Introduction to Shipborne Satellite Automatic Identification System (S-AIS) Networks and Equipment

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Abstract: This paper introduces the main technical characteristics of current Radio Automatic Identification System (R-AIS) and development new Satellite AIS (S-AIS) as more reliable solution for enhanced tracking and detecting systems for maritime applications. The technical parameters and comparison of current Radio AIS (R-AIS) and new developed Satellite AIS (S-AIS) with their advantages and disadvantages are described. The possibility in upgrading of a particular AIS configuration depends mainly on its mission objectives, development trends of radio and satellite mobile tracking and surveillance service, modernization of onboard and coastal equipment and characteristics of the satellite payloads for S-AIS. The R-AIS network provides local coverage in coastal waters of VHF-band range, while new S-AIS will be able to provide global beam coverage using Low Earth Orbit (LEO) or even Geostationary Earth Orbit (GEO) spacecraft. In this paper is introduced the R-AIS network and its classes, basic technical details of AIS transponder, Communication, Navigation and Surveillance (CNS) Systems for AIS Base Station (BS) and software, The S-AIS Network, enhancements of surveillance and security, improvement of counter piracy and suspicious movement of ships, better facilitated fisheries and environmental monitoring, more Reliable Search and Rescue (SAR) operations and Nano satellite AIS (Nano S-AIS) are discussed.

Key words: R-AIS, S-AIS, GEO, LEO, BS, CNS, SAR, Nano S-AIS, GMDSS, IMO, Orbcomm, CubeSat

1. Introduction

The Global Maritime Distress and Safety System (GMDSS) radio and satellite integrated networks are already developed and implemented for ships safety, distress alert and SAR communications. Namely, this system is not enough effective to provide a real tracking and detecting system of ships for every day navigation aids. The GMDSS radio and satellite networks need an additional integration with new CNS systems as a proposal that has to be developed providing seafarers with global communications and tracking networks introduced in this research.

At this point, the GMDSS has to integrate CNS systems that use radio and satellite technologies for automated distress alerting, rapid tracking and detecting of ships in navigation and distress. Thus, this important integration has also to prevent all emergency situation during navigation employing more sophisticated, modern and reliable technique for improving collision avoidance and enhanced safety and security. On the basis of these daily requirements and necessity for modern maritime radio and satellite tracking and detecting systems onboard ships are already developed R-AIS and S-AIS working at VHF frequency band, which can be integrated with current and new CNS networks and equipment onboard ships, vehicles and aircraft.

The R-AIS network and equipment are automatic tracking system used onboard ships and by Vessel Traffic Services (VTS) network for identifying and locating vessels by electronically exchanging data with other nearby ships, AIS BS for coastal waters, and via LEO satellites globally. The AIS network and equipment are providing information that supplements marine radar, and in such a way continues to be the primary method of collision avoidance for water transport.

Because of usual problems during extremely bad weather conditions at sea sometimes VHF-band is so limited or interrupted by reduced propagation effects and interference characteristics caused by rainfall, very deep clouds and thunderstorms too. Therefore, the VHF-band AIS, whether radio or satellite, affected by these weather factors will be not able to provide reliable service for tracking and detecting of ships even via additional satellite VHF-band. For that reason will be necessary to deploy GEO or LEO satellite constellations via L or S-band.

Information provided by AIS equipment, such as unique identification, position in real time, course and speed, can be displayed on a screen or an Electronic Chart Display and Information System (ECDIS). The AIS network is intended to assist watchstanding officers onboard ships and allow maritime authorities in each country to track and monitor ships movements in costal navigation. The AIS equipment integrates a standardized VHF transceiver with a positioning system such as an GPS, GLONASS or LORAN-C receiver, and with other electronic navigation sensors, such as a gyrocompass or rate of turn indicator.

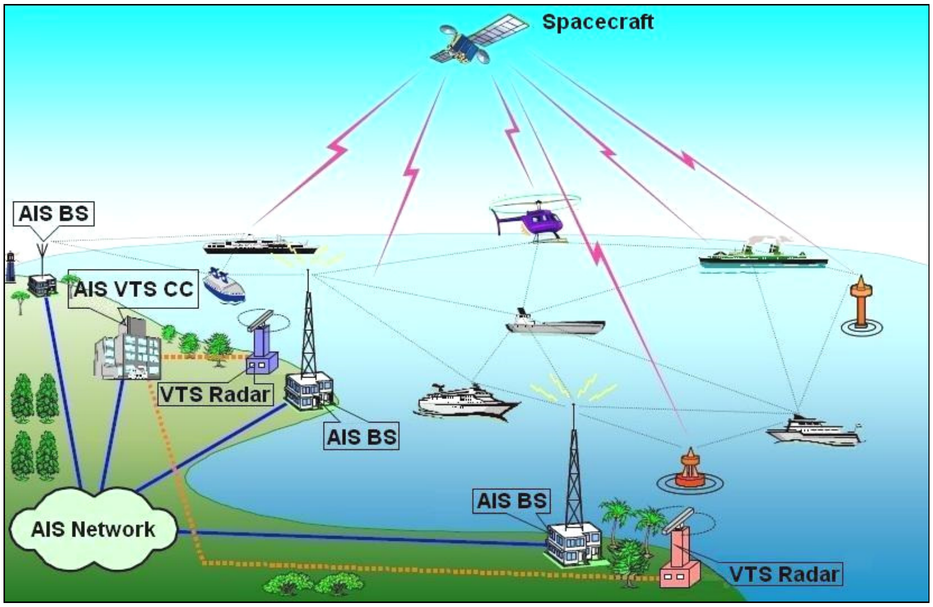

Figure 1. Maritime AIS Network – Source: IMO **[1]**

Ocean vessels fitted with AIS transponders and transceivers can be tracked by AIS BS located along coast lines or when are out of radio VHF ranges of terrestrial networks, through a growing number of satellites that are fitted with special AIS receivers. In fact, the S-AIS network needs ships to be equipped with other types of devices than R-AIS network and to use special assigned frequencies different from R-AIS network. However, the integration has to be realized in the Control Centre, which main task will be to collect position data received via both R-AIS and S-AIS for the same ships and distribute to all users.

2. Radio VHF Automatic Identification System (R-AIS) Network

The VHF Radio Automatic Identification System (R-AIS), also know as a Radio VHF Data Link (R-VDL) is a most attractive system at present for tracking and detecting of ships for short range service in coastal navigation. Thus, more adequate designation for AIS will be Radio AIS (R-AIS), because recently is developed new Satellite AIS (S-AIS) with similar service for ships and aircraft.
The new Regulation 19 of the SOLAS Chapter V provides requirements for shipborne navigational equipment and sets out this equipment to be carried onboard according to ship type. In 2000, International Maritime Organization (IMO) team adopted a new requirement, as part of a revised new Chapter V that all ships have to carry VHF AIS transponders capable of providing necessary information about the all ship to other ships and to coastal authorities automatically.
The R-AIS is a new maritime surveillance system using the VHF-band to exchange all information between ships and shore Base Stations, including positions, identification, course and speed, which network is shown in **Figure 1**. It mainly aims is to provide collision avoidance between ships. The link budgets allow receiving transmitted R-AIS signals from space, and consequently a global maritime surveillance can be considered.
However, later arise some challenges, especially regarding message collisions due to the use of a Self Organized Time Division Multiple Access (SOTDMA) protocol (not designed for satellite detecting). Thus, advanced signal processing for separation of received signals is needed.
According to the IMO regulations provided by 31 December 2004 each oceangoing vessel has to install AIS transponder equipment onboard ships, which automatically broadcast regularly to the coast station ships name, call sign and navigation data. This data is programmed soon after the equipment is installed onboard and after that all this information will be transmitted regularly.
The signals are received by R-AIS transponders fitted on other ships or on land based network, such as VMS systems. The received information can be displayed on a screen or a chart plotter, showing the other vessels positions in much the same manner as a radar display. Ships fitted with R-AIS onboard equipment shall maintain AIS in operation at all times, except where international agreements or rules provide for the protection of navigational information.

Figure 2. Maritime VDL Classs A R-AIS Stations – Source: CNS Systems **[4]**

The R-AIS standard comprises several substandard called as “types” that specify individual for each product type. The specification for each product’s type provides a detailed technical specification, which ensures the overall integrity of the global R-AIS system, within which the entire product types which must operate. Namely, there are two types of R-AIS Transceivers (for transmit and receive) “Class A” and “Class B”.

The IMO regulation requires that AIS shall provide information by transmitter including the ship’s identity (ID), navigational status and other safety-related information automatically to the appropriately equipped shore stations, other ships and aircraft, than to receive automatically such information from similarly fitted monitor, track ships and exchange data with shore SB facilities.

At its 79th session in December 2004, IMO’s Maritime Safety Committee (MSC) agreed that, in relation to the issue of freely available AIS-generated ship data on the worldwide Web. The publication on the worldwide Web or elsewhere of all AIS data transmitted by ships could be detrimental to the safety and security of ships and port facilities. It also was undermining the efforts of the IMO expertise and its Member States to enhance the safety of navigation and security in the international maritime transport sector. In addition, the Committee condemned those who irresponsibly publish AIS data transmitted by oceangoing ships on the world-wide Web, or elsewhere, particularly if they offer services to the shipping and port industries **[1, 2, 3].**

2.1. CNS Systems R-AIS Class A Station

The VDL 6000 Class A ship R-AIS transponder station of the Swedish Company CNS Systems provides IMO SOLAS compliance and also Bundesamt für Seeschiffahrt und Hydrographie (BSH) certification for installation onboard all oceangoing vessels, illustrated in **Figure 2 (Left).** The screen presentation of this transponder is indicating the call signs of other ships and enables a user and other ships to make direct contact by text or voice communication.

Another model of CNS Systems is VDL 6000 Secure Class A shipborne R-AIS transponder that operates in Standard, Silent and Secure Mode, shown in **Figure 2 (Middle).** This R-AIS is also serving for naval operation can be configured in ”receive only” mode or both ”receive and transmit” mode for positive identification and positioning of all ships in the vicinity. The R-AIS units secure system is designed on existing technology and supports a user to receive, schedule and transmit encrypted messages to other users. This service can include transmission of secure text messaging and to receive encrypted range and bearing. The secure R-AIS can also support simulated targets for naval operations.

Main component parts of a Class A shipborne AIS station are (1) Global Navigation Satellite System (GNSS) receiver – S plies the time reference to the AIS station to ensure all transmissions are synchronized. (2) VHF Transmitter/Receiver – There is one VHF transmitter and two VHF receivers for TDMA operation. The VHF transmits and receives the radio signals that form the data links that interconnect the AIS station to each other. Data is transmitted and received in short time slots (26.76 ms) by the VHF radio. (3) AIS VHF Antenna – It is a vertical polarized omni-directional antenna, and its location is critical to the success of the installation. The antenna should be installed away from interfering high power energy sources like radar and other antennas.

Both R-AIS transmitters generate output power (adjustable) 1 and 12.5 W and 50 Ohm load. The unit bandwidth is 25 kHz employing TDMA (AIS) protocol with baud rate 9600 b/s (AIS)/1200 b/s Digital Selective Call (DSC) and GMSK (AIS)/FSK (DSC) modulation. Both transceivers are using frequency bands from 156.025 to 162.025 MHz with default channels 87B (161.975 MHz) and 88B (162.025 MHz), 70 (156.525 MHz). Both AIS units of Secure Class A system have 3 (2 AIS TDMA, 1 DSC) number of receivers and Minimum Keyboard and Display (MKD) unit.

Figure 3. Maritime Classs B R-AIS – Source: ICOM **[6]**

The R-AIS Class A transponder is easy to install onboard any seagoing ship by connecting it to an GPS and VHF antenna or to the own antenna, illustrated in **Figure 2 (Right)**, and is complete after immediate connecting it to the onboard sensors. To maximize the benefit of the investment, the R-AIS Class A transponder is delivered with an interface to the electronic chart system and/or Automatic Radar Plotting Aid (ARPA). Moreover, the system is designed to support long-range reporting via satellite, which will be introduced in the next context below. To maximize the benefit of the functionalities, both R-AIS Class A transponders are delivered with an interface to the chart system and/or ARPA radar.

The data link communication covers identity, position, destination and other required static, data voyage-related and dynamic data, which gives all vessels in an area increased situational awareness and improves safety at sea for the individual ship. Positive identification and positioning of all ships in the vicinity reduces the unnecessary "ship on my port bow" calls. Less information overload greatly enhances safety at sea.

The SOTDMA technology is used in the R-AIS transponder, which transmits and receives useful information on all vessels within VHF coverage. This information includes position, identity (ID), course over ground, heading and rate of turn as well as navigational status and the destination of the ship. Thus, the information received from, and provided to, the ships is easily plotted on any ARPA radar or electronic chart system. This gives the officer of the watch a situational awareness that could never be achieved prior to AIS. In such a way, information on draught, type of cargo and destination could also be used to make decisions related to the ship maneuvering, so at this point is accomplished the maximum awareness.

Targeted at large commercial oceangoing ships, SOTDMA mode requires an AIS transceiver to maintain a constantly updated slot map in its memory such that it has prior knowledge of slots, which are available for it to transmit. Moreover, the SOTDMA transceivers will then pre-announce their transmission and effectively reserving theirs transmit slot. Thus, this transmission is achieved through two receivers in continuous operation. Class A unit has an integrated display, transmit at 12 W, interface capability with multiple ship systems, and offer a sophisticated selection of features and functions. In default transmit rate it sends information every few seconds providing tracking control of vessel. Described system is transmitting all necessary tracking information with help of the VHF transmitter to other nearby ships and to coastal Base Station (BS) **[2, 4, 5].**

2.2. Icom MA500TR Class B AIS Transponder

The MA-500TR is a Class B R-AIS transponder for Non-SOLAS vessels such as pleasure craft, workboat, fishing and small vessels. Its power of this unit is 2 W and not required to have an integrated display. Class B R-AIS transponder can be connected to most display systems, which the received messages will be displayed in, lists or overlaid on charts. In **Figure 3** is presented interface of Icom MA-500TR Class B AIS transponder with antenna, which can be installed onboard small vessels, and which does not complain to the necessary requirements of IMO regulations **[2, 6, 7].**

3. Basic Technical Details of AIS Transponder

Vessel with mounted onboard both R-AIS type Class A and B transceivers employ Carrier Sense TDMA (SCTDMA) or Self Organizing TDMA (SOTDMA). The system is automatically sending and receiving data via the standard vessel's radio units. In such a way, they use two VHF channels simultaneously, such as 87B at 161.975 MHz and channel 88B at 162.025 MHz.

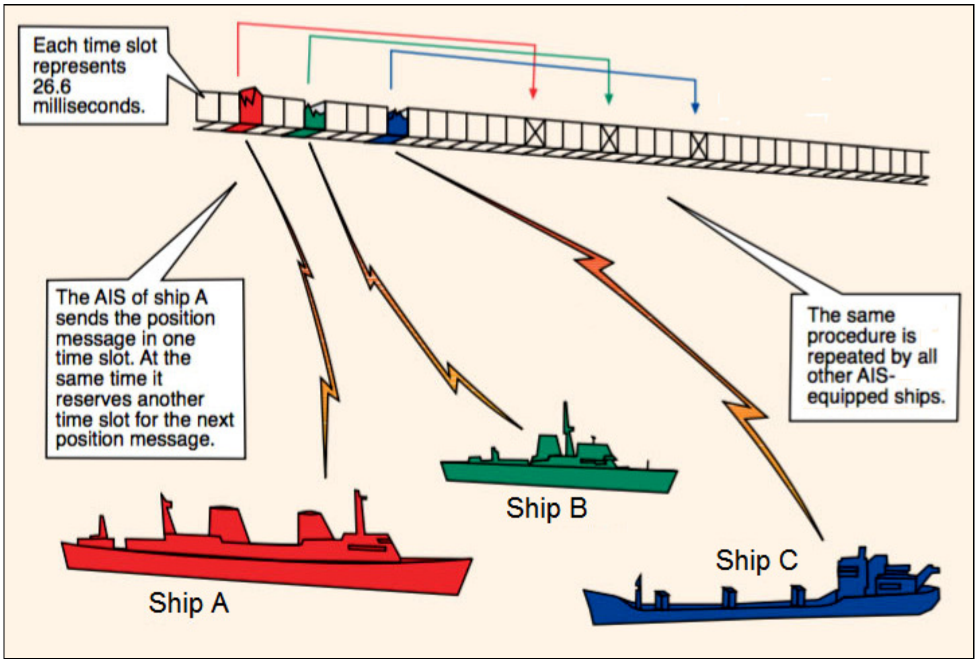

Figure 4. Maritime SOTDMA AIS Transmissions – Source: AMSA **[8]**

Therefore, to order a lot of vessels sending out their data, the AIS transmission protocol works with 2250 slots per minute which can be used by different senders to transmit their information. The SOTDMA modulation mode is used to autonomously divide the available timeslots between different senders, which AIS network is illustrated in **Figure 4**. Due to the limited range of VHF and the different transmission intervals of senders the number of slots is sufficient and collisions hardly occur. An AIS system sends out via Base Station different types of information in varying time intervals. In total, AIS is able to communicate 27 different message types. Message #1 e.g. is the position of the vessel.

In such a way, transmitted information by this unit is: Maritime Mobile Service Identity (MMSI) code, Vessel name, Call sign, Type of ship, GPS antenna position, Ship's position, SOG (Speed Over Ground), COG (Course Over Ground), UTC date and time, GPS antenna type, PA (Position Accuracy) and Simple operation. Not all messages are regularly used.

The AIS Plotter display looks like a usual marine radar display. North-up, course-up and range zoom from 0.125 to 24 NM (miles) are supported. The Target list display shows all detected AIS equipped vessels and targets. The Danger list display shows a list of vessels that are within 6 NM of Closest Point of Approach (CPA) and 60 minutes of Time to CPA (TCPA) from own vessel. Therefore, the Danger list can be sorted by CPA or TCPA order. In addition to these display types, the Detail screen shows various information about the selected R-AIS targets, such as CPA and TCPA for collision-risk management. When an oceangoing vessel comes into the CPA and TCPA range, the unit icon blinks on the Plotter display and emits a beep sound. When connected to external audio equipment installed on the deck tower, the collision alarm function will alert operator even when is away from the AIS transponder **[2, 4, 8].**

4. CNS Systems AIS Base Station (BS)

Maritime R-AIS Shore Stations are used for surveillance and management of vessel traffic along coastlines, on inland waterways and in ports. These stations are providing all the features required for surveillance and management of vessel traffic at R-AIS VTS.

They are easily configured to the specific needs of necessary service and solutions, from a basic unit to a fully redundant system with an embedded controller providing extensive processing and logging functionality. These R-AIS base stations fulfill the requirements of international AIS standards, provide service for national maritime authority implementing an R-AIS network and are also suitable for stand-alone operation at VTS or seaport.

Figure 5. Maritime AIS Base Stations – Source: CNS Systems **[4]**

The Swedish Company CNS Systems has two designs of Maritime R-AIS Base Stations: VDL 6000/FASS, illustrated in **Figure 5 (Left)** and VDL 6000/FASS Advanced, shown in **Figure 5 (Right).**
All AIS ships stations automatically broadcast information on dedicated VHF maritime channels. The AIS broadcasting system consists of static (geostationary), dynamic (non-geostationary) and navigation information, shown in **Figure 6.** All this information is originating from ships sensors connected to the R-AIS transponder. R-AIS Station sends position reports every 2 seconds to 3 minutes, depending on type of R-AIS transponder, speed and turn rate. Thus, the received R-AIS information at Base Station can be shown on a VTS Operator's screen or an ECDIS display.

4.1. CNS Systems AIS Base Station VDL 6000/FASS

The VDL 6000/FASS is configured as an AIS BS terminal shown in **Figure 5 (Left)**, which includes two VDL 6000/FASS (Fixed AIS Station System), one BS transponder and one controller in each FASS unit and one Power and Antenna Distribution (PAD) unit. The AIS network with AIS internship reports and reports between ships and AIS BS are shown in **Figure 7 (Left).** In **Figure 7 (Right)** is shown the Multifunction Displays for Marine's Integrated Platform Management System (IPMS) for AIS VTS infrastructure, which also can be used as Integrated Bridge System (IBS) display for installation onboard ships
The AIS BS configuration is a cross redundant shore terminal with high reliability and full redundancy on all electronic components. On the other hand, this unit exceeds all the requirements of international AIS BS standards and provides all the features required for surveillance, detecting and management of vessel traffic. The AIS BS will automatically switch over to the stand-by FASS unit if the active one goes down (hot stand-by). It can also use the controller and BS terminal crosswise in case of dual failures of hardware **[2, 3, 9].**

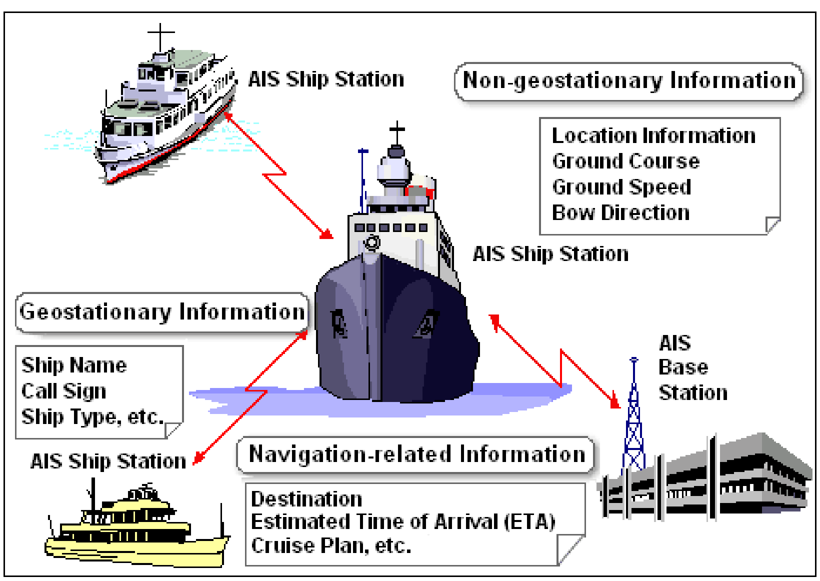

Figure 6. Maritime AIS Network – Source: MRS **[9]**

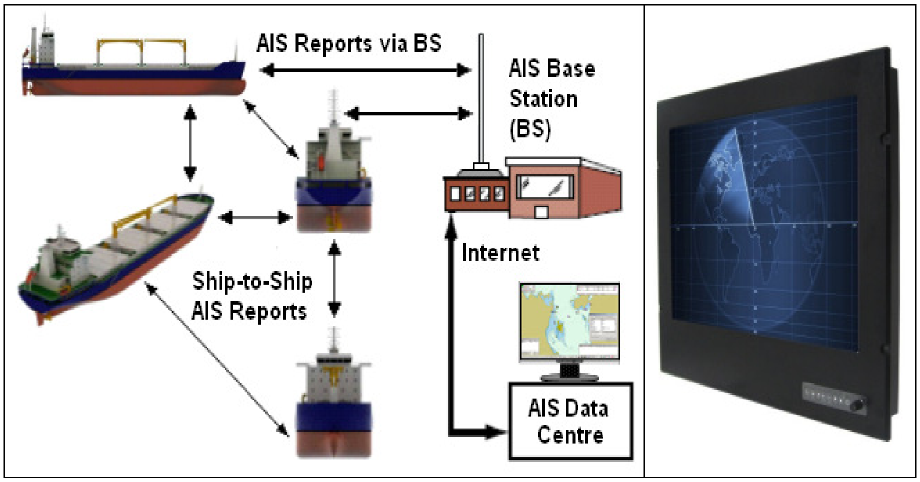

Figure 7. Maritime R-AIS Network and Display – Source: Ilcev **[2]**

This solution gives extremely high Mean Time Between Failure (MTBF) and availability and a very low mean time to repair, reducing the need for unscheduled maintenance. The calculated MTBF of the AIS BS is more than 3 million hours, provided faulty units are replaced within 72 hours. The PAD unit contains an VHF antenna switch which can be used when only one VHF antenna is required. If dual VHF antennas are used at the installation site, the VHF switch can be bypassed by connecting directly to the two VDL 6000/FASS units VHF antenna ports. The AIS BS station provides much additional remote functionality, including configuration, software updates, virtual targets and more.

Other functions are local storage of AIS messages, local target filtering and Simple Network Management Protocol (SNMP). Power management is also integrated in the PAD unit. This feature makes it possible for the user to remotely switch the FASS units power on and off, what is giving the operator full control. Therefore, the AIS BS is designed for operation in secure mode by handling encrypted AIS data. The secure mode enables secure communication between ship-to-shore station and the control centre. Thus, by adding the secure modules to the network software, encryption and decryption can be managed between the users in a secure AIS network. The AIS BS transponder can be supplied with a third AIS channel as well as increased receiver sensitivity.

The AIS BS is employing Power IP relay IF TCP/IP and RJ45 Ethernet with transmitter and receiver tuning range at 156.025 –162.025 MHz and with channel spacing of 12.5 and 25 KHz. Modulation scheme is 25 KHz GMSK (AIS TDMA), 2.5 KHz GFSK (AIS TDMA) and 25 KHz FSK (DSC). The AIS BS station is containing GNSS Receiver as well with GPS L1, 16 parallel channels and DGNSS support **[2, 3, 9]**.

4.2. CNS Systems AIS Base Station VDL 6000/FASS Advanced

The Advanced configuration has one transponder and embedded controller hardware running unique software from CNS Systems, shown in **Figure 5 (Right).** This BS terminal can be installed as a single equipment providing AIS message logging, remote configuration and software update, virtual and synthetic targets, SNMP, local target filtering, remote power on/off and more. Two shore BS terminals can be locally connected to form a fully redundant installation, where their hot-standby operation including mutual cross-wise redundancy transponder and controller between the units provides very high availability.

This AIS shore BS is delivered with the Monitor and Control Tool (MCT) and the Power Supply Management Tool (PSMT). Therefore, the MCT is a graphical interface that provides monitoring and control capabilities such as; change of status of the base station and its subunits, change of operational mode, enabling and disabling of services, configuration of the base station and its subunits, display of number of transmitted and received messages as well as software update.

The PSMT allows a user to control the power supply to the base station and its subsystems. It can be factory configured for the following base station types: AIS BS, Limited AIS BS, Repeater BS and Aids to Navigation (AtoN) transmitting only BS.

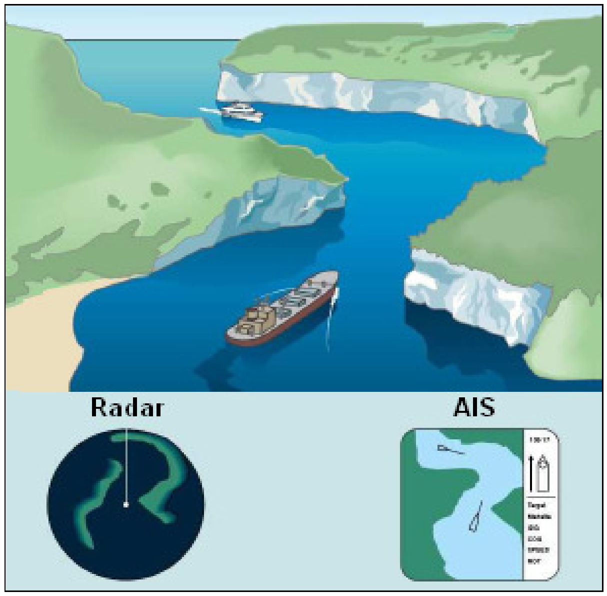

Figure 8. Radar vs AIS – Source: Ilcev **[2]**

With the Repeater station this BS is the perfect choice when implementing an AIS network where extended coverage at remote locations is required. This AIS BS is equipped with dual VHF antennas provides a number of functions, including filtering of AIS targets by selection of MSG type and/or filtering of a defined area. Otherwise, the dual antenna configuration allows the Repeater station to receive and transmit on directional antennas.
In order to simplify the functionality of AIS network it is necessary to construct the network model basing on a LAN. The system can use two ways to construct such a network. The first way is based on computing node, which communicate and exchange data or message each other via computer. The second is based on switching node, which contains data switches and equipment for controlling, formatting, transmitting, routing and receiving data packets
This infrastructure greatly improves coverage and distance in an AIS network, so for example in **Figure 8** is shown advantage of AIS vs Radar. Both ships do not have radar contact due to the difficult terrain, but can see each other by AIS. However, sometimes in more mountainous shore line there is not LOS between ships or between ships and base station, so can be used Satellite AIS instead **[2, 4, 8].**

5. CNS Systems AIS BS and Ship Station Software

The CNS Systems company is also supplier of important software for use by the AIS base and ship stations. There are two CNS Systems software for supporting onboard AIS stations, such as Aldebaran II and Sentinel. However, there are four software solutions used at Base stations, such as Horizon, DataStore, DataSwitch and Maestro.
1. Aldebaran II – This is Electronic Charting System (ECS) software for use onboard ships. In fact, it is designed with advanced navigation and communication features and is used by AIS operators worldwide. However, the ECS solutions improve efficiency and safety in today's fast paced computer-aided navigation and situational awareness environments. It offers complete AIS units integration with the ability to display static, dynamic and voyage related information in real time on a multitude of electronic chart formats.
2. Sentinel – This is AIS surveillance and secure information system built on proven AIS display technology for use by operators in the need for secure communication. It offers AIS standard and private communications capabilities to deliver a common operating picture to all users. It permits the simultaneous covert tracking of standard AIS participants, allowing operators to monitor the network without being detected.
3. Horizon – This is shore-based (BS) vessel monitoring solution designed for vessel traffic and monitoring centres. Horizon is ideal for vessel traffic monitoring in national waters, and has been proven to increase safety, security and efficiency.

It provides a complete AIS interface that includes the ability to view and track all vessels, display specific vessel information and send and receive safety related and text messages. Its interface and display of AIS related data offers a substantial leap forward in the ability to communicate and interact with vessels. Since Horizon is fully configurable, operators can adjust the display of information panels, customize color patterns for AIS targets and set entry and exit alarms**.**

4. DataStore – This is a real-time data logging and playback software solution for National Marine Electronics Association (NMEA) and NMEA-formatted data, specifically AIS data. The "back-end" of the solution is a service that interfaces with a database, and the "front-end" interfaces with an application that allows a user to control logging and playback of data. DataStore can be configured to store all data or a user defined subset of data. Data stored in the AIS database can be queried and played back in the ECS system or an external application.

5. DataSwitch – This is a special data routing and management software application that provides a reliable flow of data to environment. DataSwitch supports the functionality defined in International Association of Lighthouse Authorities (IALA) Recommendation A-124, LSS Layer and Part IV. It is ideal for the collection, filtering, logging and sharing of AIS data over networks. For shore BS networks, it enables the flow of information from one or more AIS base stations and/or receivers to a Vessel Traffic Service (VTS) centre. Similarly, a VTS center can send vital data to a regional headquarters, and then on to a national entity via another DataSwitch. For a vessel-based network, DataSwitch can send information from attached NMEA devices (sensors) to a number of stations on the vessel. The distribution of both standard and proprietary data messages from one central location to shared locations makes DataSwitch essential in many diverse environments.

6. Maestro – This software provides top layer control for the AIS network, supporting the functionality defined in IALA Recommendation A-124, Functionality of the AIS Service Management (ASM) and Part V. It is a graphical display interface and configuration utility for the AIS network. Maestro monitors all AIS network components including status and failure of all components, warnings about failover and backup systems, user account status, and all other relevant events. From the single interface accessed via a web browser, Maestro users can monitor, maintain, and manage all elements of the AIS network, which is an independent process that runs without affecting the other AIS services **[2, 3, 4, 5].**

6. Satellite Automatic Identification Systems (S-AIS) Network

The recently developed VHF Radio - Automatic Identification System (R-AIS) network, being an RF-based communications system was never designed for reception of signals from space, however Satellite AIS (S-AIS) greatly extends the range of the original system and creates new application possibilities for competent maritime and aeronautical authorities. Visibility scope is significantly enhanced using S-AIS and in such a way this solution provides global coverage and creates increased CNS situational awareness well beyond the 50 NM range from shore. Similar to the VHF R-AIS ship terminal, the VHF S-AIS unit is easy to install onboard any seagoing ship by connecting it to GPS receiver, gyro and the Pilot Plug interface.

Therefore, most terrestrial-based R-AIS networks provide only limited shore-based coverage via VHF-band to track and monitor vessels, and thus are not able to provide global, open ocean coverage. The Orbcomm and other LEO satellite network including Nano (CubeSat) satellites overcomes many of these challenges with unique S-AIS data service that can monitor a vessel's location and daily status well beyond coastal waters and ports to assist in navigation and improve maritime safety and security. More importantly, the Orbcomm and other LEO networks can do this cost-effectively and in near-real-time transmissions. The Orbcomm system was the first commercial satellite network providing licensed S-AIS data services to over 100 different ships customers in a variety of government and commercial organizations.

The Orbcomm S-AIS network and service offers valuable data for applications that maximize global maritime safety and security, enabling the maritime industry to know where nearly every vessel is located, where it is going and when it will arrive at its destination. Orbcomm has already provided access to tracking and detecting information from well over 120,000 unique vessels daily by leveraging proven expertise and existing worldwide ground infrastructure. In addition, by partnering with some of the most trusted maritime information providers in the world, such as Inmarsat, the Orbcomm satellite system may offer the most complete situational picture of global vessel activity.

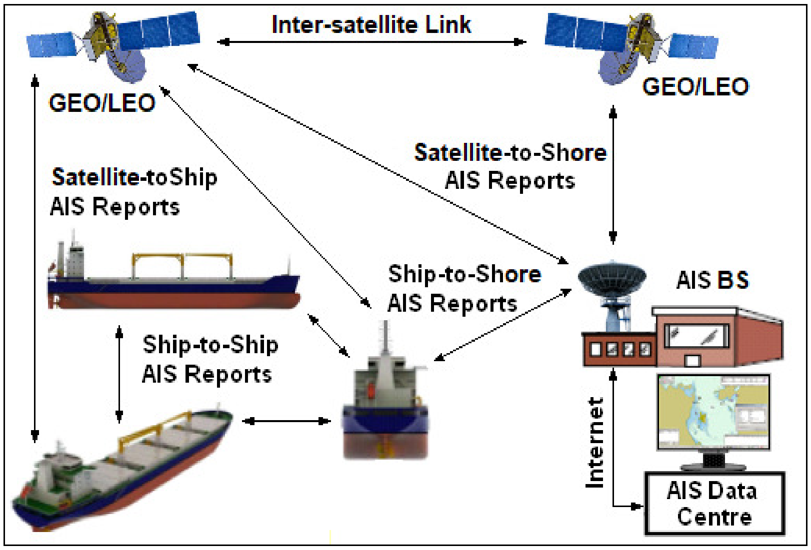

Figure 9. Maritime S-AIS Network – Source: Ilcev **[2]**

In May 2004, the US Coast Guard awarded Orbcomm a contract to develop and supply new S-AIS service and network to meet their national security requirements. By utilizing Orbcomm S-AIS service, security and intelligence departments around the world can know where nearly every vessel is located, where it is going and when it will get there. In fact, these valuable data can be used to quickly react to anomalies at sea such as piracy and suspicious movements, contraband and route deviation, SAR, fishery and environmental monitoring and other unusual behavior. Except Orbcomm satellite system, to establish S-AIS system can be used existing GEO and Non-GEO satellite networks on L or UHF-band, shown in **Figure 9.**

In fact, it will be necessary to provide adequate satellite constellation, CES terminals, mission operation, data processing centre, operation centers and customer delivery of S-AIS service. Onboard ships S-AIS equipment can send two types of messages, the first type is inter ship communication of ship-to-ship AIS reports, and second type is direct transmission of AIS messages via SES, Internet or terrestrial communication line to the AIS Data Centre. The shore AIS Data centre provides processing of all receiving data and is forwarding S-AIS messages instantly to the customer facilities via Internet.

6.1. Enhancements of Surveillance and Security

The proposed S-AIS system and network will improve monitoring, surveillance and security in navigation of ships at deep sea and coastal waters where R-AIS has not coverage. Namely, the new S-AIS network maximizes maritime safety and security, which service is thought to be the most significant development in maritime navigation safety and security since the introduction of radar.

This system is a shipboard broadcast system that also transmits a vessel's identification, position and other critical information to provide the most complete and timely situational picture of vessel activity worldwide. Thus, the benefits of S-AIS in helping maritime authorities and shippers globally are to enhance maritime domain awareness and surveillance through detecting and identification of all ship's sailing route deviation and suspicious movements. In fact, by utilizing S-AIS service, security and intelligence departments around the world can find out where nearly every vessel is located, where it is going and when it will get there. These agencies can use this valuable data to quickly react to any anomalies at sea, such as suspicious movements, route deviation and other unusual behavior of pirate and contraband boats.

The use of data fusion by merging S-AIS data with sensors such as electro optical imaging and Satellite Synthetic Aperture Radar (SSAR) enables the rapid and reliable identification of S-AIS-emitting vessels and highlights non-S-AIS-emitting vessels. This data has proven to be beneficial for government authorities responsible for security, fisheries, exclusive economic zones and environmental monitoring in improving security and safety efforts. From more efficient management of port traffic, to support of national surveillance initiatives, to collision avoidance and other benefits, S-AIS service is helping to keep global waterways more safe and secure.

Therefore, received data from these ground agencies can be used just for commercial purposes, however for collision avoidance new S-AIS system cannot work without establishment of special Ground Tracking Centres (GTC), which have to provide positions of all adjacent ships to the certain ship requesting these data in corresponding area. In such a way, ships captain getting this electronically information with positions of all surrounded ships can easily and safe navigate even in the extremely bad weather conditions.

6.2. Improvement of Counter Piracy and Suspicious Movement

Piracy in high-risk areas has become a major threat to regional trade and maritime security in recent years. As the frequency and aggressiveness of pirate attacks has increased, the need for S-AIS service in mitigating the risk of piracy is more important than ever before. As stated before, it can be used to locate approach of pirate boats, suspicious movements and to identify ships of interest, such as terrorist attacks, contraband and so on. Namely, the S-AIS can help alert vessels to a potential threat so fleet operators can avoid, deter or delay piracy attacks and greatly reduce risks to the vessel and crew. This system reduces the escalating threat and dangerous impacts of piracy and improves vessel safety and security is more important than ever before.

The S-AIS system and network enhance detecting of ships movement at sea, identifies vessels of interest and filter out “friendly” ships, especially in high-danger areas. If there is a data anomaly with regard to ID, location or speed, maritime authorities can use S-AIS data to determine the variance in reported versus actual status and take immediate action.

This satellite system can also be used to reduce the need for routine patrol missions at sea and help dispatch the appropriate authorities quickly when security incidents occur and in such a way significantly to improve the efficiency of all maritime operations. In addition, by providing proven and reliable real global coverage, S-AIS network delivers uninterrupted satellite data service even when the traditional shipboard communications systems and alarm transponders may have been compromised.

Post-piracy tracking and reporting via S-AIS can be also used to identify typical ships traffic patterns and activities in high-risk sea areas, which can significantly help local and national security organizations proactively counter piracy hijackings, kidnappings and extortion.

6.3. Better Facilitated Fisheries and Environmental Monitoring

The new S-AIS network is providing access to timely, accurate vessel data as an instrumental solution in supporting fisheries management, environmental protection, all pollution preventions and modern transport operational compliance programs in global waterways. From the prevention of some marine daily pollution incidents to the enforcement of fishery regulations to vessels traffic management, S-AIS service provides the maritime industry with complete and reliable visibility over ships activity worldwide.

The S-AIS information service is also cost-effective and reliable resource for shippers, ship operators, seaport authorities and government agencies to help prevent environmental disasters, enforce fishery regulations and ensure the safety of mariners. The S-AIS service can be used to manage fishing activities, quotas and harvesting limits by alerting authorities of vessels entering closed or protected environmental zones. Namely, the best result is a reduction in illegal fishing and the preservation of depleting ocean resources. Thus, this system is also able to track historical traffic patterns and identify violators within these protected areas.

Environmental organizations leverage S-AIS data to determine if a vessel has been in an area where oil, hazardous waste or ships ballast has been deliberately discharged or leaked to determine who is responsible for polluting the water. This service can also provide valuable data to all maritime authorities regarding the activity of vessels around and within such environmental or navigation hazards area at sea, enhancing maritime safety and enabling those authorities to take immediate necessary actions.

Besides, in support of fisheries control and environmental protection, relevant maritime authorities around the world have to detect and identify illegal, unreported and unregulated fishing activities. As stated earlier, the S-AIS system can integrate its satellite data with sensors such as surveillance radar and deliver comprehensive monitoring reports to authorities responsible for fishery ships, exclusive economic zones and environmental monitoring.

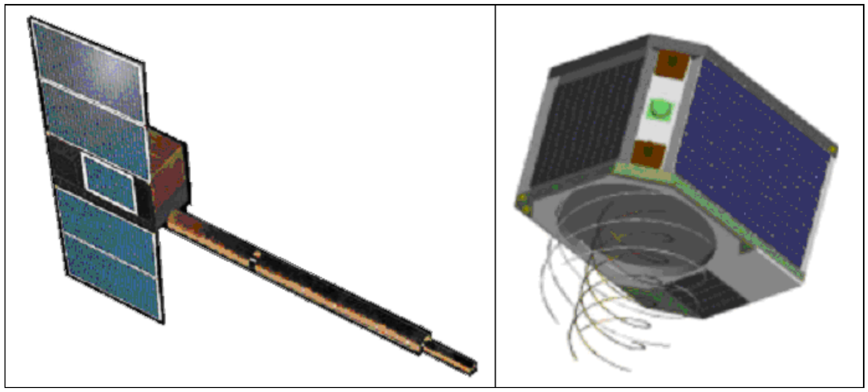

Figure 10. Satellite AIS Network – Source: Ilcev [5]

6.4. More Reliable Search and Rescue Operations

In an emergency incident when loss of life or the watercraft is imminent or threatened by grave danger, timing is becoming everything. The faster that information can be communicated to the first responders such as coast guards, maritime or other competent authorities, the faster that help can be sent on the way.

The most effective solution for improving ship safety including the precision and efficiency of international SAR operations is Cospas-Sarsat, LRIT and after that global S-AIS data service. This service is a new shipboard broadcast system that transmits a vessel's identification, position, speed and detecting other critical data to provide a complete and reliable situational picture of near-real-time vessel activity worldwide. For vessels in distress alert and during SAR operations the S-AIS service can identify exactly where a vessel is located anywhere in the world even if it continues to drift from the distress location.

Access to accurate, reliable and timely data about the position and status of a vessel and its crew can greatly improve response time by focusing SAR resources to a specific area and enhancing overall rescue coordination. Most importantly, S-AIS data can help minimize damage to and loss of the vessel, potentially saving lives. This valuable positioning service is also helpful in tracking the status of the rescue team and reducing risk to the rescuers, especially in treacherous heavy weather or water conditions.

Orbcomm and other Non-GEO satellite operators today are providing efforts to develop VHF or UHF S-AIS network for all mobile applications and especially for maritime commercial and SAR on scene operations. In such a way, Orbcomm Little LEO satellite operator is the first mobile commercial satellite network who is developing and implementing S-AIS Data Service.

In 2008, Orbcomm team launched the first LEO satellites specially equipped with the capability to collect AIS data and has plans to include these capabilities on all future satellites for ongoing support of global safety and security initiatives. Orbcomm mobile satellite operator recently has successfully launched six satellites with S-AIS equipped payloads. Orbcomm next launches started in 2011, which AIS satellite is shown in **Figure 10 (Left).** Following the development of Orbcomm system is designed sample of the M3MSat Maritime AIS CubeSat (Nano) satellite for the Canadian government, shown in **Figure 10 (Right),** which was launched in 2012. The future S-AIS network is ideal for global satellite ships tracking and surveillance useful by maritime and government administration, but as stated earlier, is not dedicated for a real collision avoidance of ships. Thus, to enhance R-AIS and S-AIS service has to be provided the similar system as proposed Global Ship Tracking (GST).

The GST system is augmented LRIT network, which except ship tracking provides tracking of captured ships by pirates and enhanced collision avoidance. Its Tracking Control Stations (TCS) is collecting positioning data of all ships in any sea area, indicating them on the radar like display and distributing them on any ship request sailing in certain sea area.

The disadvantages of Nano and LEO satellites is that they need several dozen of spacecraft to build complete coverage, could interfere with satellite operations and space missions, short equipment lifespan, enhanced atmospheric drag, increasing danger from space debris from many non-working satellites, handover problems and short visibility over horizon. To get more reliable S-AIS network has to be employed GEO satellites, as the best solutions for S-AIS.

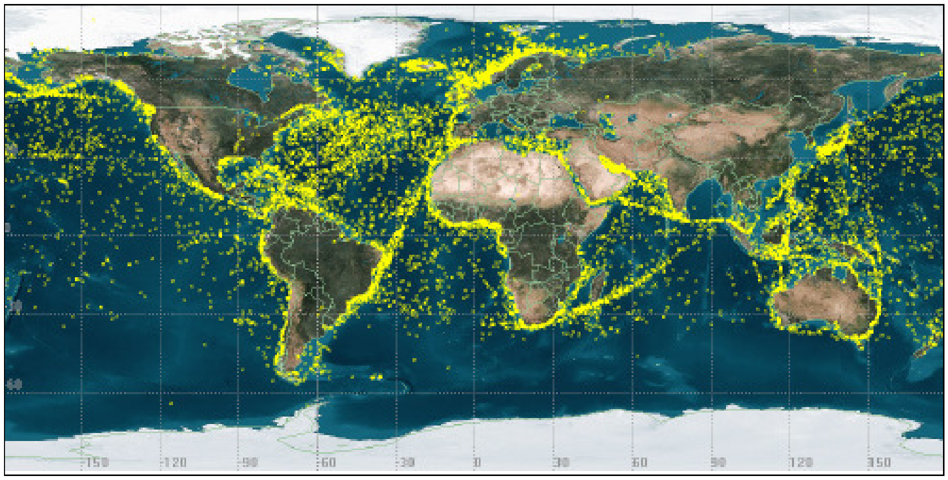

Figure 11. Operational results of S-AIS Network – Source: Cain (10)

In **Figure 11** is shown by Cain & Meger one of the S-AIS operational results to globally track the ships, which is useful for commercial purposes **[2, 3, 5, 10].**

7. Nano Satellite AIS (Nano S-AIS)

An AIS receiver using satellite will be able to extend the VHF-band range of R-AIS systems considerably and make it easier to monitor ship traffic and fishing in the High North areas.

Recently many countries developed cost effective small satellites in LEO constellations. They are categorized by their weight, such as Pico less than 1 – 5 Kg, Nano less than 10 – 50 Kg and Micro satellites less than 100 – 200 Kg, which measure less than 0.5 meter The ITU regulations are not geared for these smaller satellites, but recently were proposed their frequencies in the range of 137 MHz to 2,450 MHz.

No matter what smaller satellites have limited lifetime, short lifetime of batteries and orbit control capabilities, they can be used as cost-effective missions for tracking, detecting and remote sensing. Based on different studies and examples in which Nano satellites were exposed to the different levels of radiation, some CubeSat electronics Secure Digital (SD) cards especially are susceptible to any errors from radiation. In addition, space radiation can be mitigated to some degree through shielding and material choice or via special software by clever use of watchdog timers and special "self-aware" coding as well, where self-verification is consistently monitored.

With regards to the smallest satellite life time, CubeSat at orbit lower than 300 Km will be 0-100 days, these from 300 to 400 Km are a danger of collision with the International Space Station (ISS), because that the orbit of ISS is usually maintained between 335 km perigee and 400 km apogee. A CubeSat in this altitude band could last for 0.5 to 2 years. In contrast, the lifetimes of higher altitude satellites than 600 Km could be theoretically up to two decades.

In **Figure 12 (Left)** is illustrated larger coverage area using S-AIS or even AIS via High Altitude Platforms (HAP) versus using smaller coverage of conventional system of VHF R-AIS. The altitude of the LEO satellite or HAP station gives the AIS receiver a large range of coverage and both can therefore make observations over extended sea areas. The VHF AIS signals are strong enough to be received by an SCP or satellite.

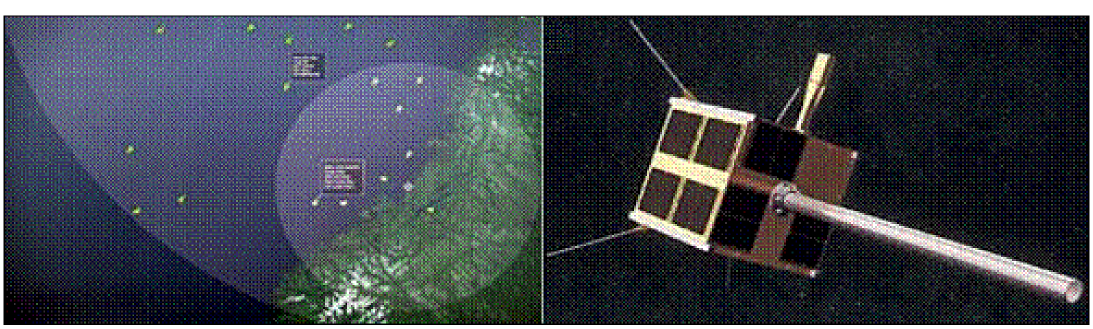

Figure 12. Coverage of AIS Networks and Nano-AIS – Source: Ilcev **[5]**

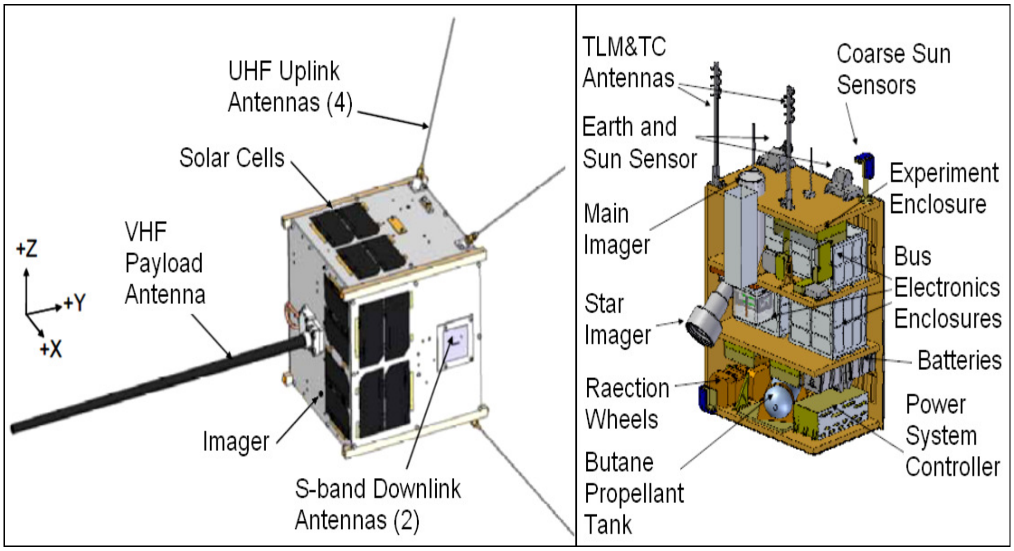

Figure 13. NTS/AISSat and SumbandilaSat Satellites – Source: SFL/US **[11, 12]**

The new developed AISSat-1 is a Nano satellite in LEO measuring 20x20x20 cm, weight is 6 Kg and is shaped like a cube (CubeSat), shown in **Figure 12 (Right).** The satellite payload is designed by the Kongsberg-Seatex AS Company and the purpose of the satellite is to improve ships surveillance of maritime activities in the High North sea areas. It is believed that the low traffic density in the High North requires one receiver and antenna only to handle the expected volume of AIS messages. So, the AISSat-1 satellite is being launched in order to test these presumptions and if is successful to be used for S-AIS facilities.

The AISSat-1 satellite will operate in a Polar orbit at an altitude of about 600 Km and is proposed to be launched by the PSLV rocket of the Indian Space Research Organization (ISRO). Thus, the Norwegian Space Centre is project owner and the Norwegian Coastal Administration (FFI) will receive the data, while the Norwegian Defense Research Establishment is responsible for the technical implementation. Additional information about this project is possible to see at Web pages of Kongsberg Maritime.

The Norwegian AIS transponder is also placed in a Canadian Nano satellite, built by the University of Toronto (UOT), which life span is estimated to three years. The Institute for Aerospace Studies/Space Flight Laboratory (UTIAS/SFL) of UOT has been developed prototype of Generic Nanosatellite Bus (GNB) to fly a verity of payloads, ranging from S-AIS tracking solutions to precision formation flying. With the successful launch of the CanX-2 mission, technological validation is paving the way for the next generation of GNB derived CanX missions.

The COM DEV Ltd launched Nanosatellite Tracking of Ships (NTS) spacecraft at the end of April 2008 following an unprecedented 8-month kick-off to launch cycle, which components are shown in **Figure 13 (Left).** In **Figure 13 (Right)** is shown CubeSat SumbandilaSat, microsatellite designed by Stellenbosch University (SU) in Cape Town, South Africa. This satellite launched 17 September 2009 by Russian Soyuz-2 launch vehicle from the Baikonur Cosmodrome will serve for Earth observation with design lifetime of 3 years at an orbit altitude of 500 Km (subject to average sun activity) **[2, 5, 11, 12].**

8. Conclusion

In this article were discussed basic of R-AIS with major class of AIS transponders for installation onboard ships and BS for shore installations. In addition is introduced new S-AIS via Orbcomm Little LEO satellite constellation and via proposed small LEO satellites. Here the question is aroused, namely, whether Little LEO satellites, such as Orbcomm or small satellites can provide full, cost effective coverage and reliable S-AIS service?

The total cost of new generation Orbcomm network with 36 satellites in constellation is about 234 million US$ and will be able to provide global coverages except both poles. However, the total cost of the AISSat-1 Nano satellite is approximately 30 million NOK (Norwegian Crown) or about 4 million US$ each.

The another question is, how many Nano satellites will be necessary for total coverage of Earth including polar areas, when in the same time Big LEO Globalstar has 40 satellites in constellation and Iridium with 66 satellites in constellation is providing full coverage of Earth including both poles. Inmarsat GEO satellite operator is only professional network providing near global coverage up to 80^0 North and South. At present ships are not sailings in Arctic Ocean, but Russian are proposing these routes, so at present only Iridium is able to provide polar coverage.
However, for additional coverage over North Pole Inmarsat needs Hybrid Satellite Orbits (HSO), such as GEO and Medium Earth Orbit (MEO) or GEO with High Elliptical Orbit (HEO) Russian Molniya spacecraft. However, at present Inmarsat is setting advanced new Inmarsat-5 GEO satellite constellation, which will provide broadcasting and broadband satellite office at sea. Perhaps cost of about 50 million US$ to launch one Inmarsat-5 spacecraft is not extremely high for significant professional maritime communications.

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