Review of Satellite-Based AIS for Monitoring Maritime Fisheries

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ABSTRACT

The AIS (Automatic Identification System) is widely used in the maritime services, such as vessel traffic, collision avoidance, fishing fleet monitoring and control, maritime security, aids to navigation, search and rescue etc. Since, the illegal, unreported and unregulated fishing (IUU) has caused consequence severe issues impacted to human and marine environment such as marine food chain, over fishing and human trafficking. To mitigate and prevent those illegal marine fisheries, the AIS can be used as one of excellent tools for identifying and tracking the fishery vessels. To enable wide area operation, the low Earth orbit satellite equipped with AIS receiver is introduced to collect and transmit the AIS data broadcasting from the fishing vessels to the shore-based Vessel Traffic Services (VTS). Several missions of satellite based AIS have been flown into space since Year 2006. This paper reviews previous and current satellite-based AIS (SAT-AIS) missions to aim for the development approach of nano-satellite based AIS.

Keyword : *IUU, AIS, VMS, Satellite based AIS, satellite engineering.*

1. INTRODUCTION

Over the past decade, the international communities have focused and tried to mitigate and prevent the illegal maritime fisheries, and protect the environment of marine food chain. The global fish stock has destroyed by the IUU fishing. In consequence, this leaded the marine habitats, distorted competition, put honest fishers at an unfair disadvantage, and weakened coastal communities, particularly in developing countries.

The term of IUU fishing includes [1]:

• Fishing and fishing-related activities conducted in contravention of national, regional and international laws.

• Non-reporting, misreporting or under-reporting of information on fishing operations and their catches.

• Fishing by “Stateless” vessels.

• Fishing in convention areas of Regional Fisheries Management Organizations (RFMOs) by non-party vessels.

• Fishing activities which are not regulated by States and cannot be easily monitored and accounted for.

The European Union (EU) issued the EU Regulation to prevent, deter and eliminate IUU fishing entered into force on 1 January 2010. The European Commission allowed only marine fisheries products validated as legal by the competent flag state or exporting state can be imported to or exported from the EU [2]. The IUU Regulation can take steps against states that turn a blind eye to illegal fishing activities: first it issues a warning, then it can identify and black list them for not fighting IUU fishing. Thailand and other Asian countries have been listed as the yellow flag by the European Commission since the IUU Regulation entered into force in 2010 [3]. However, some countries have been revoked recently such as South Korea and the Philippines.

Geographically, Thailand is bordered on two coastal sides: the western coastal is the Andaman Sea and the Malacca Straits. The eastern coastal is the Gulf of Thailand. The total maritime area is about 320,000 square km. The total coastal longs 3,010 km (1,972.5 km in the Gulf of Thailand and 1,037.5 km in the Andaman Sea). In Year 2014, the estimated value of national maritime interests worth over 24 trillion baht a year [4]. The fisheries area in Thailand is 250,000 square km. For each year, the catch fishery volume is 2.8 million tons, and worth for 1.58 billion baht [5].

In April 2015, the EU pre-identified and issued an official warning (yellow card) to Thailand. The allegation was that the Royal Thai Government (RTG) had not been doing enough to tackle IUU fishing. The yellow card warning was a wake-up call for RTG to clean up its fishing industry to avoid EU trade bans. The imposition of trade sanctions could cost Thailand's seafood industry over between USD 200 million and USD 500 million. In the worst case, the failure to resolve the IUU issue would result in a ban on Thai fishery exports to the EU, worth over USD 700 million [6].

Food and Agriculture Organization of the United Nations (FAO) reported that IUU fishing has escalated in the past 20 years, especially in high seas fisheries. The rough calculations indicated that IUU fishing across the world's oceans was around 11–26 million tons of fish each year or a price tag of US$10–23 billion [1].

As pointed out that the IUU fishing therefore threatens livelihoods, exacerbates poverty, and augments food insecurity to the world community. The AIS is the one of excellent tools that can be used to mitigate the IUU fishing by identifying and tracking the fishery vessels. The advantage of AIS; the system is fully automation, not affected by rains, and its propagation better than radar due to the longer wavelength.

However, there are limitations of AIS such as the VHF coverage range depends upon the height of the antenna, typical range is 20 NM. The system accuracy depends upon what is entered in the static/voyage or safety messages data. The OOW (officer on watch) should always be aware that AIS fitted on other ships under certain circumstances, can be switched off on the master's professional judgment.

Another similar system, so-called "VMS" (Vessel Monitoring System) is dissimilar and independent to AIS. The comparison between AIS and VMS is shown in Table 1.

Table 1 *AIS compare and contrast with VMS [7]*

	AIS	VMS
system type	digital VHF-based radio system	satellite-based
service provider	open, non-proprietary protocol	closed, proprietary protocols
range	2-way exchange of info between ships and ship-shore	primarily 1-way (ship-shore) either scheduled or manual
use	line of sight (20-40 nm)	line of sight (with satellite, not ground station)
applica bility	REQUIRED per SOLAS V/19.2.4 or 33 CFR 164.46 (NLT 2005 on certain vessels)	REQUIRED on some fishing vessels (~2000)

A horizontal range of AIS signals is approximately 40 nautical miles (74 km). Therefore, the AIS traffic information will available only around coastal zones or within a ship-to-ship zone. In general, the radio system requires only one radio channel. However, each AIS transmits and receives over two radio channels to avoid interference problems, and to allow channels to be shifted among ships without communications loss.

In order to track seafaring vessels beyond coastal areas, the satellite-based AIS (SAT-AIS) equipped with AIS tracking devices is introduced. The SAT-AIS is a promising solution to overcome terrestrial coverage limitations with the potential to provide AIS service for any given area on the globe.

The objective of this paper is to review previous and current (SAT-AIS) missions for the purpose of finding an approach of suitable platform development for satellite-based AIS constellation in the near future.

2. AUTOMATIC IDENTIFICATION SYSTEM

The AIS was first developed in 1993 by the U.S. Coast Guard (USCG). At that time, it was called the Automated Dependent Surveillance Shipboard Equipment (ADSSE), based on Digital Selective Calling (DSC) protocol [8]. The required system had to be continuous that could automatically communicate and portray a ship's location to other ships and to shore-based VTS (Vessel Traffic System).

Currently, the AIS widely uses for improving maritime safety by enabling a vessel navigator to view the identity, position and direction of other ships in their vicinity. The automatic shipboard system operating on marine VHF channels for the purpose of transmitting and receiving vessel position, speed, heading and other vessel specific information. The AIS communication makes use of two VHF frequencies; 161.975 MHz and 162.025 MHz, and a bandwidth of 25 kHz.

The most importantly, since 2004, the International Maritime Organization (IMO) has required AIS transponders to be aboard most vessels. Previously, the SOLAS (Safety of Life at Sea) Convention, Chapter V, Regulation 19, Article 2.4 states: all ships of 300 gross tonnage and upwards engaged on international voyages and cargo ships of 500 gross tonnage and upwards not engaged on international voyages and passenger ships irrespective of size shall be fitted with AIS [9].

The heart of the AIS is a transmission protocol called Self Organised Time Division Multiple Access (SOTDMA). The SOTDMA is the most complex TDMA scheme defined for AIS, and provides the backbone for autonomous and continuous operation of the network offshore [10]. The principle of SOTDMA is described in Fig. 1.

AIS information is categorised into two classes. The Class A: Regulated Vessels, makes use of the SOTDMA protocol. The Class B: non-Regulated Vessels, makes use of the CSTDMA (Carrier Sense Time Division Multiple Access) protocol which politely interweaves with Class A transmissions. The comparison the Class A and B transmissions are summarized in Table 2. [11]

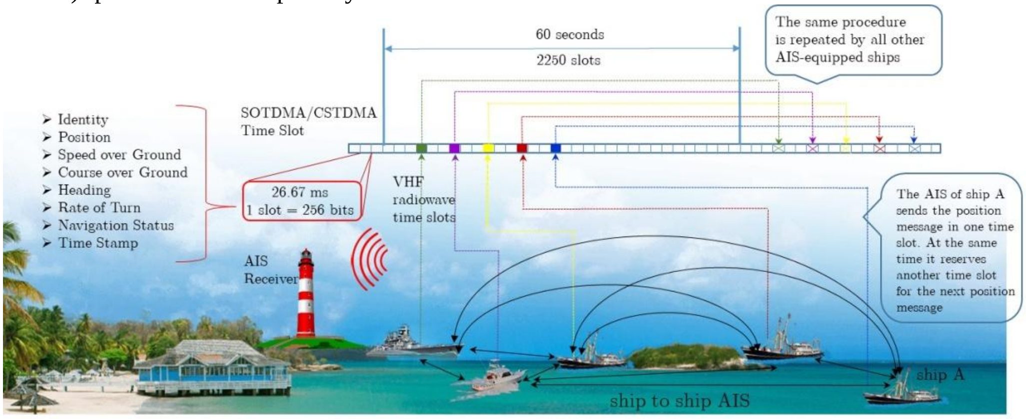

Fig. 1 *Principle of Self-Organised Time Division Multiple Access (SOTDMA)*

Table 2 *Comparison of AIS Class A and Class B devices [11]*

Class	Class A	Class B - SO	Class B - CS
Primary Access Scheme	SO-TDMA per ITU-R M.1371		CS-TDMA
Frequency Range	156.025−162.025 MHz (25 kHz bandwidth)		161.500−162.025 MHz (25 kHz bandwidth)
Digital Selective Calling	Dedicated receiver	Time-shared with a TDMA receiver	
Transmit Power	12.5 W (1 W low-power)	5 W (2 W low power)	2 W only
Positioning Source	interfaced to vessel's primary Electronic Positioning Fixing System; Internal GNSS as a fall-back	Internal GNSS	
Positioning Report	every 2 s if > 23 kts ; 3.33 s if > 5° course change ; 6 s if > 14 - 23 kts ; 10 s if 2-14 kts ; 3 min. if at anchored, moored, or = < 3 kts; via Message 1	every 5 s if > 23 kts ; 15 s if 14-23 kts ; 30 s if > 23 kts ; 3 min. if at anchored, moored, or = < 2 kts ; via Message 18	every 30 s (±4 s), subject to slot availability ; 3 min. if at anchored, moored, or = < 2 kts ; via Message 18
	Message 1 reports : MMSI, Time-stamp, Position, Position Accuracy flag, RAIM flag, COG, SOG, HDG, ROT, Navigation Status, Communication State; Message 18 omits ROT and Navigation Status, but, adds various Class B flags for: Type (SO/CS), Operating Mode, and, availability of a Display, DSC Receiver, Full/Limited Bandwidth, and Channel Management		
Static & Voyage Data Reporting	every 6 min. via Message 5	every 6 min. via Message 24A&B	
	Message 5 reports: MMSI, IMO#, Call-sign, Name, Ship Type, Dimensions, Static Draft, Destination, ETA, EPFS type, Data Terminal availability, AIS version; Message 25A&B omits IMO#, Static Draft, Destination, ETA, Data Terminal availability, AIS version but, adds Vendor ID.		
Application & Safety Text Messaging	Receive & transmit	Receive optional, cannot transmit	
Display and Interfacing	Minimal Keyboard Display (MKD) required Two input-output ports; multiple interfaces	Display optional; One input-output interface	Both optional
Test Standard	IEC 61993-2	IEC 62287-2	IEC 62287-1
USCG Approval NR.	USCG 165.155/x/x	USCG 165.157/x/x	USCG 165.156/x/x

Following the ITU-R M.1371, and IEC standards (IEC 61993-2, IEC 62287-1 and IEC 62287-2), each AIS accommodated on vessel consists of one VHF transmitter, two VHF TDMA receivers, one VHF DSC receiver, and standard marine electronic communications links (IEC 61162/NMEA 0183) to shipboard display and sensor systems as shown in Fig. 2.

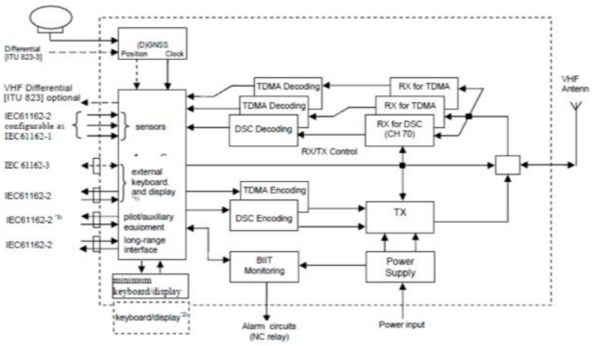

***Fig. 2** Schematic Diagram of Class "A" Ship-borne AIS Station [12]*

The information transmitted by AIS can be categorized in 3 groups; Static, Dynamics, and Voyage related. In addition Safety related messages could be transmitted when needed. Fixed or Static Information is entered into AIS during installation. This information need only be changed if the ship changes its name or undergo major conversion from one major conversion from one ship type to another such as MMSI (Maritime Mobile Service Identity) number, IMO number, call sign & name, length & beam, type of ship, location of position fixing antenna etc. Dynamic Information which apart from navigation or status information is automatically updated by the vessel sensors connected to AIS such as ship's position with accuracy indication and integrity status, position time stamp (UTC), course over ground (COG), speed over ground (SOG), heading and navigational status (e.g. at anchor, underway, aground etc. – this input manually). Voyage related information, which might need to be manually updated during the voyage such as ship's draught, hazardous cargo (type), destination and ETA (Estimated Time of Arrival), route plan (waypoints) [13].

Position and timing information is normally derived from an integral or external global navigation satellite system (e.g. GPS) receiver, including a medium frequency differential GNSS receiver for precise position in coastal and inland waters. Other information broadcast by the AIS, if available, is electronically obtained from shipboard equipment through standard marine data connections. Heading information and course and speed over ground would normally be provided by all AIS-equipped ships. Other information, such as rate of turn, angle of heel, pitch and roll, and destination and ETA could also be provided.

3. SATTELITE-BASED AIS MISSIONS

Since 2006, several missions of satellite-based AIS were launched into space. The summarised information of each mission is detailed in Table 3

Launched in December 2006:

The first satellite-based AIS, TacSat-2 (Tactical Satellite-2) was a DoD technology demonstration mission of AFRL (Air Force Research Laboratory) within AFRL's (Kirtland AFB, Albuquerque, NM). The Navy's Target Indicator Experiment (TIE) payload was designed and developed to collect the AIS message from space, and made use of a phased array antenna to reduce the other in-band and near-band licensed spectrum users. The on-orbit results showed the TIE payload successfully collected AIS messages from space, even in areas of high traffic density, supporting maritime safety and security [14]. TacSat-2 used S-band frequency for downlink AIS data with 5 Mbit/s to the ground station. TacSat-2 reentered Earth's atmosphere on 5 February 2011.

Launched in April 2008:

The CanX-6 was a nano-satellite demonstration mission of UTIAS/SFL (University of Toronto, Institute for Aerospace Studies/Space Flight Laboratory) in collaboration with COM DEV International Ltd. to develop and demonstrate key elements of spaceborne AIS technology. This spacecraft was also known as NTS (Nanosatellite Tracking Ships) [15]. As a technology demonstration, the CanX-6/NTS mission originally expected to survive in orbit-operation only for 1 month, and hoped to characterise the RF environment for last as long as 6 months. Nevertheless, the CanX-6/NTS spacecraft operated nominally in 2012, and became an operational part of the exactView constellation [16] until April 2015. The CanX-6 made use of S-band downlink (GMSK modulation, AX.25 protocol) with data rates between 32 kbit/s and up to 1 Mbit/s for transmitting AIS data to the ground station.

Launched in June 2008:

The Orbcomm-CDS 3 (Concept Demonstration Satellite) was developed to provide standard ORBCOMM service, and was to have a U.S. Coast Guard AIS payload. This satellite was to receive signals emitted from vessels, enhancing U.S. Coast Guard monitoring techniques as part of their homeland security initiatives. The Orbcomm-CDS 3 suffered from

***Table 3** Previous and Current Satellite-based AIS*

No.	Mission	Launch	Organisation	Orbit Type	Altitude (km)	Inclination	Weight (kg)	Status
1	TacSat-2	DEC 2006	USAF AFRL	Near-Circular, 92.9 min.	413 – 424	40º	367	EOM
2	CanX-6 (EV-0)	APR 2008	COM DEV	SSO, 96.9 min.	604 – 626	97.6º	6.5	EOM
3	Orbcomm-CDS 3	JUN 2008	Orb comm	Near-Circular, 97.8 min.	653 – 663	48.5°	80	EOM
4 5	AprizeSat-3 AprizeSat-4	JUL 2009	Aprize Satellite	SSO, 96.8 min.	562 – 686	98.3º	12	-
6 7	Rubin 9 (9.1 & 9.2)	SEP 2009	LuxSpace	SSO, 99.9 min.	720 – 799	98.0º	8	-
8	Sumban dilaSat	SEP 2009	SunSpace/ CSIR	SSO, 92.4 min.	401 – 402	97.1º	82	2011
9	AISSat-1	JUL 2010	FFI	SSO, 96.9 min	610 – 624	98.1°	7	-
10	Resource sat-2 : HIP-1 payload (EV-2)	APR 2011	ISRO	SSO, 101.3 min.	813 – 825	98.8º	Sat (1200) HIP-1 (1.4 kg)	OPER
11	AprizeSat-5 (EV-5)	AUG 2011	exact Earth	SSO, 97.8 min.	628 – 693	98.3º	12	-
12	AprizeSat-6 (EV-6)	AUG 2011	exact Earth	SSO, 97.8 min.	628 – 693	98.3º	12	OPER
13	Vessel Sat-1	OCT 2011	LuxSpace	Near-circular, 102 min.	853 – 873	20º	29	EOM
14	Vessel Sat-2	JAN 2012	LuxSpace	SSO, 94 min.	472 – 484	97.5º	29	EOM
15	SDS-4	May 2012	JAXA	SSO, 97.9 min.	662 – 671	98.4°	50	-
16	Exact View-1 (EV-1)	JUL 2012	exact Earth	SSO, 101 min.	811 – 827	99.1°	100	OPER
17	AAUSAT3	FEB 2013	Aalborg University	SSO, 100 min.	771 – 789	98.5°	0.8	EOM
18	AprizeSat-7 (EV-5R)	NOV 2013	exact Earth	SSO 97.0 min.	594 – 654	97.6°	12	OPER
19	AprizeSat-8 (EV-12)	NOV 2013	exact Earth	SSO 97.0 min.	595 – 670	97.6°	12	OPER
20	AprizeSat-9 (EV-11)	JUN 2014	exact Earth	SSO 98.0 min.	618 – 719	97.8°	12	OPER
21	AprizeSat-10 (EV-13)	JUN 2014	Spacequest	SSO 98.0 min.	618 – 737	97.8°	12	OPER
22	AISSat-2	JUL 2014	FFI	SSO, 97.1 min	625 – 632	98.4°	7	-
23 - 28	OG2	6 Sat. : JUL 2014	Orbcomm	Near-Circular, 99.0 min	715 – 719	47.0°	216	3 Sat OPER
29	Exact View-9 (EV-9)	SEP 2015	exact Earth	Equa torial 97.5 min.	642 – 653	6.0°	5.5	OPER
30 - 40	OG2	11 sat : DEC 2015	Orbcomm	Near-Circular, 99.0 min	715 – 719	47.0°	216	9 Sat OPER
41	M3MSat (EV-7)	JUN 2016	Canadian Govt.	SSO 94.7 min.	502 – 519	97.4°	95	OPER
42 43	NorSat-1 NorSat-2	JUL 2017	NSC	SSO 96.6 min	593 - 610	97.6°	30 16	OPER
44 45	GOMX 4A & 4B	FEB 2018	Gom Space	SSO, 94.5 min.	489 – 515	97.3°	2 x 6U	OPER OPER

Remark;
SSO : Sun Synchronous Orbit
EOM : End of Mission,
OPER : Operational

problems with their reaction wheels, and total loss in May 2009 [17].

Launched in July 2009:

Two of 25 cm cubesat, AprizeSat-3 and -4, had dual-purpose mission to demonstrate AIS instrument and M2M (machine to machine) technologies. The collected AIS data can be downlinked to the ground station over the UHF and S-band frequencies. In addition, both satellites were capable of producing analog recordings of AIS message traffic on either channel or both, simultaneously. The recordings can then be "played back" on either the UHF or S-band frequencies. The advantage of recording and transmitting the AIS signal samples in analog as opposed to digital is that the samples can be transmitted with far less bandwidth as analog signals, reducing antenna size and power requirements [18]. The last nominal operation was updated in 2011. Currently, there is no mission status report.

Launched in September 2009:

The Rubin-9.1 (AIS-Pathfinder 2) was developed for providing an insight into the issue of message collisions that limit detection in areas of dense shipping. Whereas the Rubin-9.2 payload was developed to test and qualify nano-technologies from Angstrom and to continue space based maritime AIS receiver experiments [19]. Currently, there is no mission status report.

Launched in September 2009:

The SumbandilaSat (formerly ZASat-002) was a pathfinder mission of the University of Stellenbosch, SunSpace Ltd. (a spin-off company of the University of Stellenbosch), and SAC (Satellite Application Center) of CSIR (Council for Scientific and Industrial Research), Pretoria, South Africa [20]. One experimental payload was SDR (Software Defined Radio) receiver. The AIS signals reception was a one of SDR features. Unfortunately, the AIS reception experiment cannot be performed to receive real AIS transmissions at sea, due to the radio front-end was not designed to receive in the 160 MHz band. The satellite's primary mission came to end of operation in July 2011 due to the ADCS and power systems onboard spacecraft.

Launched in July 2010:

The AISSat-1 was a Norwegian nano-satellite technology demonstration mission in LEO, funded by the NSC (Norwegian Space Center, O) with program management by the FFI (Norwegian Defense Research Establishment). However, it was constructed by UTIAS/SFL (University of Toronto, Institute for Aerospace Studies/Space Flight Laboratory) which had an experience on building the CanX satellite series. The satellite design was based on the Gryphon Bus (GNB), 200 × 200 × 200 mm in size. The S-band transmitter was used for the AIS data downlink. It was capable of data rates in the range of 32 to 256 kbit/s. The AIS receiver, designed and developed at KSX (Kongsberg Seatex AS). The SDR (Software Defined Radio) based on FPGA (Field Programmable Gate Array) was used to process and analyse the received AIS data. From the on-orbit results showed that AISSat-1 was a very successful operational nano-satellite. Within the total mission budget of 3-4 million EUROs, the satellite-based AIS service can be provided and met users' operational requirements globally. The contribution of the satellite to the Norwegian monitoring of the maritime activities in the High North was clearly recognized [21].

Launched in April 2011:

The HIP-1 accommodated on-board the ISRO's (Indian Space Research Organization) remote sensing satellite, Resourcesat-2, was a AIS payload of COM DEV International Ltd. This AIS service on-board the Resourcesat-2 became a part of the exactView constellation, known as exactView 2 or EV-2 [22]. The HIP-1 design was based on the AIS-MS03 which provided by Honeywell. The AIS data was downlinked to the ground station by S-band communication based on QPSK (Quadra-Phase Shift Keying) modulation scheme, at high data rate up to 16 Mbit/s.

Launched in August 2011:

Two microsatellites, AprizeSat-5 [exactView-5 (EV-5)] and AprizeSat-6 [exactView-6 (EV-6)] were developed by SpaceQuest or COM DEV/exactEarth. The Ownership of AprizeSat 5 and 6 was transferred to exactEarth after a 90 days check out phase [23]. Currently, there is no mission status report of EV-5, but EV-6 is still operating in space.

Launched in October 2011 and January 2012:

The VesselSat was refer to a constellation of two microsatellites (VesselSat-1 and VesselSat-2), which built by LuxSpace Sarl, and leased to Orbcomm for AIS data. The AIS data collected from both satellites was downlinked from 64 up to 512 kbit/s, various modulations, error correction, encryption selectable, via UHF frequency [24]. In March 2016, both VesselSat-1 and -2 have stopped responding, and have completed an operational mission of about 4 years, where the design life was 3 years.

Launched in May 2012:

The main mission of the SDS-4 microsatellite was to demonstrate the space-based AIS experiment (SPAISE), and others The SPAISE receiver developed by AES (Advanced Engineering Services CO., Ltd), was constructed mainly from COTS components. The data of the AIS signals received in space was transmitted by S-band transmitters, using QPSK (Quadrature Phase Shift Keying) modulation and the USB (Unified S-band). The data rate for the QPSK method was up to 1 Mbit/s [25]. The last nominal operation was updated in October 2015. Currently, there is no mission status report.

Launched in July 2012:

ExactView-1 (EV-1), formerly known as ADS-1B (AIS Data Services-1B) was built under contract for exactEarth. The advanced AIS transceiver payload system provided by d COM DEV Europe (UK). The spacecraft platform was built at SSTL on the SSTL-100 platform. The AIS data was downlinked by C-band communication, using QPSK and OQPSK methods, at data rate up to 20 Mbit/s [26].

Launched in February 2013:

The AAUSat3 was the third student-developed 1U CubeSat in the Department of Electronic Systems of Aalborg University (AAU), Aalborg, Denmark. The objective of the AAUSat3 mission was to fly two different types of AIS (Automated Identifications System) receivers. One of the AIS receivers onboard AAUSat3 was an SDR (Software Defined Radio) based AIS receiver, which based on a DSP module from Bluetechnix. The other one was a conventional hardware AIS receiver, which its design was based on the Analog Devices ADF 7021 radio transceiver. The goal was to investigate the quality of ship monitoring from space. The AIS data downlinked to ground station by using UHF frequency. The impressive result of received AIS signals from 1U cubesat (0.8 kg) showed in Fig 3 [27]. In October 2014, the AAUSat3 mission was end of life due to battery problems.

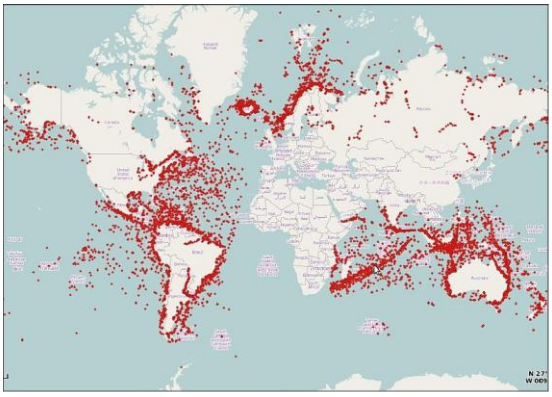

Fig. 3 *Over 52,000 ship positions were received in 5 hours on Sept. 22, 2013 (image credit: AAU)*

Launched in November 2013:

Two microsatellites, AprizeSat-7 (EV-5R) and AprizeSat-8 (EV-12) were launched to reinforce the exactView constellation. Currently, both satellites are operating in space [28].

Launched in June 2014:

Two microsatellites, AprizeSat-9 (EV-11) and AprizeSat-10 (EV-13) were launched to reinforce the exactView constellation. Currently, both satellites are operating in space [28].

Launched in July 2014:

AISSat-2 was build-to-print copy of AISSat-1, and to serve as an in-orbit spare for AISSat-1. The last updated status, March 2, 2016: AISSat-1 and AISSat-2 were still operational. Currently, there is no mission status report of both missions.

Launched in July 2014:

The second launch of OG2 (Orbcomm Second Generation) with six satellites was in July 2014. The six satellites were Orbcomm FM103, FM104, FM106, FM107, FM109 and FM111. However, 3 satellites were no longer operational.

*The first launch with one satellite Orbcomm FM101 (Orbcomm-OG2 1, H1) was in October 2012. Unfortunately, the launch vehicle was failure.

Launched in September 2015:

ExactView-9 (EV-9), 2U cubesat, was built by UTIAS/SFL. The EV-9 incorporated high performance three-axis attitude control, a next generation AIS receiver for high ship-detection rates, and a high speed downlink transmitter for high data volume transfers. The satellite was designed to operate in a low inclination orbit to service some of the more remote and not-as-well covered areas of Earth. The downlink was achieved with an S-band transmitter, also designed by SFL. Its data rate and modulation can be scaled on-the-fly from 32 kbit/s to 2048 kbit/s, with typical operation at 2048 kbit/s. The payload onboard EV-9 was an advanced Kongsberg Seatex AIS receiver. In addition, high performance detection of low power class B AIS transceivers, ABSEA (Advanced Class B Satellite Enabled AIS) was accommodated on-board EV-9. The ABSEA was a unique new technology which enables the transmissions from AIS Class B and Identifier type AIS transceivers using SRT (SRT Marine Technology) core technology to be reliably received by the exactEarth global satellite network [29][30].

Launched in December 2015:

The third launch of OG2 (Orbcomm Second Generation) with 11 satellites was in December 2015. However, 2 satellites were no longer operational.

Launched in July 2017:

NSC (Norwegian Space Center) awarded the contract to UTIAS/SFL for constructing two satellites. NorSat-1 (< 30 kg) carried three instruments: An AIS receiver, a Langmuir Probe Instrument, and CLARA (Compact Lightweight Absolute Radiometer), intended to observe total solar irradiation and variations over time. The NORSAT-2 satellite, with a mass of 16 kg, carried a AIS receiver from Kongsberg Seatex, along with a VDE (VHF Data Exchange) payload that was enable two-way communication at higher data rates than possible with AIS [31].

Launched in February 2018:

The GomSpace missions GomX-4A and GomX-4B were two 6U CubeSats with the objective to demonstrate key technologies to handle large satellite formations, such as AIS and ADS-B (Automatic Dependent Surveillance - Broadcast) tracking [32]. The Satlab QubeAIS was a fully self-contained SDR based AIS receiver which accommodated on-board GomX-4A and GomX-4B. The S-band transmitter was used for the AIS data downlink.

4. APPROACH FOR COST-EFFECTIVE SAT-AIS

From reviewing of previous and current missions of satellite-based AIS, the nano-satellite is the most attractive platform for developing SAT-AIS and its constellation in the near future. There are several reasons to support this approach.

The first reason is the technology readiness for cubesat or nano-satellite platform development. From literature review, the 20 cm side length cube of CANX-6 and ExactView-9 (5.5kg), AISSAT-1 and 2 (7kg each), 8kg of Rubim 9.1 and 9.2, and the impressive of 1U-AAUSAT3 (0.8kg) have already proven their in-orbit operations. These missions made use of COTS (Commercial Off-The-Shelf) components, devices, and subsystems which were applicable for space applications. The other important parts are communication subsystem and payload. The S-band transmitters and SDR (software defined receiver) for AIS applications are rapidly developed to reduce size and power consumption, but high integrity and reliable. It flew on many nano-satellite based AIS missions, such as AprizeSat series, AISSat-1 and -2, ExactView-9 (EV-9), AAUSat3, GomX-4A and so forth. These insisted that the nano-satellite platform is applicable for individual and constellation of space-based AIS. In addition, the cost affordable of space proven CPU and processing unit such as ATmegaS128, is now released to market. This leads the institute or small enterprises have more opportunities to develop the open platform for variety mission requirements.

The second reason is that the nano-satellite platform is suitability for cost-effective satellite network. Since the coverage area and access time for regional marine fisheries cannot be handled by using a single SAT-AIS, therefore, the cost-effective satellite network based on nano-satellite platform is the promising approach for wide area operation. The Exact View constellation is an example which is currently operating in space.

Lastly, the trend of launching cost for nano-satellite is gradually decreased due to more new-comer launch services. The reason is that new innovative technologies for making the launcher are rapidly developed for cost-effective launching, such as Rocket Lab (Engine created through 3D printing and using electric turbopumps). These kind technologies offer affordable, high-frequency launches of small satellites.

These above three reasons have correlation, and supporting the programme budget for making satellite constellation in term of satellite development, launching, and replacement the new satellite in the orbit within time frame of operator requirement and time frame of satellite construction.

5 CONCLUSIONS

This paper presents the realisation and substantial reasons for mitigating and preventing the IUU fishing. The consequence from IUU fishing leads to several severe issues which threatens livelihoods, exacerbates poverty, and augments food insecurity to the world community. AIS is one of excellent tools that can be used to mitigate and prevent the IUU fishing by identifying and tracking the fishery vessels. The fundamental of AIS is described, and discussed in comparative context to VMS. The previous and current missions of satellite-based AIS over 4 missions are reviewed. Finally, this paper suggests and provides the reasons to support the use of nano-satellite platform for performing the SAT-AIS and and SAT-AIS constellation.

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