (NSS); 2012.

[24] Saifudin MA, Mukhayadi M. *LAPAN-A2 Attitude Control Strategy for Equatorial Surveillance Mission*. Proceedings of the 9th IAA Symposium on Small Satellites for Earth Observation. 2013.

[25] Judianto CT, Nasser EN. The Analysis of LAPAN-A3/IPB Satellite Image Data Simulation Using High Data Rate Modem. *Elsevier, Procedia Environmental Sciences*. 2015; 24: 285–296.

[26] Hasbi W, Suhermanto. *Development of LAPAN-A3/IPB Satellite-An Experimental Remote Sensing Microsatellite*. Proceedings of 34th ACRS (Asian Conference on Remote Sensing). 2013.

[27] Burzigotti P, Ginesi A, Colavolpe G. Advanced Receiver Design for Satellite-Based Automatic Identification System Signal Detection. *International Journal of Satellite Communications and Networking*. 2012; 30: 52–63.

[28] Hassanin A, Lazaro F, Plass S. *An Advanced AIS Receiver Using a Priori Information*. In Proceedings of the OCEANS 2015 Conference; 2015.

[29] Bonacci D, Prévost R, Millerioux JP, LeMaitre J, Coulon M, Tourneret JY. *Advanced Concepts for Satellite Reception of AIS Messages*. In Proceedings of Toulouse Space Show; 2012: 25–28.

[30] Nasser EN. *Multi Mission Low Earth Orbit Equatorial Satellite for Indonesian Regions*. 2014 IEEE International Conference on Aerospace Electronics and Remote Sensing Technology. 2014.

[31] Clazzer F, Munari A, Plass S, Suhr B. *On the Impact of Coverage Range on AIS Message Reception at Flying Platforms*. 7th Advanced Satellite Multimedia Systems Conference ad the 13th Signal Processing for Space Communications Workshop (ASMS/SPSC); 2014.

[32] Bradbury LM, Diaconu D, Laurin SM, Beattie AM, Ma C, Spydevold IS, Haugli HC, Zee RE, Harr J, Udnæs F. NorSat-2: Enabling advanced maritime communication with VDES. Acta Astronautica. 2018.